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Technology, Safety and Costs of Decommissioning a Reference Uranium Fuel Fabrication Plant

Main Report

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Prepared by
H. K. Elder, D. E. Blahnik

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
Division of Engineering Standards
Office of Standards Development
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
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STUDY CONTRIBUTORS

STUDY LEADER

H. K. Elder

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H. K. Elder

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FOREWORD

BY

NUCLEAR REGULATORY COMMISSION STAFF

The NRC staff is in the process of reappraising its regulatory position relative to the decommissioning of nuclear facilities.(1) As a part of this activity NRC has initiated two series of studies through technical assistance contracts. These contracts are being undertaken to develop information to support the preparation of new standards covering decommissioning.

The basic series of studies will cover the technology, safety and costs of decommissioning reference nuclear facilities. Light water reactors, fuel cycle and non-fuel-cycle facilities are included. Facilities of current design on typical sites are selected for the studies. Separate reports will be prepared as the studies of the various facilities are completed.

The first report in this series was published in FY 1977 and covered a fuel reprocessing plant;(2) the second was published in FY 1978 and covered a pressurized water reactor;(3) the third of the series was published in FY 1979 and dealt with a small mixed oxide fuel fabrication plant.(4) An addendum to the pressurized water reactor report(5) was issued during FY 1979 which examined the relationship between reactor size and decommissioning cost, the cost of entombment, and the sensitivity of cost to radiation levels, contractual arrangements, and disposal site charges. The fifth report in this series dealt with

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(1) Plan for Reevaluation of NRC Policy on Decommissioning of Nuclear Facilities. NUREG-0436, Rev. 1, Office of Standards Development, U.S. Nuclear Regulatory Commission, December 1978.

(2) Technology, Safety and Costs of Decommissioning a Reference Nuclear Fuel Reprocessing Plant. NUREG-0278, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1977.

(3) Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG/CR-0130, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, June 1978.

(4) 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.

(5) Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG/CR-0130 Addendum, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, August 1979.

a low-level waste burial ground.(6) The sixth report dealt with a large boiling water reactor power station.(7) The following report, seventh in the series, provides information on the technology, safety, and costs of decommissioning a uranium fuel fabrication plant. Additional topics will be reported on the tentative schedule as follows:

FY 1981 • Non-Fuel-Cycle Nuclear Facilities

FY 1981 • Multiple Reactor Facilities

The second series of studies covers supporting information on the decommissioning of nuclear facilities. Three reports have been issued in the second series. The first consists of an annotated bibliography on the decommissioning of nuclear facilities.(8) The second is a review and analysis of current decommissioning regulations.(9) The third of this series covers the facilitation of the decommissioning of light water reactors.(10) The major purpose is to identify modifications or design changes to facilities, equipment and procedures which will improve safety and/or reduce costs.

The information provided in this report on the uranium fuel fabrication plant, including any comments, will be included in the record for consideration by the Commission in establishing criteria and new standards for decommissioning. Persons wishing to comment on this report should mail their comments to:

Chief
Fuel Process Systems Standards Branch
Division of Engineering Standards
Office of Standards Development
U.S. Nuclear Regulatory Commission
Washington, DC 20555

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(6) 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.

(7) 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.

(8) Decommissioning of Nuclear Facilities - An Annotated Bibliography. NUREG/CR-0131, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, September 1978.

(9) Decommissioning of Nuclear Facilities - A Review and Analysis of Current Regulations. NUREG/CR-0671, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, August 1979.

(10) Facilitation of Decommissioning of Light Water Reactors. NUREG/CR-0569, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, December 1979.

ABSTRACT

Safety and cost information is developed for the conceptual decommissioning of a commercial uranium fuel fabrication (U-Fab) plant. Two decommissioning alternatives are studied to obtain comparisons between costs and safety impacts. The alternatives considered are DECON and passive SAFSTOR.

DECON includes the immediate removal (following plant shutdown) of all radioactivity in excess of unrestricted release levels, with subsequent release of the site for public use. Passive SAFSTOR requires decontamination and preparation and maintenance and surveillance for a period of time after shutdown, followed by deferred decontamination and unrestricted release.

The decommissioning methods assumed for use in each decommissioning alternative are based on state-of-the-art technology. The elapsed time following plant shutdown required to perform the decommissioning work in each alternative is estimated to be: for DECON, 9 months; for passive SAFSTOR, 3 months to prepare the plant for safe storage and 9 months to accomplish deferred decontamination. Planning and preparation for decommissioning prior to plant shutdown is estimated to require about 7 months for DECON and about 6 months for preparing for passive SAFSTOR. Planning and preparation prior to starting deferred decontamination is estimated to require about 8 months.

Decommissioning cost, in terms of 1978 dollars, is estimated to be \$3.54 million for DECON. For passive SAFSTOR, preparing the facility is estimated to cost \$0.85 million, the annual maintainance and surveillance cost is estimated to be about \$0.28 million, and deferred decontamination is estimated to cost about \$3.84 million. Therefore, passive SAFSTOR for 10 years is estimated to cost \$7.52 million in nondiscounted 1978 dollars. All of these estimates include a 25% contingency. Waste management costs for DECON comprise about 7% of the total decommissioning cost and are kept low by minimizing the amount of material shipped to licensed low-level waste burial.

Safety analyses indicate that radiological and nonradiological safety impacts from decommissioning activities should be small. The 50-year committed dose equivalent to members of the public from airborne releases from normal decommissioning activities is estimated to be about 0.06 man-rem.

Radiation doses to the public from accidents are also found to be very low for all phases of decommissioning. Occupational radiation doses from normal decommissioning operations (excluding transport operations) are estimated to be about 16 man-rem for DECON and about 22 man-rem for passive SAFSTOR with 10 years of safe storage. The number of fatalities and serious lost-time injuries not related to radiation is found to be small for both decommissioning alternatives.

Comparison of the cost estimates shows that DECON is the least-expensive alternative. The annual cost of maintenance and surveillance and the higher cost of deferred decontamination makes passive SAFSTOR more expensive.

Methods to assure that the licensee has adequate funds for decommissioning are considered. Methods investigated (all based on expected decommissioning costs) range from a single payment when plant operations begin, to accumulative payments during the normal plant operating period, to a single payment when normal plant operations cease and decommissioning begins.

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1.0 INTRODUCTION

The purpose of this study is to provide information on the technology, safety, and costs of decommissioning uranium fuel fabrication (U-Fab) plants. This information is intended to contribute background data for U-Fab plant owners and for the NRC and to provide bases for future regulations regarding decommissioning of such facilities. Decommissioning techniques are reviewed and conceptually applied to a reference facility. Potential new guidelines and criteria are developed and used where appropriate.

Decommissioning of a nuclear facility can be defined as the measures taken at the end of the facility's operating lifetime to ensure the continued protection of the public from the residual radioactivity and other potential safety concerns associated with the retired facility. A spectrum of decommissioning alternatives, all resulting in unrestricted release, are possible for such a facility and, for this study, two specific alternatives are examined: DECON and passive SAFSTOR.

As used in this study, these decommissioning alternatives are defined as follows:

- DECON - Radioactive materials are removed and the facility is decontaminated and disassembled immediately following final shutdown. Upon completion, the property is released for unrestricted use.
- Passive SAFSTOR - Radioactive materials and contaminated areas are secured, and the structures and life support systems are deactivated for a period of time ending in deferred decontamination. Until deferred decontamination is finished, the facility remains under a modified nuclear license. Decontamination is deferred for reasons specified by the facility owner, with NRC approval. Upon completion of decontamination, the property is released for unrestricted use.

An existing facility, the Wilmington, North Carolina, plant owned by the General Electric Company, is selected for this conceptual analysis. The

Wilmington facility has operated since 1972 in fabricating uranium oxide fuels. It is believed to be representative of existing commercial U-Fab plants in the United States.

For each of the decommissioning alternatives studied, a work plan is developed for the conceptual decommissioning of the reference U-Fab plant. These plans describe decommissioning methods, technology, and scheduling, from the planning phase through disposal of material and completion of decommissioning. From these plans, estimates are developed of manpower, major equipment and material needs, material disposal requirements, and the resultant costs. The primary guidelines for the development of these plans are:

- to ensure adequate public and occupational safety while utilizing cost-effective decommissioning practices
- to use only current, proven decommissioning techniques.

To accomplish the decommissioning options, a number of variations in the work plans and techniques described in this study is possible. However, the methods postulated in this study appear to be representative of activities expected to be used for decommissioning a U-Fab plant, and are believed to reflect an appropriate balance of safety and cost.

The safety aspects of performing the decommissioning activities, as they affect both the general public and the decommissioning workers, are assessed. Safety and cost issues are evaluated for the safe storage period of passive SAFSTOP, wherein periodic surveillance and maintenance at the site will be required to assure the continued protection of the public from the radioactive materials remaining in the facility.

Safeguards and accountability for handling fissile materials, quality assurance needs, and methods for assuring decommissioning finances are examined. Relative environmental and societal advantages and disadvantages are compared, where possible, for the decommissioning alternatives studied. Suggested criteria are developed for permissible contamination levels for unrestricted facility and site reuse, based on the potential for radiation exposure to the public.

Many aspects of decommissioning (e.g., plans, methods, safety, and costs) may be sensitive to variations in facility location, specific facility shutdown conditions, and residual contamination levels in the plant. The bases and assumptions used in this study must be carefully examined before the results can be applied to a different facility and site.

The results of the study are reported in two volumes. Volume 1 (Main Report) summarizes the key information developed, and contains a summary as well as general background information (i.e., past experience in decommissioning selected types of facilities, decommissioning alternative definitions, study approach, applicable regulations and safeguards considerations, plant and site descriptions, and an overview of the suggested methodology used to develop acceptable residual contamination levels). Decommissioning techniques are described, and cost and safety analyses for each of the decommissioning alternatives are presented. Also included in Volume 1 is a discussion of basic methods for assuring financial capability for decommissioning, and a glossary of terms used in the report. Volume 2 (Appendices) contains the supporting data, methodology, and analyses, in appendices that are organized in sections corresponding to those in Volume 1. In both volumes, references are presented at the end of each major section.

2.0 SUMMARY

The results of this study to conceptually decommission a reference uranium oxide fuel fabrication (U-Fab) plant are summarized in this section. The purpose of the study is to identify the technology available and to evaluate the safety and costs related to decommissioning such a facility. The study is intended to provide background information related to decommissioning for use in the development of regulations, designs, and operational characteristics of commercial U-Fab plants.

The General Electric Company's Wilmington facility is selected as the reference plant and is characterized for the conceptual decommissioning activities. The Wilmington plant is considered to have characteristics similar to other existing commercial U-Fab plants. For this study, the facility is assumed to be located on a reference site having characteristics typical of midwestern or southeastern areas. Decommissioning plans, procedures, and schedules are developed for all plant areas that contain radioactive materials and for the inseparable adjacent areas that contain no radioactivity.

Two decommissioning alternatives[a] are considered in detail: 1) DECON and 2) passive SAFSTOR. Costs and safety impacts are estimated for both of these alternatives, and comparisons of overall costs and potential risks are made. Methodology developed for previous decommissioning studies is modified and applied to determine example acceptable contamination levels for selected facility and site uses.

Some of the key bases for the study are:

- Decommissioning plans are selected on the basis of providing good public and occupational safety in a cost-effective manner.
- Decommissioning operations are evaluated assuming efficient performance of the work.
- Current decommissioning technology and techniques are used.

(a)See Section 4 for descriptions of these alternatives.

- Expected contamination levels within the facility/site at the time of plant shutdown are based on known typical housekeeping practices during plant operation. This residual radioactive material is assumed to have accumulated at the rate of 1/40 per year for the assumed 40-year plant life.
- A radiation dose of 50 mrem/year to the maximum-exposed individual is used as the basis for the determination of suggested levels of radioactivity that can remain on the site and the facility when the property is released for unrestricted use.

The results obtained in this study are specific to the above key bases and to the other bases and assumptions used in this study. Use of other conditions, bases, and assumptions (e.g., contamination levels) may change the results significantly.

2.1 REVIEW OF DECOMMISSIONING EXPERIENCE

A review of past decommissioning cases of related nuclear facilities shows that most of the plants that have been shut down were high-level enriched facilities. Two low-level enrichment LWR fuel fabrication plants have been shut down and partially decommissioned. The review shows that: 1) experience exists in government and private organizations regarding methods and equipment for accomplishing decommissioning of nuclear fuel cycle facilities, and 2) there are no major technical impediments to the successful decommissioning of U-Fab plants.

2.2 FEDERAL REGULATIONS AND GUIDELINES

Regulatory and federal guidelines are reviewed relative to their general application to decommissioning of U-Fab plants. The review shows that in many cases the regulations do not speak specifically to decommissioning but can be interpreted as being applicable.

Areas where our review of current regulations indicate that more specific guidance could be helpful are:

- Financial qualifications and responsibilities for decommissioning need to be clarified to better define the commitments of the facility owner for achieving the final decommissioned status of the property. Specific definitions need to be established as to what are acceptable methods for assuring funds at the time of decommissioning.
- Some centralization, or a central indexing, of regulations pertaining to decommissioning in the Code of Federal Regulations would be very helpful.
- Existing guidance on what levels of residual radioactivity are acceptable on materials, structures, and sites for unrestricted use is somewhat fragmentary and does not have a common identifiable basis. The suggested methodology demonstrated in this study could form that basis, predicated on a decision by regulatory agencies as to what constitutes an acceptable annual radiation dose to the maximum-exposed individual from unrestricted use of decommissioned property.
- Existing guidance on safeguarding of fissile materials could be addressed more directly to specific safeguards needs as decommissioning progresses.

2.3 APPROACHES TO FINANCING DECOMMISSIONING

Three general approaches to financing future decommissioning costs are identified. They are: 1) payment of costs when they are incurred during decommissioning, 2) creation of a sinking fund by annual payments during the operating lifetime of the facility, and 3) an initial payment into a trust fund at the time of facility startup. A set of five criteria is identified that may be helpful in evaluating the desirability of each of these financing approaches. These criteria are: 1) the extent to which decommissioning is financially assured, 2) the present value cost of each approach, 3) the extent to which the beneficiaries of the operation of the facility pay for its decommissioning costs, 4) the extent to which the approach facilitates the consideration of decommissioning costs when making selections between alternative power generation systems, and 5) the ease with which the approach can be administered.

2.4 SUGGESTED METHODOLOGY FOR DETERMINING ACCEPTABLE RESIDUAL RADIOACTIVE AND CHEMICAL CONTAMINATION LEVELS FOR A U-FAB FACILITY

Methodology presented in this report is used to develop numerical values for acceptable residual radioactive and chemical contamination levels for decommissioned U-Fab facilities and sites. The suggested methodology for radioactive levels is based on maximum annual doses to any member of the public from all probable radiation exposure pathways resulting from unrestricted use of the reference facility or site.

Numerical dose limits for unrestricted use of decommissioned facilities and sites by members of the public are currently being investigated by the Nuclear Regulatory Commission and the Environmental Protection Agency. For this study, it is assumed that the limit that will apply is an annual dose of 50 mrem. The use of 50 mrem in this study should not be construed as a recommendation of that value as a dose limit for decommissioned nuclear facilities, but rather as a reasonable value to use in example calculations. Example calculations for a maximum annual dose of 50 mrem are summarized in Table 2.4-1. These numbers are based on a specific radionuclide mixture expected to be present in the reference U-Fab facility and in the site soil, resulting from normal production operations and associated atmospheric releases. For the site, acceptable residual contamination levels are determined for various times between plant shutdown and final decommissioning. The principal contributors to the calculated annual dose are found to be ^{234}U, ^{235}U, and ^{238}U.

The methodology developed to determine chemical contamination levels is based on the radiological methodology. Acceptable residual chemical contamination levels are determined for inhalation and ingestion pathways. Inhalation exposure level limits are based on 0.01 of the threshold limit value, and ingestion limits are based on exposure not exceeding EPA drinking water standards. These levels provide a safety factor that accounts for exposures to most susceptible individuals.

As dose limits for decommissioned facilities and sites are promulgated by federal agencies, corresponding acceptable residual contamination levels can be

TABLE 2.4-1. Example of Acceptable Residual Contamination Levels for Unrestricted Release of the Decommissioned Reference U-Fab Plant and Site

Location	Organ	Surface Contamination (μCi/m^2) Corresponding to an Annual Dose of 50 mrem[a]
Class W Material[b]		
U-Fab Facility	Total Body	10.0
	Lungs	0.14
	Bone	0.98
	LLI	29.0
U-Fab Site	Total Body	8.5
	Lungs	2.8
	Bone	0.69
Class Y Material[c]		
U-Fab Facility	Total Body	26.0
	Lungs	0.029
	Bone	5.5
	LLI	28.0
U-Fab Site	Total Body	8.5
	Lungs	0.52
	Bone	0.69

(a) The maximum annual dose to any organ of reference from all probable exposure pathways.

(b) Class W materials are translocated from the lungs over times on the order of a few days to a few months.

(c) Class Y materials are translocated from the lungs over times on the order of 6 months to several years.

derived using the suggested methodology developed in this study for conditions specific to a particular facility. The examples of acceptable contamination levels derived in this study are specific to the facility and site conditions assumed to exist at the reference U-Fab plant.

2.5 FACILITY CHARACTERISTICS

The plant is assumed to be operated for 40 years, at a production rate of 1000 metric tons of uranium oxide fuel per year. The feed to the plant is slightly enriched uranium in the chemical form of UF_6. The plant uses two head end processes for converting the UF_6 to UO_2. The primary method is a chemical process in which UF_6 is reacted with ammonia to form ammonium diuranate (ADU) precipitate, and reduction and calcining of the ADU to dry UO_2 powder. The secondary method involves direct conversion of the UF_6 to U_3O_8 to UO_2 powder in a reduction-calciner. The UO_2 powder from each process is subsequently milled and pressed into pellets that are sintered and ground to size. The pellets are loaded into rods and sealed. The rods are assembled into fuel bundles ready for use in light water reactors.

Liquid waste streams containing uranium are kept separate to facilitate uranium recovery operations. They are classified as nitrate wastes, fluoride wastes, and radwastes. Uranium-bearing nitrate sludge is sent to an offsite contractor for uranium recovery. Calcium fluoride solids entrap uranium residuals in the waste from the UF_6 to UO_2 conversion process. CaF_2 solids are stored onsite for eventual reprocessing to recover the uranium residuals.

2.6 ESTIMATED RADIONUCLIDE INVENTORIES

Estimates are made of the amount of residual radioactivity within the plant (after final operational flushing and chemical decontamination) and on the plant site from 40 years of normal operation. Numerous activities could occur during the operational phase of the facility that could significantly affect radionuclide inventories. The inventories used in this study are presented in Table 7.4-1 of Section 7 and are based on engineering judgment that considers the characteristics of the reference facility. After operational inventory cleanout, the total uranium inventory in the building is estimated to be about 270 kg. Chemical decontamination activities during decommissioning reduce this inventory to about 100 kg of uranium.

2.7 DECOMMISSIONING METHODS

A plan and a set of procedures are developed for each of the two alternatives studied for decommissioning the reference U-Fab plant. Decommissioning is assumed to start after termination of production operations. Termination includes a process inventory cleanout and audit similar to that done periodically between operating campaigns for material segregation and accountability.

The first decommissioning phase for each alternative is termed "planning and preparation." This phase takes place during the last year of normal plant operation. During this phase, the decommissioning staff is assembled; a decommissioning plan and procedures are prepared; safety and safeguards analysis reports and an environmental impact evaluation are prepared; an application for an amended license is prepared; a quality assurance program is established; health and safety requirements are developed; and bulk quantities of unneeded process chemicals, radioactive materials, and nonessential uncontaminated equipment are removed.

In general, decommissioning work is assumed to be done on the basis of 5 days per week with one shift of workers. Certain operations such as calcium fluoride recovery and plant security are carried out on a 3-shift-day, 7-day-week basis.

2.7.1 DECON Procedures

After about 7 months of planning and preparation, DECON activities are initiated. These activities are generally divided into four phases:

- physical and chemical decontamination of equipment and facilities
- removal of equipment and facilities
- materials handling, packaging, and shipping
- final cleaning and survey.

These phases can proceed simultaneously in different parts of the facility. Approximately 9 months are needed to complete all phases and release the site for unrestricted use.

Chemical decontamination involves flushing of internal surfaces of process piping and equipment. Physical decontamination involves disassembly of equipment and enclosures and removal of the contaminated materials. Physical decontamination also involves removal of contaminated portions of structural and site materials. These contaminated materials are packaged and transported offsite as waste, or they are processed through the plant radwaste and incinerator facilities for recovery. Upon completion of dismantlement, decontamination, shipping, and final cleaning and survey, the facility can be released for unrestricted use.

2.7.2 Passive SAFSTOR Procedures

After about 6 months of planning and preparation, active decommissioning efforts (preparations for safe storage) are divided into four phases:

- waste treatment facilities stabilization
- equipment deactivation
- isolation of contaminated areas
- final preparations for safe storage.

Many of the decommissioning activities associated with preparations for safe storage can proceed simultaneously. It is estimated that approximately 3 months are required to place the plant and site in passive SAFSTOR.

Decontamination efforts for passive SAFSTOR are similar to those performed for DECON, but are performed to a lesser extent. Also involved are deactivation and isolation of contaminated areas, sealing of contamination by adding durable seals or covering with paint, refurbishment of the plant ventilation system, and installation of improved alarm and protection systems for fire, intrusion, or malfunctioning equipment.

Activities during the safe storage period include routine inspection, corrective and preventive maintenance on the safety systems, environmental surveillance, and prevention of unauthorized intrusion by man.

Safe storage must be terminated eventually by deferred decontamination. Activities are generally similar to those for DECON, with allowances for the prior decontamination efforts and for retraining of new decommissioning staff. An estimated 17 months are needed to decontaminate the facility at the conclusion of the period of safe storage, including 8 months for planning and preparation and 9 months of active decommissioning.

2.8 COSTS

Table 2.8-1 summarizes the estimated costs in 1978 dollars for the two decommissioning alternatives analyzed in this study. These cost estimates include 25% contingencies. For DECON, the cost is estimated to be \$3.54 million; for placing the plant in passive SAFSTOR, \$0.85 million; and for deferred decontamination of the plant \$3.84 million. The annual cost of maintaining the plant in passive SAFSTOR is estimated to be about \$0.28 million. Therefore, passive SAFSTOR with final decontamination after 10 years is estimated to cost about \$7.5 million. All costs are in non-discounted 1978 dollars. This analysis of decommissioning costs indicates an economic disincentive to defer decontamination, primarily because of the cost of safe storage. Deferred decontamination costs more than DECON because of increased labor costs for the following items: 1) removal of seals and barricades erected for safe storage, 2) replacement and testing of ventilation filters, and 3) training of the decommissioning staff.

TABLE 2.8-1. Summary of Estimated Costs for Decommissioning the Reference U-Fab Plant (Millions of 1978 Dollars)(a)

Item	DECON	Passive SAFSTOR with Deferred Decontamination After 10 Years
Initial Decommissioning(b)	3.54	0.85
Safe Storage	--	2.83
Deferred Decontamination(b)	--	3.84
Total Costs	3.54	7.52
Other Possible Costs(c)		
Chemical Sludge Disposal	0.40	--
Contaminated CaF_2 Disposal	9.00	--
Misc. Contaminated Material	1.20	--
Total Other Possible Costs	10.6	--

(a) Cost estimates include 25% contingencies.

(b) Costs are based on five shifts/week (single shift) for most of the decommissioning. Decommissioning on a two-shift/day basis would reduce time requirements but costs would be about the same.

(c) These costs are not appropriate if the wastes are disposed of during operation or plant cleanup or if the uranium in the solids is recovered.

The breakdown of costs by major cost element is given in Table 2.8-2. Labor costs are 60 to 80% of the total costs. Thus, there is considerable incentive to develop plans or techniques that could reduce labor costs. The deferral of decontamination requires additional costs to modify facilities, to reinstitute a trained decommissioning organization, and to provide a new safety analysis and an additional license application. Also, passive SAFSTOR costs increase with longer storage time. Other costs of deferred decontamination are about the same as for DECON.

Cost of management of the wastes from DECON amounts to about 7% of the total costs. Of the waste management costs, transportation accounts for about 20% and disposal costs account for about 50%.

TABLE 2.8-2. Decommissioning Cost Distribution of the Reference U-Fab Plant (Millions of 1978 Dollars)(a)

Item	DECON	Passive SAFSTOR with Deferred Decontamination After 10 Years(b)
Labor	2.05	5.94
Materials	0.15	0.21
Waste Management	0.24	0.24
Subcontracts	0.08	0.08
Utilities, Taxes	1.02	1.05
Totals	3.54	7.52

(a) Includes 25% contingency.
(b) Includes the costs of safe storage for the years before decontamination.

2.9 SAFETY

Generally conservative estimates are made of the potential safety impacts on the public and on the workers from decommissioning the reference U-Fab plant. Events are analyzed relative to potential consequences and approximate frequency of occurence. Radiation exposures from normal operations and potential accidents are investigated for immediate and deferred decommissioning activities, safe storage of partly decommissioned facilities, and transportation of radioactive materials. The results are summarized in Table 2.9-1.

TABLE 2.9-1. Summary of Safety Analysis - Decommissioning of Reference U-Fab Plant

Type of Safety Concern	Source of Safety Concern	Units	DECON	Passive SAFSTOR with Deferred Decontamination After 10 Years(a)
Public Safety(b)				
Radiation Dose	Decommissioning Operations	man-rem(c)	0.06	0.06
	Transportation	man-rem	0.53(d)	0.53(d)
	Safe Storage	man-rem(c)	NA	0.05
		Totals	0.57	0.62
Occupational Safety				
Serious Lost-Time Injuries	Decommissioning Operations	no./mode	0.42	0.46
	Transportation	no./mode	0.03	0.03
	Safe Storage	no./mode	NA	0.47
		Totals	0.45	0.96
Fatalities	Decommissioning Operations	no./mode	0.003	0.003
	Transportation	no./mode	0.002	0.002
	Safe Storage	no./mode	NA	0.005
		Totals	0.005	0.010
Radiation	Decommissioning Operations	man-rem	15.7	16.1
	Transportation	man-rem	2.6(e)	2.6(e)
	Safe Storage	man-rem	NA	6.0
		Totals	18.3	24.7

(a)Time after reference facility final shutdown; includes 1 year of preparations for safe storage.

(b)Radiation doses from postulated accidents are not included. They are given in Section 11 of this report.

(c)50-year committed dose equivalent to the lung.

(d)These doses would increase 0.39 man-rem if the stored CaF_2 is disposed of.

(e)These doses would increase 20 man-rem if the stored CaF_2 is disposed of.

The 50-year committed dose equivalent to the populace located within 80 km of the facility from airborne releases resulting from DECON activities is conservatively estimated to be about 0.06 man-rem to the lungs. This radiation dose is a very small fraction of the dose received by the affected population from naturally occurring radiation. Radiation doses to members of the public during the period of passive SAFSTOR are essentially negligible. All of the postulated radiation doses are low, primarily because of greatly reduced radionuclide inventories during most of the decommissioning operations and the utilization of efficient process and ventilation filtration systems.

The estimated occupational radiation dose for DECON is 15.7 man-rem, and the doses for passive SAFSTOR are 0.4 man-rem for preparations for safe storage, 0.6 man-rem for each year of safe storage, and 15.7 man-rem for deferred decontamination. Because of the long-lived radionuclides, deferral of decontamination does not reduce the occupational dose.

Potential radiation doses to members of the public from accidents are generally found to be quite low. The major accident postulated with a high frequency (greater than 10^{-2} per year) is the loss of an intermediate HEPA filter immediately following decontamination of the upstream ductwork during decontamination of the plant. This accident is estimated to give a 50-year committed dose equivalent of 1.9×10^{-4} rem to the lungs of the maximum-exposed individual.

Chemical pollutants that could be released during decommissioning activities are found to come from residuals from plant operation and from decontamination chemicals. Chemical releases during decommissioning are examined and the quantities released are not found to have a significant effect on the public. Occupational exposure to toxic chemicals is assumed to be limited by conventional industrial contamination control techniques.

2.10 WASTE MANAGEMENT

Radioactive wastes generated during the decommissioning of a U-Fab plant are packaged and shipped to a licensed low-level waste burial ground. There are no high-level or TRU wastes present in the reference plant. Only about

3% (1100 m^3) of the theoretical total compacted radioactive waste volume of 36,900 m^3 for the reference plant is shipped to low-level waste burial. The remainder is either decontaminated and disposed of in commercial waste dumps or is processed to recover residual uranium. Most of the material not sent to licensed burial consists of calcium fluoride solids from the fluoride waste lagoons (29 [illegible]00 m^3). The rest of the waste (about 6200 m^3) is decontaminated and sent to the local commercial dump or is sold for scrap.

CaF_2 is assumed to be processed by a contractor to recover the residual uranium. The decision to recover the uranium would be based on an economic study to determine if the cost of recovery would be less than the value of the uranium recovered and of any valuable products of the recovery process. The economic value of the recovered uranium (estimated to be $30 million at end of 40-year plant life) and other valuable products of the recovery process is expected to exceed the cost of recovery.

If the calcium fluoride and other wastes that are assumed to be decontaminated are shipped instead to low-level waste burial, the additional cost is estimated to be $10.6 million. Licensed disposal of the CaF_2 is estimated to be 85% of the cost (approximately $9.0 million).

Development of methods to recover the uranium from the plant wastes (mainly CaF_2) would help minimize the volume of radioactive waste generated during decommissioning.

2.11 STUDY CONCLUSIONS

Decommissioning of a U-Fab plant is technically feasible with current technology. Decommissioning can be done with virtually no impact on the safety of the general public. Further development of some techniques (such as decontamination and waste volume reduction) could lead to reductions in costs.

A comparison of the decommissioning alternatives for the various parameters used in this study is given in Table 2.11-1. The main parameters considered are the costs, the potential radiation doses, and the impacts of the DECON and passive SAFSTOR alternatives on staffing requirements and on space requirements at waste disposal facilities.

TABLE 2.11-1. Comparison of Decommissioning Alternatives for the Reference U-Fab Plant

Parameter	DECON	Passive SAFSTOR with Deferred Decontamination After 10 Years
Decommissioning Cost[(a)] (millions of 1978 dollars)	3.54	7.52
Occupational Radiation Dose (man-rem)	15.7	22.1
Staff Required (man-years)	53.2	76.2[(b)]
Waste Volume (m^3)	1 100	1 100
Final Site Status	Unrestricted	Unrestricted

(a) Estimates include a 25% contingency.

(b) Includes 17.4 man-years for preparations for safe storage and 9.1 man-years for safe storage.

DECON costs are considerably lower than the cost of passive SAFSTOR, mainly because of the cost of safe storage. Radiation doses to workers are higher for the passive SAFSTOR alternative because of the doses received during safe storage. The total radiation doses (received mostly by the decommissioning workers) do not decrease with time for deferral of decontamination. The waste volume is essentially the same for both decommissioning alternatives.

The decontamination of U-Fab facilities is highly labor intensive. Thus, labor is a major component of the total decommissioning cost. Facility and equipment designs and decontamination systems and techniques that minimize labor could help reduce overall decommissioning costs.

The conditions in effect at a specific facility at the time it is decommissioned, including sociological aspects, may dictate the choice of the decommissioning alternative to be used. Therefore, the results and conclusions in this report should be used only in the context of the reference site and facility studied and the key bases and assumptions used.

3.0 REVIEW OF DECOMMISSIONING EXPERIENCE

This section contains a review of information from uranium fuel fabrication (U-Fab) facilities that have been decommissioned. Information specific to U-Fab facilities is limited, because only a few of the small number of commercial plants constructed have been decommissioned. Information in the open literature regarding these decommissioning projects is fragmentary and poorly documented. For these reasons, information on the decommissioning of other types of uranium processing facilities is included in this section, since their decommissioning problems are similar in nature to those anticipated for commercial U-Fab plants. These facilities include several high-enriched fuel fabrication plants where the buildings were decontaminated, usable source and special nuclear materials were recovered, and unusable containment enclosures and processing equipment were discarded as radioactive waste to low-level waste burial grounds.

To date, the decommissioning of most uranium-handling facilities has not resulted in the release of the facility and site for unrestricted use.

3.1 HISTORY AND STATUS

Table 3.1-1 gives a brief outline of information on U-Fab facilities in the United States. A discussion of experience at decommissioned U-Fab facilities follows.

Several U-Fab plants have ceased operations and are in various stages of decommissioning. Two facilities have high-level enrichment operations that have been shut down, leaving a low-level enriched operation still in production. These are a Babcock and Wilcox plant at Apollo, Pennsylvania, and a Combustion Engineering plant at Hematite, Missouri. At the Combustion Engineering plant, there has been a partial cleanup, but at neither plant has the facility been completely decommissioned. Babcock and Wilcox also has a high-level enriched plant at Leechburg, Pennsylvania, that is shut down. Some equipment has been removed, but the ventilation system is still intact. United Nuclear closed a high-level enriched plant at New Haven, Connecticut, several years ago and U.S. Nuclear closed a high-level enrichment test and

TABLE 3.1-1. Information on LWR Fuel Fabrication Plants in the U.S.

Licensee	Plant Location	Plant Feed Material	Plant Product	Present Status
Babcock and Wilcox	Lynchburg, VA	UO_2 Pellets	Fuel Assemblies	Operating
Babcock and Wilcox(a)	Apollo, PA	UF_6	UO_2 Powder or Pellets	Operating
Combustion Engineering	Windsor, CT	UO_2 Powder	Fuel Assemblies	Operating
Combustion Engineering(b)	Hematite, MO	UF_6	UO_2 Powder or Pellets	Operating
Exxon Nuclear Co.	Richland, WA	UF_6	Fuel Assemblies	Operating
General Electric	Wilmington, NC	UF_6	Fuel Assemblies	Operating
General Electric	Pleasanton, CA	UF_6	Fuel Assemblies R&D	Dismantled
Kerr-McGee(c)	Crescent, OK	UF_6	UO_2 Powder or Pellets	In Standby
Nuclear Fuel Services(c)	Erwin, TN	UF_6 Pellets	UO_2 Powder or Pellets	Shutdown
United Nuclear	New Haven, CT	UO_2 Pellets	Fuel Assemblies	Shutdown
Westinghouse	Columbia, SC	UF_6	Fuel Assemblies	Operating

(a)Formerly Nuclear Materials and Equipment Corp. (NUMEC).
(b)Formerly Gulf United Nuclear.
(c)Kerr-McGee and Nuclear Fuel Services data are from USAEC Regulatory files.

research facility at Oak Ridge, Tennessee. The latter has been decommissioned and released for unrestricted use by the NRC. Atomics International at Canoga Park, California, decommissioned a small plant which manufactured highly enriched uranium fuel for the space nuclear program. The plant has been removed and the site used for other purposes, but no documentation on the decommissioning is available in the open literature.

Among the low-level enriched U-Fab plants, two facilities that have been shut down are examples of decommissioning experience. A Kerr-McGee plant at Crescent, Oklahoma, has been partly decommissioned. The plant is still intact, and the waste ponds were cleaned up and waste was loaded into drums and shipped to a low-level waste burial ground.

The most complete experience with decommissioning a low-enrichment plant has been the General Electric U-Fab plant in San Jose, California. At shutdown, the area was cleaned to administrative control levels not exceeding 1000 dpm/100 cm^2 for alpha radiation. Decommissioning was accomplished by dismantling and removing all of the equipment and ventilation system and cleaning the building. Pipes and lighting fixtures were vacuumed or hosed down with water; fluorescent tubes were replaced; ceilings, walls, pipes, and lighting fixtures were damp-wiped; baseboard moldings and tile floors were removed; and concrete floors were vacuumed and mopped. Pump basins that had been formed by constructing concrete berms were cleaned up by removing the berms and wet-grinding any hot spots. The decommissioning effort was more extensive than should have normally been necessary because, on one occasion, an accident occurred that released a large amount of UF_6 inside the plant. This accident contaminated not only all of the building and fixture surfaces in the production areas but also the otherwise clean areas.

3.2 LESSONS LEARNED FROM DECOMMISSIONING EXPERIENCE

The necessary technology for decontamination and decommissioning exists and has been successfully applied to a wide variety of nuclear installations. Because of the uniqueness of each facility, no two have had identical problems or conditions. However, the basic approach to any mode of decommissioning remains virtually unchanged (i.e., the gathering of staff manpower and a period of planning and preparation, followed by chemical decontamination and mechanical removal operations). The fundamental course of events varies primarily with building design and with the inherent refinements potentially available or needed for a given facility. Areas that could use improvements in technology are remote handling equipment, disassembly techniques, decontamination techniques, and waste volume reduction.

From the standpoint of decontamination, all walls should be seamless and have a smooth, durable surface to aid in flushing and cleaning. Separation of process areas into compartments allows for more effective control of radioactive migration. Sealed-off access areas behind processing pipes or glove boxes provide an effective means of controlling radioactive contamination, while also providing a suitable work area for personnel. Building and glove box fluid services, located either beneath the floor level or in some area away from work areas, tend to minimize the hazardous effects of pipe leaks. Location of building service systems (such as vacuum systems, corrosive vapor removal systems, and glove box exhaust systems) in isolated areas allows maintenance work to be performed with little interruption of ongoing processing operations. These are some of the most obvious improvements in design that could enhance decommissioning. A more comprehensive listing of design considerations favorable to decommissioning of the reference facility is given in Section 13. New techniques, as well as improvements in current decommissioning techniques, can be expected to occur. These improvements, in turn, will directly impact future decommissioning considerations.

4.0 DECOMMISSIONING ALTERNATIVES AND STUDY APPROACH

Once a uranium fuel fabrication (U-Fab) plant reaches the end of its useful operating life, it must be decommissioned or placed in a condition that future risk to public safety from the facility and its site is within regulatory limits. Several alternatives are possible to satisfy the general requirements for decommissioning. These alternatives range from minimal initial cleanup requiring continued surveillance and physical security followed by later more complete cleanup, to immediate complete cleanup and removal of contaminated materials resulting in unrestricted public use of and access to the facility and site. For all of the alternatives categorized, the goal is unrestricted access of the facility.

In this section, decommissioning alternatives are evaluated for a reference U-Fab plant and the reasons for selecting certain alternatives are discussed. The approach of this decommissioning study is also discussed. Certain assumptions must be made in the absence of specific data, to permit general application of the results. The important overall assumptions for the study and the rationale for their selection are identified.

4.1 DECOMMISSIONING ALTERNATIVES

The general characteristics of the basic decommissioning alternatives are summarized in Table 4.1-1. Each of the alternatives as applied to the reference U-Fab plant is defined and discussed in the following subsections.

4.1.1 Definition of and Rationale for DECON

DECON (immediate decontamination to unrestricted release) provides a way to meet the requirements for termination of a nuclear possession-only license in the near term, thus eliminating long-term security, maintenance, and surveillance needs and making the site available for unrestricted use within about 1 year following facility shutdown. To accomplish DECON requires that all potentially contaminated systems be disassembled and removed from the facility and transported to a regulated disposal site.

TABLE 4.1-1. Characteristics of the Various Decommissioning Alternatives

Alternative	Facility Status	Facility/Site Use
DECON	Equipment - removed if radioactive Surveillance Staff - none Security - none Environmental Monitoring - none Radioactivity - removed Surveillance - none Structures - removal optional License - terminated	Facility - Unrestricted Site - Unrestricted
SAFSTOR		
Custodial	Equipment - some operating Surveillance Staff - some required Security - continuous Environmental Monitoring - continuous Radioactivity - confined Surveillance - continuous Structures - intact License - amended version maintained	Facility and site are restricted to nuclear use until deferred decontamination is accomplished.
Passive	Equipment - none operating Surveillance Staff - routine periodic inspections Security - remote alarms Environmental Monitoring - routine periodic Radioactivity - immobilized/sometimes sealed Surveillance - periodic Structures - intact License - amended version maintained	All of the facility and most[a] of the site are restricted to nuclear use until deferred decontamination is accomplished.
Hardened	Equipment - none operating Surveillance Staff - none on site Security - temporary hardened barriers; fencing and posting; remote alarms Environmental Monitoring - infrequent Radioactivity - sealed in hardened structures Surveillance - infrequent Structures - partial removal optional License - amended version maintained	Most[a] of the facility and most[a] of the site are restricted to nuclear use until deferred decontamination is accomplished.
ENTOMB	Equipment - none operating Surveillance Staff - none on site Security - hardened barrier; fencing and posting Environmental Monitoring - infrequent Radioactivity - sealed in monolithic structure Surveillance - infrequent Structures - partial removal optional License - amended version maintained	Most[a] of the facility and some[a] of the site are restricted to nuclear use until the confined radioactivity has decayed to unrestricted release levels.

(a) Implies a release of part of the site or the facility for unrestricted use, while maintaining control of the licensed portion that contains radioactive materials above releasable levels.

In the DECON alternative, larger initial commitments of money are made in exchange for prompt availability of the plant site for other purposes, reuse of plant components, and elimination of continuing costs for security, maintenance, and surveillance.

4.1.2 Definition and Rationale for SAFSTOR

SAFSTOR includes all operations needed to prepare for safe storage, surveillance and maintenance during safe storage, and complete decontamination to unrestricted release following safe storage. The facility is placed in such a condition that risk to the public can be kept within acceptable bounds while the facility is maintained in storage, and the facility can be subsequently decontaminated to unrestricted release at the end of the safe storage period.

Several subcategories of safe storage for the SAFSTOR alternative are possible. These are:

- Hardened SAFSTOR [temporary entombment(a,b)] - A comprehensive cleanup effort is coupled with the construction of barriers around areas containing sufficient quantities of radioactivity. These barriers are of sufficient strength to make accidental intrusion impossible and deliberate intrusion extremely difficult. Surveillance requirements during safe storage are limited to detection of intrusion through the barriers and maintenance of the integrity of the structures. The primary restriction to facility and site use is that of prohibiting activities such as excavating, drilling, or any other means of breaking the barriers that isolate the radioactivity, until deferred decontamination is accomplished.
- Passive SAFSTOR [mothball,(a) protective storage(b)] - A significant cleanup effort is performed initially, sufficient to permit deactivation of the active protective (ventilation and utility) systems during the period of safe storage. The structures are strongly secured and electronic surveillance is provded to detect accidental or deliberate intrusion. During the safe storage period maintenance of the integrity of the structures is required. Plant use is limited to nuclear only while site use may be non-nuclear, with certain restrictions, until deferred decontamination is accomplished.

(a) This nomenclature is used in Regulatory Guide 1.86.(1)

(b) This nomenclature is use [illegible] NUREG-0278.

- Custodial SAFSTOR [layaway[a]] - A minimum cleanup effort is made initially, followed by a period of safe storage with the active protection systems (principally the ventilation, utility, and fire protection systems) kept in service throughout the storage period. Fulltime onsite surveillance by security forces is required to prevent accidental or deliberate intrusion into the facility and the subsequent exposure to radiation or dispersal of radioactivity beyond the confines of the facility. Use of the facility and site is generally limited to nuclear activities until deferred decontamination is accomplished.

All categories of safe storage are open-ended and some positive action is required at the conclusion of the period of safe storage to release the property for unrestricted use and terminate the license for radioactive materials. Depending on the nature of the nuclear facility and its operating history, the necessary action can range from a radiation survey that shows the property to be releasable, to dismantlement and removal of residual radioactive materials. These latter actions, whatever their scale, are generically identified as deferred decontamination.

SAFSTOR is used as a means to satisfy the requirements for protection of the public while minimizing the initial commitments of time, money, occupational radiation exposure, and waste repository space. Modifications to the facility during the preparation stage are limited to those that assure the security of the buildings against intruders and to those required to assure containment of radioactive or toxic material. It is generally not intended that the facility would ever be reactivated, although reactivation is a possible option. For a U-Fab plant, there is no significant decay of residual radioactivity and personnel exposure to radiation is not reduced during reasonable periods of safe storage (a few tens of years). Thus, placing an inactive U-Fab facility in safe storage for a reasonable period of time produces no benefit in terms of reducing radiation exposure to decommissioning personnel.

The reduced initial effort (and cost) of the SAFSTOR alternative is tempered somewhat by the need for continuing surveillance and physical security

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(a) This nomenclature is used in NUREG-0278.[2]

to assure the protection of the public. For all SAFSTOR alternatives, electronic surveillance devices are in service full-time, with off-shift readouts monitored in a local law enforcement office or a private security agency. These devices, which monitor for intruders, radiation-level increases, and fire detection, require periodic checks and maintenance. For custodial SAFSTOR, a small operating and security staff is required at the retired facility to provide for equipment operation, general maintenance, and plant security. This staff also guards against unauthorized access to any residual inventory of Special Nuclear Materials (SNM).

Maintenance of the facility's outer-confinement barriers and surfaces and an on-going program of environmental surveillance are also necessary for all SAFSTOR alternatives.

The duration of the period of safe storage before final decommissioning may vary, depending on the needs of the plant owner, based primarily on economic and safety trade-offs. For example, if the value of the site property for unrestricted use is large and the cost of storage is also large, there would be incentive to complete decontamination reasonably soon. On the other hand, a potential alternative use of the facility may suggest maintaining the facility in safe storage for an extended time period. Regulatory requirements and public concerns may also influence the duration of the safe storage period.

At the end of the safe storage period, several things remain to be done before the facility can be made available for unrestricted use and before the amended license for radioactive materials can be terminated. The remaining quantities of long-lived radioactivity that exceed unrestricted release limits must be removed and contaminated equipment must be packaged and removed to a regulated disposal site. Once the remaining radioactive materials are less than the unrestricted release limits, the nuclear facility license can be terminated.

For a U-Fab plant there is not much difference in the amount of cleanup required for either the passive or custodial SAFSTOR alternatives. Passive SAFSTOR involves shutdown of the ventilation and utility systems, and less surveillance is required during the safe storage period than for the custodial alternative. Thus, the passive SAFSTOR alternative appears to be most applicable to short-term inactivation (e.g., 5 to 10 years) of a U-Fab plant; to a multi-facility site where surveillance, security, maintenance and operating capabilities exist; or to the situation where the likelihood exists for later use of the retired facility.

Deferred decontamination, as would occur at the end of an extended period of safe storage, perhaps a few tens of years, continues decommissioning activities beyond those done during the preparations for safe storage. Decontamination activities will still be controlled by residual long-lived radioactivity in the plant. The benefits to be gained by deferred decontamination of a U-Fab plant (i.e., the possibility of re-use of the facility and the deferral of decontamination costs) will depend on the characteristics of each facility at the time of final production shutdown. These benefits must be weighed against disadvantages of deferring decontamination (i.e., costs of safe storage, value of and need for the reclaimed site, and the need to familiarize the new decommissioning staff with the facility.

4.1.3 Definition of and Rationale for ENTOMB

Based on the guidance in NRC Regulatory Guide 1.86,(1) entombment of a nuclear reactor facility requires the encasement of the radioactive materials in concrete or other structural materials sufficiently strong and structurally long-lived to assure retention of the radioactivity until it has decayed to levels that permit unrestricted use of the site. The amount and half-life of the residual radioactivity in the facility to be entombed determines the time period that the integrity of the structure must be assured and whether or not re-entry for additional decommissioning is required. ENTOMB refers to the entire process of first entombing and then continuing some surveillanceto assure the integrity of the structure until the entire site is confirmed to have decayed enough to allow unrestricted release.

The Environmental Protection Agency (EPA) is developing generally applicable environmental protection criteria for management of all radioactive wastes that will impact NRC decommissioning standards and guidelines. In a background report entitled Considerations of Environmental Protection Criteria for Radioactive Waste,(3) the EPA proposes a criterion limiting reliance on institutional controls to a finite period of time. The EPA suggests that the use of institutional control to protect the public from hazards in retired nuclear facilities should be limited to a period of 100 years at most and preferably to less than 50 years. After the allowable institutional care period is over, the site would have to meet radioactive protection levels established for release for unrestricted use.

Extrapolating from the intent of Regulatory Guide 1.86, a nearly identical draft guide relating to non-reactor facilities,(4) and the EPA-proposed criteria,(3) it is concluded that any "permanently" entombed structure must be designed to outlast any contained radiological or chemical hazard to man, or to be designed perhaps to dilute these hazards to innocuous levels as the structure disintegrates. Unless the structure is to be re-entered later and decommissioned further, these potential chemical and radiological hazards should vanish in no more than about 100 years, in order to fulfill the bases for ENTOMB. Taking no credit for the dilution effects of entombment, these criteria and guidance virtually prohibit entombing any nuclear facility containing long-lived radionuclides or toxic chemical elements.

In addition, while it is reasonable to assume that man can design and construct high-integrity, long-lived surface structures, it is also reasonable to assume that any long-term human controls on or responsibility for that facility will ultimately disappear and that the long-lived radionuclides, chemicals or toxic elements contained therein will ultimately be dispersed into the environment. The ENTOMB alternative also results in the proliferation of decommissioned plant sites containing residual radioactivity. Therefore, ENTOMB is considered not viable for a U-Fab plant.

4.1.4 Alternatives Selected for Study

The principal alternative selected for study is DECON (immediate decontamination), since the half-lives of the uranium isotopes are so long (^{235}U: 7×10^8 years; ^{238}U: 4.5×10^9 years) deferring decontamination for any reasonable time period (<100 years) would have no effect on the levels of contamination or the radiation dose rates.

The only likely reason to select a safe storage alternative would be if the owner wished to retain the capability to restart the plant sometime in the near future (probably within 5 years). Since passive SAFSTOR would permit restart of the facility, this alternative is also examined.

