Descriptions of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles

**K. J. Schneider
T. J. Kabele**

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DESCRIPTIONS OF REFERENCE LWR FACILITIES
FOR ANALYSIS OF NUCLEAR FUEL CYCLES

K. J. Schneider, Study Coordinator
T. J. Kabele, Project Manager

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Pacific Northwest Laboratory
Richland, Washington 99352

LIST OF CONTRIBUTORS

Introduction: K. J. Schneider, T. J. Kabele

Summary: K. J. Schneider, T. J. Kabele

Technical Approach: K. J. Schneider, T. J. Kabele

Fuel Cycle Definition: K. J. Schneider

Reference Sites: W. E. Kennedy, C. E. Jenkins, K. J. Schneider

Mining: W. I. Enderlin, T. B. Powers, M. H. Arndt

Milling: D. H. Lester, D. K. Davis, S. W. Heaberlin,
T. B. Powers

Uranium Purification
and Conversion: D. H. Lester, J. N. Hartley, D. K. Davis,
T. B. Powers

Uranium Enrichment: D. F. Newman, M. H. Arndt

Fuel Fabrication:

UO_2 : W. J. Bailey, K. J. Schneider

PuO_2 : W. J. Bailey, T. B. Powers

Reactors:

 PWR: N. Brooks, H. D. Oak, T. B. Powers

 BWR: H. D. Oak, T. B. Powers

Reprocessing: G. A. Winsor, T. B. Powers

Other Contributors: R. L. Aaberg, J. K. Young, D. T. Aase

Edited By: E. L. Owzarski

Project Manager: T. J. Kabele

ABSTRACT

To contribute to the Department of Energy's identification of needs for improved environmental controls in nuclear fuel cycles, a study was made of a light water reactor system. A reference LWR fuel cycle was defined, and each step in this cycle was characterized by facility description and main-line and effluent treatment process performance. The reference fuel cycle uses fresh uranium in light water reactors. Final treatment and ultimate disposition of waste from the fuel cycle steps were not included, and the waste is assumed to be disposed of by approved but currently undefined means. The characterization of the reference fuel cycle system is intended as basic information for further evaluation of alternative effluent control systems.

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BACKGROUND AND SUMMARY

1.0 INTRODUCTION

This report is one of a series of reports that document information developed for the program "Analysis of Nuclear Fuel Cycles," sponsored by the U.S. Department of Energy's Division of Environmental Control Technology. The goal of this program is to provide an independent overview of environmental control technology development for nuclear fuel cycles to ensure that environmental control technologies will not limit the implementation of these cycles.

The operation of nuclear fuel cycle facilities will introduce noxious materials, both radiological and chemical, into the environment through routine discharges of both liquid and airborne effluents. The environmental control implications of continued development of existing nuclear fuel cycles and implementing new fuel cycles must be determined on a systems basis to assure the timely development and demonstration of technologies which control or eliminate the discharge of noxious materials to the environment. Improvements in facility process and treatment and confinement systems will reduce the environmental impact of nuclear fuel cycle operations, but will also increase nuclear fuel cycle capital and operating costs. A major objective of this program is to recommend where R&D will improve effluent control on a cost-effective basis.

The approach selected to meet the program objective is to evaluate the Light Water Reactor fuel cycle as a reference point for analysis of alternative fuel cycles and advanced nuclear energy systems, and evaluate specific topics identified as important issues in environmental control of nuclear fuel cycles. Studies are under way in the areas of Fusion, Thorium and Advanced Uranium Resource Extraction, and Alternate Fuel Cycles.

The technical approach within each program objective is to (1) develop generic descriptions of the fuel cycles and facilities in question, (2) identify potential environmental releases from each facility, (3) assess current capabilities to control environmental releases, and (4) identify areas where environmental control technologies could be improved on a cost-effective basis.

This report documents the descriptions of nuclear facilities employed in typical LWR fuel cycles. These descriptions provide not only the basis for our analysis of the adequacy of environmental control technologies for a LWR fuel cycle, but also provide a self-consistent source book for an entire LWR fuel cycle. Since these facility descriptions can have general uses separate from the "Analysis of Nuclear Fuel Cycles" program, only the descriptions are presented in this report. The details and results of the analysis of environmental control technology that was based on these descriptions are presented separately in subsequent reports.

2.0 SUMMARY

This report provides descriptions of reference light water reactor (LWR) fuel cycle facilities and the basic physical requirements of these facilities. The reference facilities are characterized with respect to mainline, effluent treatment, and waste treatment process descriptions; overall process performance; plant and facility descriptions; and factors for use in environmental impact, capital and operating cost, and nonaccident cost effective analyses.

This information was developed for the program, "Analysis of Nuclear Fuel Cycles", sponsored by the U.S. Department of Energy's Division of Environmental Control Technology. The program's objective is to identify needs for improved environmental controls based on cost effectiveness studies of current and alternative nuclear fuel cycle concepts.

For purposes of this study, effluents are defined as nonproduct process materials that are intentionally discharged to man's environment; wastes are nonproduct process materials that are disposed of with the intent of isolation from our environment.

Each fuel cycle step was studied by selecting an existing contemporary facility as a reference facility, and using information pertinent to the reference facility. Exceptions to this were the use of conceptual facilities for the gaseous diffusion and centrifugation enrichment facilities (assumed to be stand-alone plants for LWR enrichment levels only) and for the plutonium conversion subfacility as part of the fuel reprocessing plant.

Two generic site definitions are given in this study to enable later comparisons of impacts of effluents from different steps in the fuel cycle. Site A is in a western, semiarid region typical of uranium mine and mill sites, with an area of 13 km^2 shaped as a rectangle 4 km by 3.25 km. The reference mines and mill are assumed to be located on individual sites such that the effluents emanate from near the center of each site. The Site B environment is characteristic of rural areas in midwestern or south mideastern United States. This site occupies 4.7 km^2 shaped as a rectangle

2 km by 2.35 km. The site has a moderately-sized river flowing through one corner. Each of the reference fuel cycle facilities except the mines and the mill are assumed to be located individually on the site such that airborne effluents emanate 1 km from three sides of the rectangle. Liquid effluents are assumed to be discharged into the river.

Ten reference facilities were studied for the 7 major fuel cycle steps. The major characteristics of the 10 reference facilities are given in Table 2-1. The reference facilities are believed to be representative of current and near-future plants. The capacity of each facility is specific to that plant, so that different numbers of each facility are required to constitute a balanced nuclear power system. Some of the numerical characteristics are estimates or assumptions by the authors, as defined in later detailed descriptions.

Effluents in this study are defined as materials intentionally dispersed into the environment. They are either dispersed into the atmosphere (i.e., airborne effluents) or to surface water (i.e., liquid effluents). An overall summary of the effluents from each reference fuel cycle facility during an operating day at 100% capacity is given in Table 2-2.

The total amount of uranium in the airborne effluents is about 0.2% of the production rate, and most of this is from mining and milling. The total uranium content in liquid effluents is also about 0.2%, and most of this is from purification-conversion. Less than $10^{-6}\%$ of the plutonium is lost in airborne effluents, and essentially none in liquid effluents.

The radioactivity in effluents is dominated by airborne radioactivity from reactors and fuel reprocessing plants, and most of this radioactivity is from short-lived radionuclides and/or radioactive noble gases. Radioactivity in liquid effluents is mostly from the reactors, and is about 3 orders of magnitude lower than in airborne effluents.

Chemical pollutants released into the air vary widely among the reference facilities, but they average greater than 2000 kg/day^(a) from each

^(a)The actual value is slightly greater than this because some chemical effluents from some facilities were not identified.

TABLE 2-1. Major Characteristics of Reference LWR Fuel Cycle Facilities

Fuel Cycle Step	Reference Facility			Plant Area (km ²)	Capacity, (a) MT Per		Process Type	Total Operating Staff, No.	Electrical Needs (kW/d)	Water Needs (10 ft ³ /d)	Estimated Operating Life (yrs)	Remarks
	Name	Operator	Location		Day	Year						
Surface Mining	Jackpile	Anaconda	Paguate, NM	9	4230 Ore	1.3E6 Ore	Drill and Blast	412	1.4E2	NA	20	
Underground Mining	Ambrosia Lake	Kerr-McGee	Ambrosia Lake, NM	0.3	4230 Ore	1.3E6 Ore	Drill and Blast	1100	NA	NA	20	Actually seven small mines
Uranium Milling	Highland	Exxon	Douglass, WY	0.12	1810 Ore	6.6E5 Ore	Acid Leach	92	NA	2.7	20	Tailings need 1.0 km ²
Purification and Conversion	Sequoyah	Kerr-McGee	Sequoyah, OK	0.3	25	9.1E3	Solvent Extraction and Fluorination	155	NA	NA	40	
Enrichment (Diffusion)	(Conceptual)	--	--	1.8	36.5	1.33E4	Gaseous Diffusion	1400	2.4E6	94	40	8.75E6 SWU/yr 2.1E3 MT/yr product U
Enrichment (Centrifuge)	(Conceptual)	--	--	1.5	36.7	1.34E4	Gaseous Centrifuge	2450	1.3E5	11	40	8.8E6 SWU/yr 2.1E3 MT/yr product U
Uranium Fuel Fabrication	Columbia	Westinghouse	Columbia, SC	0.24	4.38	1.6E3	ADU and Mechanical Press	1850	8.8E3	1.3	40	BWR and PWR fuel; Assemblies MOX
Mixed Oxide Fuel Fabrication	Anderson ^(b)	Westinghouse	Anderson, SC ^(b)	0.07	1.1 MOX ^(c)	400 MOX ^(c)	Mechanical Mix and Press	260	2.7E3	0.2	40	
Reactor	Trojan	Portland General Electric	Rainier, OR	0.08	1130 MWe ^(d)	--	Pressurized Water	210	4.0E4	160	40	
Reactor	WNP-2	Washington Public Power Supply System	Richland, WA	0.12	1100 MWe ^(d)	--	Boiling Water	170	5.0E4	84	40	
Fuel Reprocessing	Barnwell	Allied-General Nuclear Services	Barnwell, SC	0.32	5 HM ^(e)	1500 HM ^(e)	Purex Solvent Extraction	470	1.2E4	15	40	

NA = Not available at this time

(a) Capacity is as MT of U input unless otherwise stated.

(b) Proposed; does not yet exist.

(c) As fuel rods only; rods are assembled in U fabrication plant.

(d) Net electrical output.

(e) As original heavy metal (HM) in fuel; or original U, plus original Pu for MOX.

TABLE 2-2. Summary of Effluents from Reference LWR Fuel Cycle Facilities

Fuel Cycle Step	Airborne Effluents						Liquid Effluents					
	U, kg/d	Other Radionuclide kg/d	Total Ci/d	Total kg/d	Chemicals(b)	Total Product in Effluent	U, kg/d	Other Radionuclide kg/d	Total Ci/d	Total kg/d	Chemicals(b)	Total Product in Effluent
					Major Components						Major Components	
Surface Mining	6.4 ^(a)	>5E-6	NA	~4200	Rock Dust	0.1	NA ^(a)	NA	NA	~800	Ca, Mg, Fe Salts	NA
Underground Mining	5.7 ^(a)	>5E-6	NA	~4200	Rock Dust	0.1	0.9 ^(a)	>6E-8	NA	2.4E4	Cl, Na, SO ₄ Ca Salts	0.014
Uranium Milling	1.6 ^(a)	~2E-5	NA	~800	Dust, Kerosene	0.06	0.8 ^(a)	~5E-4	NA	1.5E4	SO ₄ , Al, Fe Mg, Salts	0.03
U Purification and Conversion	0.09	NA	NA	~1000	Hexane, NO _x , SO _x	3.5E-4	27	NA	NA	~1600	Cl, Na, SO ₄ Ca Salts	0.11
Uranium Enrichment (Diffusion)	0.055	NA	NA	~210	Trichloroethylene, Freon, Co, NO _x	9.6E-4	0.37	NA	NA	2800	Na, Cl, Ca, SO ₄ Salts	0.0065
Uranium Enrichment (Centrifuge)	0.055	NA	NA	~170	Trichloroethylene, CO, NO _x	9.6E-4	0.45	5E-11	2E-3	~950	NO ₃ , Cl, Na, SO ₄ , Ca	0.0078
U Fuel Fabrication	5.1E-3	NA	NA	~900	NH ₃	1.2E-4	5.3E-4	NA	NA	~2100	Ca, SO ₄ , Na Salts	1.2E-5
MOX Fuel Fabrication	1.4E-8 (Pu, 6.5E-10)	NA	NA	~2000	N ₂ , H ₂	1.5E-9 (1.5E-9, Pu)	1.5E-7 (Pu, 6.9E-9)	NA	NA	4	NO ₃ , Na	1.6E-10 (1.6E-10, Pu)
PWR	NA	1E-5	18	NA	NA	NA	NA	4E-7	4	7300	SO ₄ , Na Salts	NA
BWR	NA	1E-5	23	8.0E2	SO ₄ , Ca HCO ₃	NA	NA	4E-9	4E-2	6800	SO ₄ , Ca, HCO ₃ , Mg, Na Salts	NA
Fuel Reprocessing	0.10	30	9E4	1400	NO _x , Fluorocarbons, H ₂	2.0E-3 9E-8	0	0	0	750	CO ₂ , K	0

NA = Not available at this time

(a) Assumes 0.15 U in ore

(b) Water, sanitary effluents, and combustion effluents are not included.

facility. Chemical pollutants released to surface waters also vary widely, and average about 7000 kg/day^(a) from each facility. For each 1000 MWd of electrical power, these values translate to approximately 750 kg/day of chemicals in airborne effluents and 11,000 kg/day in liquid effluents.

Wastes in this study are defined as materials from the nuclear fuel cycle that are disposed of with the intent that they remain isolated from man's environment, and do not enter our environment in significant quantity to become a major health hazard during the life of their important toxicity. Disposal of wastes was not studied here, but is typically done by shallow land burial or deep geologic burial, and is frequently preceded by pretreatment and conversion of "raw" wastes into solid forms with low mobility.

Wastes from each of the reference nuclear fuel cycle facilities operating at 100% capacity are summarized in Table 2-3. A total of about 8.2% of the uranium is lost in the wastes from the total fuel cycle, whereas a total of about 1.4% of the plutonium is lost in the wastes. Most of the uranium in waste is from milling of the uranium ore. Essentially all of the plutonium in the waste is from mixed oxide fuel fabrication and spent fuel reprocessing. The total radioactivity in the wastes from spent fuel reprocessing represents more than 99.9% of the total. The largest weight or volume of radioactive waste is from uranium mining and milling, and accounts for more than 99% of the total waste.

Relatively little information was obtained about quantities and constituents of nonradioactive wastes from the reference fuel cycle.

A considerable amount of plant descriptive and effluent performance information that is necessary to perform cost effectiveness analyses of alternative effluent management systems was not identified within the resources of this study. Consequently, additional derivation of pertinent information is needed. However, it is believed that the compilation of information presented in this study provides a basis for decisions related to meaningful and more comprehensive studies on effluent control effects and improvements needed in nuclear fuel cycles.

^(a) The actual value is slightly greater than this because some chemical effluents from some facilities were not identified.

TABLE 2-3. Summary of Wastes from Reference
LWR Fuel Cycle Facilities

Fuel Cycle Step	Source	Form	Radioactive Waste			Product in Waste		Nonradioactive Waste		
			Volume, ℓ/d	Weight, kg/d	Ci/d	kg U/d	%	Form	Volume, ℓ/d	Weight, kg/d
Surface Mining	Mine Equipment	Rock Rubble, Hardware	NA NA	4.2E6 NA	NA ~0	low low	~0 ~0	Rock Rubble, Hardware	NA NA	NA NA
Underground Mining	Mine Equipment	Rock Rubble, Hardware	NA NA	NA NA	NA ~0	low low	~0 ~0	Rock Rubble, Hardware	NA NA	NA NA
Uranium Milling	Ore, Process	Tailings	NA	~2.3E6	(a)	170	6.5	Miscellaneous	NA	NA
U Purification and Conversion	Process	Precipitate	NA	8.5E4	NA	11	0.044	Ashes, Trash	NA	NA
Uranium Enrichment (Diffusion)	Process, (b) Ash, Trash, Equipment	Sludge, (b) Varied	390 NA	NA NA	NA NA	NA NA	NA NA	Ashes, Trash	NA	NA
Uranium Enrichment (Centrifugation)	Traps and Failed Centrifuges	Alumina, Aluminum, Steel, Iron, Brass Alnico V, Plastic, Rotor Material	NA	3.4	2.4E-3	3.4	5.9E-2	Ashes, Trash	NA	NA
U Fuel Fabrication	Process, Scrap	Sludge, Varied	<52,000 >1,050	NA NA	NA NA	9 <4.5	0.12 0.1	Scrap, Hardware	~11	~70
MOX Fuel Fabrication	Process, Scrap	Sludge, Ash, Hardware	>240	7 U, ~0.3 Pu	NA	~4.6, 2.2E-1 Pu	~0.5 ~0.5 Pu	Trash, Hardware	>2.1	>0.1
PWR	Process, Miscellaneous	Slurry, Miscellaneous	160	NA	NA	low	~0	Miscellaneous	NA	NA
BWR	Process, Miscellaneous	Slurry, Miscellaneous	1,150	NA	NA	low	~0	Miscellaneous	NA	NA
Fuel Reprocessing	Process, (c) Equipment, Miscellaneous	Varied, Hardware, Miscellaneous	~3,600 ~1,400 ~12,000	~2,400 NA ~12,000	~5E5 (d) NA low	15 U 0.12 Pu low low	~0.3 U ~0.3 Pu low low	Miscellaneous	2,000	NA

NA = Not available at this time

(a) Approximately 85% of the total curies in the fresh ore.

(b) Does not include tails of U depleted in ^{235}U . These constitute 3.6E4 kg/day total, or 2.5E4 kg/day U, for a total of 83% of the U in the feed.

(c) Does not include high level or intermediate level wastes, which are accumulated in this study. High level waste is assumed to contain 0.5% of the input uranium and plutonium. Intermediate level contains 0.1% of uranium and plutonium.

(d) Essentially all of this radioactivity is from cladding hulls.

3.0 TECHNICAL APPROACH

The overall approach in the study was to select a reference LWR fuel cycle, select reference facilities for each step in the fuel cycle, and characterize and describe each reference fuel cycle facility.

The reference fuel cycle and facilities were selected primarily based on their applicability to conditions that were typical at the start of this study (1976) or may be typical in the near future. The fuel cycle system selected was the LWR fuel cycle without plutonium recycle but with fabrication of PuO_2 - UO_2 fuels that are stored for future use. Processes and technology that have not advanced at least through pilot plant scale were not considered. Actual facilities were selected wherever possible; in some cases, these real facilities were conceptually modified to accommodate the fuel cycle concept. Where existing or planned facilities do not exist, conceptual facilities were used. In some cases, more than one facility was studied.