Hardened SAFSTOR or ENTOMB are not viable alternatives for decommissioning a U-Fab plant because the plant is relatively easy to decontaminate and decay of the uranium isotopes over any reasonable storage period would be negligible. Since the initial cost of either hardened SAFSTOR or ENTOMB would be greater than that of passive SAFSTOR, and the total cost of these alternatives would exceed that of DECON, there are no incentives to use these alternatives; thus, they are not considered further.

4.2 TECHNICAL APPROACH

The initial effort in this study is to develop a plan to accomplish the study objectives. The plan is developed by a team of key personnel with expertise in the primary areas of interest. The areas of expertise include fuel fabrication plants and their operation, decommissioning techniques, chemical decontamination, chemical and radiological toxicant regulations, safety analyses (including pathways of toxic materials in the environment), operational health physics, and cost and benefit estimating and analyses. The resultant approach is shown in simplified form in Figure 4.2-1. The study is then carried out by the same staff or by staff with similar backgrounds.

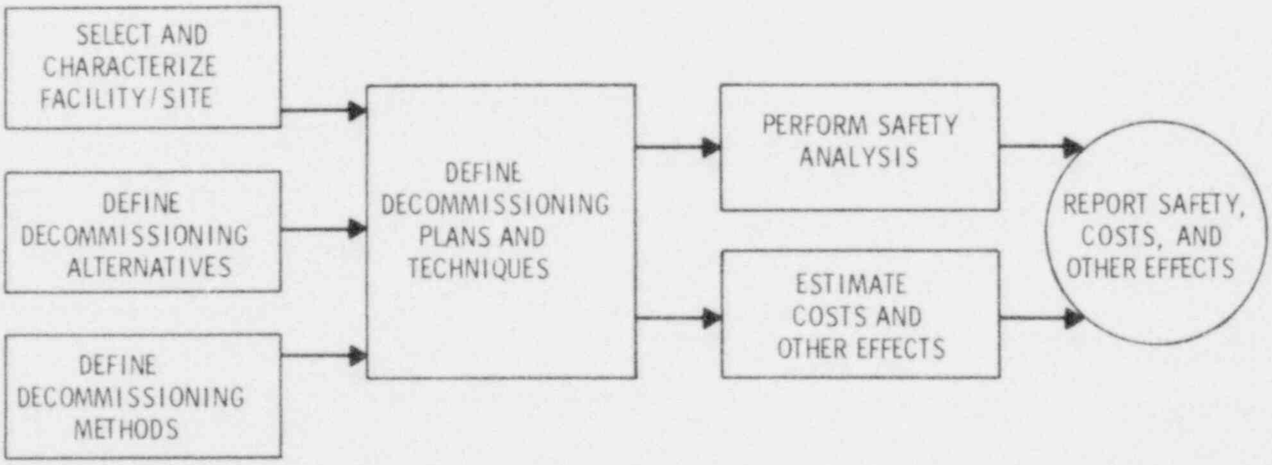

FIGURE 4.2-1. Approach for Decommissioning Study

The first step in conducting the analysis is to select and characterize the reference facility in sufficient depth to perform an engineering and safety analysis of decommissioning the facility. An existing plant is selected on the basis of having characteristics typical of U-Fab plants that will be subjected to decommissioning in the foreseeable future.

The total facility is assumed to be on a conceptual generic site that is also being used in similar and related studies of other fuel cycle facilities. A detailed description of the facility is compiled that includes information such as plant equipment and material sizes, volumes, surface areas, and weights. Pre-decommissioning conditions for the plant and site are defined, including residual radioactivity levels.

Viable decommissioning alternatives (i.e., DECON and passive SAFSTOR) and site use limitations for facilities being decommissioned (i.e., restricted to nuclear use only and unrestricted use) are selected. Related regulatory guidance is reviewed, summarized, and used as an aid and basis in the study.

Methodology is developed for defining suggested residual radioactivity levels in facilities and sites that would permit unrestricted use of decommissioned facilities, in terms of allowable radiation dose to the maximum-exposed member of the public. The variety of potential pathways through which radionuclides could reach man are considered in determining these acceptable levels. This methodology is applied to develop example acceptable levels of residual radionuclides, based on the assumed radionuclide mixtures at the plant/site.

Past decommissioning experience of facilities with characteristics related to the reference facility is reviewed. From this review, a summary of insights from these decommissioning experiences is derived and applied where applicable to this study.

Techniques for decontamination of facilities are reviewed. For both decommissioning alternatives, a work schedule and a time schedule are developed to conceptually decommission the reference facility. The techniques used are selected on the basis of engineering judgment, while maintaining a balance of safety and cost.

Safety analyses are performed for the decommissioning alternatives studied. These analyses include radiological and chemical exposures to the public and workers from normal decommissioning operations and from potential accidents. Nonradiological industrial accidents to workers are also estimated. The safety analyses utilize established data and methodology to estimate the various factors required, such as release mechanisms, dispersion pathways, and exposure modes for the released materials.

Direct costs of decommissioning are estimated, including labor, materials, equipment, packaging, transportation, waste disposal, and surveillance costs where applicable. Alternatives for financing decommissioning are examined. For both decommissioning alternatives, all of these factors are combined into an overall comparison of their safety-costs-benefits and advantages and disadvantages.

The study is documented in this report, with Volume 1 containing the main study information and Volume 2 containing supporting details.

4.3 KEY STUDY BASES

From the outset, a number of important ground rules are established to guide the emphasis of the study. These bases are derived from the primary objective of the study, which is to provide an analysis of safety, costs, and other factors involved in decommissioning a U-Fab plant. The study is intended to provide background information useful to regulators, plant designers, and operators of such facilities. From these objectives, the key bases are established for all aspects of the study to assure that the overall study objectives (see Section 1) are achieved. These key bases can have major impact on the issues of safety, cost, and time for decommissioning. Many aspects of decommissioning will change with facility location, specific facility shutdown conditions, and residual contamination levels in the plant. The bases and assumptions used in this study must, therefore, be carefully examined before the results can be applied to a different facility and site.

The key study bases are:

1. The study is to yield realistic results based on 1978 cost data. This primary basis is a requisite to meeting the objectives of the study, and provides the foundation for most of the other study bases.

2. The objective of decommissioning is to assure the continued protection of public from the residual radioactivity and any other potential safety hazards in the retired facility.

3. The study is to evaluate a real and contemporary facility. This basis is an obvious necessity to meet the study objectives and the primary basis above. The facility selected as reference for the study, the General Electric Company's Wilmington Plant, is felt to satisfy this condition.

4. The study is to include an analysis of the viable decommissioning alternatives: DECON and passive SAFSTOR.

5. Only facilities expected to contain radioactive material and contiguous areas are included in this study. Decommissioning of separate nonradioactive subfacilities is to be accomplished by conventional demolition/salvage techniques and is outside the scope of this study.

6. The U-Fab facility is assumed to have operated for 40 years prior to plant shutdown and the onset of decommissioning operations. During the operation, the plant is assumed to have had a production capacity of 1000 metric tons per year of uranium oxide fuel, based on operation of the plant by three full shifts per day, 365 days per year.

7. Current and proven decommissioning technology and techniques are used in the study. Where developmental techniques are conceptualized, they are in an advanced state of development and believed to be ready for application in this study.

8. A single decommissioning plan is evaluated for each of the two decommissioning alternatives analyzed. Where different techniques or assumptions have significant impact on the study results, the effects of alternatives are discussed at least qualitatively.

9. Decommissioning techniques conform to the principle of keeping occupational radiation doses As Low As is Reasonably Achievable (ALARA).

10. Decommissioning plans are selected to provide public/occupational safety in a cost-effective manner.

11. All personnel assigned to decommissioning operations are assumed to be experienced radiation workers with previous experience in the operation of a U-Fab plant or other similar nuclear facilities.

12. The performance of decommissioning is assumed to be relatively trouble-free; that is, no scheduling or cost allowances are made for unforeseen events that might impede the conduct of the work. This assumption may lead to somewhat optimistic results, but is believed to be achievable with good planning and preparations.

13. It is assumed that plant process areas have been kept relatively clean during the operating period to allow for easier operational maintenance. As a result, expected contamination levels are generally modest and should be reasonably consistent with the quality of operation expected in modern commercial facilities. Any major contamination episodes are assumed to have been reasonably well cleaned up immediately following the event.

14. A final operational cleanup of the more important inventories of radionuclides is done as part of normal operations, and is not charged to decommissioning. This cleanup is assumed to be routine and similar to those done periodically between normal processing campaigns to improve equipment performance, segregate materials, and to recover materials unaccounted for. Subsequent decontamination efforts are charged to decommissioning.

15. The quantity and mixture of radioactive contamination present at plant shutdown is assumed to represent an accumulation of contamination that is fairly difficult to clean during operations. Specifically, contamination inventories are assumed to accumulate at the rate of 1/40th per year of the total accumulation, for the assumed 40 years of plant operation.

16. The isotopic inventory of input to the plant is typical of that used in the manufacture of uranium fuel.

17. All materials shipped to the plant and fuel rod and waste shipments from the plant are assumed to be transported by truck. There are no rail facilities at the plant.

18. Estimates of external radiation exposure to the public and to decommissioning workers from normal decommissioning activities are based on assumptions believed to be realistic. Estimates of internal radiation exposure (i.e., those from internally deposited radioactive material) from normal decommissioning activities and from potential accidents are based on assumptions believed to be conservative.

REFERENCES

1. *Termination of Operating Licenses for Nuclear Reactors*, U.S. Atomic Energy Commission Regulatory Guide 1.86, June 1974.

2. K. J. Schneider and C. E. Jenkins, *Technology, Safety and Costs of Decommissioning a Reference Nuclear Fuel Reprocessing Plant*, NUREG-0278, U.S. Nuclear Regulatory Commission report by Pacific Northwest Laboratory, October 1977.*

3. *Considerations of Environmental Protection Criteria for Radioactive Waste*, EPA Docket No. PR-30, 40, 50, 70 (43 FR 10370), August 1978.

4. *Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-Product, Source, or Special Nuclear Material*, U.S. Nuclear Regulatory Commission Draft Guide, November 1976.

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*Available for purchase from the National Technical Information Service, Springfield, VA 22161.

5.0 REGULATORY AND SAFEGUARDS CONSIDERATIONS

A viable plan for decommissioning a low-enriched uranium fuel fabrication (U-Fab) plant must include consideration of applicable regulations that exist to ensure public and occupational safety. Because of the anticipated presence of contaminated facilities and dispersed forms of special nuclear material (SNM) in shutdown U-Fab plants, consideration must also be given to the necessity and methods for safeguarding the material. These issues are discussed in general and as they apply to the reference U-Fab plant in the following sections.

5.1 EXISTING REGULATIONS, STANDARDS AND GUIDES

This section provides a general discussion of the background of present regulatory responsibility and the division of the responsibility among the regulatory agencies. In the past, decommissioning activities have not been a principal focus of government regulatory activity. Although an extensive framework of government requirements apply to decommissioning of nuclear facilities, many of the requirements that affect decommissioning do so only indirectly. Extensive government requirements regarding nuclear facility construction and operation, the possession of certain nuclear materials, and limitations of occupational radiation doses are examples of requirements that apply to decommissioning but that were originally directed towards some other primary purpose.

Regulations and guidelines in this area are dynamic and national policy relating to the LWR nuclear fuel cycle is changing and new regulations are forthcoming. The U.S. Nuclear Regulatory Commission (NRC) is considering the development of a more explicit overall plan with regard to decommissioning.(1) With increasing public and regulatory attention being paid to decommissioning issues, requirements can be expected that will have the purpose of establishment of rules for governing the decommissioning of nuclear facilities.

5.1.1 Federal Jurisdiction

Several federal agencies have jurisdiction that can affect the decommissioning of nuclear facilities. The principal agencies with jurisdiction are the NRC, the Environmental Protection Agency (EPA), the Department of Transportation (DOT), and the Department of Energy (DOE). This subsection briefly identifies these agencies and summarizes their regulatory jurisdictions, as identified in Table 5.1-1.

TABLE 5.1-1. Principal Federal Agencies and Statutory Authority that May Affect Decommissioning

Agency	Statutory Authority
Nuclear Regulatory Commission	• Atomic Energy Act of 1954 • Energy Reorganization Act of 1974
Environmental Protection Agency	• Reorganization Plan No. 3 of 1970 • Clean Air Act Amendments of 1977 • Safe Drinking Water Act
Department of Transportation	• Hazardous Materials Transportation Act
Department of Energy	• Energy Reorganization Act of 1974 • Department of Energy Organization Act

Pursuant to the Energy Reorganization Act of 1974, the AEC was abolished.(2) The DOE assumed the disbanded AEC's research and development functions and its promotion of new technology activities and the NRC inherited its regulatory authority under the Atomic Energy Act of 1954.(3) Among other things, NRC is responsible for assurance of safety to life and property from the civilian use of nuclear material. NRC authority extends to all persons who possess, use or transfer byproduct, source, or special nuclear materials.

The EPA is the federal government's chief environmental regulator. The EPA assumed the duties of the Federal Radiation Council under the President's Reorganization Plan No. 3 of 1970.(4) The EPA has authority to regulate radioactive emissions into the air under the Clean Air Act Amendments of 1977.(5) The EPA also has authority to regulate doses from radioactive discharges under the Safe Drinking Water Act.(6) Under these authorities, the EPA has established maximum contaminant levels in public drinking water systems. To date, regulations have not been issued by the EPA that establish standards for radioactive contaminant levels in drinking water.

The principal federal agencies concerned with the transportation of radioactive materials are the DOT under the Hazardous Materials Transportation Act of 1974,(7) and the NRC under the Atomic Energy Act of 1954. Federal safety regulations concerning nuclear materials transportation are outlined in Reference 8.

The transportation or packaging for transport of radioactive material is subject to issuance of the appropriate licenses. Applicants for a license to package or to transport radioactive material must show by a combination of analysis and experiments that the proposed package or transport vehicle satisfies all the requirements set forth in the Code of Federal Regulations.

The following Federal Regulations are applicable to the transport of radioactive materials:

- Title 49 Code of Federal Regulations Parts 170-199 (49 CFR 170-199) - DOT regulations governing the transport of hazardous materials.
- 10 CFR 71 - NRC regulations governing the packaging and shipment of radioactive materials.
- 14 CFR 103 - FAA regulations for shipment of radioactive materials by air.
- 47 CFR 146 and 149 - U.S. Coast Guard regulations governing the shipment of radioactive materials by water.
- 10 CFR 73 - NRC regulations for the protection of special nuclear material in transit.

The DOT and the NRC regulations are the most important for shipments made during the decommissioning of nuclear facilities.

Occupational safety is also of major importance during decommissioning. Radiation protection to workers is regulated by 10 CFR Part 20. Section 20.101 defines the external exposure limits. The operating philosophy of ALARA (As Low As is Reasonably Achievable) applies to these exposure limits. The NRC describes this operating philosophy in Regulatory Guide 8.8, "Information Relevant to Maintaining Occupational Radiation Exposure as Low as Practicable (Nuclear Reactors)," and Regulatory Guide 8.10, "Operating Philosophy for

Maintaining Occupational Radiation Exposure as Low as is Reasonably Achievable." Although not specifically cited for application to decommissioning activities, the guides are intended to apply. Additional information can be found on how to comply with the ALARA concept in the NRC Standard Review Plan, Section 12.1, "Assuring that Occupational Radiation Exposures are As Low As is Reasonably Achievable."

One of the goals of decommissioning a nuclear facility is to make the land available for other uses if desired. To release the facility and/or site for unrestricted use, the residual radioactive contamination must be at a level acceptable for public protection. Several attempts have been made to define the permissible levels of residual radioactivity. Guidance is found in Regulatory Guide 1.86(9) and 40 CFR 190(10) and the proposed ANSI Standard N328, Control of Radioactive Surface Contamination on Materials, Equipment and Facilities to be Released for Uncontrolled Use. Another guidance(11) that the NRC uses for terminations of byproduct, source, and SNM licenses (similar to Regulatory Guide 1.86) contains a table of "Acceptable Surface Contamination Levels" identical to that in Regulatory Guide 1.86.

The DOE may also play an important role in nuclear decommissioning. The DOE owns and operates nuclear facilities as well as transportation equipment. It will operate the federal high-level nuclear waste repositories (which will be licensed by NRC). In addition, some have proposed that the DOE also operate low-level radioactive waste burial grounds.(12) Accordingly, the DOE may make an important contribution to the NRC's establishment of standards and specifications for radioactive wastes and decommissioned facilities and equipment that require internal disposal in government waste repositories.

Thus, the NRC, the EPA, the DOT, and the DOE are the federal agencies with the principal responsibilities affecting decommissioning. To the extent that regulations of more than one agency apply, a nuclear facility operator needs to comply with all such regulations.

5.1.1.1 NRC Regulations

U-Fab plants are currently licensed under 10 CFR 70. However, 10 CFR 50, which applies to reactors, deals more with decommissioning issues than does part 70. It is anticipated that, in the future, regulations much like those that exist in Part 50 will be established in Section 10 CFR 70 for U-Fab facilities and other facilities licensed under Part 70. NRC ideas on improving regulations for decommissioning are outlined in NUREG-0590(13). The references currently existing in 10 CFR 50 that relate to decommissioning activities for reactors include 10 CFR 50.33(f) relating to financial qualifications for facility shutdown, 10 CFR 50.82 outlining information and procedures for license termination, 10 CFR 51.5(b) relating to environmental impact statement requirements in licensing proceedings involving decommissioning Regulatory Guide 1.86 on decommissioning of nuclear reactors,(9) and guidelines for decommissioning other nuclear facilities.(11)

10 CFR 50.33(f) requires that the applicant for an operating license provide information to show:

> "That the applicant possesses or has reasonable assurance of obtaining the funds necessary to cover the estimated costs of operation for the period of the license or for five years, whichever is greater, plus the estimated costs of permanently shutting the facility down and maintaining it in a safe condition."

As can be seen, this regulation is not specific or detailed but leaves open for development on a case-by-case basis the information and activity necessary to provide a "reasonable assurance" of the applicant's financial qualifications.

Appendix C of 10 CFR 50 does little to elaborate on the information required under 10 CFR 50.33(f) for decommissioning financing. While construction financing information requirements are comparatively detailed, financial information requirements for operating and shutdown are basically repeated from 10 CFR 50.33(f). The NRC is now considering the need for additional assurance that adequate funds are available for decommissioning when required.

5.1.1.2 License Termination

Under 10 CFR 70.32(h) the licensee must notify the NRC when he decides to permanently shut down his plant. The licensee will request amendment of his license to allow him to possess radioactive and/or special nuclear materials but not to operate the facility in a production mode. Because of the nature of some of the decommissioning activities anticipated at the site, the NRC may elect to issue an amended license with administrative controls and facility requirements appropriate for the decommissioning option selected. The rationale behind this logic is that, although the plant operating functions have changed significantly during decommissioning, many unit operations may be similar (i.e., chemical decontamination, waste treatment, and solidification). There will be active operations conducted in the plant involving radioactive materials and utilizing existing systems and components that can result in release of effluents to the environment.

The NRC requirements for terminating a license for nuclear reactors and fuel reprocessing plants are contained in 10 CFR 50.82. They require an application that specifies certain information on planned decommissioning procedures. The regulation authorizes termination procedures, specifies additional conditions, provides for notice to interested persons, and states that if such procedures and conditions are followed, then a termination of license will be granted. In lieu of formal regulatory guidance in 10 CFR 70, the NRC has currently adopted the decommissioning guidelines provided in Reference 11. The clear implication of the 10 CFR 50.82 regulation is that dismantling and disposal are the exclusive objectives of the decommissioning process. However, regulatory guides discussed below also provide for other decommissioning alternatives that may not return a site to unrestricted use.

10 CFR 50.82 is broad in scope as to the extent of information that can be requested by the NRC and as to the NRC's power to specify conditions for acceptable decommissioning. However, in the past the NRC exercise of authority under this section has been limited. The NRC has approached the implementation of decommissioning policy on a case-by-case basis by inserting license conditions into applications, amending existing licenses, and by issuing informal policy statements. Such a case-by-case or informal approach is useful during the interim period while more detailed regulations are being developed. This is also a useful mechanism for obtaining public reactions, testing new ideas, and making decisions that are tailored to specific situations.

10 CFR 50.82 is intended to provide reasonable assurance that the dismantleling of the nuclear facility and the disposal of the components will be performed. However, this apparent policy goal seems to be considerably revised in

References 9 and 11 in that they appear to permit in some cases, as an acceptable decommissioning alternative, the safe storage (layaway, mothballing, temporary entombment) of facilities as well as dismantlement and conversion to a new nuclear or non-nuclear system. Apparently the safe storage decommissioning alternatives and conversion to other uses are to be interpreted as compatible with the dismantling and disposal policies of the regulations.

For reactors, 10 CFR 50.59, Authorization of Changes, Tests and Experiments, and Section 50.90, Application for Amendment of License or Construction Permit, provide the rules by which a licensee of a nuclear reactor or a fuel reprocessing plant may amend his license. This amended state of facility license results from NRC approval to amend requirements in the technical specifications that are applicable to normal facility operations. It is likely that similar rules will be developed specifically for Part 70 facilities. It appears that the necessary requirements to ensure public safety during decommissioning can be identified.

Another potential question arises from the fact that there is an implication that the long-term care outlined in the Regulatory Guides could extend for a period that considerably exceeds the normal licensing period for nuclear facilities (typically 1 to 5 years between licensing renewals for 10 CFR 70 facilities). There is no indication in the regulations what the term of an amended license might be. This raises questions as to whether renewal of an amended license would be permitted and what the standards for such renewal would be.

5.1.2 State and Local Jurisdiction

A nuclear facility operator is also subject to state statutes, regulations, orders, and court decisions. Where conflicts exist between state and local requirements, state requirement generally will prevail. Similarly, where there is a conflict between a federal requirement and a state requirement, the federal requirement is controlling, with some exceptions as noted in the Clean Air Act. Where no conflict exists, or where Congress has elected not to fully occupy a given legislative area, an operator must generally comply with all applicable federal, state, and local requirements in the conduct of his affairs.

Section 274k of the Atomic Energy Act of 1954 provides that "nothing in this section shall be construed to affect the authority of any state or local agency to regulate activities for purposes other than protection against radiation hazards."(14) Thus, state requirements relating to such matters as land use, zoning, building construction standards, fire protection, parking requirements, drainage regulations, elevator standards, traffic regulation, and similar requirements are generally not preempted under the Atomic Energy Act even though they can have an important impact upon the location, construction, and operation of licensed nuclear facilities.

The 1977 Clean Air Act Amendments make clear that states are no longer precluded from establishing and enforcing standards regulating radioactive emissions into the air. Thus, any state or locality may potentially establish standards more stringent than federal standards, or, where a federal standard has not been established, may establish any standards it deems appropriate.(5)

State governments also exercise some control over shipments of radioactive materials. State highway departments regulate gross vehicle weights, vehicular dimensions and other parameters for radioactive shipments just as they do for other kinds of shipments. Currently, about half of the states have adopted the DOT Hazardous Materials Regulations to cover intrastate shipments. Several states have adopted or proposed additional regulations concerning radioactive materials.(15,16) The variation of regulations between adjacent states can often require special considerations for interstate shipments.

There is potential conflict between some of the proposed state laws and the provisions of the Hazardous Materials Transportation Act of 1974 (Public Law 93-633 signed in 1975).(7) This law prohibits the states from adopting laws or regulations more stringent than federal regulations unless the state regulations improve transportation safety. Even in this case, such rules can be adopted only if they do not unreasonable burden commerce.

A more-detailed review of the regulations pertaining to the transport of radioactive material can be found in ERDA-76-43, Volume 5, Appendix E, Alternatives for Managing Waste from Reactors and Post-Fission Operations in the LWR Fuel Cycle, May 1976.

5.1.3 Regulation of Effluents

During decommissioning operations, it will be necessary for radioactive air and water emissions to be kept as low as reasonably achievable. Specific regulations pertaining to radioactive emissions during decommissioning have not been issued. In the license termination application, however, an operator must ensure that decommissioning will not be inimical to public health and safety (see 10 CFR 50.82 as an example).

The radioactive effluents from waste processing operations or other activities during decommissioning must comply with EPA regulations as well as with 10 CFR Part 20. Currently, no specific EPA regulations exist for decommissioning. The EPA's 25 mrem/yr limit of exposure to any member of the general public from operating facilities of the nuclear fuel cycle, defined in 40 CFR Part 190, Environmental Radiation Protection Standards for Nuclear Power Operations, excludes waste management activities, but such limits are now being developed. It is anticipated that a radiation dose limit from waste management operations similar to the 25 mrem/yr fuel cycle limit will be developed by the EPA. This new limit may well include the impact of decommissioning.

The Clean Air Amendments of 1977(5) includes radioactive emissions within the regulatory framework of the Clean Air Act. Section 122 of the Clean Air Act Amendments of 1977 creates an important statutory exception to the NRC's primary jurisdiction over radioactive emissions from licensed nuclear facilities. The 1977 Amendments make it clear that radioactive emissions into the air (which is presumed to be applicable to effluents from decommissioning) are subject to the regulatory framework of the Clean Air Act in addition to determine whether emissions of radioactive pollutants will endanger public health.

5.1.4 Safeguards Considerations

The requirements governing the safeguarding of SNM and nuclear facilities are contained in Title 10 CFR 70, Special Nuclear Material, and Part 73, Physical Protection of Plants and Materials. Although decommissioning operations are not mentioned specifically in these regulations, the provisions of Parts 70 and 73 apply to such operations if and when the licensee comes into the possession of significant quantities of SNM during decommissioning. Applicable regulations and guidelines in addition to 10 CFR 70 and 10 CFR 73 are as follows:

- 10 CFR 70.22(g) requires inclusion of a physical security plan in applications for licenses and for license amendments
- Regulatory Guide 5.52, Standard Format and Content for the Physical Protection Section of a License Application
- NRC Standard Review Plan, NUREG 75/087, 13.6, Industrial Security
- Regulatory Guide 5.7, Control of Personnel Access to Protected Areas, Vital Areas and Material Access Areas
- Regulatory Guide 5.10, Selection and Use of Pressure Sensitive Seals on Container for Onsite Storage of Special Nuclear Material
- Regulatory Guide 5.12, General Use of Locks in the Protection and Control of Facilities and Special Nuclear Materials
- Regulatory Guide 5.14, Visual Surveillance of Individuals in Material Access Areas
- Regulatory Guide 5.15, Security Seals for the Protection and Control of Special Nuclear Material
- Regulatory Guide 5.20, Training, Equipping, and Qualifying of Guards and Watchmen
- Regulatory Guide 5.27, SNM Doorway Monitors
- Regulatory Guide 5.43, Plant Security Force Duties
- Regulatory Guide 5.44, Perimeter Intrusion Alarm System
- Regulatory Guide 5.45, Standard Format and Content for the Special Nuclear Material Controls and Accounting Section of a Special Nuclear Material License Application
- Regulatory Guide 5.57, Shipping and Receiving Control of Special Nuclear Materials (Being Revised)
- ANSI Standard N15.26-1976, Physical Protection of Special Nuclear Material Within a Facility

It is expected that many of the regulations that apply specifically to the operation of a U-Fab plant may not be applicable. Strict interpretation of these requirements for safeguarding SNM during decommissioning may be unnecessarily restrictive. These regulations, as well as others, are meant to apply to bulk or concentrated quantities of SNM normally found in operating facilities. While maintaining a uniform level of public protection, such regulations could be relaxed when applied to decommissioning but compliance with the intent and principles of these regulations should still be maintained.

5.2 REGULATORY CONSIDERATIONS DURING DECOMMISSIONING

The principal regulatory issues during decommissioning are public safety, environmental protection, and nuclear material safeguards. Table 5.2-1 presents licensing and regulatory issues that are important in decommissioning U-Fab plants. These issues are taken from sections of the Code of Federal Regulations as follows:

10 CFR 20: Standards for Protection Against Radiation
10 CFR 50: Licensing of Production and Utilization Facilities
10 CFR 51: Licensing and Regulation Policy and Procedures for Environmental Protection
10 CFR 70: Special Nuclear Material
10 CFR 71: Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions
10 CFR 73: Physical Protection of Plants and Materials
40 CFR 190: Environmental Radiation Protection Standards for Nuclear Power Operations
40 CFR 1500: Council on Environmental Quality
49 CFR 170-189: Hazardous Materials Regulations

In several areas, new regulations may be appropriate. The existing regulations and guidelines do not clearly meet the needs of U-Fab plant decommissioning when existing safeguards are evaluated for the decommissioning situation. It would be desirable to consider revising old or developing new safeguard regulations for nuclear materials that would be found, generated, measured, stored, transferred, and disposed of as a part of the decommissioning of plants licensed under 10 CFR 70.

TABLE 5.2-1. Licensing and Regulatory Consideratio

	Subject	Action Required	Regu
A	Decommissioning Plan	Prepare Plan	(10 CFR
		Provide contingency planning for case in which SNM(c) or SNM scrap is found during decommissioning	(10 CFR
B	License, FNMC[d] Plan and Physical Security Plan Changes		
	1. Normal Operation License	Terminate license for normal operation	(10 CFR
	2. Decommissioning License	Initiate license for decommissioning operation	
	3. SNM[c] Ownership, Custody, Handling and Transfer License	Amend license to show • termination of normal ownership, but allow • short term ownership, handling and transfer of SNM or SNM scrap that is discovered during decommissioning • ownership, handling and transfer of SNM waste generated during decommissioning	(10 CFR 70.18, 70.41)
	4. FNMC Plan for MC&A[e] of SNM Waste, SNM Scrap and SNM during Decommissioning	Amend FNMC Plan to include • MC&A procedures applicable to SNM Waste • contingency MC&A procedures for SNM or SNM scrap should they be found during decommissioning	(10 CFR
	5. FNMC Plan for Transfer of SNM, SNM Scrap and SNM Waste	No change required	10 CFR 70.42, 70.58g
	6. Physical Security Plan for SNM, SNM Scrap and SNM waste on Site	Modify Physical Security Plan for Decommissioning	73.40(a
C	Environmental Impact		
	1. Impact Statement	Prepare Environmental Impact Statement for Decommissioning	40 CFR (10 CFR
	2. Release to the Environment from the Uranium Fuel Cycle	Limit Radioactivity Releases to Environment During Decommissioning	40 CFR
	3. Releases to the Environment from Transportation of Radioactive Material	Limit radioactivity releases to environment during transport of SNM waste, SNM and facility component parts during decommissioning	49 CFR
D	Human Safety from Radiation		
	1. Public Safety	Limit releases to the public in the general environment	40 CFR
	2. Public and Occupational Safety - Plant Unrestricted Areas	Limit exposure of public or plant employees in the unrestricted areas of the plant	10 CFR
	3. Occupational Dose - Plant Restricted Area	Limit exposure of plant employees and other personnel working in restricted areas of the plant	10 CFR 103, 1
E	Waste Disposal	Dispose of Radioactive Waste in an Approved Manner	10 CFR 303, 3

(a) The licensing and regulatory considerations included apply to some of the more important issues but are not exhaustive.
(b) References enclosed in parenthesis do not directly apply to the decommissioning of a U-Fab plant.
(c) SNM = Special Nuclear Material.
(d) FNMC = Fundamental Nuclear Material Control.
(e) MC&A = Material Control and Accounting.

ns for U-Fab Plant Decommissioning[a]

lations	Comments
50.82)[b]	A new regulation for facilities licensed under Part 70 is desirable. The regulation would presumably be similar to 10 CFR 50.82. The plan must provide information on proposed procedures for the disposal of radioactive material, decontamination of the site, dismantling of the facility etc. in a manner that is not inimical to the common defense and security or to the safety of the public.
70)	A new regulation addressing the short term and contingency aspects of controlling and accounting for SNM that might be discovered during decommissioning is desirable. The decommissioning plan must include a section that addresses the material control, material accounting and physical security aspects of the issues. See the section below on modifying the FNMC plan.[d]
50.82)[b]	A new regulation under Part 70 similar to 10 CFR 50.82 is desirable.
	A new regulation under Part 70 similar to 10 CFR 50.82 is desirable.
70.34, 70.21,	A new regulation under Part 70 is desirable to providefor temporary ownership, custody, handling and transfer of SNM or SNM scrap in the event such material is found during decommissioning. The amended license must also allow ownership, custody, handling and transfer of SNM waste.
70.58)	A new regulation under Part 70 is desirable to provide forthe licensee's organizational and operational responsibilities for the Material Control and Accounting of SNM waste SNM scrap and SNM during decommissioning.
70.41, 70.54,	No major regulation change is needed except to review the condition that 70.58 applies only to licensees authorized to possess more than one effective kilogram of SNM.
)	No major regulation changes are forseen unless special physical security problems associated with plant decommissioning are identified.
1500.6 51.5)	A new regulation similar to 10 CFR 51.5 is desirable for facilitieslicensed under Part 70. Regulation 40 CFR 1500.6 requires that a detailed environmental impact statement be prepared in the case of "major federal actions" significantly affecting the quality of the human environment.
190.10(b)	40 CFR 190.10(b) is geared to releases from Uranium Fuel Cycle Facilities. The allowed release is related to the amount of power produced. A regulation for facilities being decommissioned is desirable.
173.393(a)	The allowable limit of radioactive material released during transportation is zero. Shipment of radioactive materials associated with decommissioning must conform with the requirements of 49 CFR 170-189.
190.10(a)	Allowed dose to individuals in the Environment due to the Uranium Fuel Cycle is specified in 40 CFR 190.10(a).
20.105, 106	10 CFR 20.105, 106 specify the allowed dose to members of the public or plant employees or other personnel in restricted areas of the plant.
20.101, 102, 4	10 CFR 20.101, 102, 103, 104 specify the allowed dose to plant employees or other personnel in restricted areas of the plant.
20.301, 302, 4, 305	10 CFR 20 applies to the disposal of Licensed Material including SNM. Improved shallow-land burial methods, which would apply to the SNM wastes found in a U-Fab Plant,are under development.

TABLE 5.2-1. Licensing and Regulatory Considerations for U-Fab Plant Decommissioning

5.2.1 Licensing Changes and Decommissioning Plan (Refer to Table 5.2-1)

If a licensee elects to discontinue the operation of his U-Fab plant, he must notify the NRC that he intends to discontinue all activities involving materials licensed under part 70. If the provisions found in 10 CFR 50 are followed, this request would be accompanied by a Decommissioning Plan that describes the procedures intended to be followed to protect the public safety and decommissioning worker safety. Major issues to be addressed in this plan are public and decommissioning worker safety, environmental impact, waste disposal, nuclear criticality accident control, and nuclear material safeguards. As noted in Table 5.2-1, the transition from the operating mode to the decommissioning mode entails termination of normal operation and the initiation of decommissioning activities. Existing regulations do not specify whether a new license will be issued or the old license amended, though the amendment approach appears to be acceptable to the NRC. As suggested here, ownership of SNM in a U-Fab plant being decommissioned would be on a short-term contingency basis. The nature of the limitations on the use and ownership of the SNM wastes and SNM would have to be delineated in the decommissioning license and associated documentation, including the revised fundamental nuclear material control (FNMC) plan.

Existing regulations and guidance pertaining to the handling and transfer of SNM appear to be applicable though somewhat unclear in certain respects as applied to decommissioning. 10 CFR 70.58(e) requires all SNM received, shipped, transferred between MBA or otherwise removed from inventory to be measured. 10 CFR 70.57 requires all material control and accounting measurements to be controlled in a rigorous manner. These regulations, which were formulated to be adequate for the control and accounting of SNM in a production facility, may be difficult to apply in their present form for a plant that is principally concerned with SNM waste.

5.2.2 Regulations for Human Safety from Radiological Hazards and Plant Environmental Protection (Refer to Table 5.2-1)

During decommissioning, people will be present both inside and outside of the U-Fab plant. Plant employees or visitors inside the plant will be in areas that are either radiologically restricted or unrestricted. 10 CFR 20 provides standards for protection against radiation. Sections 20.101 through 20.104 describe allowable doses to both adults and minors within restricted areas of the plant. A restricted area is an area whose access is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. In contrast, an unrestricted area does not have to have its access controlled by the licensee, because no radioactive material is present (this includes residential quarters).

Section 20.105 describes permissible levels of radiation in unrestricted areas inside the plant, while 20.106 describes the limits placed on radioactivity in effluents to these unrestricted areas. Similarly, 40 CFR 190 is concerned with environmental radiation protection standards for the uranium fuel cycle and for nuclear power operations.

Section 40 CFR 190.10(a) provides standards for allowed radiological dose to any member of the public outside the plant, and Section 190.10(b) provides standards for the total quantity of radioactive materials allowed to enter the general environment from the entire uranium fuel cycle. As used in 40 CFR 190, the uranium fuel cycle includes milling of uranium ore, chemical conversion of uranium, isotopic enrichment of uranium, fabrication of uranium fuel, generation of electricity by a light-water-cooled nuclear power plant using uranium fuel, reprocessing of spent uranium fuel to the extent that these directly support the production of electrical power for public use. The definition, however, excludes mining operations, operation of waste disposal sites, transportation of any radioactive material, and the reuse of recovered nonuranium SNM and byproduct materials from the cycle.

In order for the licensee to be compliant with these regulations during decommissioning, he must ensure that effluent releases to unrestricted areas of the plant do not exceed the values or cause dose rates in excess of the values given in 10 CFR 20. He must also ensure that releases to the environment and related doses to the public do not exceed the values given in 40 CFR 190.

For restricted areas of the plant, the licensee must provide employees with the necessary protective clothing, protective equipment, and dose monitoring systems to ensure that the 10 CFR 20-prescribed dose levels for restricted areas are not exceeded.

5.2.3 Waste Disposal (Refer to Table 5.2-1)

As called for in 10 CFR 20.301, no licensee shall dispose of licensed material except:

> "... by transfer to an authorized recipient; as authorized pursuant to 10 CFR 20.302; or as provided in 10 CFR 20.303 or .304."

Further regulations and guidelines relevant to shallow-land burial of waste may be in the offing as a result of burial ground experience gained in the past several years and technology now being developed to characterize the performance of low-level waste burial sites.

5.3 SAFEGUARDS CONSIDERATIONS DURING DECOMMISSIONING

Prior to initiating decommissioning of a U-Fab plant, consideration must be given by the licensee to the necessity of safeguarding the quantities of residual special nuclear material (SNM) anticipated to be found in the facility following normal operational cleanout. Regulations for operating facilities licensed to use or possess SNM in quantities exceeding specified threshold amounts require special internal material controls for accounting and reporting procedures for SNM, both in process and in storage. In addition, physical protection systems are required for protecting the SNM and vital facilities. The types of SNM remaining after plant operation and considerations relating to safeguarding of SNM during decommissioning of a U-Fab plant are discussed in this section.

5.3.1 Types of SNM Anticipated During Decommissioning

At the end of normal operations the types of nuclear material remaining in the facility will be similar to the types of nuclear materials stored and processed in the plant prior to shutdown. After decommissioning cleanout of the facility and the process equipment, the physical form and concentration of the nuclear material may be different from its original form because of the methods used to remove the material from the areas in which they had been entrapped during normal operation.

Four types of SNM could be found in the plant. These are: high-grade SNM, scrap SNM, Type I waste SNM for retention, and Type II waste SNM for disposal. High-grade SNM, as used here, is material that is sufficiently pure chemically and uniform physically to be directly input to processes which require high quality feedstock. Both scrap and waste contain SNM, but scrap is considered to be a desirable material for return to the fuel cycle because the contained SNM is economically recoverable (at today's price, using current recovery technology). SNM scrap is defined in 10 CFR 70.40 as:

> "... the various forms of special nuclear material generated during chemical and mechanical processing, other than recycle material and normal process intermediates, which are unsuitable for use in their present form but all or part of which will be used after further processing."

10 CFR 70 does not contain a definition of nuclear waste per se but the following definitions of Type I and Type II waste as applied to decommissioning can be inferred, as follows:

- Type I waste SNM - an SNM-containing material that is normally discarded from the low-enriched uranium fabrication process rather than retained as useful scrap. Type I waste may become a viable source of SNM in the foreseeable future and therefore may be retained in retrievable storage rather than disposed of during plant decommissioning.
- Type II waste SNM - an SNM-containing material discarded from the low-enriched uranium fabrication process. Having negligible potential as a viable source of SNM in the forseeable future, it is to be disposed of during plant decommissioning.

Waste of either type I or II is considered to be undesirable for near-term return to the fuel cycle because the SNM contained in it is not economically recoverable at today's prices (using present technology). The division of waste into two types recognizes the possibility that some materials originally discarded from the U-Fab plant but not qualified to be considered SNM scrap, such as fluoride sludge, may be economically recoverable in the future. In light of this consideration, Type I waste would not be disposed of (in an ultimate sense) during decommissioning.

Although all four types of SNM could be found at one time or another during decommissioning, the final steps of the operational phase would normally include removal of all accessible SNM and SNM scrap under the terms and conditions of the approved operating license. Thus, the beginning of decommissioning would involve nuclear material safeguards and safety and environmental protection measures appropriate for Types I and II low-level, nontransuranic waste only (i.e., protective measures for the two types of waste described above). SNM or SNM scrap would be found in the plant during decommissioning only if the process of decontmination and dismantlement revealed quantities of SNM or SNM scrap that were not previously known to be present. Safeguarding of these materials would be handled in the baseline decommissioning safeguards plan.

5.3.2 Nuclear Material Safeguards

Many of the issues and requirements attendant to safeguarding SNM are specific to the percent enrichment and total quantity of fissile isotope contained in the material. For this study, it has been assumed that all nonwaste type SNM or SNM scrap will have been removed from the plant prior to the time decommissioning is initiated. As a result, it is assumed that selection of nuclear material safeguard procedures, personnel, and equipment to be employed in a U-Fab plant during decommissioning will consider the following situations:

1. Baseline Situation - The plant and its environs contain various forms of SNM waste but no known high-grade SNM or scrap.
2. Contingency Situation - SNM or SNM scrap is discovered during decommissioning As soon as the discovered material is identified, measured, packaged, and sealed, it is shipped to an authorized SNM receiver.

Existing regulations under 10 CFR 70 were formulated to apply to plants that processed SNM in the course of their normal operation. Nuclear waste per se is not defined in 10 CFR 70. Because of the significant dissimilarity between SNM and SNM waste in a safeguards sense, many of the regulations contained in 10 CFR 70 may not be directly applicable to the decommissioning situation.

Under 10 CFR 70, the threshold of applicability of many regulations for low enriched uranium occurs when the quantity of SNM involved is one effective kilogram or more, as defined in 10 CFR 70.4. The calcium fluoride waste accumulated and stored at the reference U-Fab plant could easily contain more than one effective kilogram of material. However, because of the significant technological problems associated with recovering uranium from CaF_2 and the relative unaccessibility of the SNM entrapped in the CaF_2 waste, it is questionable whether such material lies within the purview of all the regulations in Part 70 that would be applicable to low enriched uranium SNM in its normal, nonwaste form. In recognition of the possible nonapplicability of all Part 70 regulations to waste SNM, but the need to provide a reasonable minimum level of safeguard control and security to the waste material, the detailed requirements to be met by the decommissioning licensee's material control and accounting and security program are relegated to the licensing conditions of the decommissioning license and to the approved procedures included in the licensee's decommissioning plan and revised FNMC plan.

Table 5.3-1 addresses several of the more important safeguard issues that will be affected under the contingency situation in which SNM is discovered during the decommissioning process. Table 5.3-2 reconsiders these issues for the baseline situation in which the SNM in the facility is entirely in the form of wastes. In the author's opinion, the major conclusion to be drawn from these studies is that additional self-consistent regulations may be appropriate for the situation of safeguarding nuclear material during plant decommissioning.

5.3.3 Criticality Accident Alarm System (See Tables 5.3-1 and 5.3-2)

Requirements for criticality safety are included in 10 CFR 70 and are addressed here to ensure that licensees consider criticality monitoring requirements.

TABLE 5.3-1. Existing Safeguard Regulations Applicable t

Regulation Identification	Regulation Para. No.	New Regulations Required	
A. Special License - SNM Ownership	(10 CFR 70.18)[b]	Yes	A de SNM lice
B. Plans, Procedures, Personnel:			
1. SNM/SNM scrap material accounting procedures (if more than 1 effective kilogram)	(10 CFR 70.22, 70.51, 70.57, 70.58)	Yes	Beca owne occu the guar the
2. Technical qualifications, training and experience of staff (any amount of SNM)	(10 CFR 70.22)	Yes	Same
3. Plan for physical protection of SNM	(10 CFR 3.40)	Yes	Same
C. Material Measurement and Measurement Control	(10 CFR 70.58(g)) (10 CFR 70.57)	Yes	Same
D. Material Transfer:			
1. SNM shipped or received is to be identified and measured; S/R[c] differences are to be evaluated for statistically significant differences	(10 CFR 70.58(g))	Yes	Same for
2. SNM is to be transferred to authorized receiver	10 CFR 70.42(a,b)	No	Exis
3. Shipper is to verify that receiver is authorized to receive SNM	10 CFR 70.42(c)	No	Same
4. SNM packaging for shipment	10 CFR 71	No	SNM
E. Inspection and Test:			
1. Inspection of facility by the NRC	10 CFR 70.55(a,b)	No	The and
2. Testing SNM facilities, radiation detection and monitoring equipment	10 CFR 70.56	No	The such regu regu
F. Records:			
1. Record of SNM discovery, identification, measurement, tamper safing and temporary addition to inventory	(10 CFR 70.51(b,e))	Yes	A ne gene
2. Record of SNM transfer to authorized receiver	10 CFR 70.51(b), 10 CFR 70.42(c)	No	Exis
3. Measurement control records	(10 CFR 70.57(b))	Yes	Same
G. Reports:			
1. SNM transfer report - NRC 741 form	10 CFR 70.54	No	Exis
2. SNM material status report (> 350 g contained ^{235}U)	(10 CFR 70.53)	Yes	Same
3. Report of loss, theft, attempted theft of SNM (>1 g contained ^{235}U)	10 CFR 70.52(b)	No	Subm SNM the
4. Report of accidental criticality	10 CFR 70.52(a)	No	Subm not sion

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(a) List of regulations is not necessarily all-inclusive.

(b) Regulations enclosed in parenthesis are not directly applicable to the safeguarding of SNM under the situatio appear in during decommissioning. See comment B-1.

(c) S/R - Shipper-Receiver.

SNM Control During Decommissioning of a U-Fab Plant$^{(a)}$

COMMENTS
ommissioning mode of operation licensing condition for the temporary ownership and custody of r SNM scrap, should it be discovered during decommissioning, is required for facilities sed under 10 CFR 70.
se the underlying assumption of the SNM safeguards program for decommissioning is that ship, custody, and safeguards responsibility over SNM will be for a limited time and will only if the decommissioning process turns up SNM that had not been found and removed during acility clean-out phase of operation, existing federal regulations applicable to material safe-s in an operating U-Fab plant are not fully appropriate for the situation of SNM safeguards in ame plant when it is being decommissioned. Additional regulatory guides are also desirable.
as comment B-1.
as comment B-1.
as comment B-1.
as B-1. The licensee's safeguards system will not be geared for SNM. Regulations formulated he contingency situations are needed.
ing part 70 regulations appear to be adequate.
as comment D-2.
hall be prepared for tranfer consistent with 10 CFR 71.
xisting regulation authorizing the NRC to inspect the facilities, the SNM, the premises he records appears to be adequate.
xisting regulation requiring the licensee to perform or "permit the Commission to perform tests as the Commission deems appropriate or necessary for the administration of the ations in this part . . ." would seem to be appropriate if additional decommissioning ations are prepared under Part 70.
regulation that would acknowledge the fact that the decommissioning process will ate some SNM waste and may turn up SNM is desirable.
ing regulations would appear to be adequate.
as comment B-1.
ing regulations appear to be adequate.
as comment B-1.
ssion of the report is contingent on the occurrence of a loss, theft or attempted theft of nd would not otherwise be submitted. The existing regulation appears to be appropriate for ecommissioning case, also.
ssion of this report is contingent on the occurrence of an accidental criticality and would therwise be submitted. The existing regulations appear to be appropriate for the decommis-ng case, also.

it might

TABLE 5.3-1. Existing Safeguard Regulations Applicable to SNM Control During Decommissioning of a U-Fab Plant

TABLE 5.3-2. Existing Safeguard Regulations Applicable to SNM Waste and Criticality Control

SNM WASTE SAFEGUARDS AND CRITICALITY CONTROL ISSUES	TYPES I AND II WASTE[(a)]		COMMENTS
	References	New Regulations Desirable	
A. Definition of SNM Waste Types	(10 CFR 70.4)[(b)]	Yes	A definition of SNM waste needs to be provided. The definition should recognize the possibility for two types of material: one with the potential for eventual recovery of SNM and the other without that potential.
B. Special License - SNM Waste Ownership and Use (applies to any amount of SNM)			
1. Ownership	10 CFR 70.18	No	The existing regulation appears to be sufficiently general to cover the case of SNM waste ownership during decommissioning.
2. Use	10 CFR 70.41	No	The existing regulation calls for ownership and use of SNM consistent with the approved license. Because there is no assumption of temporary ownership of SNM waste within the duration of the decommissioning period, as there is in the case of SNM or SNM scrap, there does not appear to be a need for a new regulation with a different intent from the existing one.
C. Plans, Procedures, Personnel			
1. SNM waste material accounting procedures (if more than 1 effective kilogram)	(10 CFR 70.22, 70.51, 70.57, 70.58(a))	Yes	A new set of regulations is desirable to address the needs of SNM accounting control and physical security for the situation in which the SNM is comprised entirely(c) of waste material, and for the situation in which the licensee and his plant are in the decommissioning mode rather than in the operating mode. Presumably a portion of this waste material will have been generated as a part of normal operation and a portion will be generated during decommission of the plant facilities. An estimate of the SNM content of the portion of waste generated during normal operation will have been entered on the SNM material quantity records maintained during the plants normal operating life time. Plant records will have to be updated to include the SNM in wastes generated during decommissioning. When the waste is removed from the plant site an attempt will have to be made to verify the quantity of SNM in the material being shipped. Also, the waste should be classified as Type I or Type II waste material. A regulatory guide or set of regulatory guides covering material safeguards during decommission is also desirable.
2. Technical qualification, training and experience of staff (for any amount of SNM)	10 CFR 70.22	No	The existing regulation is sufficiently general and appears to be applicable to the case of low-enriched uranium fabrication plant decommissioning.
3. Plan for physical protection of SNM waste	10 CFR 73.40	No	Same as C-2. The details of the physical security plan would be included in the licensee's decommissioning plan.
D. SNM Waste Measurement and Measurement Control	(10 CFR 70.58) (10 CFR 70.57)	Yes	See comment C-1.
E. SNM Waste Material Transfer			
1. SNM waste shipped to be identified and measured and S/R differences to be evaluated	(10 CFR 70.58(g))	Yes	See comment C-1.
2. SNM waste to be transferred to authorized receiver	10 CFR 70.42(a,b)	No	Existing regulations are sufficiently general to appear to be applicable to the situation of SNM waste shipment. The requirement to ship to an authorized receiver would appear not to be changed by the fact that the material is SNM waste rather than SNM or SNM scrap.
3. Shipper to verify receiver authorized to receive SNM	10 CFR 70.42(c)		See comment E-2.
4. SNM waste packaging for shipment	10 CFR 71	No	SNM waste to be transferred shall be containerized per 10 CFR 71 to assure safe shipment.
F. Inspection and Test	10 CFR 70.55a,d 10 CFR 70.56	No	See comment E-1 and E-2 in Table 5.2-2.
G. Records			
1. Record of SNM waste generated on inventory, received and shipped	(10 CFR 70.51(b,e))	Yes	Regulations and guidelines are needed to delineate the separate and combined record keeping needs of Type I waste, Type II waste and SNM during the period of decommissioning.
2. Record of SNM transferred to authorized	10 CFR 70.51b	No	Existing regulation would appear to be adequate.

TABLE 5.3-2. Existing Safeguard Regulations Applicable to SNM Waste and Criticality Control

receiver	10 CFR 70.42(c)		
3. Measurement control records	10 CFR 70.57(b)	Yes	See comment C-1.
H. Reports			
1. SNM waste transfer report - NRC 741 Form (for transfer of 1 g or more of contained ^{235}U	(10 CFR 70.54)	Yes	Existing regulation and NRC 741 Form may or may not be adequate to report the transfer of Type I and Type II SNM waste.
2. SNM material status report (>350 g contained ^{235}U)	10 CFR 70.53	Yes	See comment C-1.
3. Report of loss, theft, attempted theft of SNM (>1 g contained ^{235}U in licensees possession)	10 CFR 70.52(b)	[illegible]	See comment C-1.
4. Report of accidental criticality	10 CFR 70.52(a)	No	Existing regulation appear to be adequate.
I. Criticality Accident Alarm System (>1500 g contained ^{235}U enriched 4% or less)	10 CFR 70.24	Yes	Existing criticality alarm requirements, which are pertinent to SNM rather than SNM waste, need to be reviewed for applicability and possible needed changes if they are to apply to the SNM waste situation.

(a)
- Type I waste SNM is an SNM-containing material that has been discarded from the low-enriched uranium fabrication process rather than being retained as useful scrap. It may become a viable source of SNM in the foreseeable future and therefore may be preserved and sent to retrievable storage.
- Type II waste SNM is an SNM-containing material that has been discarded from the low-enriched uranium fabrication process. Since it is considered to have negligible potential as a viable source of SNM in the foreseeable future it is disposed of during plant decommissioning.

(b) References enclosed in parentheses do not apply directly to the decommissioning of U-Fab plants.

(c) Subject to the contingency that SNM might be found during the decommissioning process.

Each licensee authorized to possess SNM in a quantity exceeding 1500 g of contained ^{235}U when the uranium enrichment does not exceed 4% in the ^{235}U isotope must maintain a criticality monitoring system that meets the requirements of 10 CFR 70.24(a)(1) or (a)(2) in each area where the material is handled, used, or stored.

5.4 OPERATOR'S CHECKLIST FOR FEDERAL REGULATIONS

The previous sections described regulatory requirements that may pertain to decommissioning activities. Many other requirements also apply because the decommissioning activity also involves other activities that are subject to regulation.

Table 5.4-1 lists the principal federal regulatory requirements that are most likely to apply to the decommissioning of a low-enriched U-Fab facility.

TABLE 5.4-1. Checklist of Principal Federal Regulatory Requirements that Apply to the Decommissioning of a U-Fab Facility

1. <u>Decommissioning Requirements</u>	
10 CFR 50.82[a]	Application for termination of license
Reg. Guide 1.86[a]	Termination of operating licenses for nuclear reactors
10 CFR 50[a]	Licensing of production and utilization facilities
10 CFR 50.33(f)[a]	Relating to financial qualification for facility shutdown
10 CFR 50, Appendix C[a]	A guide for financial data and related information required to establish financial qualifications for facility construction permits and operating licenses
10 CFR 50, Appendix F[a]	Policy relating to the siting of fuel reprocessing plants and related waste management facilities
2. <u>Material License Requirements</u>	
10 CFR 30, 40, and 70	Regulations for materials licenses relating to byproduct, source, and special nuclear material
3. <u>Environmental Protection</u>	
10 CFR 51	Licensing and regulatory policy and procedures for environmental protection
10 CFR 20, Appendix B	Offsite releases
10 CFR 20.300	Waste disposal
40 CFR 190.10	Environmental radiation protection requirements for normal operations in the uranium fuel cycle (EPA)
40 CFR 1500	CEQ guidelines on the preparation of environmental impact statements
	Guidelines for decontamination of facilities and equipment to release for unrestricted use or termination of licenses for byproduct, source or special nuclear material (NRC, Nov 1976)
	Proposed guidance on dose limits for persons exposed to transuranium elements in the general environment (EPA 520/4-77 [illegible])
4. <u>Employee Protection</u>	
10 CFR 20	Standards for protection against radiation
5. <u>Safeguards and Physical Protection</u>	
10 CFR 70	Domestic licensing of special nuclear material
10 CFR 73	Physical protection of plants and materials
6. <u>Quality Assurance</u>	
10 CFR 50, Appendix B[a]	Quality assurance criteria for nuclear power plants and fuel reprocessing plants
Reg. Guide 3.3	Quality assurance program requirements for fuel reprocessing plants and for plutonium processing and fuel fabrication plants
7. <u>Transportation</u>	
10 CFR 71	Packaging of radioactive material for transport and transportation of radioactive material under certain conditions
49 CFR 170-199	Department of Transportation hazardous materials regulations

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(a) It is recognized that these regulations apply specifically to nuclear reactors and fuel reprocessing plants. It is anticipated that decommissioning actions analogous to these regulations will be required for U-Fab plants.

REFERENCES

1. U.S. Nuclear Regulatory Commission, Plan for Reevaluation of NRC Policy on Decommissioning of Nuclear Facilities, issued by the Office of Standards Development of Engineering Standards, USNRC, NUREG-0436, Ref. 1, December 1978.*

2. 42 USC 5801 et seq., Energy Reorganization Act of 1954.

3. 42 USC 2011 et seq., Atomic Energy Act of 1954.

4. 35 Federal Register 15623 (July 9, 1970; effective December 2, 1970); 23 USC 4321, 1973.

5. 42 USC 7401 et seq., Clean Air Act Amendments of 1977.

6. 42 USC Amendments, 300 f-j-9, Safe Drinking Transportation Act of 1974.

7. 49 USC 1801 et seq., Hazardous Material Transportation Act of 1974.

8. U.S. Department of Transportation, A Review of DOT Regulations for Transportation of Radioactive Materials, August 1976.

9. U.S. Atomic Energy Commission Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors, June 1974.

10. U.S. Code of Federal Regulations, Title 40, Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations," Superintendent of Documents, GPO, Washington, DC 20555, January 1977.

11. U.S. Nuclear Regulatory Commission, Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-Product, Source, or Special Nuclear Material, November 1976.

12. J. M. Deutch, Task Force Leader, Report of Task Force for Review of Nuclear Waste Management, DOE/ER-004/d, Department of Energy, Directorate of Energy Research, March 1978.

13. G. D. Calkins, Thoughts on Regulation Changes for Decommissioning, Office of Standards Development, U.S. NRC NUREG-0590, Rev. 2, August 1980, Draft Report.**

14. 42 USC 2021(k), Atomic Energy Act of 1954.

15. W. A. Brobst, "The State of State Regulations," in Proceedings of the 4th International Symposium on Packaging and Transportation of Radioactive Material, CONF-740901, Miami Beach, FL, September 1974.

16. C. K. Beck, "Intergovernmental Relationships in the Transport of Radioactive Materials," in Proceedings of the Second Annual Legislative Workshop, CONF-730588, Oak Ridge, TN, May 1973.

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service, Springfield, VA 22161.

**Available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

6.0 ALTERNATIVE APPROACHES TO FINANCING DECOMMISSIONING

This section discusses alternative approaches to providing funds for decommissioning of a uranium fuel fabrication (U-Fab) facility. The emphasis is on financial issues. Legal-institutional issues, such as what entity should own the land on which the facility sits, are outside the scope of this study and are not discussed.

When a nuclear facility ceases operation, there should be sufficient funds available to perform a thorough decommissioning and to care for the property until the site is released for unrestricted use. This financial concern exists for plants that operate throughout their anticipated life, as well as for plants that are shut down prematurely. Funds should also be available to provide for unexpected accidents and contingencies, both during the operating life of the facility and before decommissioning is completed.

The need for assurance of decommissioning funds is discussed in Section 6.1; several approaches to funding decommissioning costs are discussed in Section 6.2; approaches to providing decommissioning funds in the event of premature closure of a facility are discussed in Section 6.3; issues associated with protection from accidents and contingency costs are discussed in Section 6.4; the question of who should actually perform the decommissioning work is discussed in Section 6.5; and the ability of states to impose financial obligations on nuclear facility owners is briefly reviewed in Section 6.6.

6.1 NEED FOR ASSURANCE OF DECOMMISSIONING FUNDS

Both federal and state governments have an obligation to protect the health and safety of their citizens. In connection with this responsibility, the governments in areas having nuclear facilities located in them have concerns regarding the financial responsibility of their decommissioning, and must ensure that sufficient funds are available for decommissioning the facility when operations are terminated. If an operator defaults or goes bankrupt, the state may have to assume financial responsibility for decommissioning. Funds should also be available to provide for unexpected contingencies during the operating life and before decommissioning is completed. Thus, there is considerable incentive to impose a means to assure financial capability for decommissioning. If decommissioning funds are paid into a trust fund outside the control of the operating company, the funds are not likely to be attachable by the company's creditors. In addition to the financial risk, delaying the commitment of funds for decommissioning entails the further concern of assuring that the obligated party will actually perform the work and pay the costs. If legal proceedings are required to fix responsibility on a case-by-case basis, many additional years and dollars could be expended before decommissioning is accomplished.

6.2 APPROACHES TO PROVIDING FUNDS FOR DECOMMISSIONING AND LONG-TERM CARE

A paramount decommissioning concern is that sufficient funds are available to decommission the plant. There is also concern that funds are available for such long-term maintenance and monitoring of the site as may be required before ultimate decommissioning. Three principal alternatives exist for achieving these objectives:

1) Creation of a sinking fund to accumulate sufficient decommissioning funds in a trust account during the facility's operating life.
2) Payment of the anticipated costs of decommissioning into a trust account prior to facility startup.
3) Payment of the costs of decommissioning when incurred (i.e., after facility closure).

Option 1 can be used for a new facility and a facility part-way into its operating life. Option 2 can be used with a new facility prior to its startup, or it can be imposed later. Options 1 and 2 both require a good decommissioning plan and decommissioning cost estimate early in the life of the plant. Option 3 is the only option available for an existing facility for which no trust account was established and whose operating life is over. Various combinations of these options are also possible. In addition, the use of such mechanisms as surety bonding and insurance to supplement the above options is possible.

To discuss and compare the alternatives, it is useful to establish several evaluation criteria. Five criteria that seem to be pertinent to evaluating the alternatives are:

1) The degree of decommissioning assurance provided by the alternative.

2) The cost of providing the assurance.

3) The extent to which the consumers of the plant's product equitably share the costs of decommissioning.

4) The flexibility of the financing alternative to respond to changes in inflation, interest, facility life, and estimated decommissioning costs.

5) The ability of the alternative to accommodate different ownership and jurisdictional arrangements.

Criterion one is probably of most importance. Criteria two and three are ranked second in importance. Criteria four and five must be met for a financing alternative to receive further consideration.

6.2.1 Creation of a Sinking Fund to Accumulate Sufficient Decommissioning Funds During the Facility's Operating Life

This option contemplates the formation of a sinking fund tied to fuel production to generate enough funds during the operating life of the facility to pay anticipated decommissioning costs. Payments would be made into a trust account permanently outside the control of the facility operator. This approach is currently used by the states that license and regulate low-level radioactive waste burial grounds, and is now being used by New Mexico(1) for uranium mills. In most instances, the funds are placed in separate trust accounts. However, in at least one state, the money is deposited in the state's general fund.

Payments to the sinking funds would be based on fuel production. The charge per unit of nuclear fuel produced would be determined by estimating total decommissioning costs and total anticipated fuel production over the facility's operating life. An amount would be paid into the fund per unit of product so that the payments, plus compound interest earned by investing the fund during and after the plant operating life, would be sufficient to pay all anticipated costs and provide a reasonable contingency of perhaps 10 to 15% in addition to the estimated decommissioning costs.

The payment per unit of product into the sinking fund could be adjusted regularly, perhaps every year. One obvious reason for change would be to provide for cost escalation. Additionally, many other variables can change with time. For example, the rate of return achieved by the fund stewards will likely change. The production rate for the facility will not be completely constant over time. The real (i.e., nonescalated) decommissioning cost can also be expected to change with time because of technological innovations, added facilities, and new regulatory requirements. It is also likely that the expected life of a plant will change. All of these changes can be periodically accounted for by adjustments to the sinking fund payment. If such changes are not severe and are regularly reflected in the payments, the value of the sinking fund should be close to the needed funds when the facility is retired. The procedure for calculating annual sinking fund payments, plus some illustrative calculations, are shown in Appendix D of Volume 2.

A variety of entities could be designated to provide stewardship for the sinking fund. Possibilities include state government, the federal government, or a private organization such as a bank. An independent "Decommissioning Assurance Agency" could also be chartered by each state or by the federal government to retain and invest the sinking fund and perhaps oversee activities and disburse payments to those conducting the activities. The pooling of decommissioning funds into such a centralized agency could help to ensure decommissioning performance even if a particular facility operator defaults in some manner. The agency would act in a fiduciary capacity for the public. Its governing board might be composed of representatives of the public, government, power-consuming industries, and power-producing industries. By including various interest groups, tendencies to overestimate or underestimate costs and the annual payments needed to fund the costs should be minimized. Payments and interest received by the stewardship entity should be exempt from federal income tax, either because the entity is a creation of the federal or state government (Internal Revenue Code, Section 115), or is an exempt scientific entity (Section 501(C)).

An advantage of the annual payment sinking fund approach is that it should generally assure that decommissioning activities actually will occur. With funds set aside to cover the costs, the question of who should pay them is alleviated and arguments about responsibility are less likely to occur.

A second advantage of the sinking fund option is that it should encourage the development of total plant costs when power generating options are being considered by a utility. Currently, future decommissioning costs of fuel cycle facilities may not be reflected in the electricity prices paid by consumers. If all fuel cycle facilities were required to create sinking funds to provide for future decommissioning and waste management expenses, their anticipated costs would be evaluated and equitably reflected in the cost of fuel and in the utilities' and consumers' power bills.

Another advantage of the sinking fund approach is that it is equitable to consumers. As long as increases in estimating decommissioning costs are reflected in adjusted payment schedules, all consumers should pay their approximately proportional share of costs in dollars of approximately equivalent buying power.

Several difficulties associated with the sinking fund option should be recognized. One of these relates to the care and investment of the fund itself. Professional management of the fund would be desirable, as would controls on the investments made by the fund. For example, the fund might be limited to investment in bonds and notes issued by agencies of the U.S. government, or municipal and private bonds with a sufficiently high rating, e.g., AA or higher. The fund steward would be faced with the same problem other investors are: i.e., how can assets be invested to earn a return that at least matches the rate of cost escalation due to inflation? If the fund is not able to match the rate of cost escalation, the payments to the fund (in year of startup dollars) will have to be increased over time at a rate that exceeds the rate of escalation. Another difficulty associated with the sinking fund option is that decommissioning costs must be estimable with reasonable accuracy to provide a basis to calculate an appropriate sinking fund payment. Although revised estimates can be made and reflected in the sinking fund payments later in the facility lifetime, the initial estimate is especially important if expected operating life is relatively short.

It must also be recognized that establishment and control of a sinking fund would, by its nature, create some administrative complexities. In addition to the problems of fund management and control, an additional government or quasi-government agency might be required to oversee the operation of one or more fuel cycle facility sinking funds, thus incurring additional costs for the administration of the fund.

6.2.2 Prepayment of Anticipated Decommissioning Costs

The general framework of the prepayment alternative is similar to the sinking fund option. A trust fund would be established. Fund stewards would invest the monies until required for decommissioning. The difference is that the present value of anticipated decommissioning and administrative costs would be paid into the fund before facility startup. Adjustments to the fund may be required to account for changes in such factors as the trust fund earnings rate versus the decommissioning cost escalation rate, facility life, added facilities, changing technology, safety, and regulatory requirements.

The principal advantage of this approach is that it provides the highest degree of assurance that decommissioning funds will actually be available when needed. This is because sufficient money should be available for decommissioning operations even if the facility ceases operation prematurely. Any funds remaining in the trust fund after decommissioning is completed could be returned to the facility owner.

One disadvantage of the prepayment option is that it may be the most expensive of the three payment options. Money invested in the prepayment fund is likely to earn less then if it were being directly utilized by the company. This is because the discount rate utilized by a facility operator will likely exceed the interest rate obtainable by the fund stewards. The discount rate favored by the operator will approximate his minimum rate of return on alternative investments. This will almost certainly exceed 10% under today's financial conditions and could be much higher. The fund steward, on the other hand, may only be able to obtain returns in the 7 to 9% range by making conservative investments in the current bond and note market. By requiring the operator to prepay the expected decommissioning costs, society loses the productive value represented by the incremental return the operator could realize on the funds over what the fund steward could realize.

To the extent debt funds are used to prepay the present value of decommissioning costs, the borrowing capacity of the operator is reduced and consequently his available supply of funds for capital investment is reduced. However, this approach would increase the amount of funds available for purchase of conservative government and private security issues.

One can argue that this approach unfairly raises the cost of nuclear power. Prepayment of decommissioning costs represents an extraordinary expense not incurred to the same degree in other industries. The prepayment option may also penalize current power consumers, because future power consumers may not pay their full share of the decommissioning costs. For instance, if the facility owner pays the present value of expected decommissioning costs out of retained earnings from past investments, future consumers will only pay for adjustments to the fund, such as those dictated by new regulatory requirements.

The facility owner is likely to fund the prepayment cost from a combination of retained earnings, equity issues, and long-term debt financing, as though it were a capital expenditure. In this case, future consumers ultimately will be charged through the pricing mechanism a sufficient amount to retire the interest and principal of the debt. If the term of debt financing is less than the facility life during the period when the debt is being retired, the plant customers may pay as much, or more, to fund decommissioning than they would pay under the sinking fund option. After the debt is retired, the customers would pay less.

6.2.3 Payment of Decommissioning Costs When Incurred

This option contemplates delaying payment for decommissioning until the costs are actually incurred. This is essentially the approach that has been used to date for U-Fab plants.

The principal concern with this approach is the relatively low assurance it provides that the decommissioning will actually be performed. As long as the facility operator is willing and financially able to perform the required work, no major problem should arise. If, however, the operator is financially incapacitated and/or unwilling to perform the required work, the burden may fall directly to the state or possibly the federal government, and required funding would likely have to come from general revenues. The risk increases if the safe storage option is utilized prior to dismantlement. Another concern is that the plant beneficiaries may not pay their proportional share of decommissioning costs because the full cost of decommissioning may not be reflected in the fuel cost.

The principal advantages of this option are that it is, at first glance, least costly, and it has the least administrative burden.

If this option is selected, it may be desirable to require the operator to purchase a surety bond or an insurance policy that would assure the availability of decommissioning funds. This approach is not unprecedented; many states require bonds from coal mining companies to ensure reclamation of strip-mined land.

There are several problems with obtaining a bond or insurance. The principal difficulty is that surety companies are not likely to be interested in selling a long-term bond because of the many uncertainties affecting their obligation. Yet, a long-term bond is needed if a state is to receive decommissioning assurance. If the bond is renewable at given intervals, the bonding company may very well decline renewal if the company becomes financially weak. Also, the guaranteed amount of the bond would have to be readjusted periodically to cover revised decommissioning cost estimates. If the bonding company does not agree ahead of time to automatic escalation of its guarantee, the usefulness of the bond is again substantially decreased. For example, over the expected 40-year operating life of a U-Fab facility, decommissioning costs could increase by at least a factor of ten in nominal dollars,(a) due to inflation.

An additional problem is that even if a long-term bond can be obtained, its degree of assurance is only as good as the surety company. Surety companies can become financially incapacitated just as any other company can.

(a) Nominal dollars are dollars of the year in which payments are made.

Finally, collecting on a surety bond would be more difficult (possibly requiring litigation) than utilizing funds previously paid into a decommissioning trust fund.

It may be possible for a well-financed company to obtain a bond for a U-Fab facility if final decommissioning is slated to occur immediately after closure. In order to get the bond, the applicant may very well have to provide up to 100% collateral.(2) For a weakly financed company, or under a custodial safe storage approach, where final decommissioning will not occur until 20 or more years after shutdown, a bond would be difficult if not impossible to obtain, especially if significant collateral is required. The cost of a bond, if it can be obtained, will likely be on the order of 1 to 2% per year of the guaranteed amount.(3) This is a significant cost burden.

Another approach to assure decommissioning performance might be for operators of fuel cycle facilities to make payments to a decommissioning assurance pool. The pool would be obligated to pay for decommissioning a facility if the operator defaulted on performance. Setting the appropriate insurance premiums could be a problem. To establish premiums, the pool administrator would have to estimate the likelihood of nonperformance or partial performance and the magnitude of the fund required to complete the decommissioning. It is possible that a decommissioning assurance pool might have to be established by the federal government, which could require congressional action.

6.3 DECOMMISSIONING FUNDING IN THE EVENT OF PREMATURE FACILITY CLOSURE

With the sinking fund and pay-when-incurred options, the state runs the risk that sufficient funds will not have been collected to cover decommissioning costs if the facility closes prematurely. If the facility operator can and will pay the difference, no problem arises. If he is financially unable to do so, the state or possibly the federal government could be forced to make up the missing funds. No special problem exists with the prepayment option because funds should be available whenever closure occurs. This is the principal advantage of the prepayment approach. With the pay-when-incurred approach, the risk of incomplete or insufficient decommissioning performance is somewhat greater in the event of premature closure because the operator may not have generated sufficient funds to cover the costs.

If the sinking fund option is chosen, a variety of options is available to assure the availability of funds in the event of premature closure. The options include one or more of the following:

- An initial extra cash payment to the sinking fund prior to production.
- Higher per unit sinking fund charges (in real, i.e., constant dollars) during early years of operation.
- A bond posted by the facility operator.
- Premature shutdown insurance.

The first two options can be considered as combinations of the sinking fund and prepayment options. The bond and insurance alternatives, while not infeasible, seem less desirable than the other two because of the difficulty of obtaining bonds, as discussed in Section 6.2.3. The bond and insurance alternatives could also be utilized in conjunction with the pay-when-incurred approach.

6.3.1 Initial Cash Payment

This option contemplates that an initial significant cash payment would be made to the sinking fund prior to startup. This money would become part of the sinking fund and would presumably be outside the reach of the facility owner's creditors. The size of the payment could be flexible and might depend on the financial resources of the operator, the probability of premature closure, the extent of anticipated decommissioning problems, the anticipated operating life of the facility, and other factors. In general, however, it seems that an initial payment on the order of at least 10% of total estimated decommissioning costs (in year of startup dollars) would be appropriate.

The principal advantage of this option is the added assurance it provides that the initial funds, plus sinking fund payments, will be sufficient to cover decommissioning costs, as well as administrative costs. If the prepayment is a small portion of total decommissioning cost, there is no significant disadvantage to this option. If the prepayment option is a significant fraction of total cost, only operators with a strong financial capability would be able to obtain a license.

6.3.2 Higher Initial Sinking Fund Charges

This option contemplates that payments to the sinking fund in constant dollars would be initially higher than average and then would decline with time. The precise sliding scale could be determined by the licensing agency. One variation in this option would be to attempt to have constant payments in nominal dollars over the lifetime of the facility. This option also could be utilized in conjunction with an initial cash payment.

The advantages and disadvantages of this option are comparable to those for the initial payment option. The main advantage of this option is that it provides more assurance than the basic sinking fund option that sufficient decommissioning funds will be available in the event of premature closure. It is also reasonably equitable to the operator and to his customers. This is because total decommissioning costs per unit of production decline as the total number of production units increase.

6.3.3 Surety Bonds

Surety bonds appear to be the least viable alternative for providing funds in the event of premature site closure. The chief difficulty is the problem of obtaining a long-term commitment from a surety company, as discussed in Section 6.2.3.

If a suitable bond commitment could be obtained, there are two potential advantages. First, it may be a more equitable alternative for the smaller company that is unable to make a significant initial cash payment. Second, it reduces the distortion effect on nuclear power generation costs of a high initial cash payment.

6.3.4 Premature Shutdown Insurance

An insurance pool is an additional approach to decommissioning assurance. The pool could be set up to assure the availability of decommissioning funds in the event of premature site closure, as well as for operator default. Seting of insurance premiums could be difficult, and the insurance pool concept might require implementation by the federal government.

6.4 PROVISIONS FOR ACCIDENT AND CONTINGENCY COSTS

This section provides a brief discussion of the issues associated with accident and contingency cost protection. States and the federal government are likely to be as interested in this protection as in decommissioning assurance. They are especially concerned if decommissioning funds are available to the operator's creditors. In this case, a large liability claim could financially incapacitate an operator and render his decommissioning performance impossible.

Contingency costs here do not refer to ordinary cost overruns incurred during decommissioning operations. These cost overruns can be allowed for by building into the sinking fund payments a reasonable contingency factor. Rather, the concern is with unexpected factors, such as corrective action needed for unexpected offsite radionuclide migration, or unanticipated increased decommissioning requirements caused by changing regulations.

During the facility's operating lifetime, liability and property protection seem to be best covered by insurance purchased by the facility operator. Only thermal power reactors, fuel reprocessing plants, and plutonium-licensed plants (possession limit must remain above 5 kg of plutonium) are covered by the Price-Anderson insurance scheme, which operates to limit aggregate liability for a nuclear incident to $560 million (42 U.S.C. 2210). Most fuel fabrication operators probably do carry liability and property insurance. Much of this insurance is carried through one or more of three pools: the Nuclear Energy Liability Property Insurance Association, the Mutual Atomic Energy Reinsurance Pool, and the Mutual Atomic Energy Liabilities Underwriters. If the states were to require appropriate amounts of liability and property insurance, concern over the availability of decommissioning funds could be lessened.

Under the safe storage decommissioning option, the plant may sit idle for years prior to dismantlement. During this period and during the final dismantlement period, it would also be desirable for the state to require liability and property insurance. After decommissioning, the site should be available for unrestricted use and further nuclear insurance should not be needed. The concern is obviously more complex for other facilities, e.g., low-level waste sites, where the possibility of contingencies may continue for many years.

A final but important issue is who should bear the risk if decommissioning costs exceed available trust funds. This issue should be covered by licensing language or contract agreement used in setting up the fund. In general, however, it seems justified to assume that the facility operator should bear the overrun. The primary reason is that he has ultimate responsibility for decommissioning with or without a trust fund. Moreover, the operator will presumably want to fully complete decommissioning to mitigate any possible future liability. If no trust fund is utilized, the facility operator should have total decommissioning responsibility regardless of cost.

If the operator is financially incapacitated at the time decommissioning cost overruns are experienced, the burden to cover the excess costs of these overruns will probably fall to the state. This possibility should encourage the state to diligently monitor operating practices in order to minimize decommissioning costs. It should also encourage the state to realistically estimate trust fund requirements. In extraordinary circumstances, funds may be available from the federal government.

6.5 WHO SHOULD CONDUCT DECOMMISSIONING ACTIVITIES?

When the facility finally ceases operation, the question arises as to who should actually conduct decommissioning activities. In large part, selection of an appropriate decommissioning agent depends upon the length of time between shutdown and dismantlement and the financing approach chosen.

A decommissioning contractor could be used, perhaps with varying degrees of effectiveness, after plant shutdown. If dismantlement is to occur shortly after shutdown, the plant operator is a likely choice to conduct the decommissioning work because of his familiarity with the facility. As the length of time between shutdown and dismantlement increases, the relative advantage of the operator doing the work decreases. Eventually, an outside contractor with decommissioning expertise may be the most suitable choice.

Selection of a decommissioning organization may depend in part upon the financing approach chosen. If the pay-when-incurred approach is chosen, it will be difficult to have anyone other than the operator or a contractor retained by him perform the work. The operator will likely want to directly control the decommissioning work when he is paying for it out of current revenues. If a trust fund is utilized to fund decommissioning, it may be reasonable for the state to provide that it or the fund steward will retain a decommissioning contractor. This could be done by putting the work up for bid or by simply selecting a contractor who may or may not be the facility operator. Trust fund monies could be allocated as work progresses, much as a bank allocates construction funds. The operator will be interested in the selection process, since he will likely be responsible for costs that exceed available trust funds, or he may receive a refund if trust fund monies exceed decommissioning costs. No matter how the selection of a decommissioning organization is conducted, it appears desirable for the state and the regulatory agency to at least retain the power to concur in the process to assure selection of a qualified organization.

6.6 POWER OF STATE GOVERNMENT TO IMPOSE FINANCIAL OBLIGATIONS ON FACILITY OPERATORS

The power of state governments to impose certain financial obligations on nuclear fuel cycle facility operators was examined in a study on financial alternatives for uranium milling operations.(4) The general conclusion was that a state may impose financial requirements as an exercise of its general police power to protect the life, health, and safety of the public. The study also concluded that a state, as a licensing condition, may require a facility operator to transfer ownership of the land to the state at the conclusion of the facility's operating life.

With appropriate legislation, it thus appears that any of the financial alternatives discussed in this section, including establishment of trust funds and bonding requirements, could be implemented. The conclusion applies whether or not the state is an Agreement State under the Atomic Energy Act.

6.7 SUMMARY

In summary, the options for providing funds for decommissioning activities that appear to be in the balanced best interest of all parties are the sinking fund, the prepayment option, or some combination of the two. These approaches provide good assurance that the work will be performed. They also provide appropriate consideration of costs in power supply planning and can be made reasonably equitable to nuclear power consumers. The options present some administrative complexities, but these are not likely to be severe.

To allow for premature facility closure, there is an incentive to supplement the sinking fund approach with additional protection. Several mechanisms are available for achieving this protection. First, before startup, the state, or possibly the federal government, can require an extra initial cash payment into the trust account. Second, the state can set higher real sinking fund charges during early years of operation. If a long-term surety bond can be obtained, or if some form of premature shutdown insurance were available, they could also be required.

The prepayment option provides the greatest assurance of decommissioning performance. Prepayment of the present value of all anticipated decommissioning costs will add a significant amount to the initial capital investment. Much of the amount can probably be borrowed, however, and then passed on to consumers through fuel prices. The most serious objection to this approach is that it is the most expensive option for society and that it taps the debt market for funds that would otherwise be available for private investment projects.

The least satisfactory option appears to be the pay-when-incurred option. The principal concern is the relatively low degree of assurance it provides of decommissioning performance. It is, however, probably the least expensive of the options.

REFERENCES

1. New Mexico Statues Annotated, 12-9-5.1, 1977.

2. *Task Force Report on Bonding and Perpetual Care of Licensed Nuclear Activities*, Conference of Radiation Control Program Directors, p. 21, April 1976.

3. *Financial Alternatives for Stabilization, Reclamation, and Long-Term Monitoring and Maintenance of Uranium Mill Trailing Piles*, Science Applications, Inc., p. 18, Los Angeles, CA, October 1977.

4. Ibid., pp. 84-90.

7.0 CHARACTERISTICS OF THE REFERENCE URANIUM FUEL FABRICATION PLANT

This section briefly describes the reference uranium fuel fabrication (U-Fab) plant, the reference site on which it is assumed to be located, and the physiochemical processes used in the plant. Estimates are presented of residual radioactivity levels and residual chemical levels on the site and in the plant when production operations are terminated.

The Wilmington, North Carolina, plant of General Electric Company(1,2) is chosen as the reference facility for this study because it is representative of contemporary U-Fab plants in the United States. Existing plants of this type are expected to require decommissioning in the future. The Wilmington plant currently uses two head-end processes for converting gaseous UF_6 to UO_2. The primary method used is a chemical process involving hydrolysis of vaporized UF_6 to ammonium diuranate (ADU) precipitate using ammonia, and 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 reduction of U_3O_8 to UO_2 powder in a reduction-calciner. The associated facility components for both processes are analyzed in this study, and the methods and costs for decommissioning each head-end process are discussed individually.

Details of the plant and the plant process descriptions are presented in Appendix A, site description details are given in Appendix B, and the bases for residual radioactivity estimates are presented in Appendix C, all in Volume 2.

7.1 SITE DESCRIPTION

A reference site is developed to aid in assessing the public safety of conceptually decommissioning the reference plant. The meteorological parameters and population distributions used for this reference site are taken from the ALAP Study(3) for the river site in the year 2000. The ecological data are taken from environmental information provided for an operating nuclear reactor.(4) The remainder of the information is obtained from a variety of sources, and is thought to be representative of potential sites for nuclear fuel cycle facilities in the midwestern or southeastern United States. This reference site description is developed for use in a series of studies examining decommissioning of nuclear fuel cycle facilities. The detailed supporting information relating to this abbreviated description is found in Appendix B.

Individual features for specific sites will likely vary from those of the reference site described in this study. It is believed, however, that use of a reference site rather than a specific site will result in a more meaningful overall analysis of the potential safety impacts associated with the decommissioning of nuclear fuel cycle facilities. Site-specific environmental information will be required for the detailed safety analysis and the environmental report submitted with the request for license modification prior to decommissioning a particular facility.

The reference site occupies 4.7 km^2 in a rectangular shape of 2 km by 2.35 km. A river of moderate size runs through one corner of the site.

The site is located in a rural area that has a relatively low population density. Higher population densities are located at distances 16 to 64 km away, and gradually reducing population densities are encountered out to 177 km. The closest moderately large city, population 40,000, is about 32 km distant. The closest large city, population 1,800,000, is about 48 km away. The total population in a radius of 80 km is 3.52 million.

The plant facilities are located within a fenced portion of the site. The minimum distance from the point of plant atmospheric releases to the outer boundary of the reference site is 1 km. About 80% of the land surrounding the reference site is used for farming.

The relatively clean river flowing through the site has an average flow rate of 1420 m^3/sec. The river is used for irrigation, fishing, boating, and other aquatic recreational activities, and is a source of drinking water for larger communities. Large supplies of flowing ground water exist at modest depths around the site. This water is widely used for drinking and irrigation.

Atmospheric dispersion factors used in this study are derived as an average from the meteorological data of 16 nuclear sites. The resulting annual average atmospheric dispersion factor at the closest point on the site boundary (i.e., 1 km) is about 5×10^{-8} sec/m^3.(4)

The reference site is slightly contaminated with radioactive material as a result of deposition from the release of normal operating effluents over the 40-year plant operating life. It is assumed that accidental releases of radioactive material are cleaned up immediately following the event. Estimates of the maximum site contamination levels at the time of plant shutdown and selected times after shutdown are shown in Table 7.1-1 for uranium enriched to 3% in ^{235}U. The site contamination estimates are based on the deposition of predicted normal operating atmospheric releases of particulates. The normal airborne operating releases are assumed to be 10^{-6} of the estimated uranium fuel throughput at the time of fabrication.(5) The plant processing capacity is assumed to be 1000 Mg of uranium metal per year. The assumptions and calculational methods for relating the normal plant effluents to site surface contamination are found in Appendix B.

TABLE 7.1-1. Estimated Maximum Quantities of Radioactive Materials Deposited on the Reference Site After a 40-Year Operating Lifetime[a]

	Deposited Radioactivity (pCi/m^2) at Plant Shutdown and Selected Times After Shutdown				
Radionuclide	Shutdown	5 Years	10 Years	30 Years	100 Years
^{230}Th	3.6×10^{-1}	4.5×10^{-1}	5.3×10^{-1}	8.8×10^{-1}	2.1×10^{0}
^{231}Th	7.6×10^{1}	7.6×10^{1}	7.6×10^{1}	7.6×10^{1}	7.6×10^{1}
^{234}Th	3.8×10^{2}	3.8×10^{2}	3.8×10^{2}	3.8×10^{2}	3.8×10^{2}
^{231}Pa	3.4×10^{-2}	4.2×10^{-2}	5.0×10^{-2}	8.3×10^{-2}	2.0×10^{-1}
^{234m}Pa	3.9×10^{2}	3.8×10^{2}	3.8×10^{2}	3.8×10^{2}	3.8×10^{2}
^{234}Pa	3.9×10^{-1}	3.8×10^{-1}	3.8×10^{-1}	3.8×10^{-1}	3.8×10^{-1}
^{234}U	2.0×10^{3}	2.0×10^{3}	2.0×10^{3}	2.0×10^{3}	2.0×10^{3}
^{235}U	7.6×10^{1}	7.6×10^{1}	7.6×10^{1}	7.6×10^{1}	7.6×10^{1}
^{238}U	3.8×10^{2}	3.8×10^{2}	3.8×10^{2}	3.8×10^{2}	3.8×10^{2}
Totals	3.3×10^{3}	3.3×10^{3}	3.3×10^{3}	3.3×10^{3}	3.3×10^{3}

(a) Values are calculated based on a release factor from Reference 5, a deposition factor from Appendix B and 3% enriched uranium.

7.2 PROCESS DESCRIPTION

Overall processing characteristics assumed for the reference U-Fab plant are presented in Table 7.2-1. A simplified block flow diagram of the process is shown in Figure 7.2-1. Details of the process are given in Section A.1 of Appendix A.

TABLE 7.2-1. Overall Processing Characteristics of the Reference Plant

Daily Processing Capacity

3300 kg U per day (i.e., 3800 kg UO_2 per day)

Average Yearly Production

1 million kg U per year

Plant Efficiency

∼80%

Annual Input

1 million kg U as UF_6 gas enriched 2 to 4 wt% in ^{235}U;
Shipped in 2300-kg, 76-cm-diameter cylinders
(Model OR-30B), packaged in a protective shipping
container.

Annual Output

99% UO_2 Pellets--79% in fuel rods, 1% UO_2 Powder;
20% as pellets only

Scrap Rate

20% of U throughput recycled as clean scrap

Effluent Losses

0.7 wt% U in solids
0.3 wt% U in liquids

Unrecovered Losses

0.45 wt% U

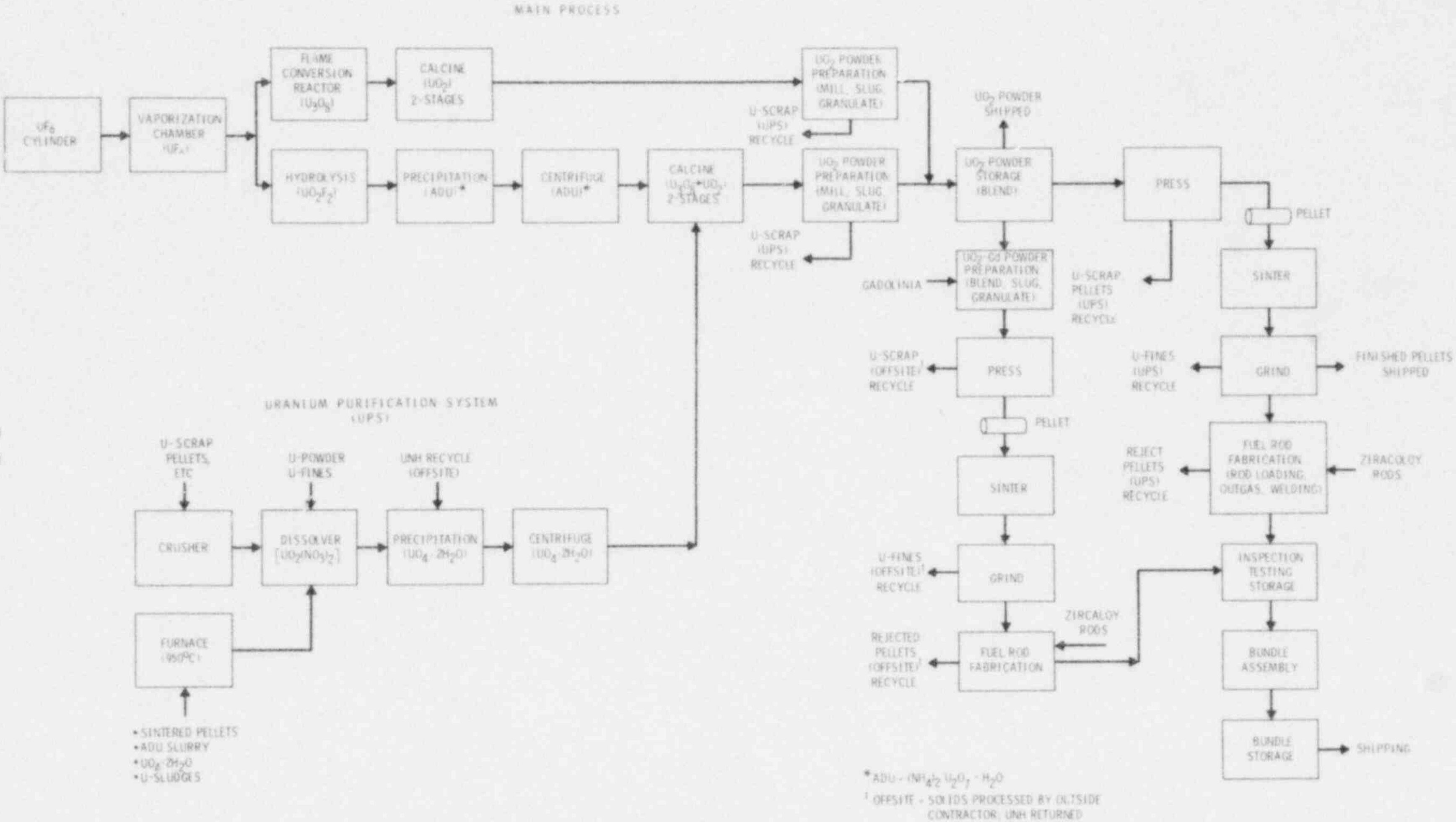


FIGURE 7.2-1. Simplified Process Flow Diagram for the Reference Plant

POOR ORIGINAL

All processes associated with fuel pellet fabrication are performed inside enclosures located in seven rooms in the process areas of the building (the UF_6 vaporization area; the first-floor chemical area; the second-floor chemical area; the press area; the sintering area; the grind, load, weld area; and the gadolinia area). Transfer of product materials from one process step to the next is accomplished both automatically and manually, using 19-ℓ cans (one safe batch).

Production activities fall into three basic categories:

1. chemical conversion of UF_6 to UO_2
2. mechanical processing, including pellet production, fuel rod fabrication, and fuel bundle assembly
3. recovery of uranium from scrap, off-specification material, and chemical wastes.

7.2.1 Chemical Conversion Head-End

Uranium is received by truck at the plant site as UF_6 sealed in pressure cylinders. The UF_6, enriched from 2 to 4 wt% in ^{235}U, arrives in 2300-kg, 76-cm-diameter cylinders (Model OR-30B) that are protected in transit by an outer shipping container. Uranium slightly enriched above 4 wt% in ^{235}U arrives in 25-kg, 12.7-cm-diameter cylinders (Model OR-5A) that are also packed in protective shipping containers.

Upon receipt, the cylinders are carefully weighed for accountability purposes and then either stored or transferred on a cart from the storage platform to the adjacent UF_6 vaporization room. Using an overhead bridge crane, each individual cylinder is lifted into position in one of 11 different vaporization chambers. After properly connecting the cylinder to a flexible discharge line, the cylinder is heated by electrically heated air to volatilize the stored UF_6. The UF_6 gas is piped to a vessel filled with water, where the gas reacts with water (hydrolized) to form UO_2F_2 and HF. The HF in the off gas is scrubbed and recovered as a byproduct. The UO_2F_2 solution is recirculated through one of two identical hydrolysis storage tanks until the proper UO_2F_2 concentration is reached. The process is then switched to the second storage tank and the

UO_2F_2 solution in the first tank is transferred to the chemical precipitation tank. In the precipitation tank, ammonium hydroxide is added to the UO_2F_2 solution to precipitate uranium as ADU. The resulting ADU solution is transferred to a digester tank to aid the precipitation process. The resulting ADU slurry is then dewatered and concentrated (by centrifuging) to a paste. The 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. The UO_2 powder is placed in 19-ℓ cans for transport to the second-floor UO_2 powder preparation area.

7.2.2 Direct Conversion Head-End

Four flame conversion reactors are used to directly convert UF_6 to U_3O_8. The four reactors are connected to three vaporization chambers. These chambers are capable of heating and stripping UF_6 from the 2300-kg UF_6 cylinders, in a cycle that permits continuous operation of the reactors. In the reactors, 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 byproduct, 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 before further processing. The U_3O_8 is further treated by crushing and granulating it to a powder suitable for further processing as necessary. The U_3O_8 powder is then fed to a horizontal, gas-fired reduction calciner, where it is defluorinated, reduced, and dried to produce ceramic grade UO_2 powder. The calciner discharges the UO_2 powder through a double rotary air lock system into 19-ℓ buckets. The UO_2 powder is then transported to the second-floor UO_2 powder preparation area for treatment to enhance its pellet-forming properties.

7.2.3 Pellet Formation and Fuel Rod Assembly

Pellet formation is a two-step operation. In the first step, the uranium dioxide is pulverized, compacted, and granulated to increase its density and size distribution to that desired for pellet formation. To perform these steps, UO_2 from the calciners is processed through a size-reduction hammer mill, a predensifier press, and a granulator that crushes the compacts from the press into material of uniform particle size. The sized UO_2 particles are placed in 19-ℓ buckets, sealed, and transferred to the mezzanine storage area. After samples of the densified material are analyzed for uranium and moisture content and found acceptable, the UO_2 particles are ready for the second step in the process of forming UO_2 pellets.

In the second step, the densified UO_2 powder is pelletized, and the pellets are sintered in a reducing (hydrogen) atmosphere. They are then ground to finished dimensions and loaded into fuel rods. To perform these steps, the densified UO_2 powder stored on the mezzanine is loaded in hoppers that feed the pellet presses located on the main floor. The pellets formed are sintered in a reducing atmosphere in one of five electrically heated furnaces (sintered to about 95% of theoretical UO_2 density) and ground to correct size through one of five centerless grinders equipped with diamond-grit work wheels. The finished pellets are placed in trays and stored until needed in storage cabinets located at one of four pellet-loading stations. Fuel pellets removed from storage are placed on fuel mock-up channels, weighed, and measured to meet required specifications. An acceptable string of pellets is pushed into an empty zircaloy tube previously welded at one end. Loaded tubes (now fuel rods) are placed in trays and transferred to one of three rod-outgas ovens to remove all traces of moisture. From the ovens, individual rods are inserted into a controlled atmosphere weld box. After air is evacuated, the rod is backfilled with helium and the end plug automatically inserted and welded into position. The rods are placed in trays and stored in cabinets for eventual assembly into fuel bundles.

7.2.4 Fuel Bundle Assembly and Final Inspection

Rod trays are removed from the storage cabinets and each fuel rod is scanned for ^{235}U content, using a neutron source (^{252}Cf) and gamma radiation detectors to confirm the enrichment. Based on rod enrichment requirements for a bundle matrix, the required number of rods are removed from the tray and laid out in a specific order on one of five assembly tables. This procedure is repeated for each enrichment, until the total number of rods needed to satisfy the bundle matrix is obtained. The correct number of rods with the right enrichments for the bundle to be assembled is now on the bundle make-up table in proper loading order. The rods are visually inspected for cleanliness and damage and replaced as necessary.

The spacer hardware is positioned with the fixtures on one of five horizontal bundle loading tables. The fuel rods on the assembly tables are inserted into the spacer hardware according to a fixed insertion schedule. 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 bundles are leak-tested in a vacuum chamber. Helium leaking from fuel rods is detected in the exhaust air, using a helium mass spectograph.