The characterization of each fuel cycle facility involved several activities:

- brief description of process, facility and site
- analysis of the mainline process performance and effluent control process performance
- description and analysis of wastes and the associated waste management steps
- description of operating and capital cost elements
- description of land, utility, and energy needs.

In this study, mainline processing includes all bulk effluent controls and recycle systems integral to the mainline process; effluent control processing entails final effluent treatment steps that prepare the effluent stream for release to the environment. Wastes are materials that are intended to be isolated from our environment. Waste management in this study includes treatment, packaging, and interim onsite storage of the wastes. Ultimate disposition of the wastes is beyond the scope of the study to date.

Two generic sites were defined in this study to allow for comparisons of overall environmental impacts of the various fuel cycle steps. One generic site, representative of dry western U.S. areas, is used for mines and mills; the other generic site, representative of midwestern or south mideastern U.S., is used for all other fuel cycle facilities.

The study was performed separately by fuel cycle step, with some distinction between mainline and effluent processing.

The information in this study was developed from public documents (e.g., technical papers and reports, Safety Analysis Reports, Environmental Reports, etc.), the Generic Environmental Statement for Use of Mixed Oxide Fuels, NUREG-0002, and investigators' judgment where information was conflicting or lacking. In some cases, tabular information is indicated as being "not available". These instances occurred when information was simply not available, when the information found was considered unreliable, or when reliable information could not be located within the time and resource constraints of the project. It is felt that information identified in this report as "not available" is of secondary importance to the objective of the project. However, its identification is considered a part of the completeness of this study and may form the basis of further inquiry for other environmental studies.

4.0 FUEL CYCLE DEFINITION

The reference LWR fuel cycle case studied here applies to both pressurized water reactors (PWR) and boiling water reactors (BWR). Each reactor is considered to be operating on only enriched uranium from natural uranium. However, the fuel fabrication step for recycle of plutonium in LWRs was included. Depleted uranium tails from enrichment and from reprocessing are considered to be temporarily stored for possible future recycle.

The reference case for each fuel cycle step is shown in Figure 4.1. Brief summaries are given below:

1. Mining
 - two mine types (1 surface, 1 underground)
 - two ore feeds to each mine (0.25% U in ore, 0.025% U in ore)
 - two products from each mine (same enrichment as ores)
2. Milling
 - one mill process (acid leach followed by solvent extraction)
 - blending at mill to give the same single feed (yellowcake or ammonium diuranate) to each mill and to be 0.15% U initially (although there may be some restrictions on what mills can handle what ores)
3. Purification and Conversion^(a)
 - one conversion process (aqueous)
 - one feed (that from the mills above, which is 74.2% U or 87.5% U_3O_8 equivalent)
 - one product (uranium hexafluoride)
4. Enrichment
 - two simplified enrichment plants, one gaseous diffusion and the other gas centrifuges for enrichment of uranium for power reactors only
 - one feed (natural uranium hexafluoride from the conversion plants)

^(a)Weight of U = 0.848 x weight of U_3O_8 or 0.7628 x weight of $(NH_4)_2U_2O_7$.

- products of one enrichment (3.2% ^{235}U). (However, the enrichment plant has the capability for a variety of enrichment levels needed for LWRs)
- tails at 0.25% ^{235}U as uranium hexafluoride, to be sent to interim storage

5. Fuel

Fabrication

- two facilities, for uranium dioxide fuel and mixed oxide (uranium dioxide/plutonium dioxide) fuel. The uranium fuel plant provides uranium dioxide to the mixed oxide plant, receives the mixed oxide pins from the mixed oxide plant, and completes the final fuel element assembly.
- two basic feeds (uranium hexafluoride and plutonium dioxide), with the uranium feeds having one enriched uranium mixture and one natural uranium
- four basic products (uranium oxide only and mixed oxide for both PWR and BWR). The mixed oxide fuels are stored for future use.

6. Reactors

- two facilities (PWR and BWR)
- each facility operating under one mode: once-through uranium after startup
- two products (one from each reactor)

7. Fuel

Processing

- one facility/process operating on spent fuels 0.5 years out-of-reactor
- one feed (from reactors above); feed is transported after as little as 120 days out-of-reactor time
- two products (plutonium dioxide, which is returned to fuel fabrication, and uranium hexafluoride, which is temporarily stored)

8. Transportation

- feeds and products are all radioactive materials transported

FIGURE 4-1. LWR Study Cases for Fuel Materials Flow for Program: Analysis of Nuclear Fuel Cycles

9. Waste

Management

- waste materials are from each case for each fuel cycle step
- facilities/processes for ultimate disposal, and transportation and ultimate disposal are not included.

For each fuel cycle step, information given in this report is based on a 24 hour operating (100% capacity) day, unless otherwise noted. Each reference facility has its own production rate and operating conditions. In later analyses of alternative fuel cycle conditions from other aspects of the study program, these will be normalized to a unit production of electricity.

The performance of each facility for product recovery, product impurities and effluent cleanup performance are expressed in decimal fractions. This allows later quantification by computer for individual nuclides or chemical constituents.

GENERIC SITES

5.0 REFERENCE SITES

Two reference sites are used to illustrate potential generic environmental effects of nuclear fuel cycle activities. Site A is a typical mine or mill location, while Site B provides a baseline for identifying environmental impacts of other steps in the LWR fuel cycle.

Each site description provides a generic basis for estimating typical environmental impacts. No intent exists to endorse these particular environments for any nuclear fuel cycle facility. The reference sites are considered to be useful for comparative environmental analyses. The plant and animal species identified in these site descriptions may not be the same as those identified at specific sites, but the impact on species (including those endangered) is considered to be sufficiently representative to make this analysis useful.

Individual features of the reference sites may not be the same as those identified in specific sites. However, the use of these generic sites should result in a meaningful overall analysis of potential impacts. Site-specific assessments would be required for individual facilities.

5.A REFERENCE SITE FOR MINE OR MILL

Reference Site A is based primarily on the site of a contemporary surface mine and mill complex in Wyoming.⁽¹⁾ It is believed to be representative of sites for the majority of mines and mills in the U.S.

5.A.1 LOCATION

Reference Site A, for a typical mine or mill, is located in the western or southwestern United States in a semiarid, sparsely populated area. A combined mine-mill complex is used because it is consistent with a significant portion of the operational or projected industry. The fenced-in site occupies approximately 13 km² (3200 acres) in a rectangular area approximately 4 km by 3.25 km.

5.A.2 DEMOGRAPHY

The site is located in a low population area far removed from large urban centers. The largest population density is located between 64 and 80 kilometers (40 to 50 miles) from the site. The average population density out to a radius of 80 kilometers (50 miles) is about 3 persons per square kilometer (7 persons per square mile) with a total population of 56,000 as shown in Table 5.A-1.

TABLE 5.A-1. Population Distribution Around the Reference Mine-Mill Site

<u>Distance from Facility</u>		<u>Population</u>		
		<u>Density</u> <u>(Persons/mi²)</u>	<u>Total in</u> <u>Ring(a)</u>	<u>Cumulative</u>
<u>Miles</u>	<u>Kilometers</u>			
0-1	0-1.6	0	0	0
1-2	1.6-3.2	0	0	0
2-3	3.2-4.8	0	0	0
3-4	4.8-6.4	0	0	0
4-5	6.4-8.0	0	0	0
5-10	8.0-16	0.81	200	200
10-20	16-32	0	0	0
20-30	32-48	3.19	5,000	5,200
30-40	48-64	0.31	700	5,900
40-50	64-80	17.75	50,100	56,000 ^(b)

(a) It is assumed that 1/16 of these persons reside within each of the 16 sectors.

(b) Rounded total

5.A.3 LAND USE

The land surrounding the mine-mill site is predominantly used for the grazing of beef cattle. Although the land within the site was used for pasture before mine or mill operations began, the use of any part of the site for anything other than operations related to the mine or the mill is now

prohibited. Limited farming is conducted on land irrigated by surface water and ground water from the nearest flowing river system, located 25 kilometers (16 miles) south of the site.

The nearest dwelling is a small farm located 0.46 kilometers (0.25 miles) from the site boundary. A milk cow is kept at this site on fresh pasture 5 months of the year. A garden, irrigated with ground water that is not contaminated by the mine operation, is maintained for fresh vegetables. The growing season is three months long.^(1,2)

5.A.4 WATER USE

Seepage water is pumped from the mines at an average rate of 20,000 liters/minute (5200 gallons/minute).^(a) The water requirements for the milling operation are partially filled by the mine discharge water and partially by input from wells.

The mill tailings from the milling operation go to the tailings pond from which the liquid largely evaporates. There is some seepage into the ground, but no known water escapes to the water table during the operating life of the mill, since major vertical communication between the pond and water table is prevented under normal conditions by the geologic structure of the site.⁽³⁾ No known migration of waste chemicals or radioactive materials from the retention pond has occurred to date and none is expected during the operating life of the mill because of the capability of the soil to remove contaminants through ion-exchange, adsorption and chemical reactions.⁽⁴⁾

The release of wastes from mill tailings through flooding of the waste retention pond is unlikely. The watershed above the pond is 2.6 square kilometers (1.0 square mile). The runoff from half of the watershed is diverted by dams above the tailings pond. Thus, the pond, with a 1.5-meter (5-foot) minimum freeboard on the dam, should retain a once-per-1000-year rain of 10.7 centimeters (4.2 inches) in six hours.^(1,2)

There are no lakes or flowing streams near the site, so there is no boating, swimming, fishing, or drinking water affected by the mine-mill operation.

^(a)Reference 3, pp. 22, 23.

5.A.5 GEOLOGY

Reference Site A is located on an intermountain plateau. The area is characterized by rolling foothill topography, typical of the region,⁽¹⁾ having elevation changes of 90 meters (300 feet) within 5 kilometers (3 miles). Local slopes are 20 to 30%. Intermittent streams flow in the lower valleys.

The rocks underlying the region, including the reference site, are relatively old sedimentary formations. Immediately beneath the surface soils, which vary from 1 to 3 meters (3 to 10 feet) deep, are alternating layers of shales and coarse sandstones. These rest on a layer of sandstone with a thickness of 600 meters (2000 feet). The rock bedding is essentially horizontal and slopes generally northward.

No surface or subsurface faults have been discovered in the area around the site, and it is classified as a Zone One Seismic Risk Category,^(1,4) i.e., one for which "minimum damage" is expected from earthquakes.

5.A.6 HYDROLOGY

The site lies in a hilly, arid region with no permanent surface water within a radius of 25 kilometers (16 miles). Intermittent creeks flow in the valleys after periods of heavy rain and during periods of melting snow. Because of low precipitation, the creek system does flow continuously at any time of the year.⁽¹⁾ The local surface drainage area of the site comprises about 80 square kilometers (30 square miles) that drain to a river 110 kilometers (68 miles) to the east. Because of the local topography, surface runoff does not reach the only continuously flowing surface water in the area, a river 25 kilometers (16 miles) to the south.

Groundwater is present in large quantities in the sandstone beds underlying the site and local area. The groundwater flow velocity is about 7 to 10 meters per year (23 to 32 feet per year).⁽¹⁾ The groundwater is potable. The quality of the water is given in Table 5.A-2.

The uranium ore body is below the local water table; therefore seepage water is pumped from the mine to ponds on the surface and to the mill for process use. The pumping results in a local depression in the water table

at the site, but there is sufficient water in the aquifer to supply the mill for its operating life without a significant reduction in the level of the water table.^(1,4) The water supply outside the plant boundary is unaffected.

TABLE 5.A-2. Water Quality Data
at the Reference
Mine-Mill Site^(1,4)

<u>Contaminant</u>	<u>Concentration</u>
Uranium	1-100 parts per billion
Arsenic	0.05 parts per million
Selenium	0.02 parts per million
Ions	4.5 to 20 meq/ℓ
pH	6.2 to 8.0
Radium-226	4.2×10^{-1} pCi/ℓ
Thorium-230	99 pCi/ℓ
Gross Alpha	100 pCi/ℓ
Gross Beta	95 pCi/ℓ

Since there are no flowing streams in the area and the groundwater is essentially uncontaminated by the mine or mill operation, there are no known liquid pathways for the dissemination of chemical or radiological contaminants from the reference site during the operating life of the plant.^(1,2,4)

5.A.7 METEOROLOGY

The site has a semi-arid climate with an average precipitation rate of 30 cm (12 in.) per year. Snowfall ranges between 89 and 170 cm (35 to 65 in.).⁽¹⁾ The potential evaporation rate is about 130 to 150 cm (51 to 59 in.) per year.

The area has persistent winds and occasional dust storms. Prevailing winds are from the south-southeast about 16% of the time. Pasquill Class D

(neutral) is the predominant stability category, with an average wind speed of about 5.7 m/sec (11 mph). For the average wind speeds shown in Table 5.A-3, Table 5.A-4 shows the national weather service joint frequency distribution for the western U.S. site. For a Gaussian plume rise from a 10 m release height, the calculated atmospheric dispersion ($\bar{x}/Q'$) for each segment versus direction is shown in Table 5.A-5.

TABLE 5.A-3. Average Wind Speed
Classes at the
Reference Mine-Mill
Site

<u>Wind Speed Class</u>	<u>Wind Speed (meters/sec)</u>
1	0.26
2	1.0
3	2.3
4	4.1
5	6.7
6	9.5
7	13

TABLE 5.A-4. Western U.S. Site for Uranium Mine-Mills

Wind Speed Class	Stability Class	Direction																Total
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	WNW	
1	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	A	0.05	0.01	0.03	0.01	0.03	0.00	0.02	0.00	0.03	0.06	0.01	0.04	0.06	0.01	0.04	0.02	0.41
3	A	0.02	0.03	0.01	0.00	0.02	0.00	0.00	0.01	0.03	0.03	0.01	0.03	0.03	0.05	0.02	0.04	0.33
4	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	B	0.33	0.08	0.25	0.05	0.24	0.04	0.21	0.27	0.48	0.58	0.38	0.27	0.27	0.20	0.23	0.18	4.03
3	B	0.23	0.05	0.13	0.02	0.10	0.05	0.05	0.12	0.14	0.23	0.11	0.16	0.15	0.15	0.15	0.13	1.98
4	B	0.14	0.04	0.07	0.01	0.03	0.01	0.04	0.05	0.11	0.18	0.05	0.12	0.05	0.12	0.10	0.16	1.28
5	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	C	0.13	0.06	0.14	0.02	0.17	0.03	0.13	0.18	0.26	0.24	0.19	0.14	0.18	0.09	0.15	0.10	2.21
3	C	0.30	0.08	0.11	0.02	0.12	0.01	0.12	0.33	0.29	0.36	0.20	0.18	0.11	0.19	0.18	0.20	2.79
4	C	0.56	0.15	0.21	0.03	0.12	0.10	0.24	0.65	0.53	0.58	0.19	0.31	0.19	0.39	0.41	0.50	5.16
5	C	0.08	0.02	0.05	0.00	0.00	0.00	0.01	0.12	0.07	0.13	0.02	0.05	0.02	0.06	0.02	0.07	0.72
6	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.02	0.00	0.01	0.00	0.02	0.01	0.02	0.16
7	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.12
1	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	D	0.34	0.15	0.28	0.02	0.14	0.03	0.13	0.15	0.26	0.22	0.05	0.13	0.17	0.14	0.30	0.28	2.92
3	D	0.71	0.26	0.33	0.06	0.25	0.07	0.21	0.32	0.26	0.43	0.16	0.19	0.27	0.26	0.32	0.58	4.67
4	D	2.01	0.69	0.86	0.20	0.41	0.23	0.50	2.02	0.95	1.20	0.26	0.46	0.40	0.80	0.87	1.92	13.76
5	D	2.47	0.54	0.40	0.07	0.29	0.14	0.37	2.98	1.15	1.93	0.21	0.34	0.17	0.80	0.97	1.96	14.77
6	D	1.03	0.15	0.14	0.01	0.04	0.04	0.03	1.25	0.29	0.83	0.10	0.17	0.04	0.32	0.47	0.96	5.87
7	D	0.53	0.06	0.02	0.01	0.01	0.00	0.01	0.70	0.20	0.68	0.15	0.22	0.00	0.19	0.26	0.65	3.69
1	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	E	0.37	0.09	0.24	0.05	0.17	0.06	0.32	0.69	0.34	0.47	0.21	0.20	0.21	0.26	0.17	0.25	4.10
4	E	0.43	0.12	0.26	0.06	0.21	0.07	0.47	2.14	0.39	0.55	0.11	0.14	0.16	0.26	0.15	0.14	5.67
5	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	F	1.26	0.31	0.77	0.15	0.72	0.20	1.67	2.49	2.93	2.83	1.61	1.39	1.00	0.69	0.85	0.90	19.77
3	F	0.41	0.13	0.24	0.02	0.15	0.07	0.51	1.40	0.60	0.72	0.33	0.32	0.19	0.19	0.20	0.30	5.77
4	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		11.41	3.02	4.53	0.81	3.22	1.20	5.02	15.93	9.33	12.29	4.46	4.88	3.67	5.17	5.86	9.36	100.16

TABLE 5.A-5. Generic Western U.S. Site for Uranium Mine-Mills.
 $\bar{X}/Q'$ for Each Segment from a 10 Meter Release Height (sec/m³).