The bundle is next placed in a lighted inspection fixture, where the rods are inspected for straightness, linearity, and other design requirements. If the bundle passes the inspection, it is wrapped in a plastic dust cover and removed with an overhead crane to the bundle storage racks. The bundles are vertically suspended from hooks on the racks by their upper tie plates until they are ready for shipment.

7.2.5 Scrap Recovery

Internally generated "clean" uranium scrap in various physical forms that do not meet quality standards or that are mixed with combustible foreign material (i.e., slugger and press residue, ADU from pad, grinder sludge, rejected pellets, etc.) is reprocessed through scrap recovery equipment known collectively as the Uranium Purification System (UPS). The simplified process flowsheet diagram for the UPS is shown in Figure 7.2-1. Material to be reprocessed through the UPS is accumulated in safe batches (normally 19-ℓ buckets) and stored until processed.

Scrap uranium to be reprocessed (∿21-kg lots) is slowly charged through a discharge chute into one of nine different 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 discharged is pumped from the long feed tank (UO_4 receiver tank) to a gas-fired reduction calciner. 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 for use in making fuel pellets.

Uranium scrap mixed with foreign materials (gadolinia slugger and press residue, gadolinia grinder sludge, rejected gadolinia pellets, nitrate wastes, combusted wastes, solid wastes, radwastes, etc.) not meeting UPS quality standards for processing is shipped to an offsite contractor for rework and recovery of uranium. The recovered uranium is returned to the facility in the form of UNH and is added back into the main process through the UPS.

7.2.6 Liquid Waste Effluent Processing

Chemically different liquid waste streams containing uranium (generated in fuel manufacturing operations) are kept separate to facilitate uranium recovery operations. They are classified as nitrate wastes, fluoride wastes, and radwastes. This separation allows individual treatment of each process waste stream in a manner compatible with the recycle of valuable materials back into the main process and/or the release of effluents into the environment. Figure 7.2-2 illustrates schematically how each of these waste streams are treated before eventual impoundment or release offsite. Each stream has its own quarantine tank system within the main building to permit temporary storage of the waste liquid. Based on uranium content, the liquid wastes are either released for final waste treatment or are recycled to recover the uranium residuals.

Nitrate Wastes

Nitrate wastes generated during scrap recovery operations are treated on a batch basis after transfer from the UPS quarantine tank system in the fuel manufacturing building to the waste treatment facility. Nitrate waste treatment consists of a lime [$CA(OH)_2$] addition to precipitate and settle out any uranium compounds present in liquid wastes. The clarified liquid (clear supernate) is pumped from the 76,000-ℓ precipitation tank to the nitrate storage lagoons (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. The paper manufacturing firm dilutes the nitrate solution (approximately 3000 to 1) by mixing it with their liquid

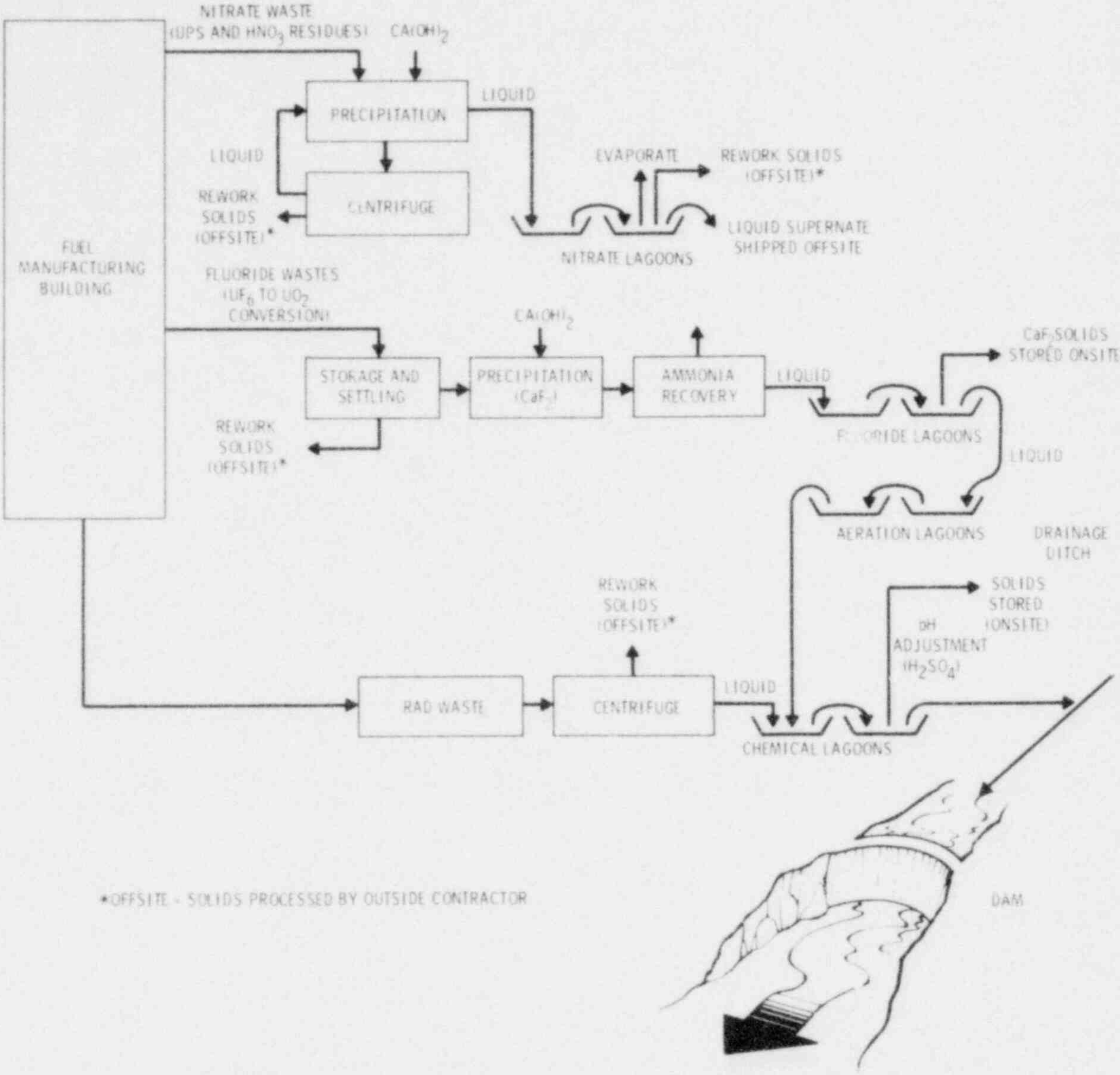


FIGURE 7.2-2. Process Liquid Waste Treatment

wastes to enhance the biodegradation processes within their waste treatment facility. The uranium-bearing sludge collected in the bottom of 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.

Fluoride Wastes

If they meet process limits, chemical wastes generated from the UF_6 to UO_2 conversion process are pumped from the fluoride waste collecting and quarantine tank system to a 246,000-ℓ storage tank. If the fluoride wastes do not meet process limits, they are recycled back into the process for rework through the utility recycle system. Liquid fluoride waste in the 246,000-ℓ storage tank is continuously recirculated to keep solids suspended until the liquid is pumped to a 379,000-ℓ settling tank. The solid material in this tank is centrifuged out and stored in 19-ℓ pails until it is recycled or discarded. The supernate from this tank is decanted on a batch basis into two 45,400-ℓ treatment tanks. In these tanks, the waste liquid is treated with lime slurry $[Ca(OH)_2]$ to precipitate and entrap uranium residuals in a calcium fluoride matrix. 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. 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 is pumped to the aeration lagoons where, if necessary, the liquid can be further treated to remove ammonia. Finally, the fluoride waste solution is sent to the chemical lagoon where it is mixed with other chemical waste liquids from the plant and released to a drainage ditch that flows offsite to the river.

CaF_2 solids on the bottom of the fluoride storage lagoons are periodically removed and stored onsite for eventual reprocessing to recover the uranium residuals. All U-Fab plants using the ADU process store the resulting CaF_2 onsite for eventual disposal.

Radwastes

Waste solutions from sources such as laboratory sinks, protective clothing, laundering machines, and floor drains are initially collected in a cylindrical floor tank. 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 chemical disposal facility or returned to the process for rework.

7.2.7 Solid Waste Processing

Solid wastes such as paper, rags, mops, plastic, wood, protective clothing, damaged tools, and equipment are constantly generated during plant operations. These waste materials are collected at the point of origin in designated containers designed to prevent the loss of contents. 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 materials in containers are segregated into noncombustible and combustible categories and treated or disposed of as illustrated in Figure 7.2-3.

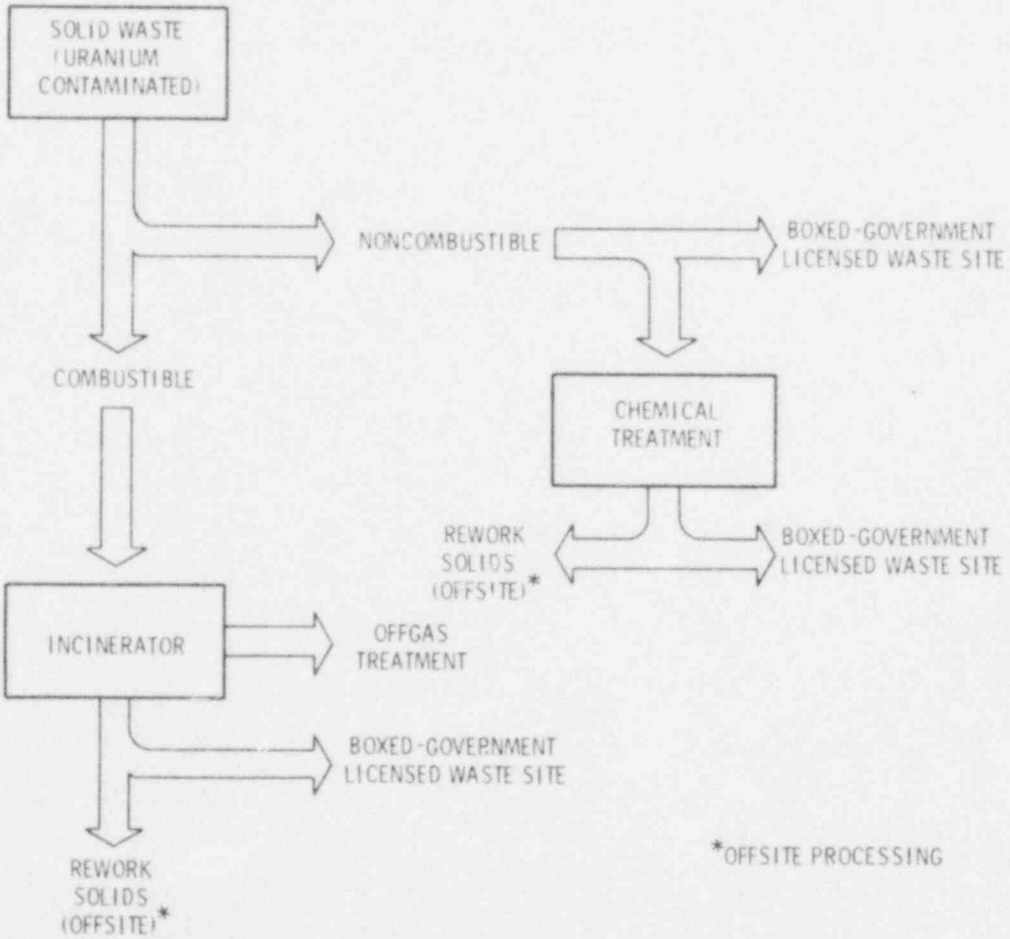


FIGURE 7.2-3. Solid Waste Treatment

Noncombustible Materials

Containers of noncombustible waste are emptied onto a hooded cleaning and sorting table. High-velocity water spray and/or steam cleaning equipment are used to decontaminate the contaminated noncombustible wastes. Decontaminated wastes are either packaged directly or reduced to a smaller volume, prior to packaging. Packaged wastes are generally shipped to a government-licensed low-level waste burial site for disposal. Noncombustible wastes not meeting the established limit for uranium are recycled (reworked) in the facility. Liquids generated from the decontamination processes are discharged to the radwaste system described in Section 7.2.6.

Combustible Wastes

Combustible wastes are generally incinerated, but may be shipped directly to a licensed low-level waste burial site if incineration is not desirable. The incineration system presently consists of a shredder, a blow-tube unit, a vortex incineration chamber, an off-gas scrubber, and a filter unit. The system is housed in a building next to the fuel manufacturing building. Materials to be incinerated are conveyed to the shredder and into the vortex incineration chamber. The incinerator combusts the material at 1090°C to produce ash and off gases. The solid ash is removed regularly on a batch control basis, using known uranium input measurements. Collected ash is placed in buckets where it is sampled and eventually shipped 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.

7.3 PLANT DESCRIPTION

The reference U-Fab plant is designed and constructed for the production of UO_2 pellets, the incorporation of these pellets into fuel rods, and the assembly of fuel rods into fuel bundles. The plant also has facilities to recover uranium from scrap and waste materials and to recover valuable chemicals from gaseous and liquid wastes. An isometric drawing of the reference plant (the Wilmington plant of General Electric Company) is shown in Figure 7.3-1. Details of the plant description are given in Section A.2 of Volume 2.

The plant is assumed to be located within a fenced-in restricted area of approximately 30,000 m^2 that is controlled and policed by security personnel. The main plant building occupies 19,300 m^2 of manufacturing, laboratory, maintenance, decontamination, storage, and office floor space. Adjacent and connected to the south side of the main building are two separate but innerconnected single-story structures. The structures house the chemical-metallurgical laboratory, the waste recycle control room, and the UO_2 powder warehouse, and occupy 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, liquid chemical waste treatment lagoons, a sanitary waste treatment plant, a propane station, a tank and pump station, equipment storage yards, an electrical substation, and warehouse and CaF_2 storage grounds.

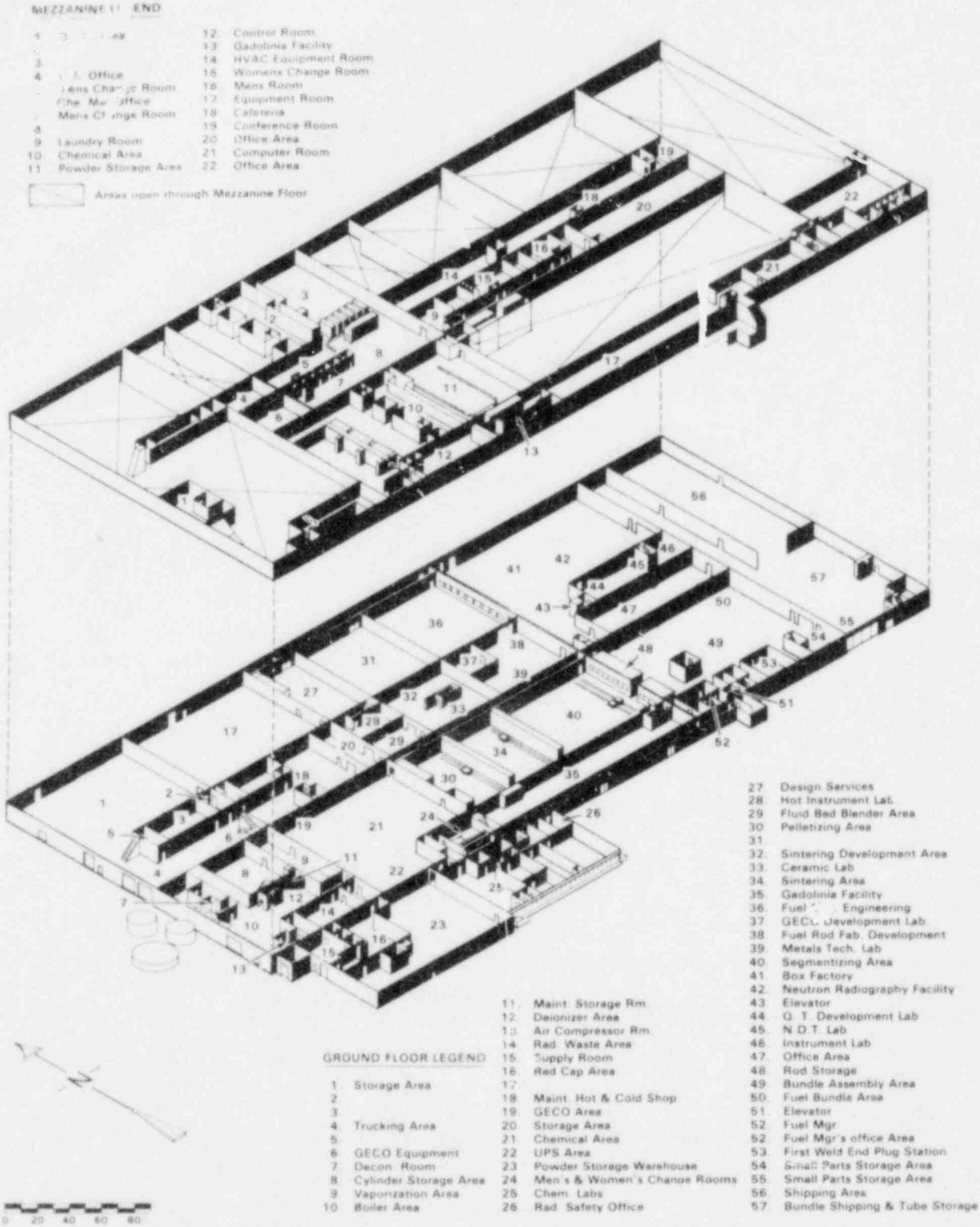
7.3.1 Facility Description

The main fuel manufacturing building is a 80-m by 211-m structure that is built to allow for future expansion to double the current production capacity. It is fabricated of 3.8-cm insulated metal siding attached to a steel framework. The interior walls are constructed of 20- by 20- by 41-cm concrete block and 1.3-cm sheet rock. The ground floor and the first meter of the outside walls are reinforced concrete 10 to 15 cm 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 3.5-cm insulated corrigated metal deck that is capped with 3.8 cm of asphalt and gravel.

In the main building, the fuel fabrication operations are divided into the following unit operations:(a)

(a)These unit operations may involve more than one room within the plant.

POOR ORIGINAL



MEZZANINE LEGEND

1 [illegible]
3
4 Q.C. Office
[illegible]ens Change Room
Chem. Met. Office
Mens Change Room
8
9 Laundry Room
10 Chemical Area
11 Powder Storage Area
12 Control Room
13 Gadolinia Facility
14 HVAC Equipment Room
15 Womens Change Room
16 Mens Room
17 Equipment Room
18 Cafeteria
19 Conference Room
20 Office Area
21 Computer Room
22 Office Area

Areas open through Mezzanine Floor

GROUND FLOOR LEGEND

1. Storage Area
2.
3.
4. Trucking Area
5.
6. GECO Equipment
7. Decon. Room
8. Cylinder Storage Area
9. Vaporization Area
10. Boiler Area
11. Maint. Storage Rm.
12. Deionizer Area
13. Air Compressor Rm.
14. Rad. Waste Area
15. Supply Room
16. Red Cap Area
17.
18. Maint. Hot & Cold Shop
19. GECO Area
20. Storage Area
21. Chemical Area
22. UPS Area
23. Powder Storage Warehouse
24. Men's & Women's Change Rooms
25. Chem. Labs
26. Rad. Safety Office
27. Design Services
28. Hot Instrument Lab
29. Fluid Bed Blender Area
30. Pelletizing Area
31.
32. Sintering Development Area
33. Ceramic Lab
34. Sintering Area
35. Gadolinia Facility
36. Fuel [illegible] Engineering
37. GECO Development Lab
38. Fuel Rod Fab. Development
39. Metals Tech. Lab
40. Segmentizing Area
41. Box Factory
42. Neutron Radiography Facility
43. Elevator
44. Q. T. Development Lab
45. N.D.T. Lab
46. Instrument Lab
47. Office Area
48. Rod Storage
49. Bundle Assembly Area
50. Fuel Bundle Area
51. Elevator
52. Fuel Mgr
52. Fuel Mgr's office Area
53. First Weld End Plug Station
54. Small Parts Storage Area
55. Small Parts Storage Area
56. Shipping Area
57. Bundle Shipping & Tube Storage

FIGURE 7.3-1. Isometric of the Reference Plant

- UO_2 power production (ground and upper level)
- pellet production
- rod loading and welding
- gadolinia rod production
- bundle assembly.

The process areas of the main building are divided into a series of enclosed or partially enclosed rooms located on both the ground and upper floors. These interior processing rooms are referred to as the:

- UF_6 vaporization room
- chemical area
- UO_2 powder production (upper floor)
- powder storage and feeding (upper floor)
- press area
- sintering area
- grind, load, and weld area
- gadolinia room
- quality control, bundle assembly, and packaging area.

Uranium recovery, chemical recovery, waste handling, maintenance, laundry, storage, boiler and water treatment, air filtering, and laboratory operations are conducted in support of production operations within the main building. Change rooms, offices, control stations (shown in Figure 7.3-1) are involved in the above support activities.

The processing areas or rooms within the main 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 30.5-cm-square tiles that 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. It 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 a 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 stacker building is a separate single-story structure that is attached to both the main building and the chem-met laboratory. It is 27 m wide by 47 m long and houses the UO_2 powder warehouse and the uranium waste and scrap processing (red cap) areas. 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, corrigated metal decking.

The warehouse portion of the stacker building contains sets of storage racks for storing 19-ℓ buckets of uranium oxide. The red cap area of the stacker building contains a crusher and blender and a drying or heat-treating furnace. Uranium scrap materials are pretreated in the red cap area before they are processed through the UPS, shipped to an offsite contractor for uranium recovery, or directly recycled back into the main process.

The waste incineration building is a 12.2-m-wide by 18.3-m-long structure approximately two stories high. It is constructed of insulated corrigated 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. Combustible materials from plant operations are incinerated in a blower furnace and, depending on the uranium content, the ash is either shipped for burial in a government-licensed burial ground or is reworked by an outside contractor to recover the uranium.

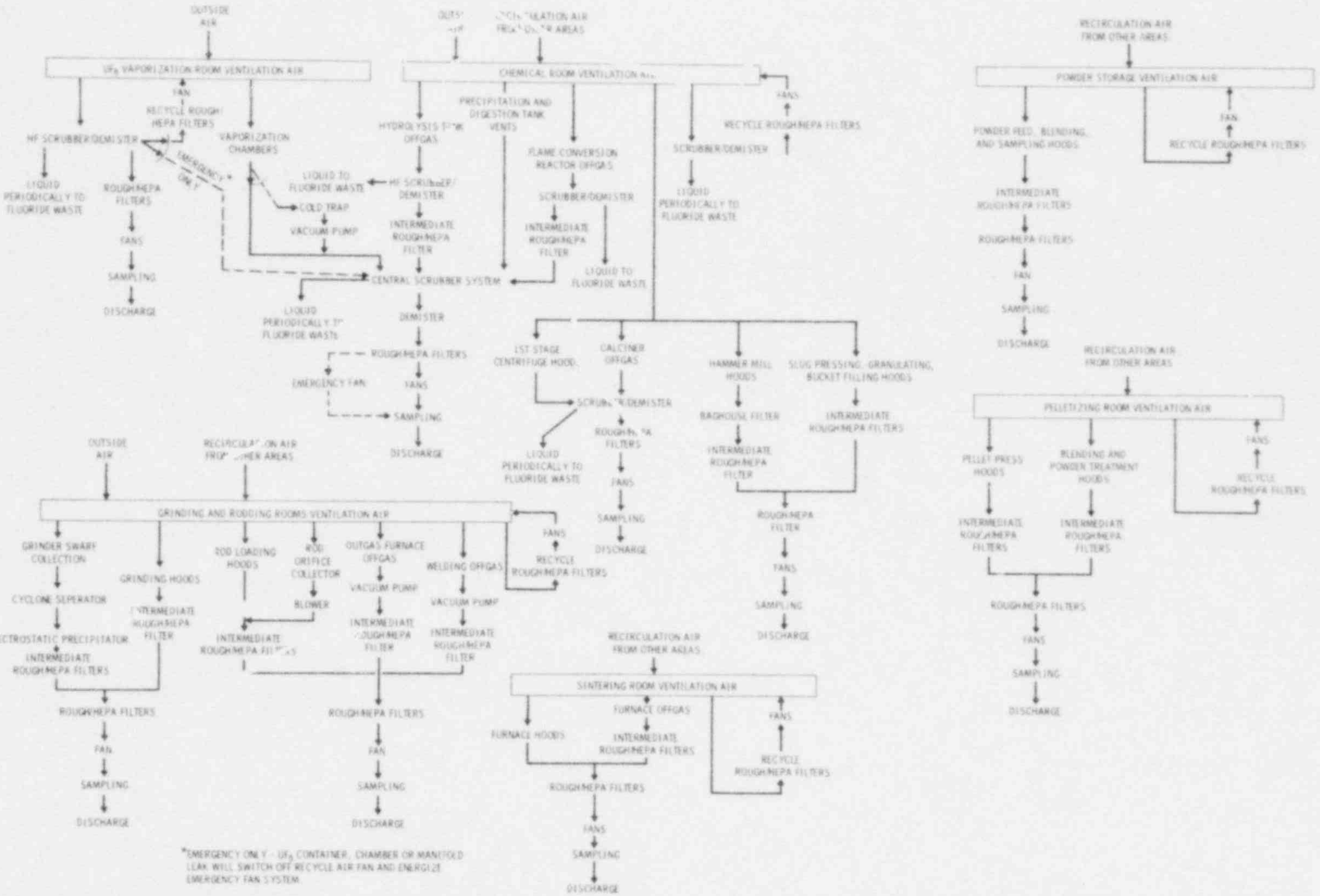
The calcium fluoride and nitrate waste treatment plant is a multistoried, roofed structure that is open on four sides. It is constructed of large steel framework members that serve as supports for the numerous tanks, columns, pumps, and piping associated with the facility. A small enclosed area on the ground floor of the building houses a control room for the facility and a uranium recovery (centrifuge) room. A separate building next to the main facility houses a boiler for supplying steam to the NH_3 stripping column. Adjacent to the waste treatment facility are six storage lagoons for the temporary impoundment of waste liquids and solids. These lagoons are lined to prevent seepage of waste liquids into ground water and are periodically cleaned of all solid residues.

7.3.2 Ventilation System Description

A simplified flow diagram for the reference U-Fab plant ventilation systems is shown in Figure 7.3-2. Each operational area in the fuels building has its own separate air handling system that is designed specifically to provide clean, thermally conditioned air to the building and to exhaust filtered or scrubbed and filtered air to the environs. The flow of air within the building is controlled so that the air moves from clean areas to areas with successively higher contamination potential.

Fresh air is supplied to each process area within the building after it has been filtered for dust, chilled to remove moisture, and heated as appropriate for the season. In the chemical (UF_6-UO_2 conversion), radwaste, and "hot" maintenance shop areas, fresh air is directly drawn to make up for all the air being exhausted. In the vaporization, sintering, UO_2 powder storage, segmenting, and pelletizing areas of the building, fresh make-up air is drawn as needed into the recirculating air ventilation system. The fresh air and recirculated air are filtered through a dust and a high-efficiency particulate air filter assembly (HEPA), respectively, before being mixed, chilled, and heated in the recirculation ventilation system for distribution in the building. Any additional air needed for a contaminated room is drawn from building areas having little or no contamination. The recirculating ventilation system in the vaporization area is equipped with a scrubber to remove contaminates from the recirculating air. An emergency dump fan is also located in the vaporization room that boosts exhaust air from the room into the UF_6-UO_2 conversion area exhaust system (water scrubber-HEPA system), in the event of an accidental UF_6 release.

There are 32 stacks associated with exhaust air systems for fuel manufacturing operations. Twenty-eight of these stacks are located on the roof of the



*EMERGENCY ONLY - UF_6 CONTAINER, CHAMBER OR MANIFOLD LEAK WILL SWITCH OFF RECYCLE AIR FAN AND ENERGIZE EMERGENCY FAN SYSTEM.

FIGURE 7.3-2. Ventilation and Hood Exhaust Systems in Main Production Areas of the Reference Plant main building. The other four are located on the roof of the incineration building. These separate air exhaust systems exhaust air from the building either through enclosures containing highly contaminated process equipment or through room exhaust systems located in potentially contaminated rooms. Exhaust air from the vaporization and chemical processing (UO_2-UF_6 conversion) areas and associated equipment is scrubbed and dried before being filtered through HEPAs. Exhaust air from other processing areas generally is filtered through two HEPAs. One HEPA is generally located at the work station for quick changeout. Some heavily contaminated enclosures have a roughing filter that precedes the first HEPA to eliminate large-diameter aerosols.

7.4 RESIDUAL RADIOACTIVITY ESTIMATES

Table 7.4-1 summarizes estimated residual radionuclide inventories of uranium in major pieces of equipment, and Table 7.4-2 shows the estimated distribution of residual radioactivity in the plant ventilation system of the reference plant after final inventory cleanout. Key assumptions and rationale on which the inventory estimates are based and detailed inventories for each room are presented in Appendix C of Volume 2. Final inventory cleanout operations and decommissioning decontamination operations are described in Appendices F and G.

At shutdown and before final inventory cleanout, the uranium inventory in the reference plant is estimated to be about 790 kg, while after final inventory cleanout it is estimated to be approximately 270 kg. Final cleanout, done periodically during plant operations between processing campaigns, removes process materials, chemicals, trash, visible quantities of contamination, scrap, scrap solutions and contaminated solutions from the facility. Empty product, scrap and waste handling tanks are also rinsed to flush out remaining process solutions. These operational inventory cleanout operations are charged to plant operations and not to decommissioning.

Decommissioning decontamination operations start with a thorough flushing and chemical decontamination of all process equipment and piping. Decontamination procedures include spray cleaning, hot corrosive acid flushing, and dry

TABLE 7.4-1. Estimated Uranium Inventory in Major Pieces of Equipment in the Reference Plant After Final Inventory Cleanout

Equipment	kg of Uranium
UF_6 Vaporization	
Vaporizers and Equipment	2.1
Chemical Process Equipment	
Hydrolyzer Tanks and Equipment	1.4
Precipitation and Digestion Tanks and Equipment	0.2
Centrifuges and Equipment	0.3
Calciners and Equipment	21.8
Milling, Pressing and Granulation	43.7
Bucket Loading Equipment	1.5
GECO Flame Reactors and Equipment	6.4
Uranium Purification System	3.1
Subtotal	78.4
Pellet Production and Assembly	
Blenders and Powder Storage	2.5
Pelletizing	4.6
Sintering	0.5
Grinding and Rod Loading	3.5
Granulators	39.7
Subtotal	50.8
Gadolinia Production	
Blenders	1.2
Sluggers	0.3
Granulators	0.1
Pelletizers	0.1
Sintering Furnace	0.3
Grinders	0.7
Rod Evacuators	<0.1
Subtotal	2.7
Waste and Scrap	
Scrap Recovery	1.4
Incinerator	8.4
Subtotal	9.8
Other	7.0
Total	150.8

TABLE 7.4-2. Estimated Distribution of Residual Radionuclide Inventories in the Reference Plant Ventilation System After Final Inventory Cleanout

Ventilation Stack Area Served	Total Uranium (kg)	% of Total
Chemical Process, North	24.63	20.7
Chemical Process, South	19.16	16.1
Grinders and Rod Loading	37.37	31.4
Sluggers	15.83	13.3
Powder Storage	0.48	0.4
Pelletizer	0.48	0.4
Pelletizer	2.86	2.4
Scintillation Furnace	1.07	0.9
Gadolinia	2.26	1.9
Pail Filling	1.31	1.1
Chemistry Laboratory	0.48	0.4
Waste Treatment Centrifuge Room	0.04	0.03
Waste Treatment Laboratory	0.02	0.02
Mill	0.83	0.7
New Decontamination Room	0.36	0.3
Hot Maintenance	0.71	0.6
Scrap Treatment Warehouse	1.43	1.2
Women's Change Room	0.1	0.08
Men's Change Room	0.12	0.1
Laundry	0.24	0.2
Mezzanine Warehouse	0.24	0.2
Chemical Process, FMOX, North	0.36	0.3
Incinerator Room, North	0.24	0.2
Incinerator Room, South	0.24	0.2
Incinerator Exhaust	6.66	5.6
Incinerator Exhaust	0.36	0.3
GECO Process	0.48	0.4
Uranium Purification System	--	--
Chemical Process, FMOX South	0.36	0.3
Stacker Warehouse	0.1	0.08
Rod Out-Gas	0.12	0.1
Totals	119	100

cleaning and handwiping of dry processing equipment. These procedures are estimated to reduce the building inventory of uranium to approximately 100 kg of uranium.

7.5 CHEMICAL INVENTORIES

Several potentially toxic chemical compounds are used in processing and scrap recovery operations in the reference plant. These compounds include acetone, anhydrous ammonia, hydrochloric acid, lime, nitric acid, sodium hydroxide, and sulphuric acid. Most process chemicals not planned to be used for decommisioning are assumed to be removed from the plant as part of final inventory cleanout operations. Inventories of these chemicals will therefore be limited to residuals in process equipment and piping at the start of decommissioning. Except for nitric acid, fluoride salts, and degreasing agents used in chemical decontamination operations, no significant inventories of toxic chemicals are anticipated in the plant when decommissioning begins.

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1. Application for Special Nuclear Material License, General Electric Company, Safety Analysis Report for its Wilmington Uranium Fuel Fabrication Plant, Docket No. 70-1113, December 1975.

2. Applicants Environmental Report, USNRC NEDO-20197, General Electric Company, January 1974.

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

4. U.S. AEC, Final Environmental Statement Related to Operation of Monticello Nuclear Generating Plant, Docket No. 50-263, pp. II-15 through II-26 November 1972.

5. Final Generic Environmental Statement on the Use of Recycled Plutonium in Mixed Oxide Fuel for Light Water Reactors, NUREG-0002, USNRC, Volume 3, p. IV D-27, August 197

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*Available for purchase from the National Technical Information Service, Springfield, VA 22161.

8.0 SUGGESTED METHODOLOGY FOR DETERMINING ACCEPTABLE RESIDUAL RADIOLOGICAL AND CHEMICAL CONTAMINATION LEVELS FOR THE DECOMMISSIONED REFERENCE URANIUM FUEL FABRICATION PLANT

This section contains a discussion of a suggested methodology for determining acceptable levels of residual radioactive and chemical contamination for decommissioned nuclear facilities. A demonstration of this methodology is also presented, using the reference radionuclide and chemical inventories and the reference site characteristics.

8.1 TECHNICAL APPROACH

The ultimate disposition of a decommissioned nuclear facility and its surrounding site depends on the degree and type of radioactive contamination remaining. Also of significance for the U-Fab plant is the degree of chemical contamination remaining. The purpose of this section is to describe and demonstrate a suggested methodology for determining acceptable radiological and chemical contamination levels for unrestricted use of the decommissioned reference plant and its site.

Examination of existing guidelines and regulations shows a need for a general methodology of deriving acceptable residual contamination levels to permit the unrestricted release of any decommissioned nuclear facility or site.(1) Currently, some guidance exists defining the levels of radioactive surface contamination that are acceptable to the NRC for the termination of operating licenses.(2,3) Other guidance addresses specific types of nuclear facilities, or accident situations involving radioactivity.(4-9)

None of these guidelines is sufficiently flexible to accommodate the various radionuclide mixtures, chemical forms, or site-specific features found at each unique nuclear facility. This suggests that the methodology used to calculate the acceptable levels of residual radionuclide contamination at decommissioned nuclear facilities should be based on a general concept that can accomodate these unique radionuclide mixtures and site-specific features. The methodology suggested by this study compares established annual dose limits with calculated annual doses to members of the public to determine acceptable radioactive contamination levels. The acceptable contamination levels derived from a maximum annual dose methodology take into account the exposure of individuals to contamination remaining at a decommissioned facility or on its site following unrestricted release.

The basic premise for the suggested methodology described in this study is that no member of the public will receive an annual dose in excess of a limit yet to be established by U.S. Federal agencies. Since there are no public exposure standards for most of the material of concern, the premise that no member of the public will be exposed to more than 1% of the most restrictive occupational chemical standard will be utilized. This safety factor of 100 is introduced to account for the fact that a large population will contain some abnormally sensitive individuals. Discussion of future use categories and the methodology, based on maximum annual doses and occupational chemical standards, for determining the acceptable contamination levels are contained in the following subsections.

8.1.1 Terminology and Definitions

The basis for acceptable radioactive contamination is the maximum annual dose to an individual. The following terminology is used in developing the methodology for residual radioactivity levels based on annual dose.

Organs of Reference

These are the organs of the human body for which radiation doses are calculated. For this study, the organs of reference are the total body, lungs, bone, and lower large intestine (LLI) of the GI-tract. The total body is the head and trunk of the human body and includes active blood-forming organs, eye lenses, and gonads.

Exposure Pathways

These are the potential routes by which people may be exposed to radionuclides or radiation. Radiation exposure pathways in the environment that are considered in this study are: external exposure to contamination deposited on the ground, ingestion of food products containing radionuclides, and inhalation of airborne radionuclides. Radiation exposure pathways inside the U-Fab facility are: external exposure from contaminated room surfaces or equipment and inhalation of airborne radionuclides. External exposure from airborne radionuclides (air submersion) is not considered, since previous decommissioning studies have shown this exposure pathway to be insignificant compared to the others.(1,10,11)

Decay Periods

The mixtures of radionuclides in the residual inventories are constantly changing because of radioactive decay, resulting in annual doses that vary with time. This time dependence is demonstrated by calculating the doses at shutdown and at 10, 30, 50, and 100 years after plant shutdown.

Maximum-Exposed Individual

This is the individual who receives the maximum radiation dose to an organ of reference. The maximum-exposed individual is assumed to reside at the location of the highest airborne radionuclide concentration. Maximized exposure pathway parameters are used.

Annual Dose

This is the radiation dose equivalent calculated during any year following the start of continuous exposure. It is the sum of the dose received by an organ of reference during the year of interest from all exposure pathways and the dose received during that year from radionuclides deposited in the organ of reference during the previous years.

Maximum Annual Dose

This is the largest of the annual doses calculated to occur during the 50 years following the start of continuous exposure.

Additional terminology, radiation dose models and parameters, and a derivation of the equations used to determine the annual doses are contained in Appendix E of Volume 2 and in the Glossary (Section 14).

8.1.2 Definition of Use Categories

During the planning stages of decommissioning, a variety of future uses may be considered for the facility and its site. Two general use categories after decommissioning are considered in this study:

1. Restricted Use In this category, only nuclear activities are permitted at the decommissioned U-Fab facility and/or site. The residual radioactive and/or chemical contamination levels for this category are expected to be similar to the levels found at licensed operating nuclear facilities. Therefore, the exposure of workers and the public is controlled by the restrictions imposed by the nuclear license or occupational standards.
2. Unrestricted Use In this category, the potential exposure to members of the public from residual radioactive or chemical contamination levels attributable to the decommissioned facility/site will not exceed either the maximum annual radiation dose established by U.S. federal regulatory agencies or 1% of the most restrictive occupational standard on chemicals. Decommissioning a site will, in general, result in the unrestricted public use of land areas which had been restricted during the operational life of the U-Fab plant.

No attempt is made to define all of the possible specific uses that may fall into each of these general categories. The ability to enforce the license restrictions required for the first use category for long periods of time requires continuous surveillance. Each potential use restriction will require its own specific analysis for acceptable contamination levels. Furthermore, the restriction can best be assured if the responsibility lies with a government agency. For these reasons, the only category for which examples are derived in this study is for unrestricted use of the decommissioned reference U-Fab facility and site.

8.1.3 Acceptable Residual Radioactive Contamination Levels

Determination of acceptable radioactive contamination levels for the reference plant is necessarily linked with other decommissioning considerations. Acceptable radioactive contamination levels are calculated using previously developed methods.(1,12) The methodology for determining acceptable radioactive contamination levels is based on the assumption that an annual radiation dose limit is established for decommissioned nuclear facilities.

Currently, there are no unique regulations or specific guidance on acceptable annual dose to individuals living on or near a decommissioned site.

Documents that could be interpreted as providing annual dose limit recommendations specifically for the cases of interest here include:

1. Recommendations of the International Committee on Radiation Protection (ICRP), Publication 9.(13)
2. Appendix I of 10 CFR 50, Guides for Design Objectives for Light-Water-Cooled Nuclear Power Reactors (NRC).(14)
3. 40 CFR 190.10 Environmental Radiation Protection Standards for Normal Operations in the Uranium Fuel Cycle (EPA).(15)
4. Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment (EPA).(16)
5. Surgeon General's Guidelines (DHEW).(17)
6. "De Minimus" Concentrations of Radionuclides in Solid Wastes (AIF).(18)

None of this guidance, written to provide limits for operating nuclear facilities, specifically addresses decommissioned nuclear facilities or sites. However, this guidance suggests annual total body radiation dose limits ranging from 3 to 500 mrem/yr.(1)

It is beyond the scope of this study to recommend annual radiation dose limits for public exposure to radioactive materials. Instead, example acceptable residual radioactive contamination levels are calculated for a single assumed annual radiation dose limit of 50 mrem. The use of this assumed limit is not intended, nor should it be inferred as a recommendation for that particular value for restricting public radiation exposure from decommissioned nuclear facilities. Corresponding levels for any other radiation dose limit can be found through direct ratio. It is also assumed that any annual dose limit established for decommissioning applies to the maximum annual dose to any organ of reference, thus ensuring that applicable regulatory limits on annual radiation dose will not be exceeded.

The suggested methodology for determining radioactive contamination levels, based on annual radiation dose, is illustrated in Figure 8.1-1 and is briefly discussed below.

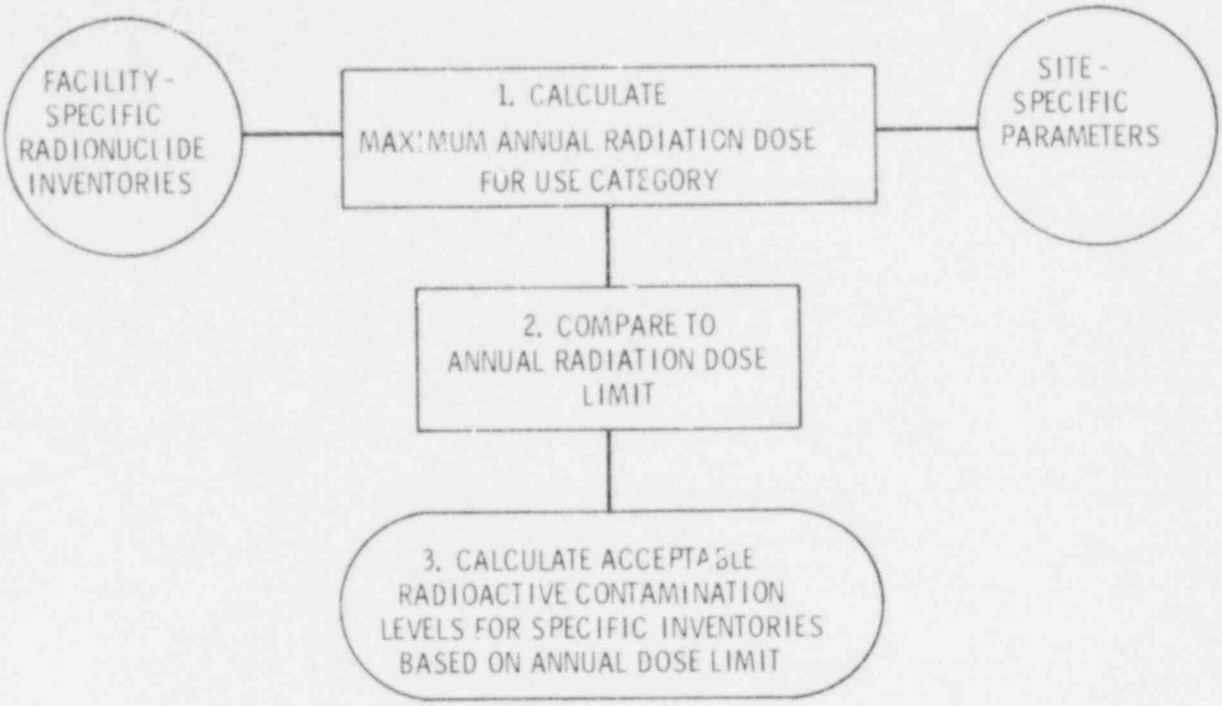

FIGURE 8.1-1. Suggested Methodology for Determining Acceptable Residual Radioactive Contamination Levels

8.1.3.1 Calculation of the Maximum Annual Radiation Dose for the Use Category Selected

For this study, the maximum annual radiation dose during 50 years of continuous exposure after decommissioning is calculated using the dose models discussed in Appendix E of Volume 2. Characteristic radionuclide inventories at the reference U-Fab plant, used in the calculations, are presented in Appendix B. Maximum annual radiation doses are calculated for the decay periods of interest to illustrate the time dependence of the radionuclide inventories. Site-specific exposure pathway parameters, defined for the reference site in Appendix B, are used in these dose calculations. After decommissioning, unrestricted use of the facility and site is assumed.

8.1.3.2 Comparison of the Maximum Annual Dose to the Annual Dose Limit

For this study, since assumed or calculated levels of contamination are used, no direct comparison is made. Rather, the quantities of the radionuclide inventories corresponding to a dose of 50 mrem/yr are calculated to demonstrate the suggested methodology both for the facility and for the site. In site-specific studies that use measured radioactivity levels, this step can be used as a decision point to determine the need for further decontamination efforts.

8.1.3.3 Calculation of the Maximum Acceptable Contamination Levels

Acceptable radioactive contamination levels are calculated and presented in Section 8.2.1. These levels are determined by selecting the largest calculated organ dose which is derived from all exposure pathways. The calculated acceptable contamination level is dependent on the composition of the radionuclide inventory and the exposure pathways, and it represents the maximum acceptable contamination level.

8.1.4 Acceptable Residual Chemical Contamination Levels

Analysis and determination of acceptable chemical contamination levels for a U-Fab plant have not previously been conducted. For consistency, the suggested methodology presented in Figure 8.1-2 is, therefore, based on the previously developed radiological methodology.

There are currently no regulations or specific guidance on acceptable chemical exposures to individuals from a decommissioned nuclear facility. Guidance that could be used includes:

- Threshold limit values (TLV) for chemical substances and physical agents in the workroom environment.(19)
- EPA interim primary and proposed secondary drinking water standards.(20)
- National Institute of Occupational Safety and Health Bulletins, Recommended Standard for Occupational Exposure to Various Chemicals.
- EPA and state environmental standards.

None of these guides provides specific information on public exposures to residual chemicals remaining in decommissioned facilities. This lack of definitive guidance makes is difficult to determine acceptable residual chemical levels. The following factors further complicate the selection process:

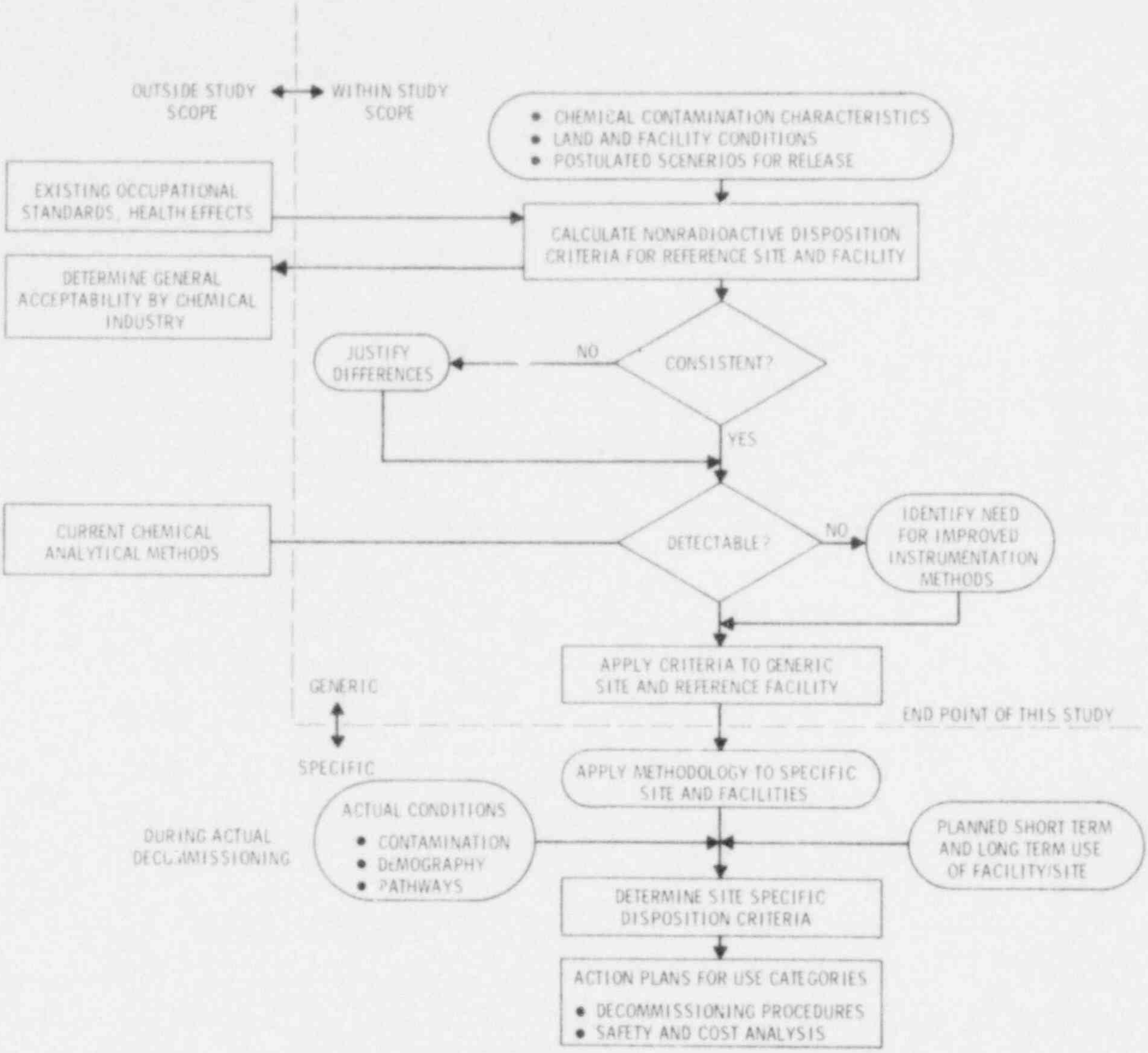

FIGURE 8.1-2. Relationship of Acceptable Chemical Contamination Levels to U-Fab Plant Decommissioning

1. Unlike radioactive contaminants, for which the combined dose to an individual or population serves as a measure of the effect, chemical contaminants must presently be considered individually, with no accepted common index of accumulated dose.