Direction	Segment Boundaries in Kilometers									
	1.6	3.2	4.8	6.4	8.0	16	32	48	64	80
S	2.7E-06	8.5E-07	3.7E-07	2.2E-07	1.5E-07	7.6E-08	2.9E-08	1.4E-08	9.0E-09	6.4E-09
SSW	7.5E-07	2.4E-07	1.0E-07	6.2E-08	4.2E-08	2.1E-08	7.8E-08	3.8E-09	2.4E-09	1.7E-09
SW	1.6E-06	4.8E-07	2.1E-07	1.2E-07	8.7E-08	4.3E-08	1.6E-08	8.1E-09	5.2E-09	3.7E-09
WSW	2.6E-07	8.2E-08	3.6E-08	2.2E-08	1.5E-08	7.9E-09	2.9E-09	1.4E-09	9.1E-10	6.6E-10
W	1.2E-06	3.9E-07	1.7E-07	1.0E-07	7.1E-08	3.5E-08	1.4E-08	6.8E-09	4.3E-09	3.1E-09
WNW	3.9E-07	1.2E-07	5.4E-08	3.2E-08	2.2E-08	1.1E-08	4.2E-09	2.1E-09	1.3E-09	9.6E-10
NW	2.5E-06	7.9E-07	3.5E-07	2.2E-07	1.5E-07	7.5E-08	2.9E-08	1.5E-08	9.4E-09	6.8E-09
NNW	4.8E-06	1.5E-06	6.7E-07	4.1E-07	2.8E-07	1.4E-07	5.4E-08	2.7E-08	1.7E-08	1.2E-08
N	4.2E-06	1.3E-06	5.9E-07	3.6E-07	2.5E-07	1.2E-07	4.9E-08	2.4E-08	1.6E-08	1.1E-08
NNE	4.4E-06	1.4E-06	6.2E-07	3.7E-07	2.6E-07	1.3E-07	5.0E-08	2.5E-08	1.6E-08	1.2E-08
NE	2.3E-06	7.2E-07	3.2E-07	1.9E-07	1.3E-07	6.8E-08	2.6E-08	1.3E-08	8.6E-09	6.2E-09
ENE	2.1E-06	6.5E-07	2.9E-07	1.7E-07	1.2E-07	6.1E-08	2.4E-08	1.2E-08	7.6E-09	5.5E-09
E	1.6E-06	5.0E-07	2.2E-07	1.3E-07	9.2E-08	4.6E-08	1.8E-08	8.9E-09	5.7E-09	4.1E-09
ESE	1.4E-06	4.2E-07	1.9E-07	1.1E-07	7.7E-08	3.8E-08	1.5E-08	7.2E-09	4.6E-09	3.3E-09
SE	1.6E-06	5.1E-07	2.2E-07	1.3E-07	9.3E-08	4.6E-08	1.7E-08	8.6E-09	5.5E-09	3.9E-09
SSE	2.0E-06	6.3E-07	2.8E-07	1.7E-07	1.2E-07	5.6E-08	2.1E-08	1.0E-08	6.6E-09	4.7E-09

Average summer temperatures are around 21°C (70°F). Extreme seasonal temperatures reach 38°C (104°F) and -40°C (-40°F).

5.A.8 ECOLOGY

Because the reference mine-mill site does not impact the aquatic systems during the operating life of the mill, only terrestrial ecological impacts are presented.

The area around the site is uncultivated and used only for limited grazing.⁽¹⁾ The dominant vegetation is shrubs and grasses; their abundance is dependent on seasonal and annual changes in environmental conditions, such as rainfall. Predominant shrubs are Big Sagebrush, Silver Sagebrush, and Small Soapweed. Grasses include Indian Rice Grass, Prairie Sandreed Grass, Western Wheatgrass, Bearded Bluebunch Wheatgrass, and Cheat Grass. Local forbs include Russian Thistle, Prairie Sunflower, Buckwheat, and common

dandelion. Some cottonwood trees grow in the valleys along the beds of intermittent streams. There is no evidence of rare or endangered vegetation species at the Reference Site A.

The most important wildlife in the area of the reference site is Pronghorn Antelope and Sage Grouse. Site A is located next to an antelope management area. The antelope population density is about 2 per km² (5 per mi²). Hunting is mainly directed at the Sage Grouse. The site is not a preferred hunting area, nor is it used as a resting place for migrating birds.

Some lesser species of mammals and birds typically found in the area are given in Table 5.A-6.

TABLE 5.A-6. Animals that Are Found Near the Reference Mine-Mill Site

Mule Deer	Red Fox
Cottontail Rabbits	Badger
Hungarian Partridge	Prairie Dogs
Mourning Doves	Song Birds
Coyotes	Migrating Waterfowl
Bobcats	

A few bird species considered to be endangered are known to frequent the area.⁽¹⁾ They are listed in Table 5.A-7. The Peregrine Falcon and Trumpeter Swan pass through the area on their annual migrations. The Golden Eagles and Bald Eagles use the area around the reference site as a wintering ground. A few Golden Eagles remain year-round.

TABLE 5.A-7. Wildlife Considered to be Rare or Endangered within the Reference Mine-Mill Site

Ferruginous Hawk	Bald Eagle
Trumpeter Swan	American Peregrine Falcon
Golden Eagle	

The soil in the area of the reference site is 30 to 90 centimeters (1 to 3 feet) deep except in the valley bottoms, where soil has been built up by alluvial deposition to depths of over 3 m (10 ft). The soils consist of brown, silty sands and are similar to the residual soils found on the hill-sides. Embankments 3 to 6 m (10 to 20 ft) high, and composed of fine sandy silt, are adjacent to both sides of the creeks.

5.B REFERENCE SITE FOR ALL FUEL CYCLE FACILITIES EXCEPT MINES AND MILLS

Reference Site B is based primarily on typical LWR sites defined in the ALAP study for 10 CFR 50 Appendix I⁽⁵⁾ for the river site for the year 2000. It is believed to be representative of potential sites for fuel cycle facilities other than mines or mills in the U.S. The ecological information was derived from the environment of an operating nuclear reactor.⁽⁶⁾

5.B.1 LOCATION

The reference site is located in a rural area with characteristics similar to those found in midwestern or south mideastern United States. The site occupies 4.7 km² (1160 acres) in a rectangular shape of 2 km (1.24 mi) by 2.35 km (1.46 mi). A moderately large river runs through one corner of the site.

5.B.2 DEMOGRAPHY

The reference site is located in a rural area that has relatively low population density, with highest population densities occurring at distances of 16 to 64 km (10 to 40 mi) away, and gradually reducing population densities out to 177 km (110 mi). The population numbers are given in Table 5.B-1. The total population out to 80 km (50 mi) is 3.52 million.

TABLE 5.B-1. Population Distribution Around the Reference Fuel Cycle Facility Site

<u>Distance from Facilities</u>		<u>Population</u>	<u>Total Population</u>	<u>Cumulative</u>
<u>(miles)</u>	<u>(kilometers)</u>	<u>Density</u> <u>(persons/mi²)</u>	<u>in Annulus^(a)</u>	<u>Population</u>
0 - 1	0 - 1.6	---	10	10
1 - 2	1.6 - 3.2	226	2,130 ^(b)	2,140 ^(b)
2 - 3	3.2 - 4.8	333	5,230	7,370
3 - 4	4.8 - 6.4	361	7,940	15,300
4 - 5	6.4 - 8.0	415	11,700	27,000
5 - 10	8.0 - 16	379	89,300	116,000
10 - 20	16 - 32	398	375,000	491,000
20 - 30	32 - 48	559	878,000	1,367,000
30 - 40	48 - 64	469	1,030,000	2,400,000
40 - 50	64 - 80	398	1,120,000	3,520,000

(a) It is assumed that 1/16 of these persons reside within each of the 16 sectors.

(b) Totals are rounded to three significant figures.

5.B.3 LAND USE

The use of any part of the total site area of 4.7 km² (1160 acres) for anything besides the fuel cycle facility is prohibited. The plant facilities are located inside a much smaller fenced-in portion (0.12 km², or 30 acres) of the site, with a minimum distance of 1 km (0.6 mi) from the point of plant airborne releases to the outer site boundary (fenced and marked).

In most of the surrounding area about 80% of the land is used for farming. The main crops in this area, which include all land within 16 km (10 mi) of the site, are soybeans (60%), corn, oats, and other grain (30%) and hay (10%). It is expected that this area will remain largely agricultural and that its population will not change significantly.

A wildlife refuge is located about 14 to 19 km (9 to 12 mi) from the site. A State Forest and campground are about 14 km (9 mi) away from the site, near the wildlife refuge. A State Park is located about 10 km (6 mi) in the opposite direction.

The nearest dwelling is a farm house located 1.3 km (0.8 mi) from the site. A milk cow is kept at this farm and is maintained on fresh pasture 7 months of the year. A family garden is kept for vegetables with a growing season of 5 months. River water is used for irrigation of this farm. There are large truck gardens in the area.

5.B.4 WATER USE

The river is used for dispersal of acceptable liquid effluents from the fuel cycle facility, and for irrigation, fishing, boating and other aquatic recreational activities. Its shores are used for hunting and for marinas and docks, and the public has complete access to the river (except to onsite shorelines). It is assumed that one-sixth of the average person's diet comes from food crops irrigated by the river water downstream of the site, and one-third of the maximum exposed individual's food intake is from the same source.

In the vicinity of the plant it is assumed that a limited number of individuals spend 50 hr/yr swimming, 50 hr/yr boating, and spend 70 hr/yr fishing on the shoreline, obtaining 20 kg of fish. Essentially no fresh water molluscs or crustacea are taken from the river. Aquatic foods are assumed to be consumed within 24 hours of the time they are caught.

Drinking water is taken from the river by larger towns and cities. Individuals living immediately downstream near the river derive their potable water from wells and not directly from the river.

For development of population radiation doses, the following assumptions were made: 20% of the residents within 80 km (50 mi) of the site obtain their drinking water from the reference river, and travel time from the site to the urban water consumer is 48 hours; each person not in the vicinity of the plant spends on the average 2 hr/yr swimming, 4 hr/yr boating, and 4 hr/yr on the

(a) Reference 5, Figure 6B-1, p. 6B-43, and Figure 6C-8, p. 6C-12.

shoreline downstream of the site;⁽²⁾ the average per capita fish consumption for this area is 6.9 kg/yr;⁽⁷⁾ and 15% of this consumption is from fish obtained downstream from the site.

The region has no large commercial fishing operations. Most of the fish catch is caught by local recreational anglers for home consumption.

5.B.5 GEOLOGY

The Reference Site B occupies a low bluff that forms a bank of the river running through one corner of the site. Several flat alluvial terraces comprise the main topographic features on the property. These terraces lie at average elevations of 280 to 284 m (918 to 932 ft) above sea level and, in general, slope away from the river at grades of 2 to 3%. The topography at the site is typical of that in the area and the region.

The rocks that underlie this region, including the reference site, are relatively old. Glaciation from probably less than 1,000,000 years ago, as well as recent alluvial deposition, have mantled the older rocks with a variety of unconsolidated materials in the form of glacial moraines, glacial outwash plains, glacial till and river bed sediments. This cover of young soils rests upon a surface of glacially carved bedrock consisting of sandstone, shale and granitic rocks. The bedrock surface is irregular and slopes generally to the east or southeast.

The nearest known or inferred fault is 37 km (23 mi) southeast of the site. There is no indication that faulting has affected the area of the site in the last few million years. Within the last 110 years, only two earthquakes were recorded as having occurred within 160 km (100 mi) of the site. The first occurred in 1917 and had an intensity of 6 on the Modified Mercalli scale. The epicenter was located about 97 km (60 mi) from the site. The second occurred in 1950 with an estimated intensity of 5 to 6, and the epicenter was located about 130 km (80 mi) from the site. For construction of facilities in this area, the Design Basis Earthquake relates to a horizontal acceleration of 0.25 g.

5.B.6 HYDROLOGY

The site lies on the outwash plain of the river running across its corner. This plain is bounded by a glacial moraine containing numerous lakes and swampy areas. Drainage from the moraine converges with drainage from the terraces and swales, and flows generally southeast into the river. The natural surface drainage of the immediate site area is mainly to the southwest, away from the river. Surface runoff tends to collect in the depression at the south end of the terrace, where it is bounded by higher ground.

The river tributaries close to the site are a creek, 8 km (5 mi) northwest, and another creek, 4.8 km (3 mi) southeast. Another river flows approximately parallel to the plant-site river along a line 6.4 km (4 mi) north of the site, joining the plant-site river 24 km (15 mi) downstream from the site.

Large supplies of groundwater are available from the plant-site river outwash plain alluvium, glacial moraine, and from underlying sandstones in the area. The general course of deep groundwater flow is to the southeast. The regional gradient broadly parallels the trend of the topography and the surface drainage.

The groundwater levels near the site are relatively flat and slope toward the river during normal river stages. During periods of high river flow, there may be some reversal of groundwater flow. These reversals would be of short duration and infiltration of water from the river would be limited. The gradient toward the river is reestablished after the high water recedes.

River flow information based on 40 years of data from the plant river gaging station shows an annual average flow rate of $1420 \text{ m}^3/\text{sec}$ (50,000 cfs). River flow and temperature data pertinent to the reference site are shown in Figures 5.B-1 and 5.B-2, respectively.

The river is assumed to be reasonably free of pollution as shown in Table 5.B-2. It is moderately turbulent during the spring. Little or no stratification of water occurs. There is no tidal influence. The average river velocity at the site varies between 0.46 and 0.76 m/sec (1.5 and 2.5 ft/sec) for flows below $2000 \text{ m}^3/\text{sec}$ (72,000 cfs). The river drops about 3 m (10 ft) from 2.4 km (1.5 mi) upstream to 2.4 km (1.5 mi) downstream of the site. Rapids frequently occur in this stretch of the river.

FIGURE 5.B-1. Recorded Daily Average and Extreme River Flows at the Reference Fuel Cycle Facility Site

FIGURE 5.B-2. Daily Average and Extreme Water Temperatures at the Reference Fuel Cycle Facility Site

TABLE 5.B-2. River Water Chemistry at the Reference Fuel Cycle Facility Site (Summary of 12 Monthly Samples)

	Minimum	Maximum	Average	Standard Deviation	Number of Samples
<u>Solids (mg/L)</u>					
Total	143	216	185	23.2	1212
Dissolved	125	208	178	27.8	12
Suspended	1.2	18.4	7.5	6.2	12
<u>Hardness (mg/L)</u> (as CaCO ₃)					
Total	98	174	147	24.8	12
Calcium	70	120	99	15.6	12
Magnesium	28	58	48	9.9	12
<u>Alkalinity (mg/L)</u> (as CaCO ₃)					
Total	91	165	140	24.3	12
Phenolphthalein	0	12	1.8	4.1	12
<u>Gases (mg/L)</u>					
Free Carbon Dioxide	--	--	--	--	--
Ammonia-Nitrogen (N)	0	0.09	0.02	0.03	12
<u>Anions (mg/L)</u>					
Carbonate (CO ₃ ⁻²)	0	14.4	2.10	4.96	12
Bicarbonate (HCO ₃ ⁻)	111	201	166	29.1	12
Hydroxide (OH ⁻)	--	--	--	--	--
Chloride (CL ⁻)	0.30	5	1.43	1.48	12
Nitrate-Nitrogen (NO ₃ ⁻)	0.07	0.55	0.26	0.15	12
Sulfate (SO ₄ ⁻²)	6.3	13.5	9.5	2.2	12
Phosphorus-Soluble (PO ₄ ⁻³)	0.012	0.057	0.030	0.012	12
Silicate (SiO ₃ ⁻²)	3.2	12.5	7.7	3.3	12
<u>Cations (mg/L)</u>					
Calcium (Ca ⁺²)	28	48.1	39.7	6.28	12
Magnesium (Mg ⁺²)	6.8	14.1	11.6	2.4	12
Sodium (Na ⁺²)	2.8	6.4	5.0	1.1	12
Total Iron (Fe ⁺²)	0.04	0.52	0.23	0.13	12
Total Manganese (Mn ⁺²)	--	--	--	--	--
Potassium (K ⁺¹)	--	--	--	--	--
<u>Miscellaneous</u>					
Color (APHA units)	20	30	39	22	12
Turbidity (JTU)	1	4.5	2.53	1.48	12
Ryznar Index (AT 25 C)	6.64	7.36	7.21	0.377	12
Conductivity (mmho)	192	350	292	49.8	12
pH	7.4	8.6	8.15	0.308	12
BOD (mg/L)	0.9	2.5	14	0.53	12
Dissolved Oxygen (mg/L)	8	15	10.6	2.1	11
Temperature (°C)	0.5	30	9.69	9.03	12

The once-in-1000-years flood would be expected to reach 281 m (921 ft) MSL (mean sea level), and the maximum flow of record (1965) was estimated to have reached 279 m (915 ft) MSL. Normal river stage at the site is about 276 m (905 ft) MSL, and the site grade is 287 m (942 ft) MSL.

The "maximum probable flood" was estimated to reach a peak stage elevation of 286 m (939 ft) MSL at the reference site. The peak level at the site would be reached in about 12 days from the onset of the worst combination of conditions resulting in the "maximum probable flood".

The nearest domestic water supply reservoir is fed by the river from an intake about 60 km (37 mi) downstream. Under emergency conditions, withdrawal of river water could be suspended for about 48 hours without curtailment of nonessential use. With curtailment of nonessential use, this period could be extended to about 100 hours.

The groundwater table under normal conditions is higher than the river; thus, groundwater and runoff drain to the river. There are numerous shallow public wells, 23 to 46 m (75 to 150 ft) deep, supplying residences and farms along the river terrace. The closest public water supply well is a small city well obtaining water 72 m (237 ft) below ground level, about 4.8 km (3 miles) downstream.

The amount and rate of dispersion of effluent materials discharged into a river depend on the flow rate, geometry, bottom roughness, and density gradients. As a result, no single dilution-distance relationship exists that will account for all the possible variations.

The point-source dilution curve initially is inversely proportional to distance and then, after vertical mixing has occurred, the dilution is inversely proportional to the square root of the distance until the limiting effect of the near-side boundary becomes important at about 1,000 m (0.6 mi). The fully mixed situation occurs at a distance of about 50,000 m (30 mi).

Values indicated in Figure 5.B-3 are assumed for evaluations of the reference river site in this study, using the case for one nuclear reactor. Adjustments can be made directly to these graphs for other liquid effluent flow rates.

FIGURE 5.B-3. Liquid Effluents Dilution for the Reference River at the Reference Fuel Cycle Facility Site

The estimates to be developed for the concentration of radionuclides in the water downstream of the liquid effluent discharge point in a river are based on the analytical model given in WASH-1258.⁽⁵⁾

5.B.7 METEOROLOGY

Reference Site B has a typical continental climate. It is characterized by wide variations in temperature, modest winter precipitation, normally ample spring and summer rainfall, and a general tendency to extremes in all climatic features. January is the coldest month and July is the warmest month.

Table 5.B-3 shows monthly temperature statistics.

TABLE 5.B-3. Monthly Air Temperature Statistics (°C) at the Reference Site for Fuel Cycle Facilities

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	-6.1	-4.4	3.3	12.8	20	25	28.3	26.7	22.2	15	4.4	-3.3
Minimum	-16.1	-14.4	-6.7	1.7	7.8	13.3	16.1	15	10	3.9	-4.4	-12.2
Mean	-11.1	-9.4	-1.7	7.2	13.9	18.9	22.2	21.1	16.1	9.4	0.0	-7.8
Extreme Maximum	15	16.1	27.8	32.8	40.6	39.4	41.7	40	40.6	32.2	23.9	17.2
Extreme Minimum	-38.9	-36.7	-34.4	-15.6	-6.7	0.6	5.6	3.3	-5.6	-13.3	-27.8	-33.9

The number of days with maximum temperatures of 32°C (90°F) and above is estimated to be 12. The number of days with a minimum temperature of 0°C (32°F) or below and -18°C (0°F) or below is estimated to be 168 and 40, respectively. The relative humidities in January at 7:00 a.m., 1:00 p.m., and 7:00 p.m. are estimated to be 76, 68, and 70%, respectively. The corresponding humidities for July are 86, 55, and 55%. Monthly average humidities are shown in Table 5.B-4.