2. Once released to the environment, many chemicals undergo reactions which alter their characteristics and effects.

3. Some chemical pollutants can cause a number of different effects, depending on factors such as concentration and duration of exposure.
4. Additive and synergistic effects of chemical combinations are poorly understood and difficult or impossible to predict.

It is not within the scope of this study to recommend annual chemical exposure limits for the public. The following limits have been assumed for the purpose of determining acceptable residual chemical contamination levels:

- Inhalation--exposures should not exceed 0.01 TLV. The factor 0.01 is a safety factor which accounts for nonoccupational exposures to most susceptible individuals.
- Ingestion--exposures not to exceed the equivalent of the EPA interim primary and secondary drinking water standards.
- Direct Contact--exposures not to cause any dermatitis or burns upon contact with open wounds or skin.

Based on the above criteria, residual contamination limits are determined as follows:

- Establish Chemical Contamination Characteristics The chemical contamination characteristics of the plant and site are established by appropriate sampling or record review.
- Compute the Maximum Acceptable Residual Chemical Contamination Levels The maximum acceptable residual chemical levels are established so the exposure to any individual by the most limiting pathway will not exceed the criteria for that pathway.

8.2 CALCULATION OF EXAMPLE ACCEPTABLE RESIDUAL CONTAMINATION LEVELS FOR THE REFERENCE PLANT

The methodology for determining acceptable contamination levels is best demonstrated by calculating example levels for the reference U-Fab facility and site based on an assumed annual dose limit of 50 mrem to the maximum-exposed individual.

8.2.1 Acceptable Residual Radioactive Contamination Levels for the Reference Plant

Example contamination levels for the decommissioned reference plant are calculated using the methodology presented in Appendix E. The surface contamination inventory of radionuclides in the reference plant is presented in Appendices B and C. Contamination is assumed to accumulate on exposed surfaces over the entire 40-year operating life of the plant. Surface contamination estimates for the reference U-Fab plant in this study are based on a variety of assumptions. In actuality, contamination levels are specific to the facility design and its operating history. Thus, the levels are best determined by measurements on a case-by-case basis for each facility. It is reasonable, however, to predict the isotopic composition of this contamination. Therefore, surface contamination levels for the facility in this study are normalized to 1 pCi/m^2 in Appendix E. The actual radioactivity levels and isotopic composition encountered in the facility at shutdown are important in determining the degree of decontamination required; however, only the isotopic composition is necessary in determining acceptable levels.

The residual radioactive contamination levels present during decommissioning operations are assumed to be known from surface radiation measurements. The decommissioning operations, discussed in Section 9 and Appendices F and G, are designed to remove surface radioactive contamination until the radiation levels are acceptable for the decommissioned state of the facility and site. These levels for the facility are derived in this section based on radioactive surface contamination, with the assumption that all volumetric wastes generated during decommissioning are disposed of as radioactive wastes.

For the maximum annual dose calculations, airborne radionuclide concentrations in the reference U-Fab facility are calculated using a constant resuspension factor of $5 \times 10^{-6}\ m^{-1}$, as discussed in Section E.3 of Appendix E. Results of actual measurements of airborne radionuclide concentrations in decommissioned facilities could alter the example acceptable contamination levels calculated here.

The maximum annual radiation doses to people who would be working in the released decommissioned facility are calculated using a 40-hr week and are listed in Tables E.4-1 and E.4-2 in Appendix E. These tables contain doses calculated for selected organs of reference from all important exposure pathways considered, and for all radionuclides that contribute more than 1% to the total dose. The doses in Table E.4-1 through E.4.4 in Appendix E apply for all times after operation shutdown, for at least 100 years. The total residual contamination level does not change significantly from radioactive decay and daughter buildup during the first 100 years. Only two radionuclides, ^{231}Pa and ^{230}Th, actually increase with time, but they do not contribute significantly to the total dose. The corresponding contamination levels are next calculated for an annual dose of 50 mrem. These calculated residual contamination levels, expressed in units of microcuries per m^2 of surface contamination ($\mu Ci/m^2$), for translocation Class W and Y material are shown in Table 8.2-1. For the total body and other organs of reference, the dominant radionuclide contributors to the dose are ^{234}U, ^{235}U, and ^{238}U.

TABLE 8.2-1. Example Acceptable Contamination Level Within the Reference Facility (unrestricted use)

Organ of Reference	Translocation Class	Surface Contamination ($\mu Ci/m^2$) Corresponding to a Maximum Annual Dose of 50 mrem[(a)]
Total Body	W	10.00
	Y	26.00
Lungs	W	0.14
	Y	0.029
Bone	W	0.98
	Y	5.5
LLI	W	29.00
	Y	28.00

(a) Ingestion pathways from contamination in the released decommissioned facility are nonexistent.

Information about the levels and nature of the radionuclide contamination present on the reference site is derived in Appendix B. Acceptable levels are calculated based on the estimated 40-yr accumulated depositions on the site from routine annual release from production operation.

Airborne concentrations of radionuclides in the plant environs are calculated using the time-dependent resuspension factor discussed in Section E.3 of Appendix E. The radionuclide inventories, showing the 40-yr accumulated ground depositions and the values at each selected decay period, are listed in Table 7.1-1 of Section 7.

At plant shutdown, these radionuclides are assumed to be mixed to a depth of 10 mm in the soil with no mechanical mixing or weathering effects. If the site contamination levels are measured to be below acceptable levels at the time of decommissioning, plowing is not required as a decommissioning activity. A dry soil "surface density" factor of 224 kg per square meter mixed to a depth of 150 mm (or soil density of 1.49 g/cm^3) is used to determine the soil radioactivity concentration. For calculational convenience, the site contamination levels are based on the surface contamination estimates after plowing (Table 7.1-1 of Section 7 values divided by 15, to account for mixing due to plowing).

It should be noted that the contamination levels assumed for the site are probably higher than might actually be encountered at a U-Fab plant. This is primarily because no credit was taken in the calculational procedure for weathering effects on the radioactive contamination either during the 40-yr U-Fab plant operating life or during the subsequent decay times. For specific sites, comprehensive measurements will be necessary at the time of production shutdown to characterize the quantity and mixture of the deposited radioactive contamination.

Maximum annual doses calculated using the reference site radionuclide inventory at plant shutdown are listed in Tables E.4-3 and E.4-4, Appendix E. Again, these tables contain the calculated doses for the environmental exposure pathways considered, the organs of reference, and the radionuclides that contribute 1% or more to the total dose. The corresponding residual contamination levels are calculated for an annual dose of 50 mrem and are listed in Table 8.2-2 for Class W and Y material. The dominant radionuclide contributors to the organ doses are ^{234}U, ^{235}U, and ^{238}U.

The residual contamination levels shown in Table 8.2-3 demonstrate that the critical organ is the bone for intakes of Class W material and the lungs for Class Y material. The dominant pathway for Class W material is ingestion and for Class Y material is inhalation. After a few years, the dominant exposure pathway for Class Y material changes to ingestion and the critical organ changes from the lungs to the bone. This is due to the decrease in the quantity of material available for inhalation each year. For the facility, the radioactivity present is characterized by surface contamination measurements. For

TABLE 8.2-2. Example Acceptable Residual Contamination Levels on the Reference Site at Plant Shutdown

Organ of Reference	Surface Contamination (μCi/m^2) Corresponding to a Maximum Annual Dose of 50 mrem(a)	
	Class W	Class Y
Total Body	8.5	8.5
Lungs	2.8	0.52
Bone	0.69	0.69
LLI	-(b)	-(b)

(a) Surface contamination is assumed to be mixed uniformly to a soil depth of 150 mm during decommissioning.

(b) LLI dose is essentially all delivered by the ingestion pathway, which is insignificant when compared to the inhalation of resuspended material.

TABLE 8.2-3. Summary of Acceptable Residual Radioactive Contamination Levels for the Reference Facility

	Critical Organ	Acceptable Residual Contamination Levels for an Annual Dose of 50 mrem[(a)] Surface Contamination (μCi/m^2)	Surface[(b)] Contamination (pCi/g)
Class W Material			
U-Fab Facility[(c)]	Lungs	0.14	---
U-Fab Site	Bone	0.59	4.6
Class Y Material			
U-Fab Facility[(c)]	Lungs	0.029	---
U-Fab Site	Lungs	0.52	3.5

(a) Assumes average ^{235}U enrichment of 3%.

(b) It is assumed that plowing the site uniformly mixes the radioactive contamination to a depth of 150 mm. A dry soil surface density factor of 224 kg/m^2 to a depth of 150 mm is used for this conversion.

(c) It is assumed that the facility disposition criteria will be used to determine the necessary decommissioning procedures.

the site, the surface contamination values are presented along with radioactivity per unit mass of soil mixed to a depth of 150 mm after plowing. Figure 8.2-1 shows the variation of acceptable contamination levels with the solubility class and enrichment of the reference mixture.

The acceptable levels for Class W material apply for at least 100 years following shutdown, since the dominant exposure pathway is ingestion and the residual contamination levels remain constant over this time period. For Class Y material, the acceptable contamination levels increase with time, because of the decreasing resuspension factor, and eventually approach the acceptable levels for Class W material. At this time, ingestion becomes the dominant exposure pathway.

8.2.2 Acceptable Residual Chemical Contamination Levels

The methodology for developing chemical contamination levels is based on human health impact potential and compliance with environmental standards.

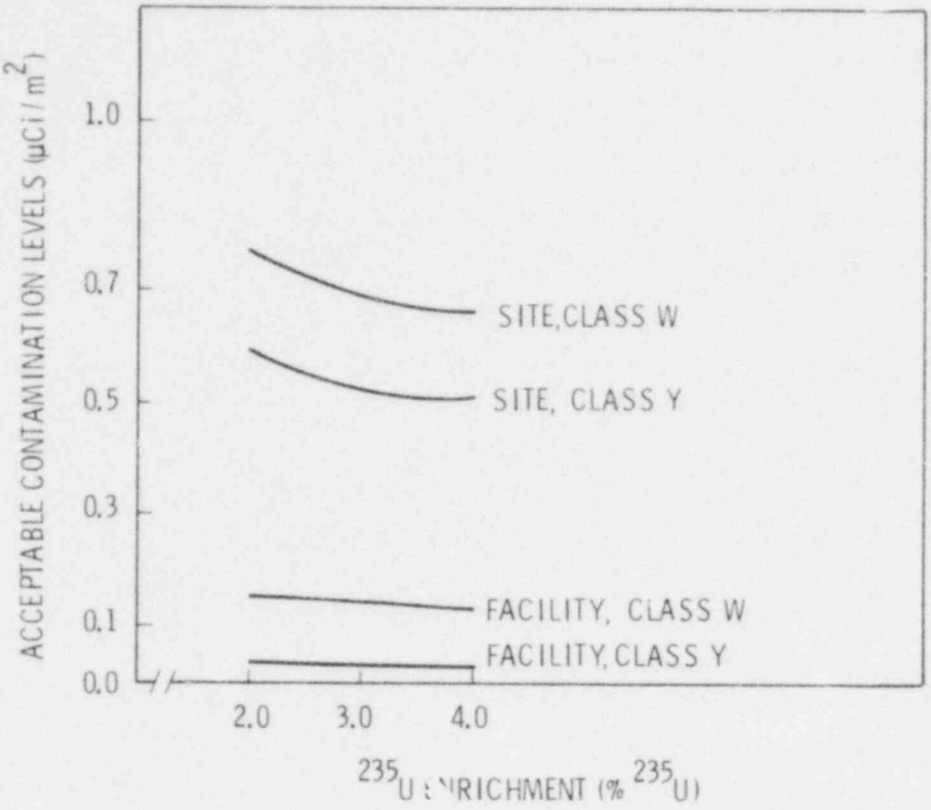

FIGURE 8.2-1. Acceptable Contamination Levels for the Reference Facility and Its Reference Site versus ^{235}U Enrichment (assumed 50 mrem/yr dose limit)

Example acceptable chemical contamination levels for the decommissioned reference plant are calculated using methodology discussed previously. Contamination is assumed to accumulate on the site over the entire 40-yr operating plant lifetime.

The residual contamination levels present during decommissioning are assumed to be known from sensitive analytical techniques similar to those used for occupational exposures to dusts, vapors and gases. It should be noted that although specifically directed towards removal of radionuclides, decommissioning activities as discussed in Section 9 and Appendices F and G, will also remove or reduce chemical contamination.

As with radioactive dose calculations, 5 x [illegible] m^{-1} is the resuspension factor used for airborne chemical exposure. Results of actual measurements of airborne chemical concentration in decommissioned U-Fab plants could alter the example contamination levels significantly. A discussion of the methodology for using the particulate resuspension factor is presented in Section E.3 of Appendix E.

Table 8.2-4 shows the example acceptable surface contamination criteria for chemicals suspected to be present in the reference site. The table shows relatively large levels of allowable surface contamination for nearly all expected chemical contaminants when considering the inhalation pathway.

TABLE 8.2-4. Example Acceptable Chemical Contamination Levels in the Reference Facility (unrestricted use)--Inhalation, Airborne Pathway

Chemical	TLV (mg/m^3)	Allowable Maximum Surface Contamination (g/m^2)(a)
Fluoride(b)	2.5	5.0
Uranium (insoluble)	0.2	0.4
Uranium (soluble)	0.2	0.4
Hydrated Lime	5.0	10.0
Ammonium Diurinate	0.2	0.4
Sulfuric Acid	1.0	--(c)
Nitric Acid (HNO_3)	5.0	--(c)
Nitrate (NO_3)	High	>50.0
Gadolinium Oxide	--(d)	--(d)
Sulfate (SO_4)	High	>50.0

(a) Corresponding to (1/100) TLV as a product of the resuspension factor.

(b) Fluoride limit is for inorganic fluoride measured as a fluoride. There is no specific limit for CaF_2.

(c) Not expected to be present as a surface contaminant over any appreciable surface area.

(d) No established TLV; expected to be present only in very small amounts.

To develop acceptable surface contamination limits based on the ingestion pathway, an acceptable ingestion exposure must be selected. The EPA drinking water standards provide one base for fluoride, nitrate, and sulfate limits. The acceptable daily ingestion of these three chemicals is assumed to be the amount consumed by an individual drinking 1.2 ℓ/day of water containing the EPA maximum level. The acceptable daily ingestion of the other soluble chemical species (for which no drinking water limit is published) will be assumed to be equal to the amount inhaled by a person breathing 1 m^3/hr at an air concentration of 1/100 x TLV for 24 hr/day. If it is assumed that the exposed individual ingests contaminants by contacting 0.5 m^2 of surface area each day and transferring the material from hand to mouth, the example chemical contamination limits are as given in Table 8.2-5.

Using this method, it can be seen that the acceptable concentrations of some chemical contaminants will be severely limited by the ingestion pathway exposures. It is recognized that the limits for inhalation and ingestion pathways represent very conservative levels of acceptable residual chemical surface contamination.

8.2.3 Acceptable Contamination Levels on U-Fab Facility Equipment

Disposal of radioactively contaminated U-Fab plant equipment after decontamination is covered by standards developed by the ANSI Committee N.13.12(9) and the NRC(3) (the NRC has not yet endorsed ANSI N.13.12). The problems of decontaminating equipment for public release are outlined in Appendix H. Decommissioning a specific U-Fab plant will probably require special procedures to dispose of equipment and some structural materials on a piece-by-piece basis. The NRC recently issued a report which uses methodology similar to the one in this report to determine the potential dose to people from recycled metals reclaimed from a decommissioned nuclear power plant.(21) It is assumed that properly transported and contained equipment that is chemically contaminated will be accepted at any hazardous waste disposal site.

TABLE 8.2-5. Example Acceptable Chemical Contamination Levels Within the Reference Facility (unrestricted use)--Ingestion Pathway

Chemical	Maximum Acceptable Daily Ingestion (mg/day)	Estimated Acceptable Surface Contamination (mg/m^2)(a)
Fluoride(b)	2.9(c)	5.8
Uranium (soluble)	0.05(d)	0.1
Hydrated Lime	1.2(d)	2.4
Ammonium Diurinate	0.05(d)	0.05
Sulfuric Acid	---(e)	---(e)
Nitric Acid	---(e)	---(e)
Nitrate	12(c)	24
Gadolinium Oxide	---(e)	---(e)
Sulfate	300(c)	600

(a) Assumes a person contacts 0.5 m^2 of surface are per day and transfers the agent from hand to mouth.
(b) Fluoride limit is for inorganic fluoride measured as a fluoride. There is no specific limit for CaF_2.
(c) Based on EPA interim primary and proposed secondary drinking water standards and a daily water consumption of 1.2 ℓ.
(d) Based on the amount inhaled by a person breathing 1 m^3/hr at 1/100 TLV for 24 hr/day.
(e) Not expected to be present as a surface contaminant over any appreciable surface area.

8.3 EXISTING GUIDANCE ON ACCEPTABLE RESIDUAL CONTAMINATION LEVELS

Existing guidance on acceptable contamination levels for the unrestricted release of decommissioned nuclear facilities is found in Attachment A of Reference 3 and ANSI Standard 13.12.(9) The levels reflected in these standards are listed in Tables 8.3-1 and 8.3-2. Since the methodology and dose bases for the example calculations presented in this study are different from those used in determining these existing guidelines, the criteria do not compare directly and require careful analysis. Using the maximum annual dose as the general basis

TABLE 8.3-1. Acceptable Surface Contamination Levels(3)

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

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[a] Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides apply independently.

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

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

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

[e] The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface wiped.

for determining acceptable residual contamination levels allows more flexibility in consideration of the various mixtures of radionuclides realistically expected at decommissioned nuclear facilities.

TABLE 8.3-2. ANSI N13.12 Surface Contamination Limits(9)

Radionuclide(a)	Limit (Activity) dpm/100 cm^2	
	Total	Removable
Group 1:		
Nuclides for which the nonoccupational MPC_a(b) is 2×10^{-13} Ci/m^3 or less or for which the nonoccupational MPC_w(c) is 2×10^{-7} Ci/m^3 or less; includes Ac-227; Am-241, -242m, -243; Cf-249, -250, -251, -252; Cm-243, -244, -245, -246, -247, -248; I-125, I-129; Np-237; Pa-231; Pb-210; Pu-238, -239, -240, -242, -244; Ra-226, -228; Th-228, -230.	Nondetectable(d)	20
Group 2:		
Those nuclides not in Group 1 for which the nonoccupational MPC_a is 1×10^{-12} Ci/m^3 or for which the nonoccupational MPC_w is 1×10^{-6} Ci/m^3 or less; includes Es-254; Fm-256; I-126, -131, -133; Po-210; Ra-223; Sr-90; Th-232; U-232.	Nondetectable(β,γ)(e) 2 000 (α)	200
Group 3:		
Those nuclides not in Group 1 or Group 2.	5 000	1 000

(a) Values presented here are obtained from 10 CFR Part 20. The most limiting of all given MPC values (e.g., soluble vs. insoluble) are to be used. In the event of the occurrence of mixtures of radionuclides, the fraction contributed by each constituent of its own limit shall be determined and the sum of the fractions must be less than 1.

(b) MPC_a: maximum permissible concentration in air applicable to continuous exposure of members of the public as published by or derived from an authoritative source such as NCRP, ICRP or NRC (10 CFR Part 20 Appendix B Table 2, Column 1).

(c) MPC_w: maximum permissible concentration in water applicable to members of the public.

(d) The instrument utilized for this measurement shall be calculated to measure at least 100 pCi of any Group-1 contaminants uniformly spread over 100 cm^2.

(e) The instrument utilized for this measurement shall be calibrated to measure at least 1 nCi of any Group-2 beta or gamma contaminants uniformly spread over an area equivalent to the sensitive area of the detector. NOTE: Direct survey for unconditional release should be performed in areas where the background is <100 c/m. When the survey must be performed in a background exceeding 100 c/m, it may be necessary to use the indirect survey method to provide the additional sensitivity required.

8.4 RESIDUAL CONTAMINATION LEVEL MEASUREMENTS

After final inventory cleanout is completed, residual contamination levels in the reference plant must be measured to determine the amount of effort required to decommission the facility and site. Methods of measurement are discussed in this section.

8.4.1 Radioactivity Measurements

Surface contamination levels given in Table 8.2-3 for direct measurement can be detected by commercially available portable instrumentation in low-background locations. Table 8.4-1 shows nominal detection levels for several

TABLE 8.4-1. Detection Capabilities for Direct Surveys with Portable Instruments

Instrument Type	Nominal Detection Level ($\mu Ci/m^2$)
Beta-Gamma Instrument with Thin-Window GM Probe	0.1 to 1[(a)]
Alpha Instrument with Alpha-Scintillator Probe	0.02

(a)Highly dependent on beta energy and total nuclide spectrum.

typically used instruments. Minimum detection levels for direct surveys with GM-type instrumentation are generally limited to the equivalent of the background reading at the survey location (i.e., a detection level of 100 c/m above a background level of 100 c/m). Minimum detection levels for direct surveys with portable alpha meters are 200 d/m per detector area. With laboratory instrumentation and no time limitations, detection levels equal to or less than 50 d/m for alpha emitters can be achieved.

The capability of measuring the maximum acceptable residual contamination levels in Table 8.2-3 is dependent on the sensitivity of the instrumentation utilized and the time available for surveying. The latest scintillation alpha survey meters have the capability to detect as low as 50 d/m per probe area. This detection level corresponds to a contamination level of 0.004 $\mu Ci/m^2$. The most restrictive acceptable levels for the reference facility shown in Table 8.2-3 is 0.029 $\mu Ci/m^2$ or 644 d/m per 100 cm^2. Thus, measurement of activity levels for the reference facility corresponding to an annual dose of 50 mrem is possible using survey instrumentation available commercially.

Inside generally contaminated spaces, in the presence of large contaminated equipment items, or over large generally contaminated surfaces, it may be necessary to use indirect survey methods to measure radiation levels. On hard nonporous surfaces, smears or scrapings may be taken and removed for analysis to a lower-background location or a low-level laboratory counting instrument.

Contamination levels and limits shown in Table 8.2-3 imply that the history of the material or the mixture of radionuclides being measured is known. Sampling for laboratory identification measurements and specific nuclide contamination levels are desirable even when the characteristics of the contaminaton are known Sampling is absolutely essential when such preliminary information is lacking.

Sampling techniques for bulk materials such as soils have many variations. Practicality limits the fraction of any large area that can be sampled and analyzed. A fixed scheme is needed for selecting sampling stations and the number, size and spacing of sample aliquots at each location. A fixed sampling scheme is desirable not only for appropriate statistical inferences but also for reproducibility and comparability. For soil, variability of overlying vegetation and inclusion of rock and gravel is a problem. Regulatory Guide 4.5(22) provides one commonly used scheme that is generally applicable for soil sampling. Adequate sampling of bulk materials requires sampling to depths of 0.3 to 1 m in soil, depending on climate and history.

There is no commonly accepted procedure for translation of surface concentration limits to mass contamination limits or vice versa. However, with reasonable assumptions as to soil bulk density and the volume of soil seen by a portable alpha probe, the value of 0.52 μCi/m^2, shown in Table 8.2-3, translates to approximately 35,000 pCi/kg or $\sim 10^3$ times the lower limit of detection (LLD) for laboratory analysis given in Table 8.4-2. For all radionuclides in environmental media, sample radioanalysis can provide the sensitivity required by any of the proposed limits in Section 8.3 or the surface contamination levels in Table 8.2-3. The cost will depend on whether chemical separation is required and on the length of counting time needed to measure a particular radionuclide at a given level above instrumental and sample background.

Scintillation alpha survey meters are capable of measuring the contamination levels presented in Table 8.2-3. Sampling of soil, vegetation and ground water would be required to assure compliance with acceptable levels. These samples would be collected based on a statistical design to assure that acceptable levels are met.(25) Analytical procedures involve chemical concentration

TABLE 8.4-2. Detection Capabilities for Environmental Sample Analysis[a]

Analysis	Water (pCi/ℓ)	Vegetation (pCi/kg, wet)	Soil IpCi/kg, dry)	Air (pCi/m3)[c]
	Lower Limit of Detection (LLD)[b]			
^{235}U[d]	2	50	30	6×10^{-5} μg/m^3
^{238}U[d]	2	50	30	6×10^{-5} μg/m^3

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[a] This table is intended to be comparable to a similar table in Regulatory Guide 4.8 reflecting current experience at a commercial radioanalytical laboratory.(23)

[b] The normal lower limit of detection is defined in HASL 300, Appendix D, Rev. 8/74, at the 95% confidence level.(24) The LLD for radionuclides analyzed by gamma spectrometry will vary according to the number of radionuclides encountered in environmental samples.

[c] LLD based on 300 m^3 sample volume and alpha proportional counter.

[d] Fluorometric analysis.

and separation on the nuclide of interest. Counting of the concentrated samples is done with gas flow proportional counters or other systems with similar or superior detection capabilities.

Table 8.4-3 summarizes relative advantages and disadvantages for common methods for determining contamination levels. Further discussion of instrument capabilities may be found in LBL-1.(26) Further discussion of environmental survey techniques may be found in ERDA-77-24(27) and NCRP Report No. 50,(28) as well as in the health physics literature.

8.4.2 Chemical Contamination Measurements

Virtually all of the chemical contaminants would require laboratory analysis to provide detection capability of all the chemical contaminants at or below the unrestricted release criterion.

TABLE 8.4-3. Comparison of Measurement Methods for Radiation Surveys to Permit Unrestricted Use

Measurement Method	Advantages	Disadvantages
Direct		
Portable Instruments(a)	Relatively fast; Relatively inexpensive; Readily available; Able to delineate hot spots.	Limited sensitivity; usually not nuclide-specific; Subject to interferences from high background and surface conditions; For alpha and beta emitters, useful for exposed surfaces only.
Aerial Survey	Extremely fast.	Useful in general for gamma emitters only;(b) Insensitive to small areas.
Indirect		
Smears, Scrapings	Avoidance of high background interference.	Not indicative of total activity present, highly variable results; Incomplete coverage of large surfaces; Not applicable to loose or confined materials.
- with direct field count	Relatively fast; Relatively inexpensive.	Not nuclide-specific.
- with laboratory counting	Nuclide identification possible (but more expensive); Greater sensitivity than direct field count.	Relatively slow and expensive.
Sampling and Laboratory Analysis	Nuclide-specific; Highly sensitive.	Relatively slow; Relatively expensive; Applicable only when sample of material can be taken to laboratory; Provides data for only small part of total surface.

(a) See Table 8.4-2 for typical examples and detection levels.

(b) With special calibrations, aerial surveys may be useful for large areas, but not to release levels specified in Section 8.3.

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*Available for purchase from the National Technical Information Service, Springfield, VA 22161.

**Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service, Springfield, VA 22161.

9.0 DECOMMISSIONING ACTIVITIES

As discussed in Section 4, two approaches to decommissioning the reference uranium fuel fabrication (U-Fab) plant are selected for evaluation in this study:

- DECON
- passive SAFSTOR.

An outline of the major components of a Master Decommissioning Plan (MDP) for both of these approaches is presented in this section, together with discussions of the major work items in each plan.

9.1 DECOMMISSIONING BY DECON

In choosing to decommission a U-Fab plant by the DECON alternative, the owner trades potential further use of the plant for the relatively rapid release of the site for unrestricted use. The program plan and the postulated work schedules and sequences for decontamination, together with a brief discussion of essential systems and services and security, are presented in the following subsections. Details specific to the DECON decommissioning alternative are found in Section G.2 of Appendix G (Volume 2).

9.1.1 Program Plan

Decommissioning of the reference U-Fab plant by the DECON alternative involves four phases: planning and preparation, dismantlement and decontamination, transportation, and the final release survey. Some of these activities will proceed simultaneously in different sections of the facility. To minimize scheduling conflicts and accidents, a well-defined sequence and schedule for dismantlement and decontamination of the various portions of the plant must be created and followed carefully. The major activities considered and scheduled for decontaminating the facility are illustrated in Figure 9.1-1.

The 7 months prior to final plant shutdown are used for planning and preparation. It is estimated that approximately 9 months are required to dismantle and decontaminate the facility and site. Uranium and contaminated materials are removed and transported in parallel. The time and work estimates

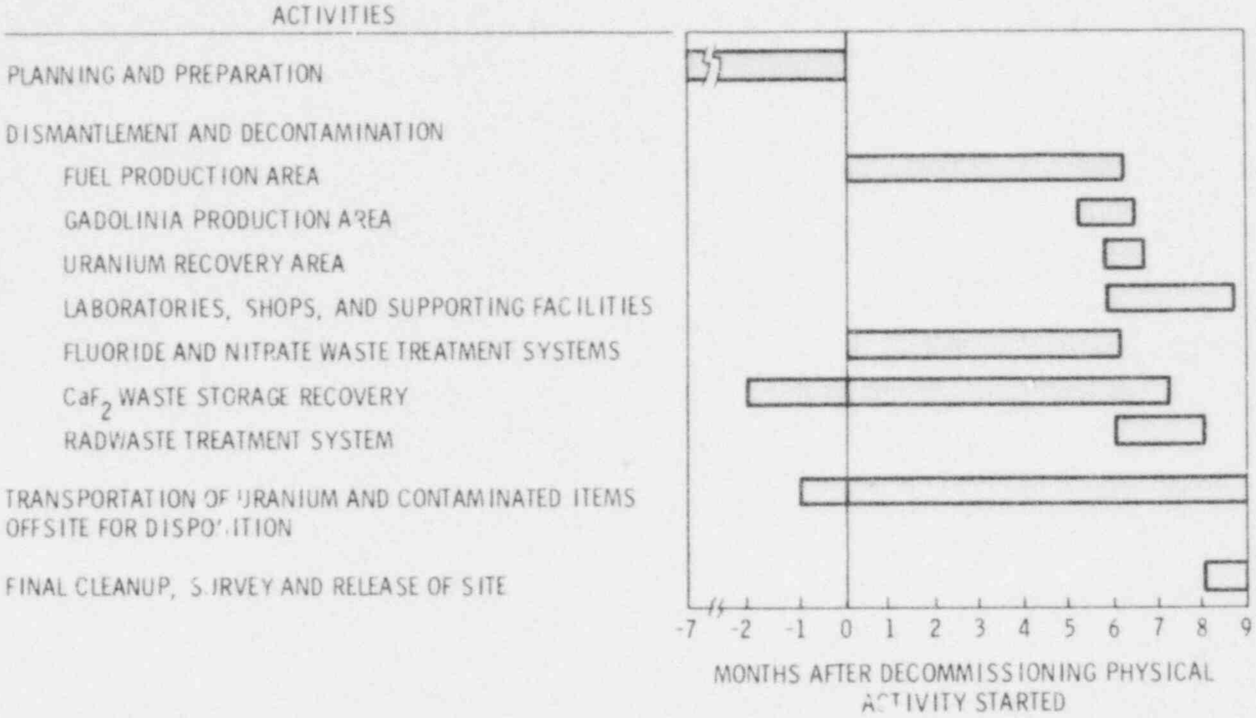


FIGURE 9.1-1. Sequence and Schedule of Major Activities for Decommissioning by DECON

assume reasonable success, with a minimum of delays and/or major unanticipated problems. A detailed schedule for the DECON phase is shown in Figure G.2-1 of Appendix G.

An extensive quality assurance (QA) program is carried on throughout the decommissioning effort to assure that 1) all applicable regulations are met, 2) the work is performed according to plan, and 3) the associated radiation releases do not endanger public and decommissioning worker safety. A more detailed review of the anticipated elements of an appropriate QA program for the decontamination effort is given in Section F.4 of Appendix F.

9.1.1.1 Planning and Preparation

Essential to the results of this study is the assumption that the facility owner/operator becomes the prime contractor of the DECON work; otherwise, a more extensive training program would be necessary to acquaint workers with details of the facility. Approximately 7 months prior to final plant shutdown work begins in the engineering and operations departments of the parent organization to perform the planning needed to amend the license to permit DECON. The proposed sequence and timing schedule for the planning and preparation phase of decommissioning the facility and site is illustrated in Figure 9.1-2.

An important part of the planning involves a review of all regulations and guides applicable to decommissioning. A review of these regulations is presented in Section 5.

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 dismantlement and decontamination of intact systems; detailed sequences for equipment and systems removal; and sectioning and disposal of contaminated equipment. In addition, design, procurement, and testing of special devices and equipment must be initiated

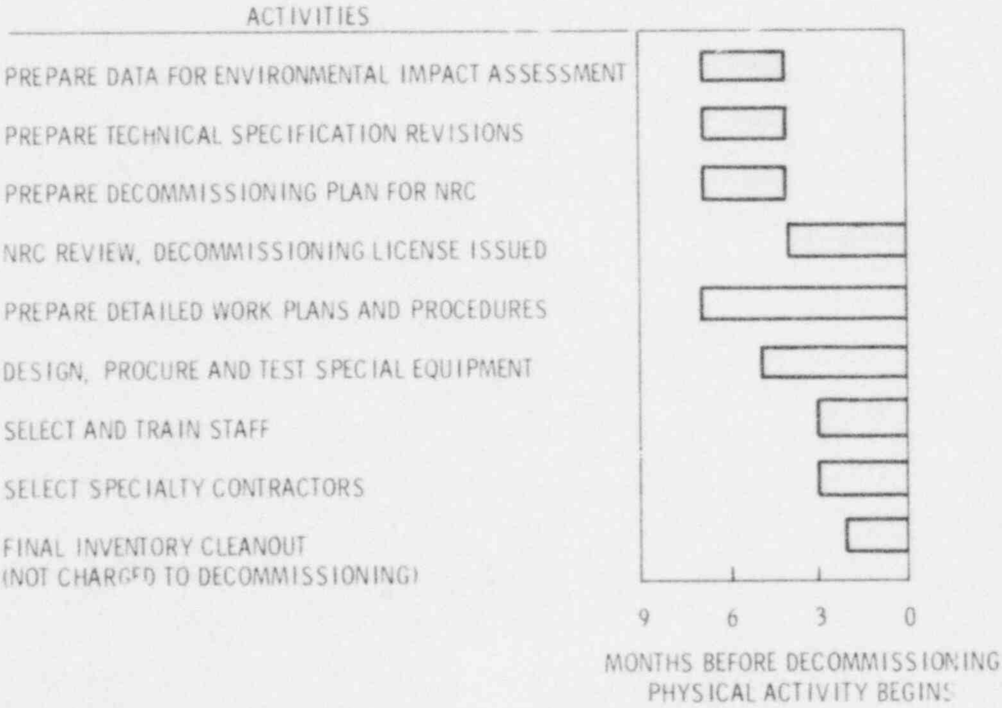


FIGURE 9.1-2. Sequence and Schedule of the Planning and Preparation Phase of DECON

during the 7-month period before final plant shutdown to ensure that work can proceed without undue delay after shutdown.

Creation of a decommissioning organization within the present organization is initiated about 7 months prior to final plant shutdown, with the structure and staffing requirements identified, and commitments obtained from engineering and operating personnel to fill key positions. Orientation and training of personnel identified as members of the decommissioning organization is carried on during the last few months of plant operation. A suggested organizational structure and staffing requirements are given in Section 10.

Selection of the various specialty contractors required for the DECON effort is accomplished during the final few months of plant operation. The types of specialty contractors anticipated to be required are listed in Section 10.1.5.

After termination of routine plant production operations, an extensive inventory cleanout and uranium audit is conducted. These cleanout operations are slightly more extensive than those conducted periodically to audit uranium or to prevent cross-contamination between differing isotopic mixtures or blends of fuel. Based on plant experience, cleanout operations are estimated to remove one-half of the residual uranium plant inventory. Because these cleanouts are done typically during plant production, they are also considered a part of normal plant operations in this study and are not charged to decommissioning. All recovered uranium products are shipped to offsite locations. Details of the final inventory cleanout and uranium audit are found in Section G.1 of Appendix G.

The final preparatory step is a comprehensive survey of radiation dose rates and contamination levels within the facility. Taken after final plant shutdown and inventory cleanout, this survey provides the baseline data for decisions on chemical and physical decontamination, as well as initial data on radiation dose rates and contamination levels likely to be encountered during the various DECON activities. Physical decommissioning is assumed to start upon completion of the survey and receipt of NRC approval for the decommissioning.

9.1.1.2 Dismantlement and Decontamination

The dismantlement and decontamination phase of the immediate DECON program was summarized previously in Figure 9.1-1. The detailed schedule is provided in Figure G.2-1 of Appendix G. Detailed descriptions of the activities are also contained in Appendix G.

The general approach is to clean up the areas that contain the largest amount of uranium contamination first. The fuel production, fluoride and nitrate waste treatment, and the CaF_2 waste storage areas are cleaned up in parallel. Within the fuel production area, work progresses from the UF_6 conversion and powder processing to pelletizing, sintering, and rod loading.

The gadolinia production area, the development laboratories, and the analytical laboratories are cleaned up near the end of the campaign because their contamination is very low.

Dismantlement of the uranium recovery areas (incinerator, radwaste facility, etc.) is saved until the bulk of the site decontamination effort is completed. Also, the other service facilities, such as the hot maintenance shops and the decontamination room, are dismantled near the end of the program.

The radwaste treatment facility is the last of the chemical treatment systems to be dismantled, so it can be utilized throughout most of the program.

The final areas to be dismantled and decontaminated are the ventilation and process exhaust systems, the laundry, and the change rooms.

9.1.1.3 Transportation

The transportation phase of the DECON alternative is initiated during the inventory cleanout stage and is maintained throughout all the physical activities. All uranium and radioactively contaminated materials or equipment (most equipment is decontaminated onsite) are transported offsite for disposition at licensed low-level waste burial sites.

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. Shipping of packaged contaminated materials from the facility to a low-level waste disposal site is accomplished using trucking companies that are licensed to transport special materials. The volume of these materials to be transported and the number of shipments required are estimated in Appendix H, and costs are summarized in Table H.2-5.

9.1.1.4 Waste Management

Radioactive wastes generated during DECON must be packaged and shipped to a low-level waste burial ground. The radioactive wastes generated include: process and facility equipment, concrete rubble, filters, trash, and sludge and material from the waste treatment lagoons.

About 3% (1100 m^3) of the total 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 residual uranium. Calcium fluoride solids from the fluoride waste lagoons comprise most of the material in this category (29,600 m^3, assuming a 40% packing factor). The balance of the material, which includes process and miscellaneous equipment (about 6200 m^3), is assumed to be decontaminated and sent to the local dump, excessed, or sold for scrap. The amount of CaF_2 and other wastes that are generated at different U-Fab plants and stored in lagoons varies over a wide range of concentrations. Of the currently operating U-Fab plants, one produces very little CaF_2 waste and the others only a moderate amount compared to the reference plant. However, some other wastes such as ammonia and nitrates are discharged to storage lagoons and not recycled as are the similar reference plant wastes.

For the reference plant, CaF_2 is assumed to be processed by a contractor to recover the residual uranium. The uranium concentration in CaF_2 and other waste products may vary from about 0.005% to 0.2% for different U-Fab plants. For our reference plant, the uranium concentration in CaF_2 is about 0.2%. There is no commercially available industrial process presently being used to separate uranium from CaF_2. However, the technology needed to develop such a process is available and it is believed that recovery of uranium from CaF_2 is feasible. A program to recover uranium from the CaF_2 must include a criticality review to ensure the safety of the process.

The decision to recover the uranium would be based on an economic study to determine whether the cost of recovery would exceed the sum of the value of the recovered uranium and the byproducts from the recovery process, and the savings achieved by disposing of the decontaminated waste at a chemical disposal site. Based on current prices for enriched uranium and the inflationary trends in yellowcake cost, it is expected that the economic value of the recovered enriched uranium would exceed the cost of recovery.

If the CaF_2 is not processed to remove the residual uranium it will have to be disposed of at a low-level waste burial ground at the time of decommissioning. The material would be loaded into drums and shipped to the nearest LLW disposal site.

A potential alternative to low-level waste disposal would be reduction of the residual activity levels by dilution and shipment to a chemical or commercial waste dump. There is presently no clear definition of what constitutes acceptable levels of enriched uranium in bulk waste. 10 CFR 70.4 defines special nuclear material (SNM), which includes uranium enriched in the isotope 235. There is no mention in 10 CFR 70 of exempt concentrations of SNM such as are given in 10 CFR 30.70 Schedule A for nuclear byproduct materials, for example.

Several proposals and requests for acceptable values for contamination in bulk materials (CaF_2, NO_3 waste) have been made to the NRC, but no specific regulation has yet been developed. Permission has been given in specific cases to discharge to the environment liquid CaF_2 and NO_3 wastes containing low levels (3 to 5 ppm) of uranium.(a,b) However, no general limit exists as, for example, in transportation regulations (49 CFR 173.389), where radioactive material is defined as "material in which the estimated specific activity is greater than or equal to 0.002 microcuries per gram."(c)

(a) NRC License #SNM 1097, Section 1.6.4 of Appendix A. (General Electric Co., Wilmington, NC, plant).

(b) Westinghouse (S.C.) Licensing Correspondence, DOCKET #70-1151, August 10, 1979, letter to USNRC.

(c) Westinghouse SNM License #1107, Condition #13 specifically prohibits use of the 49 CFR 173.389 cutoff level (0.002 μCi/g) if the activity is a result of contamination with SNM.

Lacking a definitive regulatory lower limit value for uranium in solid waste, for this report, estimates of residual levels of uranium in CaF_2 that would permit disposal as nonradioactive waste are based on guidance developed in the National Environmental Studies Project report AIF/NESP-016 "de minimis Concentrations of Radionuclides in Solid Wastes."(1) Based on a maximum total body dose of 1 mrem/yr, the acceptable level of activity for ^{235}U was found to be about 100 picocuries per gram of CaF_2. At 0.2% uranium content and 3% enrichment, the activity level of the CaF_2-uranium mixture would be about 5700 pCi/g of CaF_2. Thus, a dilution factor of about 60 parts soil to 1 part CaF_2 would be required to satisfy the limit based on Reference 1. The residual uranium concentration in CaF_2 that corresponds to this lower limit would be about 35 ppm, compared to 2000 ppm for the waste CaF_2 stored at the reference U-Fab plant.

Since the EPA does not have any restriction on the disposal of CaF_2 as a hazardous waste, the question of chemical or commercial waste burial would be determined by regulations of the state where the U-Fab plant is located.

Solid waste from the nitrate lagoons is packaged and shipped to an offsite contractor for recovery of uranium as part of final inventory cleanout. The residual waste from the aeration and chemical lagoons is assumed to be buried onsite during the reclamation operations. If the residual radioactivity levels in the lagoons are high, this waste would have to be shipped to an LLW burial ground.

9.1.1.5 Final Release Survey

The final task is to perform a radiation and chemical survey of the fuel facility, the auxiliary facilities, and the entire site. Any remaining spots of radioactivity and chemical contamination higher than the amount allowable for unrestricted use are removed and the contaminated materials are disposed of at a licensed low-level waste burial site.

This concludes the DECON responsibilities of the site owner. The NRC then audits the project and sponsors an overcheck survey. In the event of a discrepancy, the owner provides the necessary corrective action.

The NRC then terminates the nuclear license, releases the site for unrestricted use, and discontinues their surveillance and responsibilities at the site. The owner is then free to use the site for unrestricted applications.

9.1.2 Essential Systems and Services

Certain of the facility systems and services must remain in place until all radioactive and/or contaminated materials are removed from the site to ensure that no significant amounts of radioactive or hazardous materials are released to the environs. In addition, certain of these systems are needed to facilitate the cleanup and disassembly efforts. As areas within the facility are readied for unrestricted use, the extensions of services into those areas are deactivated and removed, while maintaining continuity of the services to the remaining work areas. The required support systems, together with the justification for retaining each system, are listed in Table 9.1-1.

Essentially the same environmental monitoring program carried on during plant operation is continued during the DECON period. This program is to identify and quantify any releases of radioactivity to the surrounding areas resulting from DECON activities. The proposed program, detailed in Section F.5

TABLE 9.1-1. Systems and Services Required During DECON

Systems or Components	Justification
Electrical power, including emergency diesel backup system	Required for HVAC, lighting and radiation monitoring
HVAC Systems	Required for ventilation and contamination confinement
Environmental Surveillance and Safeguards Program	Required to identify and quantify any releases of radioactivity to the environs from dismantlement activities and to identify and safeguard any significant quantities of uranium discovered during dismantlement
Water Supply (service and domestic systems)	Required for decontamination, clean up, fire protection, and general potable water usage
Fire Protection System (direction and suppression)	Required for health and safety
Compressed Air Systems (control and suppression)	Required for operation of pneumatic controls, for operation of pneumatically operated tools
In-Plant Communications Systems (telephones and intercoms)	Required to facilitate and coordinate activities
Radiation Monitoring Systems	Required for protection of personnel
Solid and Liquid Contaminated Waste Systems	Required for treatment and disposal of potentially contaminated liquids and solids
Clean Scrap and Dirty Scrap Recovery Systems	Required for recovery of uranium from liquid, solid non-combustible, and incincerated wastes
Sewage Treatment Plant (septic tanks and sewage lagoon)	Required for sewage treatment

of Appendix F, is sufficient to permit evaluation of any significant releases. Additional short-term surveillance efforts may be added for emergency situations involving radionuclide releases from events such as fires or malicious acts that may necessitate prompt emergency action.

9.1.3 Security

Protection of the public (often against the consequences of their own actions) is an important dimension of the security program throughout the decommissioning effort. Security during decommissioning is assumed in this study to be similar to, but less stringent than, that needed during plant production operations.

9.2 DECOMMISSIONING BY PASSIVE SAFSTOR

The goal of the passive SAFSTOR alternative is to achieve a condition that ensures that residual radioactivity is kept confined to the U-Fab site. Modifications to the facility are limited to those that ensure the security of the buildings and to those required to ensure containment of radioactive material. The passive SAFSTOR alternative allows deferral of the decision regarding final disposition until no further use is found for the plant. To achieve this goal, the facility is left structurally sound. All loose contamination in readily accessable locations is removed. Hoods and equipment are vacuumed and hand-wiped. Access into contaminated areas is limited. All systems and equipment not required to be in operation during the safe storage period of passive SAFSTOR are deactivated. The preparations for safe storage and the period of safe storage that follows should be recognized as only temporary stages in the total decommissioning process. Current NRC philosophy encourages a decommissioning approach that ends in the termination of the plant's nuclear license and the release of the property for unrestricted use within a finite period of time. Thus, decontamination to unrestricted levels is required eventually.

The major benefits gained from decommissioning the facility by the passive SAFSTOR alternative are: 1) postponement of final decommissioning activities, 2) possible reuse of the facility by the owner, if so desired, and 3) low initial outlay of funds.

The passive SAFSTOR period may vary from a few years to a few tens of years, depending on the needs and desires of the facility owner and the public safety risks.

General work sequences and procedures for passive SAFSTOR are presented in this section. These sequences and procedures are developed under the assumption that the physical activities commence immediately following plant shutdown and final operational inventory cleanout operations. The program plan is discussed below.

9.2.1 Program Plan

The passive SAFSTOR alternative is divided into seven major phases:

- planning and preparation
- waste treatment facilities stabilization
- equipment deactivation
- isolation of contaminated areas
- final preparations for safe storage
- safe storage (security, surveillance, and maintenance)
- deferred decontamination or restartup of production.

The approximate schedule for these work phases is given in Figure 9.2-1. It is estimated that the planning and preparation will take about 6 months. About 3 months are required for physical decommissioning activities before the facility and site enters the period of safe storage. Safe storage consists primarily of security, surveillance, and maintenance. At the conclusion of safe storage the site undergoes deferred decontamination to prepare it for unrestricted use. An estimated 17 months are required to plan and prepare for and to perform deferred decontamination. An unlikely alternative is to restartup the plant for uranium fuel production. The time and work estimates assume reasonable success with a minimum of delays and/or major unanticipated problems.

Most of the time in this decommissioning alternative is spent in safe storage. During that state, the plant condition is one where most of the transportable radioactivity is either removed or confined. The small amount of radioactivity remaining is spread thinly throughout the facility.