TABLE 5.B-4. Mean Monthly Relative Humidity (%) at the Reference Site for Fuel Cycle Facilities

<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Jun</u>	<u>Jul</u>	<u>Aug</u>	<u>Sep</u>	<u>Oct</u>	<u>Nov</u>	<u>Dec</u>
74	75	73	66	62	66	68	70	70	66	73	78

The months of May through September have the greatest amounts of precipitation, with an average rainfall during this period of 432 to 457 mm (17 to 18 in.), 70% of the 610-mm (24-in.) annual rainfall. The maximum 24-hr total rainfall for the period 1894 through 1965 was 127 mm (5 in.) and occurred in May. Thunderstorm frequency is 36 storms per year; they are the chief source of rain from May through September. Snowfall averages 1070 mm (42 in.) annually, with occurrences recorded in all months except June, July and August. The extremes in annual snowfall of record are 152 mm (6 in.) minimum and 2235 mm (88 in.) maximum.

Annually, the winds are predominantly bimodal. This bimodal distribution is characteristic of the seasonal wind distributions as well. The average wind speed for spring is 11 km/hr (7 mph) and for the other seasons is about 16 km/hr (10 mph). The maximum reported wind speed of 148 km/hr (92 mph) was associated with a tornado. Tornadoes and other severe storms occur occasionally. Eight tornadoes were reported from 1916 through 1967 in the county where the site is located. The probability of a tornado striking a given point in this area is about 5×10^{-4} per year. For design purposes a wind velocity of 480 km/hr (300 mph) is assumed to be associated with tornadoes.

Natural fog restricting visibility to 0.4 km (0.25 mi) or less occurs about 30 hr/yr. Icing due to freezing rain can occur between October and April, with an average of one to two storms per year. The mean duration of icing on utility lines is 36 hr.

Diffusion climatology is typical of the region, with relatively favorable atmospheric dilution conditions prevailing. Frequency of thermal inversion is expected to be about 32% of the year, and the frequency of thermal stabilities is 19% slightly stable, 27% stable, 20% neutral, and 34% unstable.

Data from a number of river sites used for nuclear reactors were used to calculate the "typical" annual atmospheric dispersion pattern in an average 22-1/2-degree sector from the site. Dispersion factors at selected distances for the average sector were determined from joint frequency distributions for each reactor site. This was done by calculating the dispersion factor, $\bar{X}/Q'$, for each sector at selected downwind distances and then calculating the average dispersion factor at each distance. In other words, the dispersion factors in those sectors corresponding to overland trajectories were added without regard to direction and divided by the number of sectors involved. For river sites all sixteen sectors were used. Thus, an average dispersion factor was obtained for each selected downwind distance for all sixteen sectors.⁽⁵⁾

Standard groups of meteorological data were interpolated from the specific reactor site data. This grouping provided four stability classes based on vertical temperature gradient and five wind speed classes based on the Beaufort wind scale. Vertical temperature gradient classes were based on Regulatory Guide 1.23 (Safety Guide 23). Pasquill classes A, B, and C were classified as B (unstable); Pasquill classes D (neutral) and E (slightly stable) were not reclassified; and Pasquill classes F and G were classified as F (moderately stable).

Wind speed data were frequently available at only one height for the reactor sites. In this event, the measured values were extrapolated to the 10-m level for building and vent release calculations and to the 100-m level for stack release calculations. Where measurements at two heights were available, the highest was extrapolated to 100 m and the lowest to 10 m using a standard power law extrapolation procedure.⁽⁸⁾

Calculations were made for a number of specific reactor sites to yield average air concentrations and average radiation doses versus distance from the release point. The values represent the average overall of the wind directions that carry the airborne effluents over land. Every sector value for each site was not calculated independently for this study. As previously stated, average sector values were used for this study.

Data on the sector with the minimum dispersion factor and the average of all 16 sectors were available for sixteen reactor sites.⁽⁵⁾ These data were used to determine the ratio of the minimum effective dilution (maximum dispersion factor) to the mean sector value, and are applied to the present study.

The value obtained for the ratio of dispersion factor in the sector with the minimum dispersion factor to the average sector dispersion factor was 2.5, and this value was used for all release heights in this study. Investigation of changes in this ratio with distance from the site determined that it remained essentially constant with distance from the point of release. The dispersion factors for the average sector as a function of height of release and downwind distance are shown in Figure 5.B-4.

To assess the effect of increased stack height, atmospheric dispersion factors for stack heights of 150, 200 and 300 m (400, 660, and 980 ft) were estimated from the original joint frequency distributions of the 16 reactor sites. These values are also presented in Figure 5.B-4.

Where large volumes of heated air are being ejected, the plume rise constant for momentum is estimated to be about $50 \text{ m}^2/\text{sec}$ ($540 \text{ ft}^2/\text{sec}$). Assuming an annual average wind speed of 2 to 3 m/sec, (4.5 to 6.7 mph) the increase in effective stack height due to momentum would be 20 to 25 m (66 to 82 ft). Plume rise due to buoyancy (heat effect) would add at least another 25 to 100 m (82 to 330 ft) of effective stack height, depending upon the temperature of the exhaust gases. Thus, the $\bar{x}/Q'$ values illustrated in Figure 5.B-4 are larger than they would be if credit is taken for buoyancy and momentum.

5.B.8 ECOLOGY

The description of the ecology at the site is divided into terrestrial and aquatic ecology. These are discussed below under separate subsections.

FIGURE 5.B-4. Average ($\bar{X}/Q'$) Values versus Distance in a Sector from the Reference River Site for Fuel Cycle Facilities

5.B.8.1 Terrestrial Ecology

Less than 20% of the land within 40 km (25 mi) of the plant site is covered with pristine vegetation. Vegetation in the area was originally identified as supporting a climax deciduous forest. Remnants of the native climax hardwood forest are found on the larger islands, with some lesser stands in isolated pockets along the river bank. Nearly all accessible virgin woodland areas in the region have been burned, cut and plowed. Trees and shrub cover remain stable from year to year except for disturbances from cattle grazing or browsing, clearing, and cutting. Because annual grasses and forbs originate each year from seed, their abundance shows pronounced fluctuation from seasonal and annual changes in environmental conditions, such as rainfall.

The river border near the plant consists predominantly of a willow-scrub thicket interspaced with cottonwood and poplar, whereas the areas adjacent to the border are largely agricultural crop and grazing land. Many of the terrestrial animals live in vegetative cover bordering the river, and periodically forage in the adjacent agriculture areas.

The shoreline and islands in this area are heavily utilized by waterfowl and shorebirds. Most waterfowl and shorebirds are migratory, and are present only seasonally, primarily during the summer and fall. The Mallard and Blue-Winged Teal are common spring breeders and summer residents. Common marsh birds are the Red-Winged Blackbird, Marsh Wren, and Great Blue Heron. A variety of upland game birds and nongame birds utilize riparian habitats for nesting and feeding, as well as for protection from predators and adverse weather.

Bird hunting is mainly directed at waterfowl, both jump shooting and hunting from blinds. This portion of the river is not a preferred hunting area, nor is it used significantly as a resting area for migrating waterfowl. Ruffed Grouse are occasionally hunted, but there is little hunting for other birds.

A list of wildlife considered to be rare, endangered, or threatened within the study state is shown in Table 5.B-5. The Southern Bald Eagle nests along the Atlantic and Gulf Coasts but moves northward after the nesting

season and is occasionally sighted in the study area. The Arctic Peregrine Falcon nests in the treeless tundra and migrates southward through the mid-western states to the Gulf Coast and South America. The Prairie Falcon, which nests in other areas, is occasionally sighted in the area. The Northern Greater Prairie Chicken is also present at the reference site.

TABLE 5.B-5. Wildlife Considered to be Rare, Endangered, or Threatened within the Reference Fuel Cycle Facility Site⁽⁹⁾

Birds	
Southern Bald Eagle	
Arctic Peregrine Falcon	
Prairie Falcon	
Northern Greater Prairie Chicken	

Some important mammals in the area are listed in Table 5.B-6. Squirrel is the principal animal hunted in the area. A one-day season for hunting deer with a gun and a prolonged season for bow and arrow hunting suggest a limited deer population. Some hunting of fox and raccoon also occurs.

TABLE 5.B-6. Some Important Mammals that are Found Near the Reference Fuel Cycle Facility Site

Badger	Gray Squirrel	Raccoon
Bats	Ground Squirrels	Red Fox
Beaver	Harvest Mouse	Red Squirrel
Bobcat	Jumping Mice	Shrews
Chipmunks	Mink	Skunk
Cottontail Rabbit	Moles	Voies
Coyote	Muskrat	Weasels
Deer Mouse	Opossum	Whitetail Deer
Fox Squirrel	Pocket Gopher	Whitetail Jackrabbits

Important fur-bearing animals include Raccoon, Mink, Muskrat, Beaver, and Fox. Other wide-ranging fur-bearing animals are probably found in the vicinity from time to time, especially the Coyote, Bobcat and possibly the River Otter.

Broad-leaved trees characteristic of the study area include oak, elm, basswood, maple and hackberry. These species occur abundantly on the larger islands, with lesser stands in isolated pockets along the river banks. The climax community was probably comprised of maple and basswood. Farming, grazing and logging activities, however, have caused considerable change from the climax vegetation. Most areas that would be in active use at the reference site (e.g., buildings, parking lot) occupy land formerly cultivated. The portion of the site on the far side of the river is in various stages of recovery from weedy species. There is no evidence of the existence of rare or endangered vegetation species at the reference site.

The soil in the area is thin and varies from sand to silty loam, with an underlay of glacial till. The water table in lower areas is close to the surface, and during river flood these areas are frequently inundated.

The numerous ponds, lakes and swampy areas bounding the site provide nesting areas for waterfowl. Most nest fairly close to water.

5.B.8.2 Aquatic Ecology

The shoreline near the site consists of a sand and gravel base that merges with soil and riparian vegetation near the high water line.

The smallest organisms of concern in the river near the proposed site are planktonic forms. The plankton consist of both the photosynthetic phytoplankton and nonphotosynthetic zooplankton. The phytoplankton form the first major link in the aquatic food chain. At the site, phytoplankton originate largely from upstream areas, including impoundments, with some contribution from the periphyton in the immediate area.

Diatoms are the principal form of phytoplankton. The abundance of diatom populations varies in an annual cycle, with the greatest density occurring in late spring and the lowest density in midwinter. Phytoplankton production is influenced by seasonal changes in light intensity, water temperature, and quantities of dissolved nutrients.

The abundance of zooplankton populations also varies in an annual cycle with the greatest density occurring during the summer and fall. The primary habitat of these forms is in the quiet and protected parts of the river. Zooplankton consume primarily phytoplankton and both forms of plankton are utilized as food by certain larger invertebrates and fish.

Diatoms and filamentous green algae dominate the periphyton, or algae communities attached to submerged substrates in the river. The periphyton population appears to be maintained in a subclimax condition, that is, typically experiencing recolonization and regrowth because of erosion by current flows and grazing by aquatic fauna. Seasonal productivity of periphyton corresponds to the annual cycle of phytoplankton growth, being highest in late spring and lowest in midwinter, and is also influenced by light, water temperature, and quantities of dissolved nutrients. Periods of high river turbidity and flow have a pronounced negative impact on periphyton growth, primarily because of siltation and scouring by high velocity currents.

Benthic organisms in the river near the site include larvae of aquatic insects, molluscs, and crustacea as the most important producers and consumers. Chironomids (Diptera, Chironomidae), caddisflies, and mayflies are the dominant insects. Molluscs and crustacea are present.

The density of the benthos varies with substrate type, which in turn is influenced by current flow. Populations include organisms characteristic of the clean, stone riffle areas and others characteristic of sand and silt areas. Generally, the density of the benthos is lower in deep water than in shallow water. Benthic organisms form secondary or intermediate links in the food chain leading to the production of more valuable forms. Aquatic insects are the major food items in the diet of many river fish, and insect larvae are the dominant components of the river drift.

Rooted macrophytes occur in certain areas along the margin of the river. Most of these are emergents such as Thpha and Juncus but some are floating plants such as Potamogeton and Lemna, while a few are submerged plants such as Anarcharis and Ceratophyllum. Biomass of macrophytes varies seasonally, with the greatest concentrations occurring during the summer and fall and the

smallest concentrations during the winter. Macrophytes provide food for waterfowl and riparian mammals, shelter for small fish, hiding areas for large fish, and production areas for many microscopic river invertebrates.

Some areas near the river are inundated by water from small swamps or marshes characterized by cattails (Typhus sp) and other forms of marsh vegetation.

Fish form the upper trophic level of aquatic organisms near the site; Several species of fish are known to be present. No significant commercial fishery exists. Sport fishing intensity is greatest in the spring and fall. Most fish spawn in the spring and early summer. Suckers and others have short upriver spawning migrations. Anadromous species are present. None of the fish present is considered to be a rare or endangered species.

Sewage wastes released upriver have been subjected to primary and secondary treatment and do not contribute a large amount of pollution in the river. However, the water may contain higher than normal amounts of phosphates and nitrates following periods of high rains due to the influx of agricultural fertilizers. Insecticides from crop spraying are known to be present occasionally in the water at the site, although fish kills from toxic chemicals have yet to be recorded.

SECTION 5.0: REFERENCES

1. United States Atomic Energy Commission, Final Environmental Statement Related to the Operation of the Highland Uranium Mill by the Exxon Company, USAEC Docket No. 40-8102, March 1973.
2. M. B. Sears, et al., Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low As Practicable" Guides - Milling or Uranium Ores, ORNL-TM-4903, Vol. 1, May 1975.
3. U.S. Environmental Protection Agency, Water Quality Impacts of Uranium Mining and Milling Activities in the Grants Mineral Belt, New Mexico, EPA 906/9-75-002, September 1975.
4. United States Atomic Energy Commission, Environmental Survey of the Uranium Fuel Cycle, WASH-1248, April 1974.
5. 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.
6. U.S. AEC, Final Environmental Statement Related to Operation of Monticello Nuclear Generating Plant, Docket No. 50-263, pp. II-15 - II-26, November 1972.
7. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.109. (For comment), Table D-1, pp. 1.109 - 1.164, March 1976.
8. Meteorology and Atomic Energy 1968, TID 24190, Edited by D. H. Slade, p. 73, July 1968.
9. Bureau of Sport Fisheries and Wildlife Redbook, U.S. Department of Interior and the Federal Register.

6.0 MINING

Two reference mine facilities are described, a surface mine and underground mine. The mines are described separately. A summary of the characteristics of each mining facility is given; this is followed by descriptions of the mainline process, effluent control process, facility and site, effluent control performance, operating cost factors, environmental impact factors, limitations and uncertainties in the study, and research and development needs.

6.A. SURFACE MINING

A reference surface mining facility representative of current technology for commercial scale uranium surface mining was defined for this study, primarily based on the existing Anaconda Company, Jackpile mine located at Pagate, New Mexico.⁽¹⁾

Surface mining at the Jackpile mine is performed by a selective stripping method. The Jackpile mine produces about 4234 MT of ore/day (1.32×10^6 MT of ore/yr, for 85.5% operating efficiency^(a) using 312 operating days/yr). The grades of ore mined at Pagate currently range from about 0.15 to 0.30% uranium oxide (U_3O_8) equivalent [0.13 to 0.25% U].

The overall characteristics of the defined reference facility include the following:

- The facility uses the selective stripping surface mining method to obtain uranium ore, which is then crushed to less than 20 cm and transported to the mill.
- There is one facility, two resource feeds or ore types (one at 0.25% U in ore, the other at 0.025% U) and two products to the mill (same as the resource feeds).

- The facility produces about 4234 MT of ore/day (1.32×10^6 MT of ore/yr, for 85.5% operating efficiency).^(a)
- The average grade of 0.15% U in the ore from the two ore sources is used for this study.
- The reference facility supplies about 6.4 MT U/day (1981 MTU/yr), or 7.5 MT/day U_3O_8 equivalent (2337 MT U_3O_8 per year).
- The facility is assumed to operate 312 days/yr and 24 hr/day for 20 years.

6.A.1 SUMMARY

The reference surface mining facility produces uranium ore at the rate of 4234 MT of ore/day (1.32×10^6 MT of ore/yr, for 85.5% operating efficiency using 312 operating days/yr). This ore is shipped to a uranium milling facility for further processing.

The reference mining facility operations consist of drilling, blasting, and hauling the overburden. The underlying ore zones are graded according to uranium content, ripped using a ripper attached to a tractor, and loaded into dump trucks. The ore is stockpiled according to grades. The ore is next blended to the two hypothetical grades used in this study, crushed, scanned, and loaded into train cars for transport to the reference milling facility.

The processes of blasting the overburden, loading, and crushing the ore release most of the mass of airborne effluents contaminants as particulates. The radioactive decay products of uranium make up a portion of the airborne effluents released by these processes. The main liquid effluent is produced by gravity flow of ground water into the pit retention ponds where water seeps into the ground or evaporates. At present, many values for airborne and liquid effluents are not readily available.

^(a) Percent operating efficiency as used in this study is the number of operating days divided by 365 days a year times 100.

The main uranium-containing wastes are the overburden, (dirt and rock) that is either dumped in a mined-out area of the pit or hauled to a dump site adjacent to the pit.

Detailed facilities and effluent information for a reference commercial surface mine are not available. Therefore much information desired for this study is not complete. Significant additional information or development of inferred information on facility and effluents is needed to perform a detailed cost-benefit analysis.

6.A.2 MAINLINE PROCESS DESCRIPTION OF SURFACE MINING

Surface mining involves mining of ore bodies on or near (within about 200 meters of) the ground surface by excavating large open pits in the surface. No underground tunneling is done.

Several mechanical operations are required in surface mining uranium ore. First the overburden is drilled and blasted, and transported. The ore is then removed by ripping, loaded, scanned for gross radioactivity and transported to stockpiles within the pit. The ore is stockpiled according to approximate uranium content. Ore is then blended, crushed, loaded into railcars and transported to the reference mill. The overall general mainline process flow diagram is given in Figure 6.A-1.

FIGURE 6.A-1. Overall Reference Mainline Process for Surface Mining

6.A.2.1 Description of Mainline Process Steps

A more detailed mainline process flow diagram is given in Figure 6.A-2. The following sections discuss the major process steps.