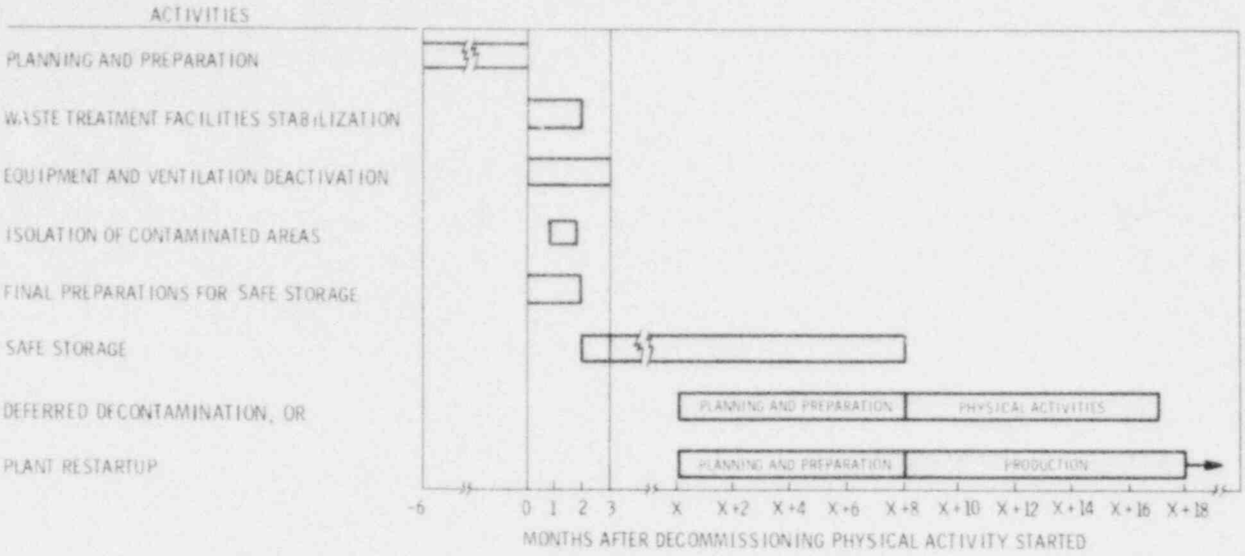


FIGURE 9.2-1. Sequence and Schedule for Major Activities for Passive SAFSTOR

The areas listed in the passive SAFSTOR decommissioning plan are kept in the restricted-use category, as defined in Section 8. The areas are in a condition amenable to security, surveillance, and maintenance, but generally unavailable for any other use. Access is limited in accordance with the requirements of 10 CFR 20.103 and the provisions detailed in Section 9.2.1.6.

The onsite restricted areas assumed in this study include:

- the contaminated portions of the fuel fabrication building
- the waste treatment facility
- the fluoride, nitrate, and radwaste treatment facilities
- CaF_2 storage pits
- excess equipment storage yard
- uranium storage pads.

Activities at the site during the safe storage period are limited primarily to 1) operation of the building utility systems and fire prevention systems, 2) system maintenance, 3) building maintenance and radiation monitoring, 4) environmental radiation surveillance, and 5) security. The facility is patrolled by a security contractor on a periodic basis during the safe storage period. Periodic surveillance and maintenance of the facility structures and of passive safety and security-related systems are also required. The outer-perimeter site fence is maintained and no unauthorized entry is permitted. Detailed accounts of the decommissioning operations are stored at the facility and made a part of the public record. These accounts are required for use when final decontamination of the facility is performed.

Discussions of the seven major work phases of passive SAFSTOR are given in the following subsections.

9.2.1.1 Planning and Preparation

The planning and preparation activities for passive SAFSTOR are carried out concurrently within the final 6 months of facility operation. Figure 9.2-2 shows the time sequence for the planning and preparation phase of decommissioning for passive SAFSTOR. Work begins in the engineering and operations departments of the company organization to prepare the analyses and documentation needed to convert the operating license to a possession-only license following final plant shutdown.

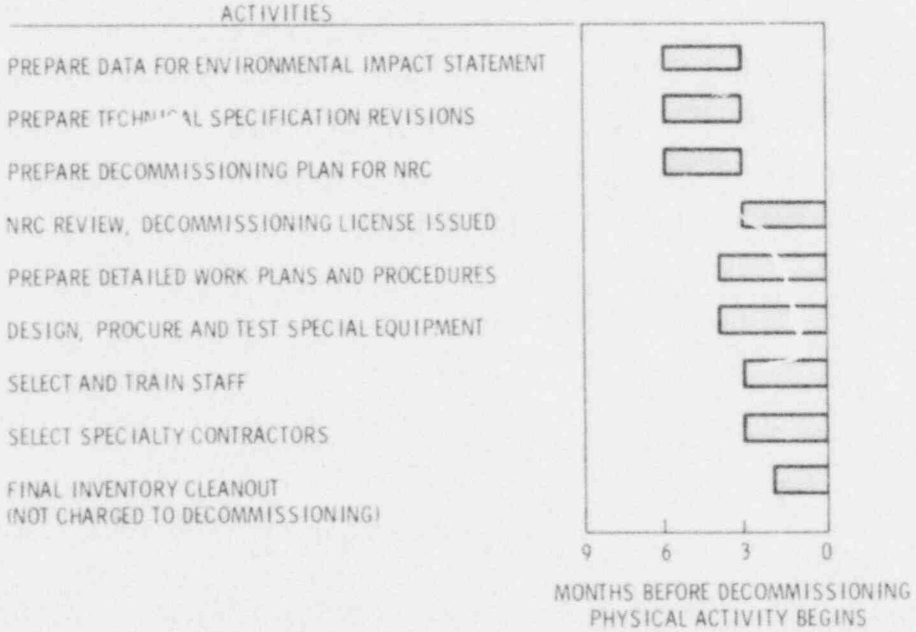


FIGURE 9.2-2. Sequence and Schedule of the Planning and Preparation Phase of Passive SAFSTOR

The initial steps include gathering data for the environmental impact assessment and the technical specification revisions. The data are used in the submittal of a decommissioning plan for a possession-only license for NRC review and approval.

The decommissioning plan submitted to the NRC includes the following types of information:

- facility current status description
- general description of the overall plan
- description of measures taken to contain radioactivity
- proposed changes to the technical specifications
- necessary disassembly/retirement activities to be performed
- safety analysis of activities
- inventory of radioactive materials and their location in the facility
- security plan for total decommissioning program.

As stated earlier, a review of regulations and guides applicable to decommissioning is given in Section 5.

Detailed work plans and procedures are prepared to accomplish the physical activities in the most efficient and safe manner. Work is divided into easily manageable tasks. Available decommissioning techniques are reviewed and decisions are made on the general techniques to be used to accomplish each task. Detailed procedures are developed, including those for the inventory cleanup of the facility. Equipment and material requirements, manpower estimates, cost estimates, and work schedules are prepared. The plan is documented in detail, safety analysis reports are prepared, and all necessary documents are submitted for approval of plant management and appropriate regulating agencies.

Design, procurement, and testing of any special devices and equipment needed for decommissioning is also accomplished. This will assure that work can proceed without undue delay after plant shutdown.

A decommissioning organization within the company is initiated, with the structure and staffing requirements identified, and commitments are obtained from key engineering and operating personnel to fill strategic positions. Orientation and training of personnel identified as members of the decommissioning staff are carried on during the final 2 months of plant operation. The decommissioning staff draws on their own experience, as well as on the experience of the operations staff to assist in the planning activities.

It is assumed that most of the planning and the actual decommissioning activities are performed by plant operating and maintenance personnel. The various specialty contractors required for the decommissioning effort are selected during the final 2 months of plant operation.

Upon termination of routine plant production operations, an extensive final inventory cleanout and uranium audit are conducted. These cleanout/audit operations are similar, but slightly more extensive, than those conducted periodically to audit uranium content or to minimize cross-contamination between differing isotopic mixtures or blends of fuel. Based on plant experience, clean-out operations are estimated to remove one-half of the residual uranium plant inventory. Because these cleanouts are done typically during plant production, they are also considered a part of normal plant operations in this study and are not charged to decommissioning. Details of the final inventory cleanout and uranium audit are found in Section G.1 of Appendix G.

A variety of other activities are carried out as part of plant shutdown and inventory cleanout operations. These activities include 1) reduction of inventories of process chemicals and nonessential materials and equipment, and 2) an engineering review of effluent control and safety systems necessary for decommissioning.

Final preparatory steps to decommissioning are confirmation of radioactive materials inventories and a comprehensive survey of radiation dose rates at contaminated areas within the facility. These steps are taken immediately after uranium inventory cleanout and plant shutdown. In addition, a comprehensive radiation survey of the site is performed.

9.2.1.2 Waste Treatment Facilities Stabilization

The waste treatment lagoons for nitrate, fluoride, and liquid radwaste effluents all require stabilization. These effluents contain uranium, which settles out in the lagoons. The nitrate lagoon is drained and residual solids are packaged and shipped to another commercial facility for recovery of the uranium. Weights are placed on the hypalon liner to keep it fixed. The fluoride, aeration, and chemical lagoons are also drained and plastic covers with weights are placed over the remaining solids.

The remainder of the waste treatment systems is made up of pipes, pumps, valves, tanks, etc., that provide a closed system that contains any of the residual radioactivity left after being flush-rinsed several times.

9.2.1.3 Equipment Deactivation

Essential safety systems (such as lighting, utilities, radiation detection alarms, security monitors, and fire detection and portable fire fighting equipment) remain in operation during the safe storage period. All other equipment and systems are placed in a condition that provides maximum safety with minimum maintenance. When possible, equipment is left in a condition that permits startup or salvage at a later date.

The first step in equipment deactivation is a safety audit of all pumps and pipes used for radioactive materials or chemicals to ensure that hazardous or corrosive materials are removed. Electrical service is disconnected from all pumps not required to be in operation during the safe storage period.

Deactivation and isolation techniques include closing and securing installed valves; sealing hoods; capping ventilation exhaust stacks; installing blank flanges; and disconnecting electrical power, compressed air, and other utilities. A safety audit of all systems is performed to ensure that all flammable and other potentially hazardous materials are removed. All deactivated equipment and systems are tagged for identification and status.

In general, all systems not necessary to prevent the spread of contamination are deactivated. (See Section 9.2.1.6 for systems retained.) All equipment, valves, circuit breakers, etc., are tagged when deactivated. These tags identify the piece of equipment, the system it is in, and its condition.

Systems inside the building are deactivated by a variety of methods. Many piping systems are isolated using the installed valves, with handles or valve operators removed. Pipes that lead from uncontaminated to contaminated zones are blanked where flanges are readily accessible. Some uncontaminated systems are drained and left open to the atmosphere. All cranes are disabled by removal of their circuit breakers to prevent their unauthorized use during the safe storage period. Other electrical equipment that should not be operated during the safe storage period is disabled in a similar manner. Electrical service is disconnected from instrumentation not required to be in operation during the safe storage period.

9.2.1.4 Isolation of Contaminated Areas

Portions of the U-Fab facility containing uranium contamination are isolated by the installation of high-security locks on entryways. Indirect access routes, however unlikely, are investigated from as-built drawings and secured. Such routes may include (but are not limited to) access through ventilation ductwork, roof plugs, or pipe trenches. Temporary barriers are constructed to block potential pathways for unauthorized entry. Warning signs are posted. The same steps are taken for the incinerator and waste treatment facilities. Fences around the waste treatment lagoons and CaF_2 storage areas are also secured, and posted with warning signs.

9.2.1.5 Final Preparations for the Safe Storage Period of Passive SAFSTOR

Final preparations for safe storage are:

- installing and/or upgrading uranium sampling, monitoring systems and radiation alarms
- installing or relocating intrusion alarms
- performing a comprehensive radiation survey of both the restricted and unrestricted areas at the site; spots of excessive contamination in the unrestricted areas are decontaminated
- shipping all recovered uranium materials offsite for disposition
- training of personnel and contractors employed during the storage period
- conducting final survey.

9.2.1.6 Safe Storage Period of Passive SAFSTOR

Activities at the site during the safe storage period are limited primarily to services operations, security, building and equipment maintenance, radiation monitoring, and environmental radiation surveillance. The facility is not manned on a continuous basis after being placed in safe storage. Periodic surveillance and maintenance of the facility structures and of active and passive safety and security-related systems are required. The outer perimeter site fence is maintained and no unauthorized entry is permitted. Detailed accounts of the decommissioning operations are stored at the facility and made a part of the public record. These accounts are required for use when final decontamination of the facility is performed.

Surveillance and Maintenance Activities. The surveillance and maintenance programs are structured so that personnel inspect various portions of the facility on a routine basis. Radiation monitoring is done at each pre-established surveillance point at least monthly. These checks are staggered so that the monitoring takes place on different days of each month. Preventive maintenance activities and routine equipment inspections are also distributed throughout the safe storage period. Warning signs and physical barriers are inspected routinely and repaired as necessary. Electrical distribution systems, fire alarms, and radiation and intrusion alarms are operated and monitored continuously by an offsite contractor. Routine inspections of these systems, which were performed by outside experts during plant operation, continue on a reduced frequency during safe storage.

Environmental Surveillance Activities. A somewhat abbreviated version of the environmental monitoring program conducted during plant operation is carried out during the safe storage period; this is to identify and quantify any releases of radioactivity to the environment. This surveillance program is adequate for evaluating most potential nonroutine or accidental releases. For situations involving releases from events such as fire or malicious acts that may require prompt emergency actions to minimize public risk, special surveillance requirements are added. This program is discussed in more detail in Section F.5 of Appendix F.

Security Activities. The protection of the public, principally against the consequences of their own actions, is an important dimension of the security program used for the safe storage period. Conventional security detection and notification systems normally used to protect the utility against loss or damage are augmented by audible alarms. These alarms, strategically located outside secured radiation zones, loudly warn an intruder of his potential danger. Silent sensors simultaneously alert offsite security personnel.

Routine patrol checks are carried out by offsite guards. A reputable private security agency is contracted to ensure adequate surveillance and prompt response to alarms. Liaison with local law enforcement agencies is maintained and their assistance is called for when necessary.

Security is provided during the safe storage period by two basic methods: offsite guards and security systems. Locks on the fence around the decommissioned facility provide the first line of security. The fence is maintained in good condition throughout the surveillance and maintenance period. Facility security is maintained at all times by intrusion alarms and high-security locks on exterior doors. Intrusion, fire, and radiation alarms are monitored continuously by an offsite security firm. Depending on the situation indicated by the alarms, offsite security agency personnel are available to respond immediately.

Physical security to prevent inadvertent radiation exposure of surveillance and maintenance personnel is provided by locked barriers, which make it extremely difficult for unauthorized access to areas where radiation or contamination is present.

The facility manager is responsible for controlling authorized access into and movement within the facility. The facility manager is further charged with the responsibilities of appropriate actions and notifications regarding breaches of security, upkeep of plant surveillance, and maintenance programs. He is also charged with administrative reporting of these events, as required by state and federal regulations. He is responsible for health physics work, SNM accountability, and record keeping.

Essential Systems and Services. The support systems requiring surveillance and maintenance during the safe storage period are listed in Table 9.2-1. These systems remain in operation throughout the safe storage period. These systems, in combination with inherent facility structural integrity, provide the primary means for minimizing the release of hazardous material to the environment. The equipment in these systems is inspected and renovated to ensure adequate equipment reliability before the surveillance and maintenance period begins. In addition, the intrusion alarm system within the facility and on the perimeter fence are both modified to provide offshift surveillance capability by a commercial security agency.

TABLE 9.2-1. Systems and Services Required During the Safe Storage Period of Passive SAFSTOR

Systems or Components	Justification
Electric power	Normal and emergency power are maintained for: radiation monitoring systems and alarms, lighting circuits, fire protection systems and alarms, and surveillance monitoring systems and alarms. Switchboards are aligned so that no electrical power is fed to deactivated systems.
Fire Protection System (detection and suppression)	Portable fire extinguishers remain at selected locations and fire detection systems remain in operation as required for safety.
In-Plant Communication Systems	Required for normal communication.
Radiation Monitoring Systems	Radiation monitors and alarms remain in operation at strategic locations throughout the facility sections. The locations of some devices may be installed to ensure that important areas are adequately covered. Selected monitoring programs are also continued.
Security Systems	Security devices and alarms (provided with both normal and backup emergency power) are maintained by a security agency subcontractor. In addition to intrusion system monitoring and maintenance, it is postulated that the security agency responds appropriately to intrusions.

9.2.1.7 Deferred Decontamination

The deferred decontamination phase is essentially the same as the DECON decommissioning case discussed in Section 9.1.

As defined in Section 4, deferred decontamination is the final stage of decommissioning when passive SAFSTOR is utilized. The facility and site must be shown to have residual radioactivity levels sufficiently low to permit unrestricted use when decontamination is complete.

The same basic operations are performed during deferred decontamination as were performed during DECON. The primary decontamination done for the safe storage period does not need repeating. A small amount of additional manual decontamination and cleanup effort is performed to collect loose smearable contamination that may have moved during the safe storage period. Some sealed areas need to be unsealed. The same disassembly techniques and contamination control methods are required.

It is anticipated that a new staff is needed for deferred decontamination. The hiring could be done by the facility operator or the decommissioning contractor. Extensive training and familiarization of this staff with the facility is necessary, because of dispersal of personnel from the operations staff during the extended period of safe storage. Additional effort is required to restore some services needed for decontamination and to remove the various enclosures, doors, locks, and temporary barricades used to secure the facility from unauthorized entry during safe storage.

In view of these considerations, it is reasonable to assume that a work force of about the same size as was used for DECON is required for deferred decontamination and over approximately the same period. Essentially, the same volumes of contaminated and uncontaminated materials must be removed and transported to an authorized burial site, except for those materials removed during decontamination for safe storage. The items that increase the costs of deferred decontamination with respect to DECON are the labor costs associated with training a decommissioning staff, removing covers from the lagoons, and restoring services needed for decontamination.

The program plan outlined for DECON in Section 9.1 is assumed to be valid for deferred decontamination, except in the planning and preparation phase. Portions of the environmental impact assessment and technical specifications have to be revised. The final inventory cleanout need not be repeated. Other elements in the planning and preparation phase (Figure 9.1-2) are likely to take slightly more manpower and time due to lack of experienced personnel.

REFERENCES

1. W. A. Rodger, et al. "de minimus" Concentrations of Radionuclides in Solid Wastes, National Environmental Studies Project, AIF/NESP-016, Atomic Industrial Forum, Washington, DC, April 1978.

10.0 DECOMMISSIONING COSTS

This section presents estimates of the costs for decommissioning the reference uranium fuel fabrication (U-Fab) plant. Cost estimates are made for DECON and for preparations for safe storage, safe storage, and deferred decontamination. The costs are based on decommissioning procedures developed in detail in Appendix G and summarized in Section 9. Costs are included for direct support and decommissioning worker labor, equipment and materials, contaminated waste packaging, transportation and disposal, utilities and other miscellaneous owner expenses, and specialty contractors. All costs are in 1978 dollars.

The basic cost estimates presented in this section assume relatively efficient performance of the decommissioning activities. A 25% contingency is added to the cost estimate totals as an allowance for unforeseen problems or scheduling delays that may arise during the decommissioning. The total costs presented are believed to be representative of actual expenses that would be incurred to decommission the reference facility using the methods described in this report.

10.1 COST ESTIMATES FOR DECON

The estimated costs for DECON of the reference plant are summarized in Table 10.1-1. DECON is estimated to require about 9 months (plus 7 months for planning and preparation) at a cost of approximately $3.54 million.

Manpower costs include both support staff and decommissioning workers and represent about 59% of the total cost of DECON. In Table 10.1-1, 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.

Waste management accounts for about 7% of the total cost of DECON. Waste management costs include shipping container costs, transportation charges, and fees for waste disposal at a commercial low-level waste burial site.

TABLE 10.1-1. Summary of Estimated DECON Costs

Cost Category	Cost in Millions of 1978 Dollars[(a)]	Percent of Total
Manpower		
Planning and Preparation	0.275	9.7
Decommissioning	1.440	50.9
Equipment and Supplies	0.126	4.4
Disposal of Radioactive Material	0.197	7.0
Miscellaneous Owner Expense	0.730	25.8
Specialty Contractors	0.061	2.2
Subtotal	2.829	100.0
25% Contingency	0.707	
Total Decommissioning Costs	3.536	
Other Possible Waste Management Costs		
Chemical Sludge Disposal	0.32	
Contaminated CaF_2 Disposal	7.20	
Misc. Contaminated Material	0.96	
Subtotal	8.48	
25% Contingency	2.12	
Total Other Possible Waste Management Costs	10.6	

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

If the calcium fluoride (CaF_2) and other radioactive wastes which were assumed to be decontaminated are instead assumed to be shipped to low-level waste burial, the estimated cost of waste disposal would be increased by \$10.6 million. Disposal of just the CaF_2 in a licensed low-level waste burial site is estimated to cost about \$9 million (85% of the \$10.6 million).

If the contaminated sludge in the chemical and aeration lagoons requires treatment and disposal, the cost, including contingency, of packaging, shipping, and disposing of the sludge is estimated to be about \$0.40 million, or about twice the other waste management costs for DECON. Thus, a substantial increase in decommissioning costs results if the sludge requires disposal. In this study, it is assumed that the sludge is left in place and covered by soil (see Section G.2.3.7). The cost of this treatment option is summarized in Section 10.1.5.

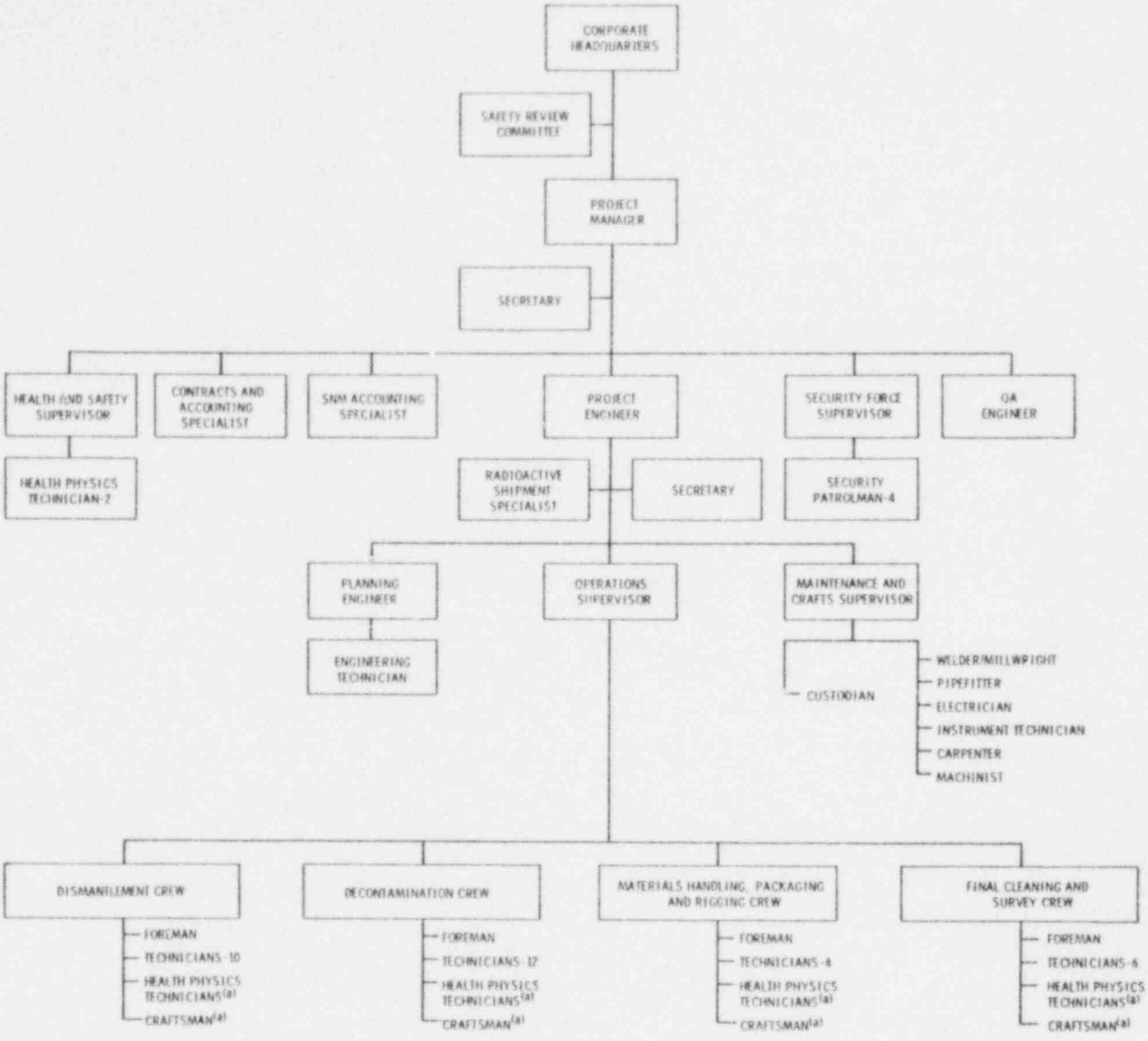
10.1.1 Manpower Requirements and Costs for DECON

Estimates are made of the work force required to plan and execute the decommissioning activities for DECON described in Section 9.1. These work-force estimates are used, together with the unit manpower costs given in Section H.1 of Appendix H, to estimate DECON manpower costs. The bases for these manpower estimates and the results in terms of decommissioning manpower costs are described in this section.

10.1.1.1 Manpower Requirements

The decommissioning work force organizational chart for DECON is shown in Figure 10.1-1. 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. The seven general types of functions performed during decommissioning are described briefly below:

- Project Management - prepare and implement the decommissioning plan in a safe and cost-effective manner.
- Quality Assurance (QA) - develop the QA plan and monitor the safety and performance of the decommissioning activities.
- Decommissioning Operations - develop the decommissioning plan and carry out the actual decommissioning activities.
- Plant Operations and Maintenance - operate and maintain plant equipment that must be operated during the decommissioning.
- Safety Protection - develop methods to assure the safety of the public and decommissioning workers.



[a] ASSIGNED TO WORK CREWS AS WORK SITUATION DEMANDS. COUNTED ONLY ONCE.

FIGURE 10.1-1. Postulated Organization Chart for DECON

- Safeguards and Security - provide protection for the site and facility against unauthorized entry and safeguard Special Nuclear Material (SNM).
- Support Services - providing accounting, procurement and stores, secretarial and clerical services in support of the decommissioning activities.

Job description activities are carried out by decommissioning crews that consist of a foreman, four to twelve 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 work procedures. The duties and experience of the members of the basic decommissioning crew are outlined below.

Foreman. This person supervises the performance of all decommissioning activities. He coordinates with the engineering staff through the operations supervisor to plan and execute each day's activities. He assembles the crew and equipment required to perform these activities and instructs the crew on procedures and safety precautions to be followed. The foreman is assumed to perform some of the actual decommissioning activities as well as supervise other members of his crew. It is anticipated that the foreman would have been employed in a position comparable to a process shift supervisor or main tenance supervisor during plant operations, so that he has detailed knowledge of plant systems and equipment.

Decommissioning Technicians. These people perform the bulk of the actual decommissioning operations. They are assumed to possess a variety of skills either through past experience in the plant or through specialized training prior to or during the decommissioning. The technicians are assumed to be employed in positions comparable to process operators, maintenance technicians or mechanical technicians during plant operations. It is anticipated that they would be qualified in several craft disciplines, including operation of much of the plant equipment.

Health Physics Technician. This person is assigned to the work crews as the work situation demands to provide instruction in radiation and industrial safety precautions to be followed for each task and to monitor compliance with written radiation work procedures for the task. He performs on-the-job radiation measurements and has the authority to stop work on the job if any potentially unsafe situation arises.

Craftsmen. These are people who are added to the basic crew to carry out particular tasks that require assistance of a/an:

- welder
- pipefitter
- carpenter
- electrician
- instrument technician
- millwright
- machinist.

The decommissioning staff is assembled during the planning and preparation phase. Initial management staff consists of the project manager, project engineer, quality assurance supervisor, and operations supervisor. Other staff personnel are added as their services are required during the planning and preparation phase. Planning and preparation activities take place during the final 7 months of plant operation. Therefore, support activities such as plant maintenance and plant security are available as part of plant operations and are not charged to decommissioning during the planning and preparation phase.

The decommissioning staff is generally sized and structured on a 1-shift, 5-day week. Certain operations such as calcium fluoride recovery and security are carried out on a 4-shift, 7-day week. Decommissioning activities require that workers wear protective clothing, and in some cases, respiratory protection. Because of the inconveniences of the physical environment in which decommissioning tasks are carried out, manpower requirements are developed on the basis of an assumed worker time efficiency of 75%. During the approximately 9-month period of dismantlement and decontamination, the staff size is estimated to remain approximately constant.

10.1.1.2 Manpower Costs

Table 10.1-2 shows manpower and associated cost estimates for the planning and preparation phase of DECON and Table 10.1-3 shows manpower requirements and costs for the dismantlement and decontamination phase of DECON. A total of

TABLE 10.1-2. Summary of Manpower Utilization and Staff Cost for Planning and Preparation Phase of DECON

Title or Function	Man-Years	Cost ($ thousands)(a,b)
Project Manager	0.75	56
Project Engineer	0.58	37
Health and Safety Supervisor	0.25	12
Contracts and Accounting Specialist	0.50	16
Radioactive Shipment Specialist	0.25	8
Q.A. Engineer	0.50	22
Planning Engineer	0.58	25
Engineering Technician	0.50	14
Operations Supervisor	0.50	22
Foreman	1.00	33
Secretary	1.50	30
Total Man-Years	6.91	
Total Cost		275

(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.

TABLE 10.1-3. Summary of Manpower Utilization and Staff Costs for the Dismantlement and Decontamination Phase of DECON

Title or Function	Man-Years	Cost ($ thousands)(a,b)
Project Manager	0.83	62
Project Engineer	0.83	53
Health and Safety Supervisor	0.80	38
Health Physics Technician	1.54	39
Security Force Supervisor	0.75	26
Security Patrolman	3.00	64
Contracts and Accounting Specialist	0.80	26
SNM Accounting Specialist	0.75	29
Radioactive Shipment Specialist	0.75	25
Q.A. Engineer	0.83	36
Planning Engineer	0.83	36
Engineering Technician	0.75	20
Maintenance and Crafts Supervisor	0.80	33
Custodian	0.75	18
Craftsman	4.23	114
Operations Supervisor	0.80	35
Foreman	3.80	125
Technician	24.48	661
Secretary	1.50	30
Total Man-Years	46.09	
Total Cost		1 440

(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.

about 7 man-years is estimated to be required for planning and preparations, at a labor cost of about $275,000. A total of about 46 man-years is estimated to be required to decontaminate and remove contaminated materials from the facility, at a labor cost of about $1.4 million. The total labor cost for DECON is estimated to be about $1.7 million without contingencies. Manpower costs shown in Table 10.1-3 include labor costs for packaging radioactive waste materials for shipment. These costs do not include specialty labor costs discussed in Section 10.1.3 for transportation and in Section 10.1.5 for other specialty contractors.

It is recognized that completion of decommissioning activities will occasionally take longer than anticipated, resulting in increased labor costs. Often, these cost increases can be offset by reducing the labor force after the most labor-intensive tasks are completed. The final deactivation and cleanup activities, for example, can be accomplished by a relatively small group.

10.1.2 Material and Equipment Requirements and Costs for DECON

Estimates of material and equipment requirements and costs for DECON are shown in Table 10.1-4. Equipment requirements are based on decommissioning procedures described in detail in Appendices F and G and summarized in Section 9.1. Costs of decontamination chemicals are calculated on the basis of quantities required for decontamination and unit costs given in Section H.1 of Appendix H. Cleaning supplies represent a major cost item and include assorted cleaning agents, rags, mops, brushes, plastic bags, plastic sheeting, etc. The cost of protective clothing includes the cost of laundering the clothing onsite and is estimated to be about $500 per week. The total cost of material and equipment for DECON of the reference plant is estimated at about $126,000 without contingency.

10.1.3 Waste Management Requirements and Costs for DECON

Waste management requirements and costs for DECON are described in this section. Estimates are made of quantities of radioactive wastes generated during DECON of the reference plant and of packaging, transportation and disposal

TABLE 10.1-4. Estimated Material and Equipment Requirements and Costs for DECON

Description	Quantity	Estimated Unit Cost ($ thousands)	Estimated Total Cost ($ thousands)
Oxyacetylene Torch	4 ea.	1	4
Guillotine Pipe Saw	2 ea.	1	2
Tube Cutter	2 ea.	0.3	0.6
Ratcheting Pipe Cutter	6 ea.	0.05	0.3
Reciprocating Saw	4 ea.	0.5	2
Nibbler	2 ea.	1	2
High-Velocity Liquid Jet	1 ea.	5	5
Low-Velocity Liquid Jet	2 ea.	2	4
Hydraulic Concrete Surface Spalling Device	1 ea.	5	5
Concrete Drill	3 ea.	0.2	0.6
Electric Pneumatic Hammer	2 ea.	0.5	1
Portable A-Frames	2 ea.	3	6
Portable Wash Sinks	2 ea.	2	4
Portable Spray Clean Booth	1 ea.	4	4
Portable Greenhouse Erection Kit	1 ea.	2	2
Portable Powered Brushes	20 ea.	0.15	3
HEPA Filter	10 ea.	0.15	1.5
Roughing Filter	100 ea.	0.05	5
Decontamination Chemicals			10
Cleaning Supplies			20
Expendable Tools			10
Protective Clothing (including laundry)			18
Office Supplies: Planning and Preparation			10
Decommissioning			6
		Total[a]	126

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[a] Total is shown as direct addition of prior numbers to retain calculational information. Precision is less than shown. Contingency of 25% is not included.

requirements and costs for managing these wastes. These estimates are based on decontamination procedures described in Section 9.1, and on unit waste management costs given in Appendix H.1.

10.1.3.1 Waste Management Requirements

Radioactive wastes generated during DECON must be properly packaged and shipped to a low-level waste burial site. Radioactive wastes generated during DECON include:

- contaminated process equipment, tanks, hoods, and piping;
- concrete rubble from the mechanical decontamination of contaminated floors and walls;

- HEPA and roughing filters;
- sections of ventilation ductwork;
- combustible and noncombustible trash (protective clothing, contaminated tools, rags, paper, plastic, metal scrap, etc.);
- sludge, liners, and soil from the waste treatment lagoons.

The bulk of the material that must be packaged for disposal will be contaminated with uranium. The equipment and material wastes are assumed to be disposed of at licensed low-level waste burial sites. Details of assumed waste shipping volumes for contaminated process equipment, tanks, hoods, piping, ducts, etc., postulated to require disposal at a low-level waste burial site are given in Table H.2-2 of Appendix H.

All shipments of decommissioning wastes are made in compliance with federal, state and local regulations, as described in Section F.3.2 of Appendix F.

Table 10.1-5 gives estimated weights and volumes of decommissioning wastes from DECON of the reference plant, together with the type of packaging and the number of shipments required for these wastes. Detailed information about waste quantities is given in Section H.2 of Appendix H. It is assumed that the sludge from the two chemical and aeration lagoons would not require removal. However, an estimate of packaging and shipping requirements for removal of contaminated sludge from the lagoons is given separately, in the event that sludge removal is required.

10.1.3.2 Waste Management Costs

The estimated costs for containers, transportation, and disposal of the radioactive wastes from DECON of the reference plant are summarized in Table 10.1-6. Cost estimates are based on projected packaging and shipping data summarized in Table 10.1-5 and on waste management cost data in Section H.2 of Appendix H. Waste management cost details are also given in Section H.2. The total waste management cost for DECON is estimated to be about $200,000 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 10.1-5. Waste Disposal Packaging and Shipping Data For DECON

Waste Category	Shipping Weight (kg)[a]	Shipping Volume (m^3)[a]	Type of Container	Number of Shipments
To Low-Level Waste Burial:				
Hoods, Equipment and Components	314 800	764.40	Plywood Boxes	18
Pipe, Conduit, Duct, Trays, Fixtures, etc.	133 200	118.52	Plywood Boxes	7
HEPA and Roughing Filters	16 500	51.66	Plywood Boxes	1
Concrete Rubble	23 800	39.66	Steel Drums	2
Contaminated Liner and Soil Materials	63 600	91.00	Plywood Boxes	5
Miscellaneous	17 400	12.5	Steel Drums	1
Miscellaneous	9 100	12.5	Plywood Boxes	1
Totals	578 400	1 090.24		35

(a)Number of significant figures shown is for computational accuracy and does not imply accuracy to three or more significant figures.

TABLE 10.1-6. Estimated Waste Management Costs for DECON

Waste Category	Costs in 1978 Dollars[a]			
	Container	Transportation	Burial	Total[b]
To Low-Level Waste Burial:				
Hoods, Equipment and Components	38 220	17 240	71 530	127 000
Pipe, Conduit, Duct, Trays, Fixtures, etc.	5 930	7 230	11 090	24 300
HEPA and Roughing Filters	2 580	950	4 830	8 400
Concrete Rubble	4 000	1 680	3 710	9 400
Contaminated Linen and Soil Materials	9 180	4 200	8 510	21 900
Miscellaneous	1 260	950	1 170	3 400
Miscellaneous	630	800	1 170	2 600
Totals	61 800	33 050	102 010	197 000

(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.

10.1.3.3 Alternative Waste Management Costs

If all radioactively contaminated equipment and materials were sent to low-level waste burial, the additional disposal costs would be about $10.6 million. Table 10.1-7 shows a summary of this estimated cost. CaF_2 comprises most of the material in this category (29,600 m^3). If the CaF_2 were sent to low-level waste burial in lieu of recovery, the cost would be about $9 million (85% of the $10.6 million), plus a loss of over $30 million in residual uranium in the fluoride waste. It is assumed that the recovered uranium value would exceed the processing costs. The cost breakdown for the LLW CaF_2 disposal is provided in Appendix H.4.

TABLE 10.1-7. Additional Waste Management Costs for Low-Level Waste Burial Disposal

	Cost in Thousands of 1978 Dollars				
Waste Category	Packaging	Transportation	Burial	Contingency	Total
Chemical Sludge	110	90	120	80	400
Contaminated CaF_2	2 776	2 057	2 367	1 800	9 000
Misc. Contaminated Material	390	270	300	240	1 200
Total Additional Waste Management Cost					10 600

The alternative cost of waste disposal for CaF_2 in a chemical or commercial waste dump after dilution material is added to the CaF_2 to bring the radioactive levels down to acceptable limits for nonradioactive disposal would be prohibitive. The large volume of material required for a 60 to 1 dilution factor would result in an extremely large transportation and handling cost and is not considered to be a viable alternative.

Packaging and disposal of the sludge from the chemical lagoons would add about $400,000 (including contingency) to the cost. The cost for low-level waste burial of the balance of the material (6,200 m^3) would be about $1.2 million (11% of the $10.6 million) including contingency.

The waste disposal costs summarized in this section are specific to the reference plant and should not be considered representative of other U-Fab plants. As noted in Section 9.1.1.4, waste volumes generated at other U-Fab facilities are different and waste disposal costs could be significantly different from those discussed in this section.

10.1.4 Miscellaneous Owner Expenses for DECON

Estimated miscellaneous owner expenses for DECON are given in Table 10.1-8.

TABLE 10.1-8. Estimated Miscellaneous Owner Expenses for DECON

Cost Category	Cost in Thousands of 1978 Dollars(a,b)
Utilities	250
Taxes	160
Inspections and License Amendments	70
Insurance	250
Total	730

(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 annual inspection fees for safety and safeguards inspections at the operating U-Fab plant are \$15,900 and \$10,300, respectively.(1) In addition, fees for license amendments for decommissioning could total \$42,000 or more. Thus, the license-related costs during the first year following shutdown of operations are estimated to be about \$70,000.

The cost of nuclear liability insurance for a facility being decommissioned has also not been determined. An allowance of \$100,000 is included for the annual insurance premium for nuclear liability and conventional insurance.

10.1.5 Specialty Contractor Costs for DECON

Specialized services are required to accomplish the dismantlement 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 is approximately 2.7 km of trench that averages 1.5 m in depth. The excavation of refilling of the trench costs about $\$1.30/m^3$ for 3800 m^3, a total of about $5,000.

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. If it is deemed necessary to remove the residual materials, a cost of about $400,000 (including 25% contingency) would be incurred to package, transport, and bury the material at a licensed low-level waste burial site.

The estimated costs for reclamation of the waste treatment lagoons are presented in Table 10.1-9. Labor costs are taken from Reference 2 and have been increased by 30% to allow for inflation to 1978 dollars.

TABLE 10.1-9. Subcontractor Costs for Reclamation of the Waste Treatment Lagoons

Activity	Basis	Cost ($)[a]
Puncture Liners	15 900 m^2 at $0.10/$m^2$	1 600
Backfilling	38 900 m^3 at $0.50/$m^3$	19 500
Grader Rental	$500/wk for 4 weeks	2 000
Dump Truck Rental	$500/wk for 4 weeks	2 000
Loader Rental	$1000/wk for 4 weeks	4 000
Foreman	$900/wk for 4 weeks	3 600
Equipment Operators	Two men at $750/wk for 4 weeks	6 000
Laborers	Two men at $550/wk for 4 weeks	4 400
Grade, Seed, Fertilize	15 900 m^2 at $0.80/$m^2$	12 700
Total		55 800

(a)Contingency of 25% is not included.

10.2 ESTIMATED COSTS OF THE PREPARATIONS FOR SAFE STORAGE PERIOD OF PASSIVE SAFSTOR

The estimated costs of preparing the reference plant for the safe storage period are summarized in Table 10.2-1. These decommissioning activities are estimated to require about 8 months at a cost of approximately $846,000.

Manpower represents about 55% of the total cost of preparations for safe storage. Manpower costs include both support staff and decommissioning worker labor. Breakdown of manpower costs are shown separately for planning and preparation activities and for decommissioning activities described later in the text. The annual costs of safe storage are described in Section 10.3.

10.2.1 Manpower Requirements and Costs of Preparations for Safe Storage

Estimates are made of the work force required to plan and execute the preparations for safe storage described in Section 9.2. These work force estimates are used, together with the unit manpower costs given in Section H.1 of Appendix H, to estimate manpower costs. The bases for these manpower estimates and the results in terms of decommissioning manpower costs are described in this section.

TABLE 10.2-1. Summary of Estimated Costs of Preparations for Safe Storage

Cost Category	Cost in Thousand of 1978 Dollars[(a)]	Percent of Total
Manpower		
Planning and Preparation	145	21.4
Decommissioning	179	26.4
Equipment and Supplies	120	17.8
Disposal of Radioactive Material	0	0
Miscellaneous Owner Expense	218	32.2
Specialty Contractors	15	2.2
Subtotal	677	100.0
25% Contingency	169	
Total Costs of Preparations for Safe Storage	846	

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

10.2.1.1 Manpower Requirements

The organizational chart of the decommissioning work force for preparations for safe storage is shown in Figure 10.2-1. This work force includes the support staff that plans, supervises and provides support for decommissioning activities and the workers who perform the actual decommissioning activities. Job description details for key individuals in the decommissioning work force are given in Section H.2 of Appendix H.

The decommissioning staff is assembled during the planning and preparation phase that takes place during the final 6 months of plant operation. Initial management staff consists of the project manager, project engineer, quality assurance engineer and operations supervisor. Other staff personnel are added as their services are required during the planning and preparation phase.

Actual decommissioning activities require approximately 2 months following plant shutdown.

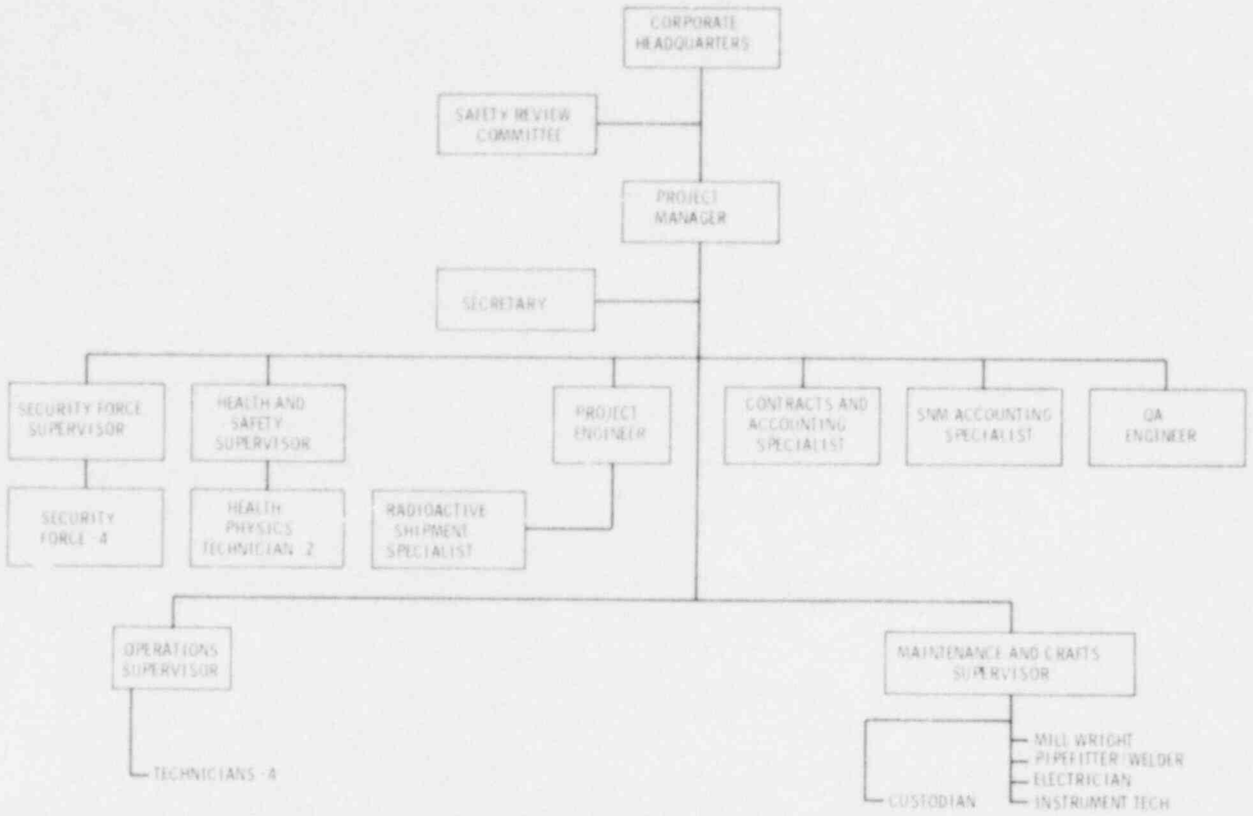

FIGURE 10.2-1. Postulated Organization Chart for Preparations for Safe Storage

10.2.1.2 Manpower Costs

Table 10.2-2 shows manpower and associated cost estimates for the planning and preparation phase, and Table 10.2-3 shows support staff and worker manpower requirements and costs for the active decommissioning phase of preparations for safe storage. About 3 man-years are estimated to be required for planning and preparations, at a labor cost of about $145,000. About 5 man-years are estimated to be required to deactivate the facility, at a labor cost about $180,000. The total labor cost for placing the facility in safe storage is estimated to be about $325,000 without contingencies.

10.2.2 Estimated Material and Equipment Requirements and Costs of Preparations for Safe Storage

Estimates of material and equipment requirements and costs of preparing the reference plant for safe storage are shown in Table 10.2-4. Equipment

TABLE 10.2-2. Summary of Manpower Utilization and Staff Costs for Planning and Preparation Phase of Preparations for Safe Storage

Title or Function	Man-Years	Cost ($ thousands)[(a,b)]
Project Manager	0.5	37
Project Engineer	0.5	32
Health and Safety Supervisor	0.25	12
Contracts and Accounting Specialist	0.25	8
Q.A. Engineer	0.38	17
Radioactive Shipment Specialist	0.25	8
Operations Supervisor	0.25	11
Maintenance and Crafts Supervisor	0.25	10
Secretary	0.5	10
Total Man-Years	3.13	
Total Cost		145

(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.

TABLE 10.2-3. Summary of Manpower Utilization and Staff Costs for Decommissioning Phase of Preparations for Safe Storage

Title or Function	Man-Years	Cost ($ thousands)[(a,b)]
Project Manager	.25	19
Project Engineer	.25	16
Health and Safety Supervisor	.25	12
Health Physics Technician	.35	9
Security Force Supervisor	.25	9
Security Patrolman	.07	14
Contracts and Accounting Specialist	.25	8
SNM Accounting Specialist	.17	7
Q.A. Engineer	.35	11
Radioactive Shipment Specialist	.17	6
Maintenance and Crafts Supervisor	.25	10
Custodian	.17	4
Craftsman	.67	18
Operations Supervisor	.25	11
Technician	.75	20
Secretary	.25	5
Total Man-Years	5.3	
Total Cost		179

(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.

TABLE 10.2-4. Estimated Costs of Equipment and Supplies for Preparations for Safe Storage

Description	Estimated Total Cost ($ thousands)[(a,b)]
Decontamination Chemicals	1
Cleaning Supplies	2
Expendable Tools	2
Protective Clothing (including laundry)	4
Intrusion Alarm System	100
Miscellaneous	5
Office Supplies	
Planning and Preparation	4
Decommissioning	2
Total	120

(a) Total is shown as direct addition of the prior numbers to retain calculational information. Precision is less than shown.
(b) Contingency of 25% is not included.

requirements are based on decommissioning procedures described in detail in Appendices F and G and summarized in Section 9.2. The total cost of material and equipment for placing the reference plant in safe storage is estimated at about $120,000 without contingency.