- Drilling and Blasting the Overburden

Blast holes are drilled into the overburden covering the uranium ore. These holes are drilled on 12-m (40-ft) centers using a rotary drill. The blast holes are loaded with ammonium nitrate and fuel oil and detonated electrically. Blasting is done twice per 24-hr work day.

- Removing the Overburden

After blasting, the overburden is loaded into back-dump trucks using front-end loaders. The overburden is either dumped in a mined-out area of the pit or is hauled to a dump adjacent to the pit.

- Grading, Breaking-Up, and Loading the Ore

Following the removal of the overburden, bulldozers and tractors with attached rippers cut vertical slices in ore zones. Control points for varying ore grades are established in the ore zone using a Geiger counter. The ore is loaded selectively, according to grade, into back-dump trucks using front-end loaders.

- Scanning and Stockpiling the Ore

The dump trucks containing the ore are routed through a gamma energy scanner to determine the ore grade to $0.01\% \text{ U}_3\text{O}_8$ (0.008% U). The ore is stockpiled according to the ore grade in up to 10 appropriate piles.

- Blending and Crushing the Ore

The stockpiled ores are blended at the mine to form two product streams. One stream has an average grade of 0.25% U in the ore; the other an average grade of 0.025% U in the ore. The blended ore is crushed to maximum dimensions of 20 cm (8 in.) and selectively loaded according to each of the two average grades into train cars by conveyor

FIGURE 6.A-2. Mainline Process Flow Diagram for the Reference Surface Mining Facility

belt. A gamma energy scanner located over the conveyor belt provides for estimation of the average grade of the ore shipped.

- Transport to Milling Facility

The two product streams of ore are shipped to the milling facility on seven trains per week. One train car holds 90.7 MT of ore and there are 40 cars per train.

6.A.2.2 Waste Management

The only radioactive solid waste from the reference surface mining facility is waste rock. The waste rock is the overburden, rock and dirt, that initially covers the intact ore zones. The main radioactive contaminants in the waste rock are uranium ($\leq 0.02\%$ U in waste rock) and radium (< 0.22 mg/MT).⁽²⁾ Management of the waste rock consists simply of stockpiling the waste either in a mined-out area of the pit or in a dump site adjacent to the pit. The exposure of this radioactive solid waste, in turn, permits a radioactive airborne effluent of uranium and its decay products including radon gases and radon's radioactive decay daughters.

The nonradioactive solid wastes are generated by supporting activities at the mining facility. These wastes, which originate in offices, lunch rooms, shops, etc., include paper, paper products, and discarded equipment or parts. The paper and paper products are assumed to be buried in a land-fill onsite, while the discarded equipment and parts are assumed to be sold as scrap or buried in the mined-out parts of the mine. Solid waste scrap that is to be salvaged is gamma scanned and swipe surveyed prior to release for offsite use.

6.A.3 EFFLUENT CONTROL PROCESS DESCRIPTIONS FOR SURFACE MINE

Materials of greatest concern for effluent control are uranium, radium, radon and radon decay daughters. These materials may be present in both liquid and airborne effluents.

6.A.3.1 Liquid Effluents

The main liquid effluent stream leaving the mine is the mine water, with a pH of 8.0 to 8.5.⁽²⁾ This water flows by gravity to a holding pond in the pit where it is allowed to evaporate and to seep into the ground. It is also used to wet down haul roads for dust control (where it evaporates).

Runoff from ore stock piles and waste rock dumps is allowed to follow the natural drainage pattern.

6.A.3.2 Airborne Effluents

The airborne effluents are made up of dust, combustion gases (including blasting gas and equipment exhaust gas), radon gas, and radon daughters; all airborne effluents are released directly to the atmosphere without treatment. The airborne effluents are given off during blasting, loading, blending, and crushing. (Radon gas emanates from New Mexico sandstone at $\geq 5 \times 10^{-14}$ Ci/cm²/sec).⁽³⁾

Dust is also released to the atmosphere by winds that entrain dust from dried out ore stock piles. The roads are periodically wetted down to minimize the formation of airborne dust.

6.A.4 FACILITY AND SITE DESCRIPTIONS OF SURFACE MINE

The descriptions of the site and of the facility and its hardware will be the primary basis for capital cost estimates and will be used as background for mine performance.

6.A.4.1 Site

The reference surface uranium mining facility, is assumed to lie on the 13 km² generic site (Site A) for mines and mills described in Section 5. The mine is defined earlier in this section.

Entrance to the mining facility is controlled by inspection at a guard house located on the entrance road. Any small streams that run through gullies after periods of high precipitation are diverted around the mine pit by dikes and/or ditches.

6.A.4.2 Facility

The mine pit (assumed to encompass about 9 km²)(a) is an irregular crescent shape about 4.8 km (3 miles) long by about 0.37 km (1200 ft) wide; it averages 0.08 km (250 ft) deep. The depth is expected to increase to 0.12 km (400 ft). A system of ramps and haul roads provides access from grade level to the pit.

Most of the ore is at a depth of less than 0.15 km (500 ft) and is found in lens-shaped formations that vary from about 5 cm (2 in.) to 6.1 m (20 ft) thick and from a few meters to 30.5 m (100 ft) long.

The expected life of the reference mining facility is 20 years with mine pit dimensions of 1860 m length, 370 m wide and 80 m deep. The process equipment locations and capacities are shown in Table 6.A-1.

TABLE 6.A-1. Major Process Equipment Descriptions -
Reference Surface Mine

<u>Equipment</u>	<u>Location</u>	<u>No.</u>	<u>Process Duty or Capacity (each)</u>
Rotary Drills	Mine Pit	NA	NA
Back Dump Trucks	Mine Pit to Dump Site	23	45 MT
Back Dump Trucks	Mine Pit to Stockpiles	23	23 MT
Front End Loaders	Mine Pit	NA	11.5 m ³
Front End Loaders	Mine Pit	NA	5.0 m ³
Caterpillar Tractors with Rippers	Mine Pit	NA	NA
Crusher	NA	1	NA
Conveyor	NA	1	NA
Scanner	NA	2 ^(a)	NA

NA = Not available at this time.

(a) One to scan trucks and one to scan conveyor belt.

(a) This number was calculated using a scaled drawing from Reference 4.

6.A.5 EFFLUENT CONTROL PERFORMANCE FOR THE SURFACE MINE

The overall input/output for radioactive and nonradioactive materials for the surface mining facility is summarized in Tables 6.A-2 and 6.A-3.

A significant amount of additional information is required to complete the determination of important effluents.

6.A.6 FACTORS FOR OPERATING COST INFORMATION FOR SURFACE MINE

Available basic plant operational requirements are presented in this section to enable later estimation of direct operating costs. Operating costs are not estimated in this report.

6.A.6.1 Labor Requirements

The reference surface mining facility is assumed to operate 24 hr/day and 6 days/wk (312 days/yr). The work force for the reference facility is assumed to include two work shifts per day plus a maintenance with a total of 412 personnel. It is assumed that 10% are management and professional staff and 90% are skilled and unskilled labor.

6.A.6.2 Material Requirements

The routine material requirements for the surface mining facility consist of those materials given as inputs in Tables 6.A-2 and 6.A-3 and packaging materials for refuse disposal. Miscellaneous materials such as office materials, office furniture, routine maintenance supplies, etc. are also required.

6.A.6.3 Unusual Maintenance Requirements

Some equipment requires replacement and/or major repairs relatively often where the service is most severe. Maintenance on all equipment is assumed to be 10%/yr of the equipment's original cost. Equipment is expected to be replaced every 5 years.

6.A.6.4 Utility Requirements

Total estimated utility requirements for the surface mining facility for each day of operation at 100% capacity are:

**TABLE 6.A-2. Overall Radioactive Material Input/Output
for Reference Surface Mining Facility**

Material	Total Material ^(a)		U ^(a) kg/day	Form		Fraction ^(c) of Plant Input
	kg/day	l/day		Chemical	Phase	
<u>Input to Facility</u>						
Uranium Ore	4.2E6 ^(b)	NA ^(b)	6.4E3	[U(SiO ₄) _{1-x} (OH) _{4x}] + UO ₂ + [Ca(UO ₂) ₂ (VO ₄) ₂ · 5-8 H ₂ O] + [K ₂ (UO ₂) ₂ (VO ₄) ₂ · 1-3 H ₂ O]	S S S S	(1.0)
<u>Output from Facility</u>						
Airborne Effluents:						
Gas - 222Rn	2.5E-6	NA	---	222Rn	G	NA
Solids - 226Ra	2.8E-6	NA	---	NA	S	NA
Radon Daughter Products					S	NA
218Po	1.4E-9	NA	---	NA	S	NA
214Pb	1.2E-8	NA	---	NA	S	NA
214Bi	9.0E-9	NA	---	NA	S	NA
214Po	1.3E-15	NA	---	NA	S	NA
210Pb	NA	NA	---	NA	S	NA
210Po	NA	NA	---	NA	S	NA
Uranium Compounds 230Th	4.2E3 ^(b) NA	NA ^(b) NA	6.4 ---	NA NA	S S	1.0E-3 NA
Liquid Effluents:						
226Ra	NA	---	NA	NA	L,S	NA
Uranium Compounds 230Th	NA ^(b) NA	NA ^(b) NA	NA ---	NA NA	L,S L,S	NA NA
Solids:						
Uranium Ore	4.2E6 ^(b)	NA ^(b)	~6.4E3	Same as Input	S	(~1.0)
Waste Rock	3.5E7 ^(b)	NA ^(b)	NA	NA	S	NA

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

(a) Values based upon one day operating at 100% capacity.

(b) Value indicates total of radioactive and nonradioactive sources.

(c) Numbers in parentheses are not released to the environment.

TABLE 6.A-3. Overall Nonradioactive Material Input/Output
for Reference Surface Mining Facility

Material	Total Material ^(a)		Chemical	Form	
	kg/day	l/day		Phase	Other
<u>Input to Facility</u>					
Explosives	NA	NA	NH ₄ NO ₃	S	NA
Diesel Fuel	NA	2.6E4	NA	L	---
Drills	NA	NA	---	S	---
Back Dump Trucks	NA	NA	---	S	---
Front End Loaders	NA	NA	---	S	---
Caterpillar Tractors with Rippers	NA	NA	---	S	---
<u>Output from Facility</u>					
<u>Airborne Effluents:</u>					
Rock Dust	4.2E3 ^(b)	NA	NA	S	NA
Nonradioactive Particulates	41 ^(b)	NA	NA	S	NA
<u>Gas -</u>					
Carbon Monoxide	7.2E2 ^(b)	NA	CO	G	NA
Nitrogen Oxides	1.2E3 ^(b)	NA	NO _x	G	NA
Sulfur Oxides	86 ^(b)	NA	SO ₂	G	NA
Aldehydes	10 ^(b)	NA	NA	G	NA
Hydrocarbons	1.2E2 ^(b)	NA	H _x C _y	G	NA
<u>Liquid Effluents:</u>					
Vanadium	6.5 ^(c)	NA	NA	S,L	NA
Selenium	0.10 ^(c)	NA	NA	S,L	NA
Molybdenum	4.2 ^(c)	NA	NA	S,L	NA
Arsenic	0.25 ^(c)	NA	NA	S,L	NA
Suspended Fines	NA	NA	NA	S	NA
Chlorides	NA	NA	Cl ⁻	L	NA
Nitrates	0.90 ^(c)	NA	NO ₃ ⁻	L	NA
Sulfates	NA	NA	SO ₄ ⁼	L	NA
Ammonia	5.1 ^(c)	NA	NH ₄ ⁺	L	NA
Kjeldahl Nitrogen	4.9 ^(c)	NA	NA	L	NA
Phosphorus	4.0 ^(c)	NA	NA	L,S	NA
Fluoride	2.2 ^(c)	NA	NA	L	NA
Aluminum	2.2 ^(c)	NA	NA	L	NA
Beryllium	0.05 ^(c)	NA	NA	L,S	NA
Calcium	5.2E2 ^(c)	NA	NA	L	NA
Magnesium	2.0E2 ^(c)	NA	NA	L	NA
Titanium	4.7 ^(c)	NA	NA	L,S	NA
Iron	38 ^(c)	NA	NA	L,S	NA
Lead	0.70 ^(c)	NA	NA	L,S	NA
Zinc	0.12 ^(c)	NA	NA	L,S	NA
<u>Solids:</u>					
Scrap Equipment	NA	NA	---	---	---
Refuse	NA	NA	---	---	---

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

(a) Values based upon one day operating at 100% capacity.

(b) Appendix A.

(c) Appendix B.

- water (Not available at this time)
- electricity 136 kW-day/day (see footnote (c), Table 6.A-4)

6.A.6.5 Transportation Requirements

Explosives, diesel fuel and other such facility inputs must be transported, usually by truck. The ore leaving the surface mining facility is transported by train to the uranium milling facility. Typical distances for transport of these materials from the mining facility to the milling facility are about 6 to 8 km (4 to 5 miles).

6.A.6.6 Waste Disposal Requirements

The solid refuse from the surface mine (Table 6.A-3) is buried in a landfill onsite. The overburden waste rock is either deposited in a mined-out area of the pit or in a separate area away from the pit.

6.A.6.7 Other Operating Cost Elements

Other major operating cost elements are those performed by outside contractors. Transportation of input materials and of the ore from the mining and milling facilities is assumed to be contracted.

6.A.7 ENVIRONMENTAL IMPACT FACTORS OF THE SURFACE MINE

Table 6.A-4 summarizes the overall direct environmental factors for the reference surface mine facility. These quantities are those involved directly at the facility. Impacts of resources required for material input or output beyond the facility boundary are not included.

TABLE 6.A-4. Overall Environmental Impacts -
Reference Surface Mine

	<u>Quantity</u>
Total Land Committed	13 (km) ²
Land Actually Used for Mining Facility	~ 9 (km) ²
Water Used	NA
Water Discharged as Liquid Effluent	2.0E7 kg/day ^(b)
Total Materials Added to Liquid Effluents	NA
Air Used	NA
Water Discharged as Airborne Effluent	NA
Total Other Airborne Effluents	NA
Electrical Energy Consumption	1.4E2 kW-day/day ^(c)
Thermal Effluent Equivalent	NA
Resource Use	See Tables 6.A-2 and 6.A-3

NA = Not available at this time.

- (a) Water is used to wet down haulage roads and comes from seepage water in the mine pit.
- (b) From a scale-up of information in Reference 5, p. A-2.
- (c) Information received by W. I. Enderlin, Battelle Northwest, from a representative of Anaconda Co.'s Jackpile Mine, April 5, 1977.

6.A.8 LIMITATIONS AND UNCERTAINTIES IN THE SURFACE MINE STUDY INFORMATION

Detailed information on a uranium surface mining facility is generally not readily available in the public literature. Much of the information that is missing in previous tables and descriptions is not available directly. Some of this information could be developed or extrapolated from available existing information, but gaps in this information may still exist.

The nature of uranium mine effluents and their long-range effect on the environment is not currently well known. Reference 5 does not address the effect of ²²⁶Ra in the food chain or the removal of ²²⁶Ra from mine

water. Uncertainty also exists as to how future changes in demand for ore, price of ore, and future mining methods used will affect the quantity and nature of mine effluents that will be released to the environment.

6.A.9 RESEARCH AND DEVELOPMENT NEEDS

This study to date has pointed out a need for the following research and development or analyses:

- The nature of uranium mine discharge water needs to be determined or made available. This study should include the distribution of the radio-nuclides in the uranium-radium family, heavy metals, and other minerals.
- The distribution of contaminants (dust, radionuclides, and gases) and their respective concentration levels in releases to air from surface mining needs to be determined or made available.
- The long-range environmental effect of blowing dust and water run-off from uranium ore stockpiles needs to be studied.
- The environmental impact of alternative methods of uranium mining, such as solution mining and heap leaching may be beneficial.

6.B UNDERGROUND MINING

A reference underground mining facility representative of current technology for commercial scale uranium underground mining was also defined, primarily based on an existing group of seven mines owned by Kerr-McGee Corporation at Ambrosia Lake, McKinley County, New Mexico. Underground mining at the Ambrosia Lake complex of mines is performed by a modified room-and-pillar mining method. The Ambrosia Lake complex produces about 4234 MT of ore/16-hr day (1.32×10^6 MT of ore/yr for 85.5% operating efficiency^(a) using 312 operating days/yr). The average grade of ore mined at Ambrosia Lake currently ranges from about 0.13 to 0.25% U, (0.15 to 0.30% uranium oxide [U_3O_8] equivalent), but for this study the average grade of mined ore is taken as 0.18% U_3O_8 (0.15% U).

The overall characteristics of the defined reference facility include the following:

- The facility uses a modified room-and-pillar mining method to obtain uranium ore, which is then transported to the mill.
- There is one facility (made up of 7 mines), two resource feeds or ore types (one at 0.25% U in the ore, the other at 0.025% U), and two products to the mill (same as the resource feeds).
- The facility produces about 4234 MT of ore/16-hr production day (1.32×10^6 MT of ore/yr for 85.5% operating efficiency).^(a)
- The average grade of 0.15% U is used for this study.
- The reference facility supplies about 6.4 MT U/day (1981 MT U/yr), or 7.5 MT U_3O_8 equivalent (2337 MT U_3O_8 /yr).
- The facility is assumed to operate 312 days/yr and 16 hr/day, with one 8-hr maintenance shift each operating day, for 20 years.

^(a) Percent operating efficiency as used in this study is the number of production days divided by 365 days a year times 100.

6.B.1 SUMMARY

The reference underground mining facility produces uranium at the rate of 4234 MT of ore/day (1.32×10^6 MT of ore/year, for 85.5% operating efficiency using 312 operating days/yr). This ore is shipped to a uranium milling facility for further processing.

The reference mining facility operations consist of drilling and blasting ore-bearing rock. This rock is collected and transported to the surface of the mine. The rock is loaded into dump trucks, scanned for ore content, and stockpiled according to the grade of the ore content. Next the ore is blended in dump trucks to the two hypothetical grades used in this study and transported to the reference milling facility.

The processes of blasting, loading, and blending the ore releases most of the mass of airborne effluent contaminants as particulates. The radioactive decay products of uranium make up a portion of the airborne effluents released by these processes. The main liquid effluent is produced by pumping water out of mine excavation areas to retention ponds on the surface, where water seeps into the ground or evaporates. At the present time many values for airborne and liquid effluents are not readily available.

The main uranium containing wastes are the waste rock that is either used as backfill in the mine or is distributed on the surface.