10.2.3 Miscellaneous Owner Expenses for Preparations for Safe Storage

Estimated miscellaneous owner expenses for preparing the reference plant for custodial safe storage are shown in Table 10.2-5. These expenses are calculated on the same bases as were similar expenses for DECON (see Section 10.1.4), except that the time period is only 2 months.

In estimating the applicable safety and safeguards inspection fees during preparations for safe storage, it is assumed that the full operating fees are paid, plus the fees for license amendments. These fees are assumed to be the

TABLE 10.2-5. Estimated Miscellaneous Owner Expenses During Preparations for Safe Storage

Cost Category	Cost in Thousands of 1978 Dollars[a,b]
Utilities	56
Taxes	36
Regulatory Fees	70
Insurance	56
Total	218

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[a] Number of figures is for computational accuracy and does not imply accuracy to the nearest thousand dollars.

[b] Contingency of 25% is not included.

same as for DECON ($70,000) during the first year. The annual insurance premium for nuclear liability and conventional insurance is assumed to be at the same rate as for DECON.

10.2.4 Specialty Contractor Costs for Preparations for Safe Storage

Specialized services are required to prepare the reference plant for safe storage. These services are assumed to be supplied by the specialty contractor.

An alarm system is installed at the decommissioned plant to detect attempts at unauthorized entry into the facility during the safe storage period. The cost of the alarm system is included as an equipment item in Table 10.2-4. The cost of installation and testing of the system by an outside contractor is estimated to be $15,000 without contingency.

10.3 COST ESTIMATES FOR THE SAFE STORAGE PERIOD OF PASSIVE SAFSTOR

This section presents estimates of the annual manpower and material requirements and costs for the safe storage period of passive SAFSTOR.

Activities carried out at the plant to assure the continued protection of the public safety during this phase include:

- monitoring of operating equipment and alarm systems
- periodic radiation surveys of the facility
- periodic environmental surveys
- maintenance of operating equipment, alarm systems and protective barriers
- inspection of facility structures, protective barriers and operating equipment and alarm systems
- site and facility security
- fulfillment of regulatory requirements.

The annual costs of safe storage are summarized in Table 10.3-1. Safe storage is estimated to cost about 283,000 annually in 1978 dollars. Staff labor costs represent about 46% of this total.

TABLE 10.3-1. Estimated Annual Costs of the Safe Storage Period

Cost Category	Annual Cost in Thousands of 1978 Dollars[a]	Percent Of Total
Staff Labor[b]	104	46.0
Supplies and Equipment	2	0.9
Security Contractor	50	22.1
Annual Allowance for Repairs	3	1.3
Utilities	25	11.1
Taxes	16	7.1
Insurance	25	11.1
Regulatory Fees	1	0.4
Subtotal	226	100.0
25% Contingency	57	
Total Annual Cost	283	

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

(b) See Table 10.3-2 for cost details.

10.3.1 Manpower Requirements and Costs for Safe Storage

Annual manpower requirements and costs for safe storage are described in this section. The work force required to perform safe storage activities at the decommissioned uranium fuel fabrication plant is shown in Figure 10.3-1.

Surveillance and maintenance activities are supervised by a full-time facility manager who reports directly to corporate headquarters. This person monitors the operation of the operating safety systems; performs routine and corrective maintenance and radiation and environmental surveys; performs routine physical inspections of the facility; arranges for third-party inspections of facility structures and equipment; assures that all regulatory requirements

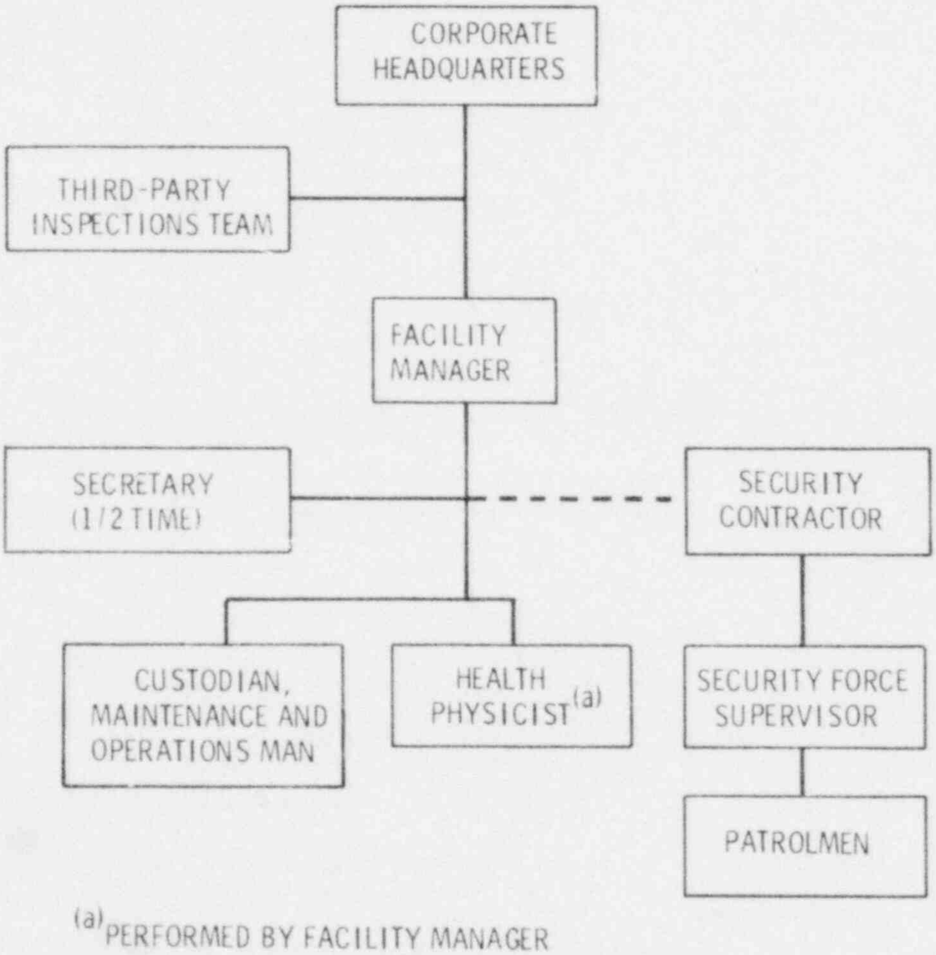

FIGURE 10.3-1. Postulated Organizational Chart for the Safe Storage Period

are fulfilled; and makes routine reports to corporate headquarters and regulatory agencies. Health physics services are also provided by the facility manager.

A maintenance and operations man is required to monitor operating safety and security systems and to perform routine maintenance and minor repairs to these systems.

Third-party inspections are assumed to be carried out by a two-man team on a semi-annual basis.

Table 10.3-2 shows annual manpower requirements and costs for safe storage. Manpower requirements are based on the safe storage staff organization chart shown in Figure 10.3-1. Costs are based on unit cost data in Section H.1 of Appendix H. Third-party inspection costs are based on an assumed cost of $500 per man-day.

TABLE 10.3-2. Estimated Annual Staff Requirements for Safe Storage

Title or Function	Man-Years/Year	Annual Cost 1978 Dollars(a,b)
Facility Manager	1.0	63 600
Maintenance and Operations Man	1.0	25 900
Secretary	0.5	10 100
Third-Party Inspection Team(c)	0.03	4 000
Total Man-Years/Years	2.53	
Total Costs/Year		103 600

(a) The number of figures carried is for computational accuracy and does not imply accuracy to the nearest dollar.
(b) Contingency of 25% is not included.
(c) Third-party inspection costs are based on an assumed $500 per man-day.

10.3.2. Security and Surveillance Costs for Safe Storage

The cost for the security and surveillance contractor is estimated to be about $50,000 per year.

10.3.3 Material and Equipment Requirements and Costs for Safe Storage

An annual allowance of \$2000 for equipment and supplies is included in the material and equipment cost estimate. This allowance includes funds for monitoring supplies, secretarial supplies, etc.

Major repairs to monitoring instruments, ventilation equipment, security alarm systems, etc., are assumed to be made by outside contractors. An annual allowance of \$3000 for major equipment repairs is included in the cost estimate.

10.3.4 Miscellaneous Owner Expenses During Safe Storage

Miscellaneous owner expenses during the safe storage period include the costs of utilities, taxes, regulatory fees and insurance. Annual costs for these items are assumed to be about 10% of the annual costs during DECON, except for the regulatory fees, because it is an inactive facility.

10.4 COST ESTIMATES FOR THE DEFERRED DECONTAMINATION PERIOD OF PASSIVE SAFSTOR

The estimated costs of deferred decontamination following safe storage of the reference plant are summarized in Table 10.4-1.

Deferred decontamination is estimated to require about 9 months (plus 8 months for planning and preparation), at a cost of approximately \$3.8 million.

Manpower costs represent about 64% of the total cost of deferred decontamination. Manpower costs include both support staff and decommissioning worker labor costs. In Table 10.4-1, manpower costs are shown separately for the planning and preparation and the decommissioning phases of deferred decontamination. Details of manpower requirements and costs for deferred decontamination are given in Section 10.4.1.

Material and equipment costs represent about 4% of the total cost of deferred decontamination. Details of material and equipment requirements and costs are given in Section 10.4.2.

Other possible costs could have a very large impact on the total cost of deferred decontamination. In particular, the disposal of contaminated CaF_2 could nearly triple the total decontamination cost.

TABLE 10.4-1. Summary of Estimated Deferred Decontamination Costs

Cost Category	Cost in Millions of 1978 Dollars[a]	Percent of Total
Manpower		
Planning and Preparation	0.462	15.0
Decommissioning	1.495	48.6
Equipment and Supplies	0.128	4.2
Disposal of Radioactive Material	0.197	6.4
Miscellaneous Owner Expense	0.730	23.8
Specialty Contractors	0.061	2.0
Subtotal	3.073	100.0
25% Contingency	0.768	
Total Decommissioning Costs	3.841	
Other Possible Costs		
Chemical Sludge Disposal	0.32	
Contaminated CaF_2 Disposal	7.20	
Misc. Contaminated Material	0.96	
Subtotal	8.48	
25% Contingency	2.12	
Total Other Possible Costs	10.6	

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

Waste management costs represent about 6% of the total cost of deferred decontamination. Details of waste management requirements and costs are given in Section 10.4.3

Miscellaneous owner expenses are assumed to be the same for deferred decontamination as they are for DECON, measured in 1978 dollars. Specialty contractor costs are also the same as for DECON.

10.4.1 Manpower Requirements and Costs for Deferred Decontamination

Estimates are made of the work force required to plan and execute the decommissioning activities for deferred decontamination. These work force estimates are used, together with unit manpower costs given in Section H.1 of Appendix H, to estimate deferred decontamination manpower costs. It is assumed that the work force organizational chart for deferred decontamination is similar to that for DECON, as shown in Figure 10.1-1. The same basic operations are performed during deferred decontamination as are performed during DECON, with the following exceptions:

- Lagoon covers will have to be removed, but not having to drain the lagoons will compensate.
- Additional time and manpower (about 16 man-weeks) will be required to remove seals and barricades erected during preparations for safe storage, to restore services, and to perform a small amount of manual decontamination and cleanup.
- All ventilation filters in the building will need to be tested and replaced as necessary. This will require about 16 man-weeks of effort.
- Because deferred decontamination occurs 10 to 30 years after plant shutdown, training of the decommissioning staff will be necessary during the planning and preparation phase.

Table 10.4-2 shows manpower requirements and costs for planning and preparation, and Table 10.4-3 shows manpower requirements and costs for the decommissioning phase of deferred decontamination. A total of about 12 man-years is estimated to be required for planning and preparation, at a labor cost of about $462,000. The decommissioning staff is generally sized and structured on a 1-shift, 5-day week.

A total of about 50 man-years is estimated to be required for decontamination activities, at a labor cost of about $1.5 million. The total labor cost for deferred decontamination is estimated to be about $2.0 million without contingencies.

TABLE 10.4-2. Summary of Manpower Utilization and Staff Costs for Planning and Preparations Phase of Deferred Decontamination

Title or Function	Man-Years	Cost ($ thousands)(a,b)
Project Manager	1.00	75
Project Engineer	0.75	48
Health and Safety Supervisor	0.67	32
Contracts and Accounting Specialist	0.67	22
Radioactive Shipment Specialist	0.38	12
Q.A. Engineer	0.67	29
Planning Engineer	0.67	29
Engineering Technician	0.67	18
Maintenance and Crafts Supervisor	0.67	27
Operations Supervisor	0.67	29
Foreman	1.50	49
Technician (training)	2.00	54
Craftsman (training)	0.30	8
Secretary	1.50	
Total Man-Years	12.12	
Total Cost		462

(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.

10.4.2 Material and Equipment Requirements and Costs for Deferred Decontamination

Estimates of material and equipment requirements and costs for deferred decontamination are shown in Table 10.4-4. Material and equipment costs are expected to be about the same for deferred decontamination as they are for DECON. A small additional cost is required for training supplies. The total material and equipment costs are estimated at about $128,000.

10.4.3 Waste Management Requirements and Costs for Deferred Decontamination

The estimated weights, volumes, and number of shipments of decommissioning wastes from deferred decontamination are the same as from DECON of the plant,

TABLE 10.4-3. Summary of Manpower Utilization and Staff Costs for Decommissioning Phase of Deferred Decontamination

Title or Function	Man-Years	Cost ($ thousands)(a,b)
Project Manager	0.83	62
Project Engineer	0.83	53
Health and Safety Supervisor	0.80	38
Health Physics Technician	1.54	39
Security Force Supervisor	0.83	28
Security Patrolman	3.00	64
Contracts and Accounting Specialist	0.80	26
SNM Accounting Specialist	0.75	29
Radioactive Shipment Specialist	0.75	25
Q.A. Engineer	0.83	36
Planning Engineer	0.83	36
Engineering Technician	0.75	20
Maintenance and Crafts Supervisor	0.80	33
Custodian	0.75	18
Craftsman	4.23	114
Operations Supervisor	0.80	35
Foreman	4.00	132
Technician	25.09	677
Secretary	1.50	30
Total Man-Years	49.71	
Total Cost		1 495

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

(b) Contingency is not included.

as given in Table 10.1-5. The estimated costs of containers, transportation and disposal of the radioactive wastes from deferred decontamination are the same as from DECON, which are summarized in Table 10.1-6. Cost estimates are based on projected packaging and shipping requirements in Table 10.1-5 and on waste management cost data in Section H.2 of Appendix H. The total waste management cost for deferred decontamination is estimated to be $197,000 without contingencies.

TABLE 10.4-4. Estimated Material and Equipment Requirements and Costs for Deferred Decontamination

Description	Quantity	Estimated Unit Cost ($ thousands)	Estimated Total Cost ($ thousands)
Oxyacetylene Torch	4 ea.	1	4
Guillotine Pipe Saw	2 ea.	1	2
Tube Cutter	2 ea.	0.3	0.6
Ratcheting Pipe Cutter	6 ea.	0.05	0.3
Reciprocating Saw	4 ea.	0.5	2
Nibbler	2 ea.	1	2
High-Velocity Liquid Jet	1 ea.	5	5
Low-Velocity Liquid Jet	2 ea.	2	4
Hydraulic Concrete Surface Spalling Device	1 ea.	5	5
Concrete Drill	3 ea.	0.2	0.6
Electric/Pneumatic Hammer	2 ea.	0.5	1
Portable A-Frames	2 ea.	3	6
Portable Wash Tanks	2 ea.	2	4
Portable Spray Clean Booth	1 ea.	4	4
Portable Greenhouse Erection Kit	1 ea.	2	2
Hand Powered Brushes	20 ea.	0.15	3
HEPA Filter	10 ea.	0.15	1.5
Roughing Filter	100	0.05	5
Decontamination Chemicals			10
Cleaning Supplies			20
Expendable Tools			10
Protective Clothing (including laundry)			18
Office Supplies			
Planning and Preparation			12
Dismantlement			6
			128[a,b]

(a) Total is shown as direct addition of the prior numbers to retain calculational information. Precision is less than shown.

(b) Contingency of 25% is not included.

REFERENCES

1. Title 10, Code of Federal Regulations, Parts 140.31 and 170.32, September 1978.

2. K. J. Schneider and C. E. Jenkins, Technology, Safety and Costs of Decommissioning a Reference Nuclear Fuel Reprocessing Plant, NUREG-0278, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, October 1977.*

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*Available for purchase from the National Technical Information Service, Springfield, VA 22161.

11.0 PUBLIC AND OCCUPATIONAL SAFETY OF DECOMMISSIONING A REFERENCE URANIUM FUEL FABRICATION PLANT

Public and occupational safety impacts from decommissioning activities at the reference uranium fuel fabrication (U-Fab) plant are evaluated, and summarized in this section. The safety evaluation includes a consideration of the impacts of public radiation exposure, occupational radiation exposure, industrial accidents, and chemical pollutants. This evaluation utilizes current data and state-of-the-art methods to estimate the information required. A conservative approach, using parameters that tend to maximize the consequences, is used to evaluate the safety impacts of each decommissioning activity. Safety assessment details are provided in Appendix I of Volume 2.

The safety evaluation is divided into three major parts: 1) public safety, 2) occupational safety, and 3) transportation safety. Within each of these major parts are discussions of the radiological and nonradiological impacts of both routine and accident situations. Public radiological considerations are determined by using the atmospheric release scenarios in Appendix I and the radiation dose evaluation methods presented in Appendix E of Volume 2. Occupational radiation doses are estimated using information about expected dose rates and man-hour job requirements discussed in Section 10 and Appendices C, G and H.

The decommissioning alternatives selected for analysis are DECON and passive SAFSTOR, as discussed in Sections 4 and 9. The radiological safety evaluation is accomplished by calculating radiation doses to the public from airborne radionuclide releases and to the decommissioning and transportation workers from external exposure.

For the public during DECON, the 50-year committed dose equivalent to the population from routine airborne releases (transportation not included) is calculated to be about 0.06 man-rem to the lungs, and the 50-year committed dose equivalent to the maximum-exposed individual from the worst postulated accident is calculated to be about 1.9×10^{-4} rem to the lungs. Radiation doses to the public resulting from preparations for safe storage during passive SAFSTOR are approximately the same as those calculated for DECON.

The estimated occupational radiation doses are calculated to be about 16 man-rem for DECON and, for passive SAFSTOR, about 0.36 man-rem for preparations for safe storage, about 0.6 man-rem for each year of safe storage, and about 16 man-rem for deferred decontamination (the same as for DECON).

Radioactive waste material transportation activities associated with decommissioning are estimated to give a radiation dose to the total population along the transport route of about 0.53 man-rem for DECON or deferred decontamination. Occupational doses from the transportation of radioactive wastes are estimated to be about 2.6 man-rem from DECON or deferred decontamination shipments. Occupational and population doses from waste transport during preparations for safe storage are negligible. Transportation of the uranium-contaminated CaF_2 waste waste to a disposal site (if required) could result in an occupational dose of 2.0 man-rem and a population dose of 0.35 man-rem.

11.1 TECHNICAL APPROACH

The results of the safety evaluation, which are summarized in this section, are based on the following key assumptions.

1. The maximum potential radiological consequences of a given decommissioning operation are associated with performing that activity in the area of the U-Fab plant with the highest radionuclide inventory.
2. The maximum release of radioactivity for a specific type of decommissioning activity applies to that activity whenever it is used in the facility. In performing the dose calculations for releases of radionuclides from normal activities, the estimated releases for the entire decommissioning period are summed and assumed to be released during a 1-year period. Estimating the releases and their consequences in such a manner is conservative, but a conservative estimate compensates for uncertainties in the analysis.
3. Monitoring, ventilation, and other support systems required during any given decommissioning phase are functional, with their operability confirmed prior to the start of a decommissioning operation.

4. Inhalation of airborne radionuclides is the dominant radiation exposure pathway to members of the public for radionuclide releases from routine decommissioning operations or from potential accidents.
5. The dominant radiation exposure pathway to the decommissioning worker is the external radiation received during normal decommissioning operations. Workers wear adequate respiratory protection gear to prevent significant internal deposition of radionuclides.
6. Because the radioactivity in the plant is entirely from long-lived radionuclides and because future populations are unknown, the public radiation doses due to radionuclide releases from normal activities and from potential accidents for deferred decontamination after safe storage are identical to those during the DECON alternative.
7. External radiation exposures to the public and to transportation workers from transportation activities are generally based on estimated dose rates from representative shipments of radioactive material in exclusive-use vehicles. This basis is highly conservative for the reference radionuclide mixture in the U-Fab facility.
8. Decommissioning and radiation protection philosophies and techniques applied conform to the principle of keeping occupational radiation doses As Low As is Reasonably Achievable (ALARA).

The public radiological safety evaluation is based on airborne radionuclide release scenarios for both routine and accident situations. These airborne release scenarios are discussed in Appendix I and listed in Tables 11.1-1 and 11.1-2. These tables show the calculated radioactivity releases for each individual decommissioning activity or postulated accident, as well as the rate of radionuclide release for each event on the basis of the radioactivity estimated to be present. The assumptions made are conservative and probably result in overestimating the resultant doses.

A more-complete discussion of the occupational radiation dose calculations is contained in Appendices E and I of Volume 2. The occupational radiation doses are based on the estimated radiation levels in the reference facility and on the man-hour job estimates for the decommissioning activities considered in Appendix H of Volume 2.

TABLE 11.1-1. Anticipated Airborne Radioactive Releases During Routine Decommissioning Activities (μCi of 3% enriched uranium)(a,b)

Incident	Airborne Radioactive Release in Building	Estimated Atmospheric Radioactive Release		Estimated Frequency of Occurrence(c)
		DECON	Preparations for Safe Storage	
Loss of intermediate-stage HEPA filter after duct decontamination	5.4×10^{3}	2.7	2.7	High
Inadvertent cutting of undecontaminated metal	0.14	6.9×10^{-5}	--(d)	High
Inadvertent dumping of contaminated solid wastes				
abraded firebrick	6.8×10^{-3}	3.4×10^{-6}	--	High
concrete dust	Insignificant		--	High
condensed metal vapor	3.4×10^{-3}	1.7×10^{-6}	--	High
Loss of local airborne contamination control, loss of vacuum filter	1.4×10^{3}	0.70	0.70	High
Temporary Loss of Services				
Electricity (normal and emergency)		2.8×10^{-5}	2.8×10^{-5}	Medium
Other	Insignificant			
Liquid leak during chemical decontamination	9.1	4.5×10^{-3}	4.5×10^{-3}	High
Fire involving contaminated combustible waste	Insignificant			Medium
Natural phenomena	Not Calculated			Low

(a) The first-year dose and fifty-year committed dose equivalent calculated for the maximum-exposed individual are listed in Tables I.3-5 and I.3-6.

(b) For the reference radionuclide inventory, see Table C.3-1, Appendix C.

(c) Frequency of occurrence: High > 1×10^{-2}; medium 1×10^{-2} to 1×10^{-5}; low < 1×10^{-5} per year. A dash in this column means that no estimate was made for the specific incident listed.

(d) A dash indicates that the postulated accident does not apply to this decommissioning alternative.

(e) Insignificant means an atmospheric release of less than 1×10^{-6} μCi and radiation doses not calculated.

TABLE 11.1-2. Postulated Accidental Airborne Radioactive Releases During Decommissioning (μCi of 3% enriched uranium)[a,b]

Operation	Airborne Radioactivity Generation Rate in μCi/min	Total Airborne Radioactivity in During Entire Operation, μCi	Estimated Atmospheric Radioactive Release (μCi)	
			Preparation for Safe Storage	DECON
Radiation survey	Insignificant[c]			
Chemical decontamination				
Flushing of wet systems	Insignificant			
Surface cleaning operations				
Handwiping	Insignificant			
Spray decontamination of glove boxes	2.6×10^{-4}	5.8×10^{-2}	2.9×10^{-5}	2.9×10^{-5}
Physical decontamination of surfaces				
Scraping metal surfaces	8.8×10^{-3}	25	1.2×10^{-2}	1.2×10^{-2}
Scraping firebrick	1.4×10^{-4}	1.4	--[d]	7.2×10^{-4}
Concrete removal	6.0×10^{-4}	5.4	--	2.7×10^{-3}
Exhaust dust decontamination	1.7×10^{5} (Total Release)	1.7×10^{5}	84	84
Removal of contaminated concrete rubble	Insignificant			
Segmenting and transfer of equipment				
Reciprocating saw	0.14 (Total Release)	0.14	--	7.6×10^{-5}
Oxyacetylene torch	6.0×10^{-2}	36	--	1.8×10^{-2}
Nibbler	Insignificant			
Packaging and transfer	Insignificant			
Exhaust filter removal	170 (Total Release)	170	8.6×10^{-2}	8.6×10^{-2}
Totals		1.7×10^{5}	84	84
Passive Safe Storage			39 μCi/yr	

(a) The first-year dose and fifty-year committed dose equivalent calculated for the maximum-exposed individual and the population are listed in Tables I.3-1 through I.3-4.

(b) For reference radionuclide inventory refer to Table C.3-1, Appendix C.

(c) Insignificant means a building release of less than 1×10^{-6} μCi and radiation doses are not calculated.

(d) A dash indicates that the activity does not apply to this decommissioning alternative.

Transportation activities are examined to evaluate the safety impact of routine and accident situations. Radiation and nonradiation transportation safety impacts are evaluated for both the public and transportation workers.

11.2 PUBLIC SAFETY EVALUATION OF DECOMMISSIONING THE REFERENCE U-FAB PLANT

The impacts on public safety of decommissioning the reference U-Fab facility by DECON or deferred decontamination are evaluated for both radiological and nonradiological events. This analysis includes consideration of both routine activities and postulated accidents.

Airborne radionuclide releases are calculated on the basis of the radionuclide inventories given in Appendix C of Volume 2. The consequences of the airborne radionuclide releases from routine decommissioning activities are calculated in terms of the radiation dose to the maximum-exposed member of the public and to the population residing within an 80-km radius of the reference facility. The consequences of postulated accidents are calculated in terms of the radiation dose to the maximum-exposed individual. Both dose calculations use the radiation dose models and data discussed in Appendix E. An estimate of the frequency of occurrence for the accidents is given in Appendix I as being high (greater than 10^{-2} per year), medium (between 10^{-2} and 10^{-5} per year), or low (less than 10^{-5} per year), based on published values or engineering judgment or experience. A rigorous probabilistic risk assessment is beyond the scope of this study. For most releases, inhalation of airborne radionuclides is found to be the dominant radiation exposure pathway to members of the public.

Nonradiological safety areas considered include the effects of chemical residues from plant operations and chemicals used during decommissioning.

11.2.1 Radiological Safety Evaluation of Routine Decommissioning Operations

During decommissioning, as during operations, the primary radiological concern to the public is the loss of containment of radioactive material that could result in members of the public being exposed to abnormally high levels of radiation. The estimated concentrations of radioactive materials present during the majority of decommissioning activities are lower than during the operating life of the facility, because of the removal of much of the plant inventory uranium during final inventory cleanout and decontamination. However, decommissioning activities are less routine than are production operations, which may tend to increase both the likelihood and magnitude of radionuclide releases during decommissioning. Due to the high degree of conservatism in the safety analysis, estimates of the routine radionuclide releases to the environment from decommissioning activities generally appear higher than those measured and known to occur routinely in an operating plant. Thus, the cumulative effects of all these conservative assumptions make it appear, when compared to known or actual routine radionuclide releases from an operating plant, that decommissioning activities violate ALARA conditions for a normal operating plant. In reality, when compared to an operating plant, a net reduction in radionuclide releases should occur from decommissioning activities.

The primary sources of radioactive effluents from routine decommissioning operations are the release of uranium powder during exhaust duct decontamination, the release of contaminated vaporized metal during cutting and equipment removal, the release of contaminated collected dust during change-out and replacement of HEPA filters, the release of contaminated concrete dust during decontamination or removal of concrete structures, and the release of contaminated liquid aerosols during spray decontamination of hoods. Equipment and concrete removal operations are minimal during preparations for safe storage.

A complete listing of the radiation doses calculated for the airborne releases from routine decommissioning operations that are listed in Table 11.1-1 is found in Appendix I of Volume 2, Tables I.3-1 through I.3-4. Tables 11.2-1 and 11.2-2 contain summaries of the calculated radiation doses for DECON and for preparations for safe storage. The radiation doses presented are all very small compared to the average background radiation exposure of 80 to 170 mrem per year received from natural sources.(1) The radionuclide releases and radiation doses are small largely because of the low specific activity of the reference uranium mixture and the utilization of efficient decontamination processes and ventilation filtration systems.

TABLE 11.2-1. Summary of Radiation Doses to the Maximum-Exposed Individual from Airborne Radionuclides Released During Normal Decommissioning Activities

	DECON					Preparations for Safe Storage				
	Release to Atmosphere	First-Year Dose, mrem		Fifty-Year Committed Dose Equivalent, mrem		Release to Atmosphere	First-Year Dose, mrem		Fifty-Year Committed Dose Equivalent, mrem	
Activity or Location	(μCi)	Bone	Lung	Bone	Lung	(μCi)	Bone	Lung	Bone	Lung
Surface Cleaning										
Spray Decontamination of Hoods and Glove Boxes	2.9×10^{-5}	1.7×10^{-10}	4.1×10^{-9}	5.9×10^{-10}	2.0×10^{-8}	2.9×10^{-5}	1.7×10^{-10}	4.1×10^{-9}	5.9×10^{-10}	2.0×10^{-8}
Physical Decontamination of Surfaces										
Scraping Metal Surfaces	1.2×10^{-2}	7.0×10^{-8}	1.7×10^{-6}	2.5×10^{-7}	8.3×10^{-6}	1.2×10^{-2}	7.0×10^{-8}	1.7×10^{-6}	2.5×10^{-7}	8.3×10^{-6}
Scraping Firebrick	7.2×10^{-4}	4.0×10^{-9}	1.0×10^{-7}	1.4×10^{-8}	4.8×10^{-7}	--(a)				
Concrete Removal	2.7×10^{-3}	1.5×10^{-8}	3.7×10^{-7}	5.5×10^{-8}	1.8×10^{-6}	--				
Exhaust Duct Decontamination	84	4.8×10^{-4}	1.2×10^{-2}	1.7×10^{-3}	5.7×10^{-2}	84	4.8×10^{-4}	1.2×10^{-2}	1.7×10^{-3}	5.7×10^{-2}
Segmenting and Transfer of Equipment										
Reciprocating Saw	2.3×10^{-4}	1.3×10^{-9}	3.2×10^{-8}	4.6×10^{-9}	1.5×10^{-7}	--				
Oxyacetylene Torch	1.8×10^{-2}	1.0×10^{-7}	2.5×10^{-6}	3.6×10^{-7}	1.2×10^{-5}	--				
Exhaust Filter Removal	8.6×10^{-2}	4.7×10^{-7}	1.2×10^{-5}	1.6×10^{-6}	5.5×10^{-5}	8.6×10^{-2}	4.7×10^{-7}	1.2×10^{-5}	1.6×10^{-6}	5.5×10^{-5}
Totals	84.1	4.8×10^{-4}	1.2×10^{-2}	1.7×10^{-3}	5.7×10^{-2}	84	4.8×10^{-4}	1.2×10^{-2}	1.7×10^{-3}	5.7×10^{-2}

(a)A dash indicates that this activity is not performed in this alternative.

TABLE 11.2-2. Summary of Radiation Doses to the Population from Airborne Radionuclides Released During Normal Decommissioning Activities

	DECON					Preparations for Safe Storage				
	Release to Atmosphere (μCi)	First-Year Dose, man-rem		Fifty-Year Committed Dose Equivalent, man-rem		Release to Atmosphere (μCi)	First-Year Dose, man-rem		Fifty-Year Committed Dose Equivalent, man-rem	
Activity or Location		Bone	Lung	Bone	Lung		Bone	Lung	Bone	Lung
Surface Cleaning										
Spray Decontamination of Glove Boxes	2.9×10^{-5}	1.7×10^{-10}	4.8×10^{-9}	5.1×10^{-8}	2.2×10^{-5}	2.9×10^{-5}	1.7×10^{-10}	4.8×10^{-9}	5.9×10^{-10}	2.2×10^{-8}
Physical Decontamination of Surfaces										
Spray Metal Surfaces	1.2×10^{-2}	7.0×10^{-3}	2.0×10^{-6}	2.5×10^{-7}	9.1×10^{-6}	1.2×10^{-2}	7.0×10^{-8}	2.0×10^{-6}	2.5×10^{-7}	9.1×10^{-6}
Scraping Firebrick	7.2×10^{-4}	4.0×10^{-9}	1.2×10^{-7}	4.4×10^{-8}	5.2×10^{-7}	--(a)				
Concrete Removal	1.1×10^{-2}	1.5×10^{-8}	4.5×10^{-7}	5.5×10^{-8}	2.0×10^{-6}	--(a)				
Exhaust Duct Decon-	84	4.8×10^{-4}	1.4×10^{-2}	1.7×10^{-3}	6.3×10^{-2}	84	4.8×10^{-4}	1.4×10^{-2}	1.7×10^{-3}	6.3×10^{-2}
Segmenting and Transfer of Equipment										
Reciprocating Saw	2.3×10^{-4}	1.3×10^{-9}	3.7×10^{-8}	4.6×10^{-9}	1.7×10^{-7}	--				
Oxyacetylene Torch	1.8×10^{-2}	1.0×10^{-7}	2.9×10^{-6}	3.6×10^{-7}	1.3×10^{-5}	--				
Exhaust Filter Removal	8.6×10^{-2}	4.7×10^{-7}	1.4×10^{-5}	1.6×10^{-6}	6.2×10^{-5}	8.6×10^{-2}	4.7×10^{-7}	1.4×10^{-5}	1.6×10^{-6}	6.2×10^{-5}
Totals	84	4.8×10^{-4}	1.4×10^{-2}	1.7×10^{-3}	6.3×10^{-2}	84	4.8×10^{-4}	1.4×10^{-2}	1.7×10^{-3}	6.3×10^{-2}

(a) A dash indicates that this activity is not performed in this alternative.

Because of the long half-lives of the radionuclides in the reference mixture, expected radiation levels are not significantly reduced with time. Thus, public and occupational radiation doses for deferred decontamination are considered to be the same as those for DECON.

Because of the limited scope of the surveillance, security, and maintenance activities performed during safe storage, the airborne radionuclide releases from normal safe storage activities are expected to be extremely small, and the radiation dose to the public is expected to be negligible.

11.2.2 Radiological Safety Evaluation of Postulated Decommissioning Accidents

The primary impact of decommissioning accidents is the release of radioactive materials to the environs and the resulting public radiation exposure. Decommissioning procedures are analyzed and accidents are postulated that result in the airborne radionuclide releases developed in Appendix I. A summary of the accidents and releases is given in Table 11.1-2. A variety of accidents is considered in Appendix I, along with the calculations, bases, assumptions, and resulting radiation doses to the maximum-exposed individual. Table 11.2-3 contains a summary of the higher-consequence accidents postulated for DECON and for preparations for safe storage, along with the associated calculated radiation doses from these accidents. A complete listing of the radiation doses considered is found in Tables I.3-5 and I.3-6 in Appendix I.

The major accident postulated for both DECON and preparations for safe storage is the loss of the intermediate HEPA filter immediately following decontamination of the upstream ductwork. It is postulated that loose contaminated dust resulting from the mechanical decontamination of the exhaust duct is made airborne by the mechanical and aerodynamic forces created by the decontamination process. The rupture of the HEPA filter is assumed to be caused by a buildup of moisture in the filter and/or the mechanical or aerodynamic forces created during exhaust duct cleanout. The final bank of HEPA filters in the exhaust fan room is assumed to remain intact. The quantity of radionuclides released directly to the atmosphere is calculated to be 2.7 μCi. The frequency of occurrence for this accident with this severity is estimated to be in the high range (greater than 10^{-2} per year).

TABLE 11.2-3. Summary of Radiation Doses to the Maximum-Exposed Individual from Accidental Airborne Radionuclide Releases During Decommissioning Activities

Incident	Release to Atmosphere (μCi)	DECON				Preparations for Safe Storage				Expected Frequency of Occurrence
		First-Year Dose, mrem		Fifty-Year Committed Dose Equivalent, mrem		First-Year Dose, mrem		Fifty-Year Committed Dose Equivalent, mrem		
		Bone	Lung	Bone	Lung	Bone	Lung	Bone	Lung	
Loss of Intermediate HEPA Filter After Duct Decontamination	2.7	2.3×10^{-3}	7.6×10^{-2}	4.5×10^{-3}	1.9×10^{-1}	2.3×10^{-3}	7.6×10^{-2}	4.5×10^{-3}	1.9×10^{-1}	High
Loss of Local Airborne Contamination Control, Loss of Vacuum Filter	0.70	6.0×10^{-4}	2.0×10^{-2}	1.1×10^{-3}	4.9×10^{-2}	6.0×10^{-4}	2.0×10^{-2}	1.1×10^{-3}	4.9×10^{-2}	High
Liquid Leak During Chemical Decontamination	4.5×10^{-3}	3.7×10^{-6}	1.3×10^{-4}	7.3×10^{-6}	3.1×10^{-4}	3.7×10^{-6}	1.3×10^{-4}	7.3×10^{-6}	3.1×10^{-4}	High

Radiation doses to the population are not calculated for decommissioning accidents. The segment of population exposed under accident conditions is different for each site sector. A conservative upper limit of the radiation dose to the population can be estimated by comparing Table 11.2-3 with Tables 11.2-1 and 11.2-2. For a release of the same quantity of radionuclides, the ratio of the radiation dose resulting from an accident to the maximum-exposed individual to the dose from routine operations can be calculated. This ratio times the population radiation dose for the release from routine activities gives an upper limit for population radiation dose from an accidental release. The actual population radiation dose for an accidental release of radioactivity is expected to be below this upper value.

Contamination remaining in the facility during the safe storage period is contained and is not readily available for airborne release. Only low-probability events with causes external to the plant, such as tornadoes and earthquakes, or certain man-related events, such as deliberate intrusion into the facility, appear to have the potential to release potentially important amounts of radioactivity into the environs. The combination of low probability of the initiating events, low radionuclide concentration per unit area, and passive plant contamination control systems reduces the impact of postulated accidents during safe storage to levels far below those postulated for other decommissioning activities.

11.2.3 Nonradiological Safety Evaluation

Chemical pollutants that could be released during decommissioning activities are examined and the quantities released are found to have an insignificant safety impact on the public. Potentially hazardous chemicals are found to come from two sources: 1) residuals from U-Fab plant production operations, and 2) chemicals employed to chemically and physically decontaminate the plant. From the relatively small quantities of hazardous chemicals used, the low likelihood of their dispersal into the environs, and the dilution factors involved in the dispersal of hazardous materials from the plant to the environs, it can be concluded that chemical pollutants from decommissioning operations do not pose a significant public hazard.

11.3 OCCUPATIONAL SAFETY EVALUATION OF DECOMMISSIONING THE REFERENCE U-FAB PLANT

Occupational safety impacts for DECON and for preparations for safe storage are evaluated for both radiological and nonradiological events. The analysis considers routine radiological events and postulated nonradiological accidents.

Radiation doses to workers are calculated based on the estimated radiation levels in various areas of the reference U-Fab plant and on the estimated labor requirements to perform the decommissioning work. Summaries of the appropriate detailed information in Appendices C and I are given in this section. An estimate of worker injuries and fatalities resulting from decommissioning activities is made and presented, based on nuclear industry experience.

11.3.1 Radiological Safety Evaluation of Routine Decommissioning Activities

Summaries of the estimated occupational radiation exposure for DECON and for preparations for safe storage are given in Tables 11.3-1 and 11.3-2. These tables summarize the decontamination and dismantlement or deactivation tasks in each of the reference U-Fab plant rooms, man-hour estimates for each task, and man-rem estimates of the accumulated external radiation dose to all workers doing each task.

The radiation doses to decommissioning workers are calculated using the manpower requirements estimated for each job and estimates of the average radiation dose rates associated with each job. The dose rate estimates are based on the data given in Appendix C and on information from an operating U-Fab facility. The radiation doses computed in Appendix I are based on constant values of dose rates for a work zone or room, regardless of where the worker is located within the zone room.

The half-lives of the major radionuclides within the facility are long, and thus they do not decay significantly within the few years considered in this study. Therefore, occupational radiation doses do not decrease with time.

The total occupational radiation dose for in-plant decommissioning activities for DECON is estimated to be about 16 man-rem. Specific decommissioning

TABLE 11.3-1. Summary of Estimated External Occupational Radiation Exposure During DECON

Event Description	Estimated Total Man-Hours	Event Total Dose (man-rem)(a)
Decontaminate Powder Warehouse	640	2.4×10^{-2}
Decontaminate UF_6 Cylinder Storage Room	720	2.7×10^{-2}
Dismantle Vaporization Room	1 860	0.35
Dismantle Chemical and Powder Processing Area	18 200	4.4
Dismantle Powder Storage and Feed Room	1 580	1.1
Dismantle Pelletizing Room	2 460	1.8
Dismantle Sintering Room	3 280	0.8
Dismantle Grinding Room	9 960	1.4
Dismantle Rodding Area	1 830	0.17
Dismantle Gadolinia Shim Rod Production Facility	2 540	0.62
Dismantle Red Cap Area	1 020	0.25
Dismantle Chemical and Metallurgical Testing Lab	1 120	9.7×10^{-2}
Dismantle Development Lab	2 120	0.53
Dismantle Hot Maintenance and Instrument Shops	1 400	0.12

(a)Rounded to two significant figures.

TABLE 11.3-1. (contd)

Event Description	Estimated Total Man-Hours	Event Total Dose (man-rem)[(a)]
Dismantle Radwaste Room	760	0.56
Dismantle Decontamination Facility	340	6.3×10^{-2}
Dismantle Incineration Facility	1 160	0.22
Decontaminate HEPA Filter Rooms	2 340	0.58
Dismantle Laundry Room	360	3.1×10^{-2}
Dismantle Change Room	380	1.4×10^{-2}
Final Cleaning of Fuel Fabrication Building	1 120	4.1×10^{-2}
Dismantle Fluoride Waste Effluent Treatment System	7 580	0.28
Dismantle Nitrate Waste Effluent Treatment System	1 720	3.6×10^{-2}
Dismantle Waste Treatment Building	980	3.6×10^{-2}
Recovery and Disposal of Solid CaF_2 Waste	2 860	0.11
Disposal of Stored Excess Contaminated Equipment	2 840	0.70
Decontaminate Uranium Storage Pads	120	4.4×10^{-3}
Dismantle Radwaste Effluent Treatment System	1 840	1.3
Totals	65 260	16

(a) Values rounded to two significant figures.

TABLE 11.3-2. Summary of Estimated External Occupational Radiation Exposure During Preparations for Safe Storage

Event Description	Estimated Total Man-Hours	Event Total Dose (man-rem)[(a)]
Drain and Ship Residuals from Nitrate Lagoon	260	9.6×10^{-3}
Drain and Cover Other Lagoons	400	1.5×10^{-2}
Audit All Pumps and Pipelines	240	5.6×10^{-2}
Secure Valves, Hoods and Conveyers	280	6.6×10^{-2}
Disconnect Services No Longer Needed	360	2.8×10^{-2}
Tag Equipment and Systems to Identify Status	280	2.2×10^{-2}
Safety Audit	280	2.2×10^{-2}
Install Building Access Locks and Warning Signs	160	6.0×10^{-3}
Perform Building Systems Check	240	1.9×10^{-2}
Install Fences and and Locks on Outside Facilities	120	4.5×10^{-3}
Complete Offsite Shipment of All Recovered Uranium	300	2.4×10^{-2}
Complete Intrusion Alarm System Installation	400	2.4×10^{-2}
Complete Radiation Monitoring System Installation	320	2.7×10^{-2}
Perform Comprehensive Radiation Survey	360	2.7×10^{-2}
Totals	4 000	0.36

(a)Values rounded to two significant figures.

activities that result in the highest accumulative worker radiation doses are: 1) decontamination of the chemical and powder processing area, 2) dismantlement of the grinding room, 3) dismantlement of the pelletizing room, 4) dismantlement of the powder storage and feed room, 5) decontamination and dismantlement of the sintering room. The estimated occupational dose for in-plant decommissioning activities during preparations for safe storage is about 0.36 man-rem.

The surveillance and maintenance staff is exposed to residual radiation levels present in the decommissioned reference facility during the safe storage period. Due to the long half-lives of the radionuclides in the reference mixture, the radiation levels will not change significantly during this period. Thus, the annual radiation dose received by workers in the retired facility for any time in the foreseeable future will remain virtually constant. Table 11.3-3 gives a summary of the man-hours of labor and man-rem of occupational dose accumulated by the staff during the safe storage period.

The estimated external occupational radiation doses for decommissioning the reference U-Fab facility are summarized in Table 11.3-4. The total occupational dose is given for DECON, and a breakdown of passive SAFSTOR activities into preparations for safe storage, the safe storage period, and deferred decontamination is presented. Occupational radiation doses for deferred decontamination are considered to be the same as for DECON, although some additional steps, such as change-out of HEPA filters, are likely to increase the total accumulated occupational radiation dose levels for deferred decontamination to levels slightly above those for DECON.

The estimates for the occupational radiation dose are sensitive to management philosophy and to the decommissioning methods utilized. Administrative controls are assumed to be in place that keep radiation records for each individual and assure that no one worker exceeds recommended limits. Estimates contained in Table 11.3-4 are based on decommissioning methods that utilize technicians who are highly trained in effective radiation work procedures. Different basic assumptions, decommissioning procedures, or increased manpower may change the occupational radiation dose estimates significantly.

TABLE 11.3-3. Summary of the Estimated External Occupational Radiation Exposure During the Safe Storage Period

	Man-Hours per Year	Collective Dose (man-rem/year)(a)	Total Dose for 10 Years of Safe Storage(a)
Foreman	2 080	0.10	1.0
Security Watchmen	2 185	0.14	1.4
Maintenance Workers	4 160	0.39	3.9
Totals	8 425	0.6	6.3

(a)Values rounded to two significant figures.

TABLE 11.3-4. Summary of the Estimated Collective Occupational Radiation Doses for Onsite Decommissioning Activities at the Reference U-Fab Facility

Decommissioning Alternative	Time After Facility Shutdown (years)	Estimated Dose (man-rem)(a)
DECON	0	16
Passive SAFSTOR		
Preparations for Safe Storage	0	0.36
Safe Storage	10	6.0
	30	18.0
Deferred Decontamination	0 to 30	16
Total for Passive SAFSTOR with Deferred Decontamination	10 30	22.4 34.4

(a)Values rounded to two significant figures.

11.3.2 Safety Evaluation of Construction or Industrial Accidents

As a result of decommissioning activities, the potential exists for worker injuries and fatalities. As with any industrial operation, proper management and industrial safety practices will minimize the potential for worker accidents. The following estimates of worker injuries and fatalities are based on data provided by the U.S. AEC for the period 1943 to 1970.(2) Table 11.3-5 lists the estimates of worker injuries and fatalities for heavy construction, light construction, and operational activities that are conducted during DECON and during preparations for safe storage.(3) As shown in the table, about 0.42 lost-time injuries and 0.003 fatalities are expected during DECON and about 0.036 injuries and 0.0003 fatalities are expected during preparations for safe storage.

Estimates of the number of injuries and fatalities that could occur to the surveillance and maintenance staff from industrial-related accidents for safe storage activities are given in Table 11.3-6. As shown in this table, about 0.47 lost-time injuries and 4.5×10^{-3} fatalities can be expected for the safe storage staff for a period of 10 years after facility shutdown.

TABLE 11.3-5. Estimated Occupational Lost-Time Injuries and Fatalities from Decommissioning Activities(a)

	Frequency (events/10^6 man-hours)		DECON or Deferred Decontamination			Preparations for Safe Storage		
Activity	Lost-Time Injuries(b)	Fatalities	Man-Hours(c)	Lost-Time Injuries	Fatalities	Man-Hours(c)	Lost-Time Injuries	Fatalities
Heavy Construction(d)	10.0	4.2×10^{-2}	1.3×10^{4}	0.13	5.5×10^{-4}	3.2×10^{2}	3.2×10^{-3}	1.3×10^{-5}
Light Construction	5.4	3.0×10^{-2}	3.5×10^{4}	0.19	1.1×10^{-3}	3.4×10^{3}	1.8×10^{-2}	1.0×10^{-4}
Operational Support	2.1	2.3×10^{-2}	4.8×10^{4}	0.10	1.1×10^{-3}	7.1×10^{3}	1.5×10^{-2}	1.6×10^{-4}
Totals				0.42	2.8×10^{-3}		3.6×10^{-2}	2.3×10^{-4}

(a)Estimates of injuries and fatalities are rounded to two significant figures.
(b)Lost-time injuries are defined in Reference 3.
(c)Labor estimates are given in Tables 10.1-3, 10.2-3, and 10.5-3.
(d)Primarily facility demolition and equipment disassembly work.

TABLE 11.3-6. Estimated Occupational Lost-Time Injuries and Fatalities from Safe Storage Activities(a)

		Frequency (accidents/10^6 man-hours)		Estimate of the Number of Occupational Safety Accidents per Safe Storage Period			
				10 Years		30 Years	
Activity	Estimated Man-Hours/Yr	Lost-Time Injuries(b)	Fatalities	Lost-Time Injuries	Fatalities	Lost-Time Injuries	Fatalities
Surveillance and Operational Support	1.7×10^{4}	2.1	2.3×10^{-2}	0.36	3.9×10^{-3}	1.1	1.2×10^{-2}
Maintenance	2.1×10^{3}	5.4	3.0×10^{-2}	0.11	6.3×10^{-4}	0.33	1.9×10^{-3}
Accumulated Totals				0.47	4.5×10^{-3}	1.4	1.4×10^{-2}

(a)Estimates of injuries and fatalities are rounded to two significant figures.
(b)Lost-time injuries are defined in Reference 3.