Detailed facilities and effluent information for a reference commercial underground mining facility are not available. Therefore much information desired for this study is not complete. Significant additional information or development of inferred information on facility and effluents is needed to perform a detailed cost-benefit analysis.

6.B.2 MAINLINE PROCESS DESCRIPTION OF UNDERGROUND MINING

Underground mining involves mining of ore bodies, typically below about 200 meters from the earth's surface, by tunnelling down to the ore-bearing horizon, and mining of the ore underground in a network of horizontal tunnels or rooms and pillars.

Several mechanical operations take place when mining uranium ore underground. The first step is to drill and blast the rock; the broken rock is collected and transported to the surface of the mine. The rock is loaded and scanned for uranium ore content; the ore is stockpiled according to approximate uranium content. Ore is then blended and transported to the reference uranium milling facility. The overall general mainline process flow diagram is given in Figure 6.B-1.

FIGURE 6.B-1 Overall Reference Mainline Process for Underground Mining

6.B.2.1 Description of Mainline Process Steps

A more detailed process flow diagram is given in Figure 6.B-2. The following sections discuss the major process steps.

FIGURE 6.B-2. Mainline Process Flow Diagram for the Reference Underground Mining Facility

- Excavating the Mine Openings

Large vertical access holes (shafts) 3 to 6 m in diameter are drilled and/or blasted from the surface to the ore horizon. From the bottom of these access holes, tunneling is done until the ore body is reached by blasting with explosives or by tunneling machines. The waste rock is taken to the surface by elevators installed in a mine opening, and transported to piles near the mine opening.

- Drilling and Blasting of Rock

Blast holes are wet drilled^(a) into the rock, called the working face, using a compressed air-operated percussive drill. The holes are loaded with smokeless explosive powder and the powder is detonated. Blasting is accomplished at 8 AM, 12 noon, 4 PM and 12 midnight. A working face is advanced approximately 3 m (10 ft) with each blast. There are about 30 working faces per mine.

- Collecting and Transporting Rock to the Mine Surface

Broken rock is moved by a slusher (mechanical scraper) using a slusher hoist^(b) from the working face into an ore pass or raise^(c). The broken rock flows by gravity down the ore pass into the ore cars on the haulage level below. The loaded ore cars are transported by diesel locomotive to the shaft station^(d) and dumped into the loading trench. The rock is scraped from the loading trench into ore skips^(e) using another slusher hoist. The skip is hoisted to the surface of the mine shaft and dumped into a back dump truck (Figure 6.B-3).

(a) Wet drilling means that water is injected beside the drill bit to reduce the amount of dust released to the atmosphere while drilling.

(b) A slusher hoist is a scraper device to pull or push materials horizontally using a double-drum hoist. One cable of the hoist is attached to the front of a scraper and is used to draw the scraper toward the hoist. The other cable is attached to the back of the scraper by a block fastened to the end of the area being mined and is used to return the scraper for another load.

(c) A raise is a vertical underground opening from one working level in the mine to another.

(d) A shaft station is the work area where ore is unloaded from ore cars, loaded into skips,^(e) and transported to the mine surface through a vertical shaft.

(e) A skip is a container for rock as it is hoisted up or down a vertical shaft in a mine.

FIGURE 6.B-3. Schematic of Ore Transportation for Underground Mine

- Scanning and Stockpiling the Rock

The dump truck loaded with rock passes under a gamma energy scanner and approximate ore grade is determined. The ore is placed onto the appropriate pile, according to the ore grade. Rock with less than about 0.02% U_3O_8 (0.017% U) is distributed near the mine shaft opening.

- Blending the Ore

The stockpiled ore is blended at the mine to form two product streams. One stream has an average grade of 0.25% U in the ore; the other has an average grade of 0.025% U in the ore. The rock is blended in bottom-dump trucks by loading rock from stockpiles of various grade with a front end loader. The two product streams are shipped by truck to a milling facility about once a week.

6.B.2.2 Waste Management

The only radioactive solid waste from the reference underground mining facility is waste rock, which does not have a high enough uranium ore content to be economically processed. The main radioactive materials in the waste rock are uranium ($\leq 0.02\%$ U in waste rock) and radium (≤ 0.22 mg/MT of waste rock).⁽²⁾ The management of the waste rock consists of distributing the waste near the mine entrance. This radioactive solid waste, in turn, generates a radioactive airborne effluent of uranium and its decay products including radon gas and radon's radioactive decay daughters.

The nonradioactive solid wastes are generated by supporting activities and mechanical mining operations. These wastes, which originate in offices, lunch rooms, shops, etc., include paper, paper products, and discarded equipment or parts. The paper and paper products are assumed to be buried in a landfill on the mining site, while the discarded equipment and parts are assumed to be either sold as scrap or buried in the mined-out parts of the mine. Solid waste scrap that is to be salvaged is gamma scanned and swipe surveyed prior to release for offsite use.

6.B.3 EFFLUENT CONTROL PROCESS DESCRIPTION FOR SURFACE MINE

Materials of greatest concern in effluent control are uranium, radium, radon and radon daughters. These materials can be present in both liquid and airborne effluents.

6.B.3.1 Liquid Effluents

The main liquid effluent stream leaving the mining facility is mine water, which is ground water pumped from underground mine excavation points to a holding pond on the surface of the mining facility. (Refer to Figure 6.B-2 for an abbreviated flow diagram of the mine water treatment process.) Some of the water from the holding pond (about 25%) is discharged to the mill for mill process water. The remainder of the water in the holding pond is passed through an ion exchange circuit to remove uranium. The uranium that is removed by ion exchange is transferred to the milling facility.

The remaining mine water coming from the ion exchange circuit is treated with barium chloride and discharged to a second holding pond. In this pond radium is precipitated with barium sulfate. Water remaining in the second pond discharges to the natural drainage system by seeping into the ground or evaporating. (A substitute treatment for radium is concentration in algae as a solid in a pond, but for this study this treatment is not used in the reference facility.)

6.B.3.2 Airborne Effluents

The airborne effluents are made up of dust, combustion gases, radon gas, and radon daughters. These airborne effluents are given off during blasting, loading, and blending. (Radon gas emanates from New Mexico sandstone at $\geq 5 \times 10^{-14}$ Ci/cm²/sec.⁽³⁾) Dust is also released to the atmosphere by winds that entrain dust from dried out ore stockpiles. Various methods of airborne effluent treatment or control are used in the reference mine, and are discussed in the following paragraphs.

Dilution is one technique used in the reference underground mining facility to control the concentration of contaminants in the air. Airborne effluents are mixed with enough fresh air to reduce the concentration of contaminants to acceptable levels. Dilution is accomplished by using ventilation fans and mine openings that provide air passage. This method is used to control the concentrations of effluents such as dust, carbon monoxide, nitrogen oxides, hydrogen sulfide, sulfur dioxide, aldehydes, radium, and radon and its daughters. For this study it is assumed that fresh air is drawn into and through the mine and pumped out at the surface.

Filtration is used to remove contaminants, mainly dust including radon daughters, from the mine air. HEPA filtration at the reference facility is used to clean ventilation air for use in remote working areas, since the ventilation air is usually well contaminated by the time it reaches these areas. Prefilters are used ahead of the HEPA filters to increase the HEPA filter life.

Electrostatic precipitators are used in place of filter units in some of the reference underground mines because the precipitators provide lower pressure drops in the mine ventilation system than filters.

Exhaust gases from diesel engines are cooled at the exhaust discharge from each engine by water coolers. The cooled gases remain close to the mine floor and are picked up and carried away by the ventilation flow. Some exhaust gases are catalytically decomposed at the engine discharge point once the engine's temperature reaches the reaction temperature needed for decomposition.

Dust suppression in various areas of the mine is accomplished using water. Excavated rock is wet down before loading to suppress dust. Loaded mine cars and trucks are wetted down before dumping, and haulage roads are also wetted down. (Certain chemicals are also used to suppress dusts on roadways and haulage roads.) Some fine air-atomized water sprays are used to remove part of the dust from the atmosphere during and after blasting. Water is pumped through hollow steel rock drills to suppress dust during drilling.

Another control method is the establishment of appropriate pressure differentials in sealed-off areas of the mine so that contaminants in the sealed-off area atmosphere do not escape to the working area atmosphere.

6.B.4 FACILITY AND SITE DESCRIPTIONS OF UNDERGROUND MINE

The descriptions of the site and of the facility and its hardware will be the primary basis for capital cost estimates and serve as background for mine performance.

6.B.4.1 Site

The reference underground uranium mining facility is assumed to lie on the 13 km² generic site (Site A) for mines and mills described in Section 5. Each of the eight individual mine sites occupies about 0.03 to 0.04 km² (8 to 10 acres). Therefore, the total mining facility area is 0.32 km² (80 acres). Entrance to mining facilities is controlled by inspection at a guard house located on the facility entrance road. Any small streams that run through gulleys after periods of high precipitation are diverted around the mine openings by dikes and/or ditches.

6.B.4.2 Facility

The reference underground mining facility is primarily based upon the existing group of seven active mines owned by Kerr-McGee Corporation at Ambrosia lake, in McKinley County, New Mexico. The depth of ore production ranges from 0.18 to 0.43 km (600 to 1400 ft). The underground workings consist of 1.2 m by 1.8 m (4 x 6 ft) stopes^(a) in the ore horizons and 2.7 m by 2.7 m (9 x 9 ft) haulage ways in the rock below the ore zone. Raises connect the stopes with the ore haulage way below. Circular concrete-lined shafts provide access from the mine surface to the underground workings. Roof bolts and backfill material are used for ground support of the underground workings.

The facility's expected operating life is assumed to be 20 years.

6.B.5 EFFLUENT CONTROL PERFORMANCE FOR THE UNDERGROUND MINE

The overall input/output for radioactive and nonradioactive materials for the underground mining facility is summarized in Tables 6.B-1 and 6.B-2. A significant amount of additional information is required to complete the determination of important effluents. In Table 6.B-2 footnote (b) refers to a number of values which are the same as for the surface mine due to lack of better numbers. It does seem likely that rock dust would be generated in approximately the same quantities per unit of ore removed in either surface or underground mine (even though it is more of a problem in the confined space underground). Pneumatic drills are usually driven by compressed air at the ore working face, and these drills are supplied by flexible pressure lines from diesel-compressor stations. Fresh air is pumped to and exhaust gas is pumped from such stations via shafts to the surface. The fresh air supply and the exhaust gas pumps are usually electrically drive at the surface installations. Therefore, the principal difference would be additional electric power for the underground mine. The diesel engine exhaust products should be about the same per unit of ore mined either at the surface or underground.

^(a) A stope is generally a horizontal underground excavation made by extracting ore.

TABLE 6.B-1. Overall Radioactive Material Input/Output
for Reference Underground Mining Facility

Material	Total Material ^(a)		U ^(a) kg/day	Form		Fraction ^(c) of Plant Input
	kg/day	l/day		Chemical	Phase	
<u>Input to Facility</u>						
Uranium Ore	4.2E6 ^(b)	NA ^(b)	6.4E3	[U(SiO ₄) _{1-x} (OH) _{4x}] + UO ₂ + [Ca(UO ₂) ₂ (VO ₄) ₂ · 5-8 H ₂ O] + [K ₂ (UO ₂) ₂ (VO ₄) ₂ · 1-3 H ₂ O]	S S S S	(1.0)
<u>Output from Facility</u>						
Airborne Effluents:						
Gas - 222Rn	2.5E-6 ^(d)	NA	---	222Rn	G	NA
Solids - 226Ra	2.3E-6 ^(d)	NA	---	NA	S	NA
Radon Daughter Products					S	NA
218Po	1.4E-9 ^(d)	NA	---	NA	S	NA
214Pb	1.4E-8 ^(d)	NA	---	NA	S	NA
214Bi	9.0E-9 ^(d)	NA	---	NA	S	NA
214Po	1.3E-15 ^(d)	NA	---	NA	S	NA
210Pb	NA	NA	---	NA	S	NA
210Po	NA	NA	---	NA	S	NA
Uranium Compounds 230Th	NA	NA	5.7 ^(d) ---	NA	S	8.9E-4 NA
Liquid Effluents:						
226Ra	6.0E-8 ^(d)	NA	---	NA	L,S	NA
Uranium Compounds 230Th	NA ^(b) NA	NA NA	0.87 ^(d) ---	NA	L,S L,S	1.4E-4 NA
Solids:						
Uranium Ore	4.2E6 ^(b)	NA	~6.4E3	Same as Input	S	(~1.0)
Waste Rock	NA	NA	NA	NA	S	NA

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

- (a) Values based upon one day operating at 100% capacity.
(b) Value indicates total of radioactive and nonradioactive sources.
(c) Numbers in parentheses are not released to the environment.
(d) Appendix A.

TABLE 6.B-2. Overall Nonradioactive Material Input/Output
for Reference Underground Mining Facility

Material	Total Material ^(a)		Form		
	kg/day	g/day	Chemical	Phase	Other
<u>Input to Facility</u>					
Explosives	NA	NA	NA	S	Smokeless Powder
Diesel Fuel	NA	NA	NA	L	---
Fresh Air	6.2E7	6.3E10	N ₂ -O ₂	G	---
Backfill	NA	NA	NA	S	Rock
Barium Chloride	NA	NA	BaCl ₂	S	---
Roof Bolts	NA	NA	NA	S	---
Filters	NA	NA	NA	S	---
Ion Exchange Resin	NA	NA	NA	S	NA
Slusher Hoists	NA	NA	NA	S	---
Front End Loaders	NA	NA	NA	S	---
Locomotives	NA	NA	NA	S	---
Drills	NA	NA	NA	S	---
Ore Skips	NA	NA	NA	S	---
Dump Trucks	NA	NA	NA	S	---
<u>Output From Facility</u>					
Airborne Effluents:					
Rock Dust	4.2E3 ^(b)	NA	NA	S	NA
Nonradioactive					
Particulates	41 ^(b)	NA	NA	S	NA
Benzopyrene	4.3E-4 ^(d)	NA	C ₂₀ H ₁₂	NA	NA
Beryllium	6.3E-3 ^(d)	NA	NA	NA	NA
Cadmium	1.3E-2 ^(d)	NA	NA	NA	NA
Sulfur (blasting)	3.1 ^(d)	NA	NA	NA	NA
Zinc	1.3E-1 ^(d)	NA	NA	NA	NA
Lead	1.3E-1 ^(d)	NA	NA	NA	NA
Gas (from diesel air compressors)					
Carbon Monoxide	7.2E2 ^(b)	NA	CO	G	NA
Nitrogen Oxides	1.2E3 ^(b)	NA	NO _x	G	NA
Hydrogen Sulfide	NA	NA	H ₂ S	G	NA
Sulfur Oxides	86 ^(b)	NA	SO ₂	G	NA
Aldehydes	10 ^(b)	NA	NA	G	NA
Hydrocarbons	1.2E2 ^(b)	NA	H _x C _y	G	NA

TABLE 6.B-2. (contd)

Material	Total Material ^(a)		Form		
	kg/day	l/day	Chemical	Phase	Other
Liquid Effluents:					
Vanadium	9.2 ^(d)	NA	NA	NA	NA
Selenium	0.35 ^(c)	NA	NA	NA	NA
Molybdenum	6.0 ^(d)	NA	NA	NA	NA
Arsenic	0.14 ^(d)	NA	NA	NA	NA
Suspended Fines	2.9E2 ^(c)	NA	NA	S	NA
Chlorides	1.1E4 ^(d)	NA	CL ⁻	L	NA
Nitrates	67 ^(d)	NA	NO ₃ ⁻	L	NA
Sulfates	2.2E3 ^(d)	NA	SO ₄ ⁻	L	NA
Copper	0.71 ^(d)	NA	NA	S,L	NA
Silica	1.0E2 ^(d)	NA	NA	S	NA
Fluoride	9.1 ^(d)	NA	NA	L	NA
Iron	1.1 ^(d)	NA	NA	S,L	NA
Magnesium	1.2E2 ^(d)	NA	NA	S,L	NA
Calcium	2.7E2 ^(d)	NA	NA	S,L	NA
Zinc	0.21 ^(d)	NA	NA	S,L	NA
Phosphate	1.4 ^(d)	NA	NA	S,L	NA
Sodium	9.4E3 ^(d)	NA	NA	L	NA
Ammonia	6.5 ^(d)	NA	NA	L	NA
Kjeldahl Nitrogen	3.0E2 ^(d)	NA	NA	---	NA
Aluminum	3.2 ^(d)	NA	NA	S,L	NA
Beryllium	7.1E-2 ^(d)	NA	NA	S,L	NA
Titanium	6.7 ^(d)	NA	NA	S,L	NA
Manganese	1.8 ^(d)	NA	NA	S,L	NA
Lead	1.4 ^(d)	NA	NA	S,L	NA
Solids:					
Scrap Equipment	NA	NA	---	---	---
Refuse	NA	NA	---	---	---

Key: S = Solids

L = Liquid

G = Gas

NA = Not available at this time

(a) Values based upon one day operating at 100% capacity.

(b) This value is the same as for the surface mine due to lack of better numbers.

(c) Appendix A.

(d) Appendix B.

6.B.6 FACTORS FOR OPERATING COST INFORMATION FOR UNDERGROUND MINE

This section presents the available basic plant operational requirements, to enable later estimation of direct operating costs.

6.B.6.1 Labor Requirements

The reference underground mining facility is assumed to operate 24 hr/day and 6 days/wk (312 days/yr). Eleven hundred (1100) employees are used with two production shifts and one maintenance shift per day.

It is assumed that 10% are management and professional staff and 90% are skilled and unskilled labor.

6.B.6.2 Material Requirements

The routine material requirements for the underground mining facility consist of those materials given as inputs in Tables 6.B-1 and 6.B-2 and packaging materials for refuse disposal. Miscellaneous materials such as office materials, office furniture, routine maintenance supplies, etc. are also required.

6.B.6.3 Unusual Maintenance Requirements

Some equipment will require replacement and/or major repairs on a relatively frequent basis where the service is most severe. Maintenance on all equipment is assumed to be 10%/yr of the equipment's original cost. Equipment is expected to be replaced every 5 yr.

6.B.6.4 Utility Requirements

Total estimated utility requirements for the underground mining facility for each day of operation at 100% capacity are:

- water Not available at this time
- electricity Not available at this time

6.B.6.5 Transportation Requirements

Explosives, diesel fuel and other such inputs to the facility must be transported, usually by truck. Ore leaving the facility is transported by truck to the uranium milling facility. Typical transport distance from the mining facility to the milling facility is about 6 to 8 km (4 to 5 miles).

6.B.6.6 Waste Disposal Requirements

The solid refuse from the underground mine (Table 6.B-2) is assumed to be buried in a landfill onsite. The waste rock is either used as backfill in excavated parts of the mine or distributed on the surface.

6.B.6.7 Other Operating Cost Elements

Other major operating cost elements are those performed by outside contractors. Transportation of input materials and of the ore from the mining and milling facilities is assumed to be contracted.

6.B.7 ENVIRONMENTAL IMPACT FACTORS OF THE UNDERGROUND MINE

Table 6.B-3 summarizes the overall direct environmental factors for the reference underground mine. These quantities are those used directly at the facility. Impacts of resources required for material input or output beyond the facility boundary are not included.

TABLE 6.B-3. Overall Environmental Impacts -
Reference Underground Mine

	<u>Quantity</u>
Total Land Committed	13 (km) ²
Land Actually Used for Mining Facility	> 0.32 (km) ²
Water Used	NA ^(a)
Water Discharged as Liquid Effluents	2.8E7 kg/day ⁽⁴⁾
Total Materials Added to Liquid Effluents	NA
Air Used	~ 6.4E6 kg/day ^(b)
Water Discharged as Airborne Effluents	NA
Total Other Airborne Effluents	NA
Electrical Energy Consumption	NA
Thermal Effluent Equivalent	NA
Resource Use	See Tables 6.B-1 and 6.B-2

NA = Not available at this time.

(a) Water is used to suppress dust by wetting down roads and using water while drilling. The water used is mine seepage water.

(b) This is equal to about 6.2E10 l/day at 7000 ft elevation.

6.B.8 LIMITATIONS AND UNCERTAINTIES IN THE UNDERGROUND MINE STUDY INFORMATION

Detailed information on a uranium underground mining facility is generally not readily available in the public literature. Much of the information that is missing in previous tables and descriptions is not available directly. Some of this information could be developed or extrapolated from available existing information, but gaps in this information may still exist.

The nature of uranium mine effluents and their long-range effect on the environment is not currently well known. Uncertainty also exists as to how future changes in demand for ore, price of ore, and future mining methods used will affect the quantity and nature of mine effluents that will be released to the environment.

6.B.9 RESEARCH AND DEVELOPMENT NEEDS

This study to date has pointed out a need for the following research and development or analyses:

- The nature of uranium mine discharge water needs to be determined or made available. This study should include the distribution of the radionuclides in the uranium-radium family, heavy metals, and other minerals.
- The distribution of contaminants (dust, radionuclides, and gases) and their respective concentration levels in releases to air from underground mining needs to be determined or made available.
- The long-range environmental effect of blowing dust and water run-off from uranium ore stockpiles needs to be studied.
- The environmental impact of alternative methods of uranium mining, such as solution mining and heap leaching may be beneficial.

SECTION 6: REFERENCES

1. J. A. Groves, "Open Pit Uranium Mining," Mining Engineering, pp. 23-25, August 2, 1974.
2. D. A. Clark, State of the Art: Uranium Mining, Milling, and Refining Industry, National Environmental Research Center, Corvallis, Oregon, EPA 660/2-74-038, 1974.
3. R. Thompkins, "Slipping the Pill to Radon Daughters," Canadian Mining Journal, September 1974.
4. Water Quality Impacts of Uranium Mining and Milling Activities in the Grants Mineral Belt, New Mexico, U.S. EPA, EPA 906/9-75-002, September 1975.
5. Environmental Survey of the Uranium Fuel Cycle, WASH-1248, U.S. Atomic Energy Commission, Fuels and Materials, Directorate of Licensing, April 1974.

7.0 URANIUM MILLING

A reference uranium milling facility representative of the predominant current technology for commercial scale plants was defined for this study. The reference mill lies on Site A, located so that airborne effluents will leave the facility equidistant from three sides of the site.

The Highland Uranium Mill operated by Exxon in eastern Wyoming was the basis for this reference mill. The Highland Uranium Mill has a design capacity of 1814 MT (2000 short tons) of ore/day. At an average ore grade of 0.15% U, the mill takes in about 2.7 MT U/day.

The overall characteristics for the reference uranium milling facility in this study include the following:

- There is one facility, two feeds from the mine (one at 0.25% U in the ore, the other at 0.025% U) which when blended contain an average of 0.15% U in the ore, and one product called yellowcake (ammonium diuranate) delivered to the uranium purification and conversion facility.
- The reference facility is capable of processing 1814 MT of ore/day (2.72 MT U/day) and producing about 3.3 MT of yellowcake/day (2.54 MT U/day).
- The facility uses the acid leach method of uranium recovery.
- The milling process recovers 93.5% of the U in the ore.
- The facility is assumed to operate 365 days/yr and 24 hr/day for 20 years.

7.1 SUMMARY

The reference uranium milling facility utilizes the acid leaching process for uranium recovery. The design capacity of the reference facility is 1814 MT of ore/day containing on the average 0.15% U in the ore.

The reference facility receives ore from the mine. The ore is blended, crushed, ground, and leached with acid. The uranium is solvent extracted

from the acid leach and subsequently stripped from the organic solvent. The yellowcake (ammounium diuranate) is formed by precipitation of the uranium in solution using ammonia. The yellowcake is washed, dried, pulverized and loaded into drums for shipment to the reference conversion facility.

About 6.5% of the uranium in the ore received from the mine is assumed to end up in either effluents or wastes. Since much of the effluent and waste information is missing, accurate totals on chemicals released in the effluents and wastes are not available at this time.

The radioactive liquid and solid wastes are confined in the tailings pond except for release of vapors by evaporation, airborne solid particulates by wind entrainment, or liquid seepage.

The facility employs 170 persons. The plant facilities occupy about 0.12 km² of the reference generic site for mines and mills. The tailings pond requires an additional 1.0 km² during the life of the facility.

Detailed process information for the reference milling facility is not presently readily available. Therefore much information desired for this study is not complete. Significant additional information or development of inferred information on effluent control processes, mainline processes, and facility description is needed to perform a detailed cost-benefit analysis.

7.2 MAINLINE PROCESS DESCRIPTION OF URANIUM MILLING

The reference milling facility receives two grades of uranium ore from the mining facility, one with 0.25% and the other with 0.025% U content. At the mill the ore is blended, crushed, and ground to proper composition and particle size. Then the ore is subjected to acid leaching, and the solids in the acid leach are separated from the liquid. The uranium is separated from the aqueous solution by solvent extraction. The uranium is next stripped from the solvent solution into another aqueous solution. The aqueous solution is filtered and the uranium is precipitated by reaction with ammonia. The precipitate is dried to yellowcake $[(\text{NH}_4)_2 \text{U}_2\text{O}_7]$. An overall flow diagram is shown in Figure 7-1.

FIGURE 7-1. Overall Reference Mainline Process for Uranium Acid Leach Mill Process

7.2.1 Description of Process Steps^(1, p. 16-32)

A detailed process flowsheet is shown in Figure 7-2. The major process steps are discussed in the following sections.

- Ore Preparation

The two grades of uranium ore assumed to be delivered to the mill are blended by appropriately stockpiling the ore as it is delivered from the mine. Additional blending is accomplished as the stockpiled ore is loaded into the ore feed hopper. From the ore feed hopper the ore is mechanically conveyed to the crusher building and then fed to a grizzly separator^(a) with vibrating bars having 7.6 cm (3 in.) spaces between the bars. The material larger than 7.6 cm is removed and crushed in an impact crusher.

The discharge from the grizzly and the crusher is mechanically conveyed to a screening area, where it is screened through 1.9 cm openings between the screen rods. Oversize material goes back to the impact crusher, and the material passing through the screening rods is mechanically conveyed to the fine ore bins. From the fine ore bins the crushed ore is mixed with heated water and is wet ground in a rod mill. The ore slurry produced by wet grinding is pumped to the leaching tanks.

- Ore Leaching

Dissolution of uranium materials in the ore is accomplished by sulfuric acid leaching. The ore slurry in the leaching tanks is diluted to 50% solids by heated water. Steam is injected into the slurry to obtain a 35°C (95°F) operating temperature. Sulfuric acid and sodium chlorate (for chemical valence control) are then added to the leaching tank slurry, which flows by gravity through a series of eight mechanically agitated holding tanks for over ten hours. Approximately 95% of the U in the ore is placed in solution through this process; the remainder stays with the unleached ore.

^(a) A grizzly is a device that separates ore into two particle sizes; it consists of a grating of parallel rails or bars used to screen large pieces of material.

FIGURE 7-2 Mainline Process Flow Diagram for Reference Uranium Acid Leach Mill

- Liquid-Solids Separation

The solution from the leaching tanks is pumped to a five-stage countercurrent decantation process to separate the solution containing the dissolved uranium from the insoluble solid waste. The continuous process takes place in large tanks called thickeners and involves repeated thickening, decantation of clarified solution, and redilution of thickened solids. Flocculants are added in the decantation steps to increase the settling rate of the solids in the thickeners.

The relatively clear uranium-containing solution from the decantation process is next pumped to a clarifying thickener designed to remove, with the aid of reagents, most of the finely suspended solids from the solution. The overflow from the thickener is filtered through one of three sand filters in parallel and pumped to the solvent extraction feed tank.

The underflow from the last decantation thickener contains most of the undissolved solids and some unreacted sulfuric acid. It is pumped to the tailings pond. The underflow from the uranium clarifying thickener which contains additional solids is recycled to the leaching tanks.

- Solvent Extraction

The solution in the solvent extraction feed tank is pumped to and through four mixer-settlers in series, where it is solvent extracted using a solvent composed of a tertiary amine, kerosene, and isodecanol. Most of the raffinate (the aqueous solution from which the uranium has been extracted) is recycled to be used to dilute the thickened solids in the last decantation thickener. A portion of the raffinate, however, is pumped to the tailings pond to avoid the buildup of impurities.

Following extraction, the solvent contains the uranium and is pumped to four mixer-settler tanks in series, which make up the stripping process. The uranium in the solvent is transferred into an aqueous solution of concentrated ammonium sulfate in this process. The

"stripped" solvent is reused in the solvent extraction process, and the aqueous solution containing the uranium is pumped to a precipitation feed tank.

- Precipitation

The uranium-bearing aqueous solution is pumped from the precipitation feed tank to a series of two precipitation tanks, into which anhydrous ammonia is bubbled. This reacts with the uranium to form a yellow ammonium diuranate precipitate (yellowcake). The aqueous solution and yellow precipitate flow into the first of a series of two thickeners. Sulfate ions and other soluble impurities are washed from the precipitate in these thickeners. The underflow from the second thickener is pumped to a continuous solid bowl centrifuge for further washing and dewatering.

- Drying and Packaging

The discharge from the centrifuge is mechanically fed into the six-hearth roaster-dryer. The moisture is driven off in the dryer, which operates at about 316°C (600°F). The dried yellowcake is pulverized in a single impactor hammer mill and loaded into 208 L (55 gal) drums in which the product is stored and shipped.

7.2.2 Waste Management

The reference uranium milling facility generates radioactive liquid wastes and radioactive and nonradioactive solid wastes. The radioactive liquid and solid wastes in the tailings pond are of the most concern in this study. Figure 7-3 shows waste management operations.

- Radioactive Liquid and Solid Wastes

Radioactive liquid and solid wastes are liquids and solids that are discharged and confined in the tailings pond. These liquids and solids come from three sources in the mill: 1) the underflow from the last decantation thickener, which contains most of the undissolved ore as solid wastes, 2) a small portion of the solvent extraction raffinate, and 3) the overflow liquid stream from the second uranium diuranate thickener.

FIGURE 7-3. Overall Waste Management Operations for Reference Uranium Mill

These liquid and solid wastes are pumped to the tailings pond where most of the solids settle out. Airborne effluents are produced by evaporation of most of the water from the ponds and windblown dust from dry areas of the pond. A small amount of liquid effluents are produced by seepage from the ponds. After the water evaporates at each portion of the tailings area, the solid wastes are covered with about 2 ft of earth. Vegetation is generally grown on the covered tailings to minimize windblown dust and water erosion and seepage from natural precipitation.

- Nonradioactive Solid Wastes

The nonradioactive solid waste consists of general refuse such as chemical containers, cardboard, etc., which is buried in a landfill onsite.

7.3 EFFLUENT CONTROL PROCESS DESCRIPTION FOR URANIUM MILL

The reference uranium milling facility produces two major sources of effluents, the in-mill processes and the tailings pond. Effluents consist of such materials as uranium and its radioactive decay daughters, dust, nitrogen oxides, kerosene, sulfur dioxides and sulfuric acid. These effluents can be present in either the liquid or the airborne effluents. Figure 7-4 shows the liquid and airborne effluent treatment systems.

7.3.1 Liquid Effluents

The liquid effluents consist of seepage from the tailings pond. The material transported to the tailings pond contains about 85% of the radioactivity of the ore because the radioactive daughters of uranium are not

FIGURE 7-4. Process Flow Diagram - Liquid and Airborne Effluent Treatment System for Reference Uranium

usually extracted with the uranium. The seepage from the tailings pond contains some of these uranium daughters and some of the process chemicals used in the mill. The tailings pond and tailings dam are constructed to minimize the seepage rate. This is done by lining the bottom and sides of the tailings pond with clay or other earthen materials having low permeability by liquids.

7.3.2 Airborne Effluents

Dust from the crushing and fine ore storage areas is collected by separate but similar wet-collection systems. These wet collection systems are estimated to be 95% efficient for the dusts encountered.^(1, p. 22) The slurries discharged from these collection systems are processed in a single, small thickener tank and the thickened stream is recycled to the rod mill, while the clear water is recycled to the wet-collection systems.

Dusts from the yellowcake dryer and drum loading operation are collected by a wet-collection system that is estimated to be 99.3% efficient for the dusts encountered.^(1, p. 31) The slurry discharged from this system is recycled to the first precipitation thickener.

Fumes from the leaching tanks and the solvent extraction building are released directly to the atmosphere without treatment. Water vapor, gaseous radon, and other airborne effluents from the tailings pond are also released directly to the atmosphere from the wet portions of the tailings pond. Where the tailings have dried out airborne particulates are suspended into the atmosphere.

7.4 FACILITY AND SITE DESCRIPTION

This description of the site and facility and its hardware will be used as the primary basis for capital cost estimates and as background for plant performance.

7.4.1 Site

The reference uranium mill is assumed to be located on the generic site for mines and mills (Site A) described in Section 5 of this report.

The plant requires an area of approximately 0.12 km^2 within the larger 13 km^2 plant site. The tailings area requires another 1.0 km^2 during the life of the facility.^(2, p. 26) The plant layout allows the airborne effluents from the mill plant to emanate equidistant from three sides of the total rectangular site and the airborne effluents from the tailings to emanate equidistant from the fourth side of the rectangular site and two sides common with those equidistant from the mill plant area. A well-labeled perimeter fence around the total site allows privacy, while another fence surrounding the smaller plant area includes a security entrance to the plant and mill tailings area.

7.4.2 Facility

The milling facility area contains an ore storage area, crusher building, fine ore storage bins, a mill building, the countercurrent decanting (CCD) pumphouse, the solvent extraction building, five ore thickener tanks and a clarifier tank, a sanitary sewage treatment plant, general offices, and miscellaneous other building and process tanks. Figure 7-5 shows the layout of the reference mill area.

The tailings pond is not shown in the layout but is less than 1 km away. Since essentially one ton of solid waste exists for each ton of ore processed, the tailings pile is large. The tailings pond is located in a natural basin. Temporary water flows from periods of high precipitation are diverted around the tailings pond by small dikes and ditches and covers a large area to provide a sufficient natural evaporation rate.

The tailings pond area was constructed by erecting an earth-filled, clay core dam across the low end of the basin. The dam is 21.3 m (70 ft) high and 1067 m (3500 ft) long at the top. The total pond area is 1.01 km^2 (250 acres). The waste discharge line to the pond is movable, and tailings can be discharged at any point. The coarse sand fraction of the tailings are deposited next to the dam with the water and the slower depositing slimes flowing upstream away from the dam. This displacement of water by sand near the dam aids in minimizing seepage through the dam. In addition, the slower depositing slimes form a less permeable liner for the pond to minimize seepage to the ground.

FIGURE 7-5. Layout of Reference Acid Leach Mill

Table 7-1 lists the major process areas and buildings, and Table 7-2 describes major process equipment.

The mill is assumed to have an operating life of 20 years.

TABLE 7-1. Major Process and Auxiliary Areas Description -
Reference Acid Leach Mill

<u>Process Area</u>	<u>Overall Dimensions L x W x H, m</u>	<u>Perimeter Construction Material</u>	<u>Other Features</u>
Crushing Area	16 x 12 x 20	Steel	Insulated Walls, Concrete Floor
Conveyor Area	41 x 9 x 18	Steel	Wood Floor
Fine Ore Bins	25 x 9 x 26	Steel	NA
Mill Building	54 x 42 x 15	Steel	Concrete Floor
Counter Current Decantation Pumphouse	40 x 15 x 10	Concrete, Steel	Concrete Floor
Solvent Extraction Building	62 x 27 x 13	Steel	NA
Thickener Tanks	34 dia. x 4.3	Wood Staves	NA
Maintenance Building	30 x 18 x 8	Steel	NA
Change House	30 x 18 x 4	Steel	NA
Office Building	38 x 15 x 3	Steel	NA

NA = Not available at this time

TABLE 7-2. Major Process Equipment Descriptions -
Reference Acid Leach Mill

<u>Equipment</u>	<u>Location</u>	<u>No.</u>	<u>Size, m L x W x H</u>	<u>Construction Material</u>	<u>Process Duty or Capacity</u>
Crusher	Crusher Building	1	NA	NA	NA
Conveyors	Crusher Building and External	NA	NA	NA	NA
Fine Ore Bins	Fine Ore Bins	2	9 Dia. x 25	Mild Steel	1360 MT
Rod Mill	Mill Building	1	2.7 Dia. x 4.6	Mild Steel	NA
Leach Tanks	Mill Building	8	5.5 Dia. x 5.5	Wood	NA
Thickener Tank	Thickener Tanks	5	34 Dia. x 5.5	Wood	NA
Clarifier Tank	Thickener Tank Area	1	20 Dia. x NA	Wood	1.6E6 liters
Flocculant Tank	CCD Pumphouse	2	4.3 Dia. x 4.0 High	NA	NA
Raffinate Holding	Solvent Extraction Building	1	24 Dia. x 3.1 High	NA	1.3E6 liters
Yellowcake No. 1 Thickener	Solvent Extraction Building	1	10.4 Dia. x 1.6 High	NA	1.8E5 liters
Yellowcake No. 2 Thickener	Solvent Extraction Building	1	6.1 Dia. x 1.6 High		5.7E4 liters

NA = Not available at this time

7.5 EFFLUENT CONTROL PERFORMANCE FOR THE MILL

The input/output information in Table 7-3 indicates the overall input/output for radioactive material from the reference facility. It is assumed that 6.5% of the uranium supplied to the milling facility ends up in either the airborne and liquid effluents or the liquid and solid wastes. Table 7-4 gives the overall input of nonradioactive materials, and Table 7-5 gives the output of nonradioactive airborne effluents. Table 7-6 gives output of non-radioactive liquid effluents, and Table 7-7 gives the output of radioactive and nonradioactive solid and liquid wastes.