11.4 TRANSPORTATION SAFETY EVALUATION FOR DECOMMISSIONING THE REFERENCE U-FAB FACILITY

During decommissioning of the reference U-Fab facility, radioactive waste materials are packaged and shipped offsite for burial. These wastes are shipped to a commercial low-level waste burial facility assumed to be located about 800 km from the site. All wastes are assumed to be shipped by truck. To minimize the risk that radioactive shipments pose to the public and to transportation workers, federal and state regulations prescribe the containers, contents, packaging, handling, and burial requirements. The procedures and standards for the packaging and transport of radioactive materials are discussed in Section 5 and Appendix F, and are summarized here.

11.4.1 Radiological Safety Evaluation of Routine Transportation Activities

Shipments of radioactive wastes from decommissioning activities will be made in exclusive-use vehicles. Department of Transportation regulations(4) set the following limits on radiation levels associated with radioactive material shipments:

- 1000 mR/hr at 0.91 m (3 ft) from the external surface of the package (provided the package is transported in a closed vehicle)
- 200 mR/hr at the external surface of the vehicle
- 10 mR/hr at any point 1.8 m (6 ft) from the vehicle
- 2 mR/hr at any normally occupied position in the vehicle.

DOT regulations(4) further require that no significant amount of removable radioactive contamination is present on the external accessible surfaces of packages when they are shipped. Levels of removable contamination on the surfaces are determined by a wipe test. The regulations in 49 CFR Part 173.397 state that removable (non-fixed) radioactive contamination is considered significant if the level of contamination, when averaged over any area of 300 cm^2 of any part of the package surface, exceeds 10^{-9} Ci/cm^2 for beta-gamma radiation from natural or depleted uranium or natural thorium, 10^{-10} Ci/cm^2 for all other beta-gamma emitting radionuclides, or 10^{-11} Ci/cm^2 for all other alpha emitting radionuclides.(4)

The method used to estimate routine radiation doses from truck transport of radioactive material is based on the method given in WASH-1238.(5) In addition, the following assumptions are made:

1. During an 800-km trip, two truck drivers spend no more than 12 hours inside the cab and 1 hour outside the cab at an average distance of about 2 m from the truck.
2. Normal truck servicing enroute requires that two garagemen spend no more than 10 minutes at about 2 m distance from a shipment, for an 800-km trip.
3. Onlookers from the general public might be exposed to radiation when a truck stops for fuel or for the drivers to eat. The onlooker dose for an 800-km trip is calculated on the basis that 10 people spend an average of 3 minutes each at a distance of about 2 m from a shipment.
4. The collective dose to the general public from truck shipments is based on an average collective dose of 1.2×10^{-5} man-rem per km traveled.(5)

The estimated routine radiation doses from truck transport of radioactive waste from DECON are listed in Table 11.4-1. These radiation dose estimates are based on the maximum allowable dose rates for each shipment in exclusive-use trucks, and are thus grossly overestimated for the reference radionuclide mixture in the U-Fab facility.

TABLE 11.4-1. Estimated Collective Radiation Dose from Truck Transport of Radioactive Wastes from DECON to a Shallow-land Burial Site(a)

Group	Radiation Dose per Shipment (man-rem)(a)	Total Radiation Dose (man-rem)(b)
Truck Drivers	0.07	2.5
Garagemen	0.003	0.11
Total Worker Dose		2.6
Onlookers	0.005	0.18
General Public	0.01	0.35
Total Public Dose		0.53

(a) Based on 800 km (500 mi) to burial site.
(b) Based on 35 shipments to burial site.

The external dose for routine transportation operation for all truck shipments from DECON is conservatively estimated to be less than 2.6 man-rem to transport workers and 0.53 man-rem to the general public.

In addition to the contaminated plant equipment and structural materials, the CaF_2 stored on the site would have to be transported to a low-level waste burial site if it were not economically feasible to process it on the site for recovery of the 0.2% uranium content. The material would be packaged in steel drums and transported by truck to the disposal site. Radiation doses from the truck transport of the CaF_2 are calculated in accordance with the methods described previously, except that the radiation levels associated with the shipments are assumed to be much lower.(6) The following specific assumptions are used:

- 3.8×10^7 kg of CaF_2, with a volume of 3.0×10^4 m^3, is moved.
- The equivalent of 1990 truckloads of material is transported to the burial ground.
- The radiation level in the truck cab is 0.02 mrem/hr.
- The radiation level at a distance of 2 m from the load is 1.0 mrem/hr.
- The collective dose to the general public along the route of the truck shipments is 1.1×10^{-7} man-rem/km.

The estimated radiation doses from truck transport of CaF_2 during DECON are presented in Table 11.4-2.

11.4.2 Radiological Safety Evaluation of Postulated Transportation Accidents

Transportation accidents have a wide range of severities. Most accidents occur at low vehicle speeds and have relatively minor consequences. In general, as speed increases, accident severity also increases. However, accident severity is not a function of vehicle speed only. Other factors, such as the type of accident, the kind of equipment involved, and the accident location can have an important bearing on accident severity.

The probabilities of truck accidents in this study are based on accident data supplied by the U.S. Department of Transportation.(5) Accidents are

TABLE 11.4-2. Estimated Collected Radiation Dose from Truck Transport of CaF_2 Waste During DECON

Group	Radiation Dose Per Shipment (man-rem)[(a)]	Total Radiation Dose (man-rem)[(b)]
Truck Drivers	6.8×10^{-4}	1.9
Garagemen	3.3×10^{-5}	9.3×10^{-2}
Total Worker Dose		2.0
Onlookers	5.0×10^{-5}	0.14
General Public	9.0×10^{-5}	0.25
Total Public Dose		0.39

(a) Based on 800 km to burial site.
(b) Based on 1990 shipments to burial site.

classified by severity into five categories as functions of vehicle speed and fire duration. The five categories and their associated probabilities for truck accidents are shown in Table 11.4-3.

The maximum-exposed individual is assumed to be located approximately 100 m from the point of a transportation accident. The calculated dose values during DECON, shown in Table 11.4-4, are for the first-year dose and 50-year committed dose equivalent to the bones and lungs.

The radionuclide inventory per truck shipment is conservatively assumed to be 100 mCi of dispersible radioactive material, based on the expected shipment of a single truckload of ventilation filters containing 37 kg of uranium. A distance of about 800 km to the low-level waste burial site is assumed. The waste inventory is assumed to be characterized by the radionuclide inventory listed in Table C.3-1 of Appendix C. Because of the low specific activity of the CaF_2 waste and the relatively low probability of it being widely dispersed in an accident, the radiological consequences of releases during transport of the CaF_2 are not estimated.

11.4.3 Nonradiological Transportation Safety Evaluation

As with any transport activity, a certain potential exists for injury or death from decommissioning transport operations.(5) Table 11.4-5 lists

TABLE 11.4-3. Transportation Accident Severity Categories[a]

Severity	Vehicle Speed (mph)[b]	Fire Duration (hr)	Probability Per Truck Mile
Minor	0-30	<1/2	6×10^{-9}
	0-30	0	4×10^{-7}
	30-50	0	9×10^{-7}
Total			1.3×10^{-6}
Moderate	0-30	1/2-1	5×10^{-11}
	30-50	<1/2	1×10^{-8}
	50-70	<1/2	5×10^{-9}
	50-70	0	3×10^{-7}
Total			3.1×10^{-7}
Severe	0-30	>1	5×10^{-12}
	30-50	>1	1×10^{-11}
	30-50	1/2-1	1×10^{-10}
	50-70	1/2-1	6×10^{-12}
	>70	<1/2	1×10^{-10}
	>70	0	8×10^{-9}
Total			8.2×10^{-9}
Extra Severe	50-70	>1	6×10^{-13}
	>70	1/2-1	2×10^{-13}
Total			8×10^{-13}
Extreme	>70	1	2×10^{-14}
Total			2×10^{-14}

(a)Data from Reference 5.
(b)1 mph is approximately 1.67 km/hr.

TABLE 11.4-4. Estimated Frequencies and Radioactivity Releases for Selected Transportation Accidents

			Radiation Dose for Maximum-Exposed Individual (rem)[a,b]			
			First-Year Dose		Fifty-Year Committed Dose Equivalent	
Accident Description	Frequency of Accidents during DECON	Release (Ci)[d,e]	Bone	Lungs	Bone	Lungs
Minor Accident	2.3×10^{-2}	No Release	--[f]	--	--	--
Moderate Accident	5.4×10^{-3}	1×10^{-7}	3.9×10^{-6}	1.3×10^{-4}	7.7×10^{-6}	3.2×10^{-4}
Severe Accident	1.4×10^{-4}	1×10^{-5}	3.9×10^{-4}	1.3×10^{-2}	7.6×10^{-4}	3.2×10^{-2}

(a)Maximum-exposed individual is assumed at 100 m from the site of the accident.

(b)The first bone doses for each accident description are calculated assuming the released radioactivity is all soluble; the lung doses are calculated assuming all released radioactivity is insoluble.

(c)Based on accident probability given in Reference 5, and shown in Table 11.4-2 for various accident severity classes.

(d)Based on an inventory of 100 mCi, the expected maximum per truck shipment.

(e)Release fraction for respirable materail for moderate and severe accidents are assumed to be 10^{-6} and 10^{-4}, respectively.

(f)A dash indicates no calculation is made.

estimates for injuries and fatalities for transportation activities associated with DECON. The number of injuries and fatalities are calculated by multiplying the roundtrip distance traveled times the probability of accidents per vehicle-kilometer times the injuries or fatalities expected per accident.

As shown in Table 11.4-5 there are about 2.9×10^{-2} injuries and 1.7×10^{-3} fatalities estimated to occur for DECON during the 5.6×10^{4} km of truck travel to a waste disposal site. If the CaF_2 is also trucked to a waste disposal site, an additional 4.5×10^{6} km of truck travel will be required, resulting in an estimated 2.3 additional injuries and 0.13 fatalities.

TABLE 11.4-5. Estimated DECON Injuries and Fatalities from Decommissioning Transportation Accidents(a)

					Estimated Nonradiological Impacts Transportation Accidents(c)	
Transportation Operation	Probability (Accidents per Vehicle km)	Injuries Per Accident	Fatalities Per Accident	Total Roundtrip Travel (km)(b)	Injuries	Fatalities
DECON	1.0×10^{-6}	0.51	0.03	5.6×10^{4}	2.9×10^{-2}	1.7×10^{-3}
CaF_2	1.0×10^{-6}	0.51	0.03	4.5×10^{6}	2.3	0.13

(a)Accident frequencies are from Reference 5, Appendix C, Table 1.

(b)Assuming truck transport of 1600 km roundtrip to low-level waste burial site. DECON requires 35 trips to burial site; CaF_2 disposal requires 1990 trips.

(c)Estimates of injuries and fatalities are rounded to two significant figures.

REFERENCES

1. Ionizing Radiation: Levels and Effects, United Nations Scientific Committee on the Effects of Atomic Radiation, Vol. 1, United Nations, pp. 29-63, 1972.

2. Operational Accidents and Radiation Exposures Experiences Within the USAEC 1943-1970, WASH-1192, 1971.

3. Method of Recording and Measuring Work Injury Experience, American National Standards Institute, ANSI 216.1, 1967.

4. U.S. Code of Federal Regulations, Title 49, Parts 170-189, "Transportation." Superintendent of Documents, GPO, Washington, DC 20555, January 1977.

5. Environmental Safety of Transportation of Radioactive Materials to and from Nuclear Power Plants, Directorate of Regulatory Standards, WASH-1238, U.S. Atomic Energy Commission, Washington, DC, 1972.

6. Environmental Survey of the Uranium Fuel Cycle, Directorate of Licensing, WASH-1248, U.S. Atomic Energy Commission, Washington, DC, 1974.

12.0 DISCUSSION OF STUDY RESULTS

This section discusses the results of this study and provides comparisons, where possible, with other known related studies. Research needs suggested by the study results are also discussed.

12.1 COMPARISON WITH OTHER STUDIES

A number of uranium fuel fabrication (U-Fab) plants have been shut down and at least partially decommissioned, but no studies on this work are known to appear in the open literature.

One study on the decommissioning of a plutonium fuel fabrication facility is available that has some application to U-Fab plants. This is a study done in 1975 by the staff at Argonne National Laboratory.(1) The Argonne study discusses, in summary form, the decommissioning methods used to dismantle one-half of their plutonium fabrication facility.

Two other studies, both involving plutonium-contaminated equipment, that have possible relationships to the decommissioning of U-Fab facilities exist in the literature. The earliest of these (September 1974) by the Argonne National Laboratory for the U.S. Atomic Energy Commission analyzed decontamination techniques and methods for plutonium-contaminated glove boxes.(2)

The third reference study (December 1974) is a more in-depth analysis by the Atlantic Richfield Hanford Company in Richland, Washington, for the U.S. Atomic Energy Commission on the decontamination and dismantlement of a government-owned plutonium criticality laboratory (called the P-11 facility).(3)

These studies were undertaken for different reasons, and the conclusions reported tend to reflect the particular interests of the study sponsor and the purpose for which the study was intended to be used. These studies are discussed briefly in the following subsections, and the purpose of each study is indicated, where known. Some discussion of results from these studies and some comparisons with results from this U-Fab study are given.

12.1.1 Reference 1: 1975 ANL Study

B. J. Koprowski, L. R. Kelman, D. R. Schmitt and S. Parker, "Dismantling a Plutonium Fabrications Facility," Proceedings of the 23rd Conference on Remote Systems Technology, pp. 263-269, 1975.

The published abstract of this paper follows:

> "The Plutonium Fabrication Facility (PFF) is being dismantled as part of a plan for consolidating and upgrading plutonium facilities at Argonne National Laboratory (ANL). The facility consists of fabrication equipment enclosed within a glove-box system interconnected by a conveyor. The glove-box system is being dismantled in sections and the sections are either being reinstalled or converted to scrap."

This report is a brief summary of decommissioning methods used to dismantle one-half of a plutonium fuel fabrication glove-box line. The principal motive for dismantling the facility was to reduce the needs for security, safety, and safeguards requirements at the laboratory site. The contents of the report are generally philosophical in approach rather than technical. The intent of the report is to demonstrate the ability to safely dismantle a glove-box line and its associated equipment, and to convert salvageable equipment and the cleaned-out building to other uses.

The study examines various alternative techniques for the dismantlement and removal of the glove-box system and discusses the rationale used for selecting the mode chosen. Decontamination methods, dismantling equipment and techniques, transport, salvage, and storage of radioactively contaminated materials are only briefly discussed. Economics and safety are not addressed. Sufficient information on the Argonne study, to enable comparison with this study, is currently unavailable.

12.1.2 Reference 2: 1974 ANL-8124 Study

A. G. Januska, W. J. Tyrrell and G. A. Bannett, "Decontamination of Plutonium Contaminated Glove Boxes," ANL-8124, Argonne National Laboratory, Argonne, IL, September 1974.

The published abstract of this paper follows:

> "In connection with the Argonne National Laboratory efforts to reduce potential hazards in the event a plutonium use facility is hit by a tornado, a decontamination experiment was carried out to establish the lowest practicable limits of loose contamination in an operating glove

> box, and to determine the relative merits of solvent wiping and vacuum cleaning as methods of decontamination. The results showed that a single wiping of the heavily contaminated test glove box with Calgon Hel-Cat, Myco Tiara, or Pennwalt 2187 solvent for a short period of time removes >95% of the loose contamination originally present, with a resultant contamination level of 10^6 - 10^7 dmp/100 cm^2. Subsequent wipings had little effect on removing the remaining (>5%) contamination. Vacuum cleaning was ineffective as the sole decontamination method; however, this cleaning method is recommended for removing loose plutonium in crevices and other hard-to-wipe areas. These results, although limited by the narrow scope of the experiment, offer the possibility of decreased decontamination costs for glove boxes compared to the standard technique, which requires successive wipings until the smears are essentially clean."

This study is part of an ongoing program at Argonne National Laboratory to reduce potential hazards and plutonium inventory and to comply with increased security, safety, and safeguard requirements for special nuclear materials. The study is similar in intent and purpose to that of Reference 1.

This paper summarizes plutonium-decontamination techniques and practices and details some experiments conducted at ANL to support the decontamination of plutonium-contaminated glove boxes. The effective decontamination techniques shown are similar to those used for U-Fab decommissioning. Economics and safety data are not given.

12.1.3 Reference 3: 1974 ARH-ST-106 Study

M. N. Raile, "P-11 Facility Cleanup - Summary Report," ARH-ST-106, Atlantic Richfield Hanford Company, Richland, WA, December 1974.

The published abstract of this paper follows:

> "This document describes methods, techniques, and equipment employed at Hanford for the cleanup, dismantling, and decommissioning of plutonium-contaminated facilities."

This paper summarizes the methods and techniques employed to clean up and dismantle a plutonium criticality laboratory that had been involved in a fire. The purpose of this decommissioning work was to restore the site to a natural state that would eliminate any potential environmental hazards to people or animals and allow alternative uses of the land area. The report documents the knowledge gained in plutonium-contamination control, dismantling and demolition methods, and special work techniques for the facility being decommissioned.

Time schedules, work plans and procedures, staff organization, auxiliary equipment needs and descriptions, radiation monitoring system, necessary building services, transportation, waste handling and packaging, and demolition techniques are discussed. A cost summary is provided. The study states that no major injuries or contamination of workers or environs occurred during the decommissioning.

12.2 DISCUSSION OF STUDY RESULTS

There are no commercial U-Fab facilities for which decommissioning is reported in the open literature and for which direct comparisons can be made with the results of this study. All of the decommissioning experiences reported in the literature deal with decontamination and dismantling of plutonium-contaminated glove boxes and glove-box systems at laboratories located within the United States. Where costs are reported, generally they are not given in sufficient detail to allow the various cost estimates to be examined on a common bases with U-Fab plants. Information in these studies on radiation doses to workers during decommissioning is generally not applicable to U-Fab decommissioning.

Several general conclusions can be drawn from the present study. No major technical impediments exist to the successful decommissioning of uranium contaminated facilities. The job can be done, using currently available technology, within the framework of present regulations, with virtually no impact on the safety of the general public.

The decontamination of uranium-contaminated facilities is a labor-intensive, hands-on effort. Thus, labor is a major fraction of the total decommissioning costs. Efforts to develop facility and equipment designs, and decontamination systems and techniques that can minimize labor could reduce overall decommissioning costs for U-Fab facilities.

The cost of handling, packaging, transporting, and disposing of radioactive waste materials is a significant fraction of the total decommissioning cost. Efforts to develop facility designs and decontamination techniques that minimize the quantities of contaminated material that must be disposed of as radioactive waste could reduce overall decommissioning costs and the waste management burden.

Realistic information on nuclear fuel cycle facility decommissioning is developed by performing detailed analysis on specific plants. Design differences among plants can have a significant impact on the types and amount of work involved in accomplishing decommissioning. Data from one facility can be used only as an order-of-magnitude estimate for a different facility.

12.3 SUGGESTED RESEARCH NEED

One of the most significant waste management items for the reference U-Fab plant is the disposal of waste effluent residuals. The CaF_2 wastes contain uranium that can be potentially valuable to the plant owner. It is estimated that the uranium residuals will have a value of about $30 million dollars by the end of the 40-year plant life. Thus, there is a strong economic incentive to process the CaF_2 and recover the residual uranium. Research on methods to routinely recover the uranium from the CaF_2 waste could decrease decommissioning costs and minimize the volume of waste disposal in licensed burial grounds.

REFERENCES

1. B. R. Koprowski, L. R. Kelman, D. R. Schmitt and S. Parker, "Dismantling a Plutonium Fabrications Facility," Proceedings of the 23rd Conference on Remote Systems Technology, pp. 263-269, 1975.

2. A. G. Januska, W. J. Tyrrell and G. A. Bennett, "Decontamination of Plutonium-Contaminated Glove Boxes," ANL-8124, Argonne National Laboratory, Argonne, IL, September 1974.

3. M. N. Raile, "P-11 Facility Cleanup - Summary Report," ARH-ST-106, Atlantic Richfield Hanford Company, Richland, WA, December 1974.

13.0 CONSIDERATIONS FOR THE FACILITATION OF DECOMMISSIONING

Title 10 Code of Federal Regulations, Part 50, Appendix F.4 describes the Nuclear Regulatory Commission's position regarding facilitation of decommissioning of fuel reprocessing plants: "A design objective shall be to facilitate decontamination and removal of all significant radioactive wastes at the time the facility is permanently decommissioned." Application of this NRC objective to other fuel cycle facilities is a logical extension of the intention of this regulation. In addition, NRC Regulatory Guide 8.8, Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations be as Low as is Reasonably Achievable (ALARA), explicitly points out that "design concepts and station features should reflect consideration of the activities of station personnel (including decontamination and decommissioning) that might be anticipated."

This study on decommissioning of a uranium fuel fabrication (U-Fab) plant describes activities that can be used to conceptually decommission a reference facility. With this study as a basis, insights have been gained as to plant design characteristics that could simplify the task of decommissioning. This section summarizes some of these potential plant and equipment design features.

It is recognized that some of the considerations intended to enhance decommissioning may not always be compatible with those plant characteristics that are desirable for normal production operations. Some of the characteristics may also be prohibitively expensive. However, the aim of this discussion is to point out design characteristics that would expedite and simplify the decommissioning task. These findings regarding desirable features for decommissioning are presented with no attempt to rank their relative importance or to determine impacts on the rest of the plant designs, on plant production operations, or on plant process performance. These insights are aimed only at areas that present obvious complexity or difficulty to decommissioning a U-Fab plant; they are not all-inclusive, and do not consider details, side effects, or variations of the alternatives. Such an analysis would require an in-depth study beyond the scope of this report.

The general criteria used in selecting design features for consideration are based on the effect they might be expected to have on decreasing decommissioning cost, improving occupational or public safety, reducing total decommissioning time, creating less radioactive waste, and the general ease of performing the decommissioning. In evaluating new design features for future decommissioning application, appropriate balance must be maintained between designs that meet these criteria and potential negative effects on plant construction and operating costs and operating characteristics. For the considerations given below, qualitative comments are made about the possible effects a given design feature might have in satisfying the selection criteria.

Non-porous Surfaces

Pre-polishing the surfaces of metal process equipment would be advantageous to decommissioning. This action at the time of plant construction would tend to reduce the holdup of radioactive materials on the equipment. It would make the equipment more corrosion-resistant, and it would render the equipment easier to decontaminate. Seal coating of original porous surfaces (e.g., concrete, brick, etc.) would also speed up decontamination.

Minimizing Crevices in Process Areas

Minimizing the crevices in process equipment, glove boxes, and hoods would ease decommissioning. An example of this technique is to fabricate hoods with all corners rounded. Minimizing crevices would reduce holdup of radioactive materials and would afford easier decontamination.

Hoods and Equipment That Could Be Disassembled

The capability to completely disassemble hoods and process equipment without cutting would beneficially affect decommissioning. The equipment should be easy to disassemble, handle, and decontaminate for disposal as noncontaminated scrap or for burial in a local landfill dump. Equipment that is easy to reassemble after decontamination may be recommissioned for further use if salvage values warrant.

Provide Flushing and Rinsing Capability

The capability to readily provide liquid flushes to process equipment, piping, tanks, and hoods would be advantageous to decommissioning. Ceilings, walls, auxiliary equipment, piping, and floors should be spray rinsable. This feature could be incorporated by such techniques as providing the capability to accept spray systems and providing drains or sumps to collect the liquids (especially in dry processing areas). These kinds of provisions would minimize time-consuming manual cleaning techniques and manual systems for handling the cleaning liquids.

Waste Volume Reduction Systems

Reduction of volumes of liquid and solid wastes is highly desirable in decommissioning to reduce waste handling and waste management costs. These systems could include evaporation for liquids and incineration for combustible solids. This capability does not necessarily need to be installed within the facility for decommissioning, but the facility should have provisions to readily accept the capability, either built-in or from portable units.

CaF_2 Waste Recovery

The calcium fluoride solids in the fluoride waste lagoons will contain a large amount of uranium residuals (est. $30-40 million in 1978 dollars) at the end of the 40-year plant life. Facilities for routinely recovering uranium from the CaF_2 would return valuable material to the plant inventory and would eliminate the need to store and/or dispose of those large quantities of CaF_2 at the time of decommissioning.

Tiled Floor Areas

Use of linoleum or strip coat in lieu of tile would reduce the amount of uranium swept into the cracks between tiles. Also the amount of labor needed to remove tile and contaminated concrete would be reduced.

14.0 GLOSSARY

Abbreviations, acronyms, symbols, terms, and definitions used in this study and directly related to decommissioning work and related technology are defined and explained in this section. The section is divided into two parts, with the first part containing abbreviations, acronyms, symbols, and a conversion table to International System of Units (SI), and the second part containing terms and definitions (including those used in a special sense for this study). Common terms covered adequately in standard dictionaries are not included.

14.1 ABBREVIATIONS, ACRONYMS, SYMBOLS, AND SI UNITS

Abbreviations and Acronyms

AEC	Atomic Energy Commission
ALARA	As Low As is Reasonably Achievable(a)
CFR	Code of Federal Regulations(a)
Ci	Curie(a)
DF	Decontamination Factor(a)
DOT	Department of Transportation
DPM	Disintegrations per Minute(a)
EDTA	Ethylenediamine tetraacetic acid
FSAR	Final Safety Analysis Report
GB	Glove Box
HEPA	High Efficiency Particulate Air (Filters)
HP	Health Physicist(a)
HVAC	Heating, Ventilation and Air Conditioning
LWR	Light Water Reactor
mR	Milliroentgen(a)
mrad	Millirad(a)
mrem	Millirem, see rem also
MT	Metric Ton(a)

(a)See Section 14.2 for additional information or explanation.

MTHM	Metric Ton of Heavy Metal
MWd/MTU	Thermal Megawatt-day per Metric Ton of Uranium, the Burnup[a]
NRC	Nuclear Regulatory Commission
Q.A.	Quality Assurance[a]
Q.C.	Quality Control[a]
R	Roentgen[a]
rad	Radiation Absorbed Dose[a]
rem	Roentgen Equivalent Man[a]
SNM	Special Nuclear Material[a]
SS	Stainless Steel
SX	Solvent Extraction
$T_{1/2}, T_R$	Half Life, Radiological[a]
UF	Urea-formaldehyde

Symbols

α	Alpha Radiation[a]
β	Beta Radiation[a]
γ	Gamma Radiation[a]
χ	Chi, Concentration, pCi/m^3
Q	Released Quantity of Radioactive Material, Ci
Q'	Release Rate of Radioactive Material, Ci/sec
$\overline{\chi}/Q'$	Chi-bar/Q prime, normalized annual average air concentration (pCi/m^3) per Ci/sec released, also written sec/m^3). Also called the annual average atmospheric dilution factor.

SI Units

SI units for use with radioactivity and ionizing radiations are as follows:

Quantity	New Named Unit and Symbol	In Other SI Units	Old Special Unit and Symbol	Relationship New to Old Units
Exposure	--	coulomb/kg (C/kg)	roentgen (R)	1 C/kg ≈ 3876 R
Absorbed dose	gray (Gy)	joule/kg (J/kg)	rad (rad)	1 Gy = 100 rad
Dose equivalent	sievert (Sv)	J/kg	rem (rem)	1 [illegible] 100 rem
Activity	becquerel (Bq)	$seconds^{-1}$ (s^{-1})	curie (Ci)	1 Bq ≈ 2.70×10^{-11} Ci

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(a)See Section 14.2 for additional information or explanation.

14.2 GLOSSARY DEFINITIONS

Actinides:	A series of heavy radioactive metallic elements of increasing atomic number (Z) beginning with actinium (89) or thorium (90) through element hahnium of atomic number 105.
Activity:	See Radioactivity.
Airborne Radioactive Material:	Radioactive particulates, mists, fumes, and/or gases in air.
ALARA:	A philosophy to maintain exposure to radiation As Low As is Reasonably Achievable.
Alpha Decay:	Radioactive decay in which an alpha particle is emitted. This transformation lowers the atomic number of the nucleus by two and its mass number by four.
Alpha Particle:	A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons, hence it is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of radiation (alpha, beta and gamma) emitted by radioactive material.
Alpha Emitter:	A radionuclide that undergoes transformation by emission of alpha particles.
Atomic Number (Z):	The number of protons in the nucleus of an atom; also its positive charge. Each chemical element has its characteristic atomic number, and the atomic numbers of the known elements form a complete series from 1 (hydrogen) through 105 (hahnium).
Background:	That level of radioactivity from sources other than the one directly under consideration, in this case those existing without the presence of the U-Fab plant.
Bag Out:	Term used to describe the techniques for transferring objects into and/or out of glove boxes without loss of confinement, utilizing various types of containers, sealing and packaging techniques.
Beta Decay:	Radioactive decay in which a beta particle is emitted or in which an orbital electron capture occurs.

Beta Particle:	An electron, of either positive or negative charge, which has been emitted by an atomic nucleus in a nuclear transformation.
Burial Grounds:	Areas designated for storage of packaged radioactive wastes in soils just below the surface.
Burnup, Specific:	The total energy released per unit mass of a nuclear fuel. It is commonly expressed in megawatt-days per metric ton of fuel material. (Also called fuel irradiation level.)
Byproduct Material:	Any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material.
Calcine:	To heat a substance to a high temperature, but below its melting point, causing loss of volatile constituents such as moisture. Material produced by this process is also called Calcine.
Cask:	A heavily shielded shipping container for radioactive materials. Some casks weigh as much as 100 metric tons.
Chemical Limits:	Maximum concentrations or quantities imposed upon chemical releases to the environment in gaseous or liquid effluents discharged from a facility, and consistent with known air or water quality standards.
Code of Federal Regulations (CFR):	The Code of Federal Regulations is a documentation of the general rules by the Executive departments and agencies of the Federal Government. The Code is divided into 50 titles that represent broad areas subject to Federal regulation. Each title is divided into Chapters that usually bear the name of the issuing agency. Each Chapter is further subdivided into Parts covering specific regulatory areas.
Contact Maintenance:	"Hands-on", or maintenance performed by direct contact of personnel with the equipment. It includes maintenance with protective equipment or clothing, such as through gloves in glove boxes. Most nonradioactive maintenance is contact maintainance.

Contamination:	Undesired materials that have been deposited on the surfaces, or are internally ingrained into structures or equipment, or that have been mixed with another material.
Critical:	A condition wherein a medium is capable of sustaining a nuclear chain reaction at a constant rate. Prompt critical is being capable of sustaining a chain reaction without the aid of delayed neutrons
Critical Mass:	The mass of fissionable material that will support a self-sustaining nuclear chain reaction.
Curie:	A special unit of radioactivity. One curie equals 3.7×10^{10} nuclear transformations per second. (Abbreviated Ci.) Several fractions of the curie are in common usage: • Millicurie. One-thousandth of a curie. Abbreviated mCi (3.7×10^7 d/s). • Microcurie. One-millionth of a curie. Abbreviated μCi (3.7×10^4 d/s). • Nanocurie. One-billionth of a curie. Abbreviated nCi (37 d/s). • Picocurie. One-millionth of a microcurie. Abbreviated pCi; replaces the term μμCi (0.037 d/s).
Custodial SAFSTOR:	A minimum cleanup and decontamination preparation followed by safe storage and terminated by deferred decontamination. The active protection systems (i.e., ventilation, utilities, fire) are kept in service, the site is secured against intrusion by physical barriers and by guards, and use of the facility and site is limited to nuclear activities.
Decay, Radioactive:	A spontaneous nuclear transformation in which a particle, gamma radiation, or x-ray radiation are emitted.
Decommissioning:	The retirement from active service of nuclear facilities, including all activities to remove the radioactive material to levels that allow unrestricted release of the facility and its site.

DECON:	Those actions required immediately after shutdown to remove sufficient radioactive or contaminated materials from the facility and site, to permit release of the property for unrestricted use.
Decontamination:	Those activities employed to reduce the levels of contamination in or on structures, equipment and materials. Also used to infer decontamination to levels corresponding to unrestricted release.
Decontamination Agents:	Those chemical materials used to effect decontamination.
Decontamination Factor (DF):	The ratio of the initial concentration of an undesired material to the final concentration resulting from a treatment process. The term may also be used as a ratio of quantities.
Deferred Decontamination:	Those actions required after the safe storage period of SAFSTOR to disassemble and remove sufficient radioactive or contaminated materials from the facility and site, to permit release of the property for unrestricted use.
Design Basis Accident:	A postulated accident believed to have the most severe expected impacts on a facility. It is used as the basis for safety and structural design.
Discount Rate:	The rate of return on capital that could have been realized in alternative investments, if the money were not committed to the plan being evaluated, i.e., the opportunity costs of alternative investments. This cost is equivalent to the weighted average cost of capital.
Disintegration, Nuclear:	The transformation of the nucleus of an atom from one element to another, characterized by a definite half-life and the emission of particles or radiation.
Disintegration Rate:	The rate at which disintegrations occur, characterized in units of inverse time; i.e., disintegrations per minute (dpm), etc.
Dismantlement:	Those actions required to disassemble and/or remove radioactive or contaminated materials from the facility and site.

Dispersion:	A process of mixing one material within a larger quantity of another. For example, the mixing of material released to the atmosphere with air causes a reduction in concentration with distance from the source.
Disposal:	The disposition of materials with the intent that the materials will not enter man's environment in sufficient amounts to cause a health hazard.
Dose, Absorbed:	The mean energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. The unit of absorbed dose is the rad. One rad equals 0.01 joules/kilogram in any medium (100 ergs per gram).
Dose, Equivalent:	Expresses the amount of radiation that is effective in the human body, expressed in rems. Modifying factors associated with human tissue and body are considered. Equivalent dose is the product of absorbed dose multiplied by a quality factor multiplied by a distribution factor. Referred to as Dose in this report.
Dose, Occupational:	The exposure of an individual to radiation as a result of his employment, expressed in rems.
Dose Rate:	The radiation dose delivered per unit time and measured, for instance, in rems per hour.
Dosimeter:	A device, such as a film badge or ionization chamber, that measures radiation dose.
Enrichment:	The ratio (usually expressed as a percentage) of fissile isotope to the total amount of the element (e.g., the % of ^{235}U in uranium.)
ENTOMB:	The encasement of radioactive materials in concrete or other structural materials sufficiently strong and durable to assure retention of the radioactivity until it has decayed to levels that permit unconditional release of the site.
Exposure:	A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely

	stopped in air, divided by the mass of air in the volume element. The special unit of exposure is the roentgen. (See Roentgen.)
Facility:	The physical complex of buildings and equipment within a site.
Fission:	The splitting of a heavy atomic nucleus into two lighter parts (atomic nuclides of lighter elements), accompanied by the release of a relatively large amount of energy and generally one or more neutrons. Fission can occur spontaneously but usually it is caused by nuclear absorption of gamma rays, neutrons, or other particles.
Fission Products:	The lighter atomic nuclides (fission fragments) formed by the fission of heavy atoms. It also refers to the nuclides formed by the fission fragments' radioactive decay.
Food Chain:	The pathways by which any material (such as radioactive material from fallout) passes through man's environment through edible plants and/or animals to man.
Fuel Assembly:	A grouping of fuel elements (hollow rods filled with nuclear fuel for LWRs) that supply the nuclear heat in a nuclear reactor. A fuel element or rod is the smallest structurally discrete part of a reactor or fuel assembly that has nuclear fuel as its principal constituent.
Fuel Cycle:	The series of steps involved in supplying fuel for nuclear power reactors, handling the spent fuel and the radioactive waste, including transportation. Head end: Mining, milling, conversion, enrichment, and fabrication of fuel. Back end: Includes reactors, spent fuel storage, spent fuel reprocessing, mixed-oxide fuel fabrication and waste management.
Fuel Element:	A rod, tube, or other form into which nuclear fuel is fabricated to use in a reactor.
Gamma Rays:	Short-wavelength electromagnetic radiation. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are best stopped or shielded against by dense materials such as

	lead or uranium. These rays usually originate from within the nucleus of the atom.
Gaseous:	Material in the vapor or gaseous state, but can include entrained liquids and solids. A gas will completely fill its container regardless of container shape or size.
Glove Box:	A box, usually made of stainless steel and large panes of glass or transparent rigid plastic, in which workers using gloves attached to, sealed, and passing through, openings in the box can safely handle radioactive materials from the outside by inserting their hands into the gloves and manually performing manipulations.
Greenhouse:	In nuclear terms, a temporary structure, frequently constructed of wood and plastic film, used to provide a confinement barrier between a radioactive work area and a nonradioactive area.
Guard:	An individual whose primary duty is the guarding and protection of material against theft and/or the protection of the facility against vandalism or undesired intruders.
Half-Life, Biological:	The time required for a biological system, such as a man or animal, to eliminate by natural processes, half the amount of a substance that has been absorbed by it.
Half-Life, Effective:	The time required for a radionuclide contained in a biological system, such as a man or animal, to reduce its radioactivity by half as a combined result of radioactive decay and biological elimination.
Half-Life Radioactive:	The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Each radionuclide has a unique half-life. Measured half-lives vary from millionths of a second to billions of years.
Health Physicist:	A person trained to perform radiation surveys, oversee radiation monitoring, estimate the degree of radiation hazard, and advise on operating procedures for minimizing radiation exposures.

Health Physics:	The science concerned with recognition, evaluation, and control of health hazards from radiation.
Heavy Metal:	Jargon used in reference to metals with atomic numbers 90 and greater. It usually refers to nuclear fissile or fertile fuels such as thorium, uranium, and plutonium.
Hood:	Vented containment space, enclosed on 5 sides, with the sixth side covered by a movable glass window to allow access and to maintain sufficient in-flow of air and splash control to protect the worker from the hazardous materials handled inside.
Hot Spots:	Areas of radioactive contamination higher than average.
Immobilization:	Treatment and/or emplacement of materials (e.g., radioactive contamination) so as to impede its movement. Concepts for interim storage include bulk or compartmented storage of solid, liquid and gaseous wastes or other materials.
Intrusion Alarm:	A means of detecting intrusion of individuals into a protected area utilizing an electromechanical, electro-optical, electronic, mechanical or similar device with a visible or audible alarm signal.
Ion Exchange:	A chemical process involving the selective absorption or desorption of various chemical ions in a solution onto a solid material, usually a plastic or resin. The process is used to separate and purify chemicals, such as fission products from plutonium or "hardness" from water (i.e., water softening).
Layaway:	See Custodial SAFSTOR.
Licensed Material:	Nuclear source material, special nuclear material, or nuclear by-product material received, possessed, used, or transferred under a license issued by the Nuclear Regulatory Commission.

Long-Lived Nuclides:	For this study, radioactive isotopes with long half-lives typically taken to be greater than about ten years. Most nuclides of interest to waste management have half-lives on the order of one year to millions of years.
Management (Waste):	The planning, execution, and surveillance of essential functions related to radioactive waste, including treatment, solidification, packaging, interim or long-term storage, transportation and disposal.
Man-rem:	A measure of radiation dose distributed to a population. To calculate radiation dose to the population, the dose equivalent in rem received by each person in the population is summed.
Mass Number:	The number of nucleons (protons and neutrons) in the nucleus of an atom. (Symbol: A).
Maximum Exposed Individual:	The hypothetical member of the public who receives the maximum radiation dose to an organ of reference. For the common case where exposures from airborne radionuclides result in the highest radiation exposure, this individual resides at the location of the highest airborne radionuclide concentration and eats food grown at that location.
Megawatt-day:	A unit for expressing the energy generated in a reactor; specifically, the number of millions of watt-days of heat output per metric ton of fuel in the reactor. Also, the net electrical output in millions of watts of electrical energy averaged over one day.
Megawatts per Metric Ton of Uranium:	Amount of thermal megawatts produced per metric ton of uranium.
Megawatt Days per Metric Ton of Uranium:	Amount of thermal megawatt-days produced per metric ton of uranium; also called burnup. (See also specific power.)
Metric Ton:	1000 kilograms (See Tonne.)
Mixed Oxide:	A mixture of uranium dioxide and plutonium dioxide.
Monitoring:	Taking measurements or observations for recognizing the status or adequacy, or significant changes in conditions or performance of a facility or area.

Mothball:	See Passive SAFSTOR
Normal Operating Conditions:	Operation (including startup, shutdown, and maintenance) of systems within the normal range of applicable parameters of an operating facility.
Nuclear Reaction:	A reaction involving a change in an atomic nucleus, such as fission, fusion, particle capture, or radioactive decay.
Offsite:	Beyond the boundary line marking the limits of plant property.
Onsite:	Within the boundary line marking the limits of plant property.
Operable:	Capable of performing the required function.
Overpack:	Secondary (or additional) external containment or cushioning for packaged materials.
Package:	The packaging plus the contents of radioactive materials.
Packaging:	The assembly of radioactive material in one or more containers and other components necessary to assure compliance with prescribed regulations.
Passive SAFSTOR:	A partial cleanup and decontamination preparation followed by safe storage and terminated by decontamination. All systems are deactivated, the structures are secured by rigid physical barriers and continuous remote monitoring, and the plant is limited to nuclear use only, while the site may have non-nuclear uses.
Plant:	The physical complex of buildings and equipment, including the site.
Present Value of Money:	The present value of a future stream of costs or payments is the present investment necessary to secure or yield the future stream of payments with compound interest at a given discount or interest rate.
Primary Wastes:	Wastes that are generated as a part of the principal operation of a facility. Secondary wastes are generated from supporting operations, such as waste treatment.

Process Cells:	Shielded rooms housing (radioactive) processing systems.
Process Equipment:	The functional equipment items or systems associated directly with the operation of a chemical or mechanical operation.
Protective Clothing:	Special clothing worn by a person in a radioactively contaminated area to minimize the potential for contamination of his body or personal clothing.
Protective Storage:	See Passive SAFSTOR.
Protective Survey:	An evaluation of the radiation and its hazards incidental to the production, use or existence of radioactive materials. It normally includes a physical survey of the arrangement and use of equipment and measurements of the radiation dose rates under expected conditions of use. Also called protection survey.
Quality Assurance:	The systematic actions necessary to provide adequate confidence that a material, component, system, process, or facility performs satisfactorily, or as planned, in service.
Quality Control:	The quality assurance actions that control the attributes of the material, process, component, system, or facility in accordance with predetermined quality requirements.
Rad:	A unit of absorbed dose. The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. One rad equals 0.01 joule/kilogram of absorbing material.
Radiation:	(1) The emission and propagation of radiant energy: for instance, the emission and propagation of electromagnetic waves, or of sound and elastic waves. (2) The energy propagated through space or through a material medium. for example, energy in the form of alpha, beta, and gamma emissions from radioactive nuclei.

Radiation Area:	Any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive in any one hour a dose in excess of 5 millirem, or in any 5 consecutive days a dose in excess of 100 millirems. (10 CFR 20.202)
Radiation Background:	See Background.
Radiation, Leakage (Direct):	All radiation coming from a source housing except the useful beam.
Radioactive Material:	Any material or combination of materials which spontaneously emit ionizing radiation and which has a specific radioactivity in excess of 0.002 microcuries per gram of material. (49 CFR 173.389 (e)).
Radioactive Series:	A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nonradioactive nuclide results. The first member is called the "parent," the intermediate members are called "daughters," and the final stable member is called the "end product."
Radioactivity:	The number of nuclear transformations occurring in a given quantity of material per unit of time with the emission of particles, gamma radiation, or x-ray radiation. Often shortened to "activity."
Radioactivity, Natural:	The property of radioactivity exhibited by more than fifty naturally occurring radionuclides.
Radiological Protection:	Protection against the effects of internal and external exposure to radiation and to radioactive materials.
Regulatory Guides:	Regulatory Guides are issued by the NRC, to describe and make available to the public, methods acceptable to the NRC staff, for implementing specific parts of the NRC's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide other guidance to applicants for nuclear operations. Guides are not substitutes for regulations and compliance with them is not explicitly required. Methods and solutions different from those set out in the guides may be acceptable if they provide

	a basis for the findings requisite to the issuance or continuance of a permit or license by the NRC.
Rem:	A unit of radiation dose equivalence. The radiation dose equivalence in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors.
Remote Maintenance:	Maintenance by remote means, i.e., the operator is separated by a shielding wall from the item being maintained.
Reporting Levels:	Those levels or parameters called out in the Environmental Technical Specifications, the Decommissioning Order, and/or the Amended License that do not limit decommissioning activities, but which may indicate a measurable impact on the environment.
Repository (Federal):	A site owned and operated by the Federal Government for long-term storage or disposal of radioactive materials.
Restricted Area:	Any area to which access is controlled for protection of individuals from exposure to radiation and radioactive materials.
Roentgen:	A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying one electrostatic unit of electrical charge (either positive or negative) in one cubic centimeter of dry air under standard conditions. One roentgen equals 2.58 x 10^{-4} coulombs per kilogram of air. (See also Exposure.)
SAFSTOR:	The decommissioning alternative wherein a preparatory period after shutdown is followed by safe storage, which, in turn, is terminated by deferred decontamination.
Safe Storage:	A period of time starting after the initial decommissioning activities cease and wherein surveillance and maintenance takes place. The duration of time can vary from a few years to more than 100 years; called "continuing care" in some other NRC decommissioning reports.

Safety-Related:	Structures, systems, and components whose functions tend to prevent or mitigate the exceeding of safety limits, as defined in Regulatory Guide 3.6, and set forth in Technical Specifications that are part of the Operating License for a nuclear power plant.
Scarfing:	A technique used to mechanically decontaminate concrete by chipping, cutting, jackhammering, or blasting the surface layer(s) away.
Secondary Wastes:	Forms and quantities of all wastes that result from treatment of primary wastes or effluents.
Security Officer:	A guard or watchman whose primary duty is the protection of material and property.
Shield:	A body of material used to reduce the passage of particles or electromagnetic radiation. A shield may be designated according to what it is intended to absorb (as a gamma ray shield or neutron shield), or according to the kind of protection it is intended to give (as a background, or thermal shield). It may be required for the safety of personnel or to reduce radiation enough to allow use of counting instruments for research or for locating contamination or airborne radioactivity.
Short-Lived Radionuclides:	For this study, those radioactive isotopes with half-lives less than about 10 years.
Shutdown:	The time during which a facility is not in productive operation.
Site:	The geographic area upon which the facility is located that is subject to controlled public access by the facility licensee (includes the restricted area as designated in the NRC license).
Solid Radioactive Waste:	Material that is essentially solid and dry but may contain sorbed radioactive fluids in sufficiently small amounts as to be immobile.
Solidification:	Conversion of radioactive wastes (gases or liquids) to dry, stable solids.

Special Nuclear Material:	Plutonium, uranium enriched in the isotopes 233 or 235, and any other material as defined in 10 CFR 51 by the NRC.
Specific Power (of Fuel Assemblies):	Commonly expressed in units of thermal megawatts per metric ton of uranium (MW/MTU). It represents the rate at which thermal energy is extracted from the fuel; burnup, commonly expressed in thermal megawatt-days per metric ton of uranium (MWd/MTU), represents the total integrated energy extracted. For MOX fuel, the unit of fuel is a metric ton of heavy metal (MTHM); i.e., a metric ton of (U + Pu).
Surface Contamination:	Contamination that is the result of the deposition and attachment of foreign materials to a surface.
Surveillance:	Those activities necessary to assure that the site remains in a safe condition (including inspection and monitoring of the site, maintenance of barriers to access to radioactive materials left on the site, and prevention of activities on the site that might impair these barriers).
Survey:	An evaluation of the radiation hazards incident to the production, use, release, disposal or presence of radioactive materials or other sources of radiation under a specific set of conditions.
Technical Specifications:	Requirements and limits that encompass nuclear safety but are simplified to facilitate use by plant operation and maintenance personnel. They are prepared in accordance with the requirement of 10 CFR 50.36, and are incorporated by reference into the amended license issued by the NRC.
Tonne:	A metric ton, or 1000 kg, or 2204.6 lb.
Transuranic Elements:	Elements with atomic number (Z number) greater than 92.
Transuranic Waste:	Any waste material measured or assumed to contain more than a specified concentration (i.e., proposed as 10 nanocuries of alpha emitters per gram of waste, or more presently proposed as 100 nanocuries/cm^3 of waste ^{239}U) of transuranic elements.

Underground Solid Waste Storage Area:	Area within an exclusion area where radioactive solid waste is stored by burial.
Wastes, Radioactive:	Equipment and materials (from nuclear operations) that are radioactive and for which there is no further known use.
Wastes, Low-Level:	Wastes containing types and concentrations of radioactivity such that little or no shielding to minimize personnel exposure is required.
Wastes, High-Level:	Wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, in a facility for reprocessing irradiated reactor fuels (10 CFR 50, App. F.2). It is also applied generally to radioactive wastes of other origins, where the rate of heat evolution becomes of concern in waste disposal or the external radiation dose rates are extremely high.
X-ray:	A penetrating form of electromagnetic radiation emitted either when the inner orbital electrons of an excited atom return to their normal state (characteristic x-rays) or when a metal target is bombarded with high speed electrons. X-rays are always non-nuclear in origin; i.e., they originate external to the nucleus of the atom.

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This report presents information on the technology, safety and cost for the conceptual decommissioning of a reference uranium fuel fabrication plant. It develops comprehensive engineering information on potential decommissioning methods and costs and on the impacts on public and occupational safety of decommissioning.

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