A significant amount of additional information is required to complete these tables to determine the important effluents.

TABLE 7-3. Overall Radioactive Materials Input/Output
for Reference Uranium Acid Leach Mill

Material	Total Material (a)		U(a,b) kg/day	From		Fraction of Plant Input(c)
	kg/day	l/day		Chemical	Phase	
<u>Input to Mill</u>						
Uranium Ore	1.8E6 ^(d)	NA ^(d)	2.7E3	See Table 6.A-3	S	(1)
<u>Output from Mill</u>						
Airborne Effluents:						
Uranium	5.4E2 ^(d)	NA ^(d)	1.6	NA	S	5.9E-4
²³⁰ Th	1.4E-5	NA	---	NA	S	---
²²⁶ Ra	27.E-7	NA	---	NA	S	---
²²² Rn	4.3E-6	NA	---	NA	G	---
Radon Daughters:						
²¹⁰ Pb	NA	NA	---	NA	S	---
²¹⁰ Po	NA	NA	---	NA	S	---
Liquid Effluents:						
Uranium	NA	NA	0.83	NA	L,S	3.0E-4
²³⁰ Th	4.9E-4	NA	---	NA	L,S	---
²²⁶ Ra	1.5E-7	NA	---	NA	L,S	---
Yellowcake	3.3E3 ^(d)	NA ^(d)	2.5E3	(NH ₄) ₂ U ₂ O ₇	S	(0.935)
Liquid Waste	2.3E6 ^(d)	2.3E6 ^(d)	4.3	NA	L	(1.6E-3)
Solid Waste	1.8E6 ^(d)	NA	1.7E2	NA	S	(6.3E-2)

(a) Values based upon one day operating at 100% capacity.

(b) Based on an average ore content of 0.15% U.

(c) Numbers in parentheses are not released to the environment.

(d) Value indicates total of radioactive and nonradioactive sources.

KEY: S = Solid

L = Liquid

G = Gas

NA = Not available at this time

TABLE 7-4. Overall Nonradioactive Materials Input for
Reference Uranium Acid Leach Mill

Material	Total Material ^(a)		Form	
	kg/day	ℓ/day	Chemical	Phase
Water	2.7E6	2.7E6	H ₂ O	L
Kerosene	NA	NA	H _x C _y	L
Ammonia	NA	NA	NH ₃	G
Sulfuric Acid	NA	NA	H ₂ SO ₄	L
Sodium Chlorate	NA	NA	NaClO ₃	S
Ammonium Sulfate	NA	NA	(NH ₄) ₂ SO ₄	S
Major Constituents in Ore	1.8E6	NA	See Table 6.A-3	S
Tertiary Amine	NA	NA	NA	L
Isodecanol	NA	NA	C ₁₀ H ₂₁ OH	L

^(a) Value based upon one day operating at 100% capacity

KEY:

S = Solid
L = Liquid
G = Gas
NA = Not available at this time

TABLE 7-5. Overall Nonradioactive Airborne Effluents
Output from Reference Uranium Acid Leach Mill

Material	Form		Output ^(a) kg/day
	Chemical	Phase	
Dust	NA	S	5.4E2
Sulfur Oxides	SO _x	G	0.57
Nitrogen Oxides	NO _x	G	43
Kerosene	H _x C _y	G	2.5E2
Hydrocarbons	H _x C _y	G	8.7
Organic Acids	NA	G	13
Aldehydes	NA	G	2.2
Ammonia	NH ₃	G	4.3
Nonradioactive Particulate	NA	S	2.2
Sulfuric Acid	H ₂ SO ₄	L	NEG
Arsine	AsH ₃	G	NEG
Stibine	SbH ₃	G	NEG
Hydrogen Sulfide	H ₂ S	G	NEG

(a) Values based upon one day operating at 100% capacity.

(b) This material does not enter the plant in this chemical form.

KEY: S = Solid
L = Liquid
G = Gas
NA = Not available at this time
NEG = Negligible

TABLE 7-6. Overall Nonradioactive Liquid Effluents
from Reference Uranium Acid Leach Mill

Material	Form		Output ^(a) kg/day
	Chemical	Phase	
Calcium	Ca ⁺²	L	2.2E2
Iron	NA	NA	4.4E2
Aluminum	NA	NA	8.7E2
Ammonia	NA	NA	2.2E2
Sodium	Na ⁺	L	87
Arsenic	NA	NA	8.7E-2
Fluoride	NA	NA	2.2
Vanadium	NA	NA	4.4E-2
Sulfate	SO ₄ ⁻²	L	1.3E4
Chloride	Cl	L	1.3E2
Tertiary Amine	NA	L	3.8
Isodecanol	C ₁₀ H ₂₁ OH	L	5.1
Beryllium	NA	NA	3.5E-2
Chromium	NA	NA	2.4
Molybdenum	NA	NA	3.5
Copper	NA	NA	0.81
Nickel	NA	NA	0.61
Lead	NA	NA	0.61
Zinc	NA	NA	1.3
Titanium	NA	NA	3.1
Sulfide	S ⁻²	NA	0.11
Cyanide	NA	NA	2.2E-3
Silver	NA	NA	2.2E-3
Manganese	NA	NA	68
Magnesium	NA	NA	2.4E-2
Silica	SiO ₂	S	NA
Potassium	K ⁺	L	NA
Chlorate	ClO ₃ ⁻	L	NA
Polyacrylamide Flocculents	NA	NA	NA
Nitrates	NA	NA	NA

^(a) Values based upon one day operating at 100% capacity.

KEY: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

TABLE 7-7. Overall Solid and Liquid Wastes from Reference Uranium Acid Leach Mill

Waste Material	Total ^(a)		U Content ^(a)		Fraction of Plant Input
	ℓ/day	kg/day	kg/day	Form	
Uranium-Contaminated					
Spent Ore	NA	1.8E6 ^(b)	1.7E2	S	6.3E-2
Liquid Tailings Waste	NA	2.3E6 ^(b)	4.3	L	1.6E-3

(a) Value based upon one day operating at 100% of capacity.

(b) Value indicates total of radioactive and nonradioactive source.

KEY: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

7.6 FACTORS FOR OPERATING COST INFORMATION

The available basic plant operational requirements are presented here to enable later estimation of direct operating costs.

7.6.1 Labor Requirements

The reference facility is assumed to operate 24 hr/day and 365 days/yr. The work force for the reference facility is assumed to be:

Management and professional	17 (18%)
Nonmanagement and nonprofessional	75 (82%)
	92 (1, p. 11,12,61)

7.6.2 Material Requirements

The routine material requirements consist of those materials given as inputs in Tables 7-3 and 7-4 and drums for packaging the yellowcake product. Sulfuric acid and sodium chlorate are two major routine materials. Miscellaneous materials such as office materials, office furniture, routine maintenance supplies, etc. are also required.

7.6.3 Unusual Maintenance Requirements

During the life of the facility various equipment is expected to require replacement or repair. These special requirements and overall maintenance requirements have not yet been identified. In the absence of good data, these maintenance requirements are assumed to be equivalent to replacing all the process equipment once in the 20-yr life of the mill.

7.6.4 Utility Requirements

Total estimated utility requirements for each day of operation at 100% capacity are:

- water 2.73×10^6 kg/day (1, p. 108)
- electricity NA
- natural gas NA

7.6.5 Transportation Requirements

All the plant input materials (except water) listed in Tables 7-3 and 7-4 must be transported to the facility. The ore is transported typically about 6 to 8 km from the mine to the mill. The yellowcake product must be transported to the conversion facility. Typical transport distances for other input materials are not within the scope of this report.

7.6.6 Waste Disposal Requirements

The liquid and solid wastes listed in Table 7-3 are confined to the tailings pond. When the water has evaporated, the solid wastes that remain are covered with earth and vegetation.

Other nonradioactive solid wastes are buried in a landfill onsite.

7.6.7 Other Operating Cost Elements

Certain major operating cost elements are those tasks performed by outside contractors. A contractor transports materials into the facility and yellowcake product out of the facility. Other known special operating cost elements include licensing and insuring the operation of such a nuclear materials processing facility.

7.7 ENVIRONMENTAL IMPACT FACTORS

Several environmental impacts result from milling operations. Table 7-8 summarizes the environmental impacts of the reference mill. There is a change in the topography of the site involving approximately 1 km² (300 acres). This results from the construction of earth dams and filling of the tailings pond, and earth cover over the tailings pile as sections of the tailings retention system have been filled and dried. Also, where a natural watershed

TABLE 7-8. Overall Environmental Impacts - Reference Uranium Acid Leach Mill

	Quantity ^(a)	Remarks
Total Land Committed	13 km ²	
Land Actually used for Mill	0.12 km ²	
Land Actually used for Tailings Pond	1.0 km ²	
Water Used	2.7E6 kg/day	
Water Discharged as Liquid Effluent	4.4E5 kg/day	Estimated seepage from pond
Total Materials added to Liquid Effluents	NA	
Air used	NA	
Water Discharged as Airborne Effluent	~2.5E6 kg/day	Evaporation from pond
Total Other Airborne Effluents	4.0E2 kg/day	Mainly ore dust
Electrical Energy Consumption	NA	
Natural Gas Consumption	NA	
Thermal Effluent Equivalent	1.4E5 kWhr/day	
Resource use	See Tables 7.3 and 7.4	

NA = Not available at this time

(a) These quantities are those used directly at the plant. Impacts of resources required for material input or output beyond the plant boundary are not included.

occurs above the tailings retention system, diversion dams and ditches are constructed to prevent surface runoff from contacting the tailings pile and pond. All liquid and solid wastes are sent to the tailings retention system.

The radioactivity associated with uranium milling results from natural uranium and its radioactive decay daughter elements present in the ore. During the milling process, the natural uranium is separated and concentrated. The bulk of the radioactive uranium daughter decay products in the ore remain in the uranium-depleted pulp (tailings).

External radiation levels associated with uranium milling activities are low, rarely exceeding a few mrem/hr at surfaces of process vessels. Liquid and solid wastes from the milling operation contain low-level concentrations of radioactive materials; however, the concentrations are greater than those specified for unrestricted areas. Therefore, these wastes are stored in an earth-dam retention system on the site with restricted access by the public. Concentrations of airborne radioactive materials such as radon gas or radioactive particulates escaping into the uncontrolled environs under normal conditions are not expected to be more than a few percent of limits specified in Title 10, Code of Federal Regulations, Part 20 (10 CFR 20).

Most chemical materials resulting from reagents used in the milling processes are not released to the environment, but are retained in the tailings retention system. For a description of the kinds and amounts of chemical materials, see Section 7.3.

In addition to the chemical and radiological effluents, a small amount of thermal effluents, which ultimately find their way to the atmosphere, originate from process and building heat in the uranium mill. This thermal effluent is assumed to be 1.4×10^5 kW/hr/day based on operation at 100% capacity. (1, p. 88)

In general, the reference mill will use about 1.5 MT of water per MT of ore processed. (3) In cases where the mill is near the mine, mine water can be used in the mill process, thus reducing the requirement for water from other sources. (4)

7.8 LIMITATIONS AND UNCERTAINTIES IN THE STUDY INFORMATION

Detailed information on the uranium milling facility is not presently available. Some of this information can be developed or inferred from available information but gaps in this information may still exist.

7.9 RESEARCH AND DEVELOPMENT NEEDS

More detailed information on the reference milling facility is needed. In particular, details are needed on the chemical inputs, the process, the effluents, the wastes and the utility requirements.

Research and development is underway on control of effluent releases from the tailings ponds and ore piles. Various controls and stabilization techniques also need to be assessed.

SECTION 7.0: REFERENCES

1. Applicant's Environmental Report, Highland Uranium Mill, Converse County, Wyoming, submitted by Humble Oil and Refining Company, Docket 408102-1, July 1971.
2. Final Environmental Statement, related to operation of the Highland Uranium Mill, submitted by U.S.A.E.C., Docket 408102-7, March 1973.
3. M. B. Scars, et al, Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low as Possible" Guides - Milling of Uranium Ores, ORNL-TM-4903. Vol. I. May 1975.
4. R. C. Merritt, The Extractive Metallurgy of Uranium, prepared by the Colorado School of Mines Research Institute for the U.S. Atomic Energy Commission, 1971.

PURIFICATION AND CONVERSION

8.0 URANIUM PURIFICATION AND CONVERSION

The reference uranium purification facility selected for this study is representative of current technology and is primarily modeled after the Kerr-McGee Facility in Sequoyah, Oklahoma. The Kerr-McGee facility presently produces about 6,709 MT UF_6 /yr (4,536 MT U/yr) and plans to produce about 13,417 MT UF_6 /yr (9,072 MT U/yr) in the near future.

The overall characteristics of the reference uranium conversion facility in this study include the following:

- One facility, one feed (ammonium diuranate -- referred to as yellowcake or ore concentrate) and one product (uranium hexafluoride).
- The reference facility produces about 37 MT UF_6 /day (25 MT U/day) or about 13,396 MT UF_6 /yr (9,057 MT U/yr).
- The facility uses the "wet" process of producing uranium hexafluoride.
- The facility is assumed to operate 365 days/yr and 24 hr/day for 40 years.

8.1 SUMMARY

The reference uranium conversion facility is designed to convert yellowcake (ammonium diuranate) to uranium hexafluoride using the "wet" process. The assumed production rate is 9,057 MT U/yr as uranium hexafluoride.

The reference facility receives yellowcake from the milling facility. The yellowcake is digested in nitric acid and the uranyl nitrate product is purified by solvent extraction. The uranyl nitrate is denitrated and chemically reduced to uranium dioxide, hydrofluorinated to uranium tetrafluoride, and fluorinated to uranium hexafluoride.

About 0.15% of the uranium received by the reference facility ends up in either effluents or wastes. Since much of the effluent and waste information is missing, accurate totals on chemicals released in the effluents and wastes are not available at this time.

The contaminated liquid and solid wastes either remain in retention ponds or are buried onsite.

The facility employs 155 persons. The plant facilities (within the restricted area fence) occupy an area of 0.30 km² of the reference generic Site B (4.7 km²).

Detailed process and facility information of the conversion facility is not presently readily available. Therefore much information desired for this study is not complete.

Significant additional information or development of inferred information on effluent control processes, mainline processes, and facility description is needed to perform a detailed cost-benefit analysis.

8.2 MAINLINE PROCESS DESCRIPTION OF URANIUM PURIFICATION AND CONVERSION

The reference uranium conversion facility receives ore concentrates called yellowcake (ammonium diuranate) from the reference milling facility as shown in the process diagram in Figure 8-1. The yellowcake is sampled and then digested with nitric acid. The uranyl nitrate that is formed is then solvent extracted, denitrated to uranium trioxide, and chemically reduced to uranium dioxide using dissociated ammonia. The uranium dioxide is hydrofluorinated to uranium tetrafluoride using anhydrous hydrogen fluoride, fluorinated to uranium hexafluoride using elemental fluorine, and collected by condensation in cold traps. The purified uranium hexafluoride is transferred to shipping cylinders for interim onsite storage and subsequent transportation to the enrichment plant.

8.2.1 Description of Process Steps

A more detailed process flow diagram is given in Figure 8-2. The major process steps are discussed in the following sections.

- Feed Preparation

The impure yellowcake containing the equivalent of 60 to 85% U₃O₈ arrives from the reference milling facility in 208 drums and is

FIGURE 8-1. Overall Reference Mainline Process for "Wet" Conversion

FIGURE 8-2. Mainline Process Flow Diagram for the Reference Uranium "Wet" Conversion Facility

weighed, unloaded, and sampled. The unloading process consists of elevating the drums to a mechanical drum dumping station and dumping the drum contents into the sampling process feed hopper. The yellowcake is next mechanically fed to the acid digestion feed hopper.

The sampling system consists of three^(1, p. 6) samplers that retain about 0.1% of the input. The sample is processed to a final stage by drying, pulverizing, and blending.

- Digestion

From the feed hopper the yellowcake and hot^(2, p. 40) 40% nitric acid are fed to one of three primary digester tanks on a batch basis for up to eight hours of digestion. A miscellaneous digester tank^(2, p. 43) which also operates on a batch basis, handles recoverable uranium from several nonproduct points in the process, including dust collected on exit filters from the fluorination towers and fluorination tower feed material ("ash") that escapes conversion to uranium hexafluoride. These materials are digested in aluminum nitrate solution in the miscellaneous digester; this solution is then blended with the primary digester solutions and continues through the main process. After digestion the uranyl nitrate solutions are adjusted to the proper acid concentration and chemical composition.^(2, p. 43)

- Solvent Extraction

The impure uranyl nitrate solution is processed by counter-current solvent extraction in pumper-decanters using 30% tributyl phosphate in hexane as the solvent. The uranium-loaded solvent is then scrubbed with slightly acidified water in mixer settlers to remove residual impurities and entrained aqueous salt solutions. Next the uranyl nitrate is stripped (re-extracted) into the aqueous phase using a pulse column as a contactor. The solvent is purified for recycle by being washed with ammonium sulfate^(2, p. 45) and sodium hydroxide. The spent ammonium

sulfate is returned to the pumper-decanter and eventually ends up in the raffinate stream going to liquid waste treatment, while the spent sodium hydroxide combines with the raffinate just prior to liquid waste treatment^(3, p. 2)

- Concentration

The uranyl nitrate-water solution is concentrated by using a primary and secondary evaporation system. The feed stream to the primary evaporation system is first scrubbed with hexane to remove tributyl phosphate, and then the aqueous phase passes through a decanter to remove residual organic matter. The feed stream is next concentrated in the primary evaporation system, a continuous single-effect evaporator. The secondary evaporation system consists of three batch boil-down tanks to concentrate the uranyl nitrate to about 1200 g U/l.^(1, p. 10) A trace of sulfuric acid is added to the concentrate in the boil-down tanks^(4, p. III-2) to enhance the chemical reactivity of the decomposition product of the next step, denitration.

- Denitration

The concentrated solution of uranyl nitrate hexahydrate is decomposed in one of three continuous trough-type denitrators that are electrically heated to about 274°C (525°F). A small stream of uranyl nitrate hexahydrate is added continuously to each denitrator bed, stirred by an agitator, and decomposed to uranium trioxide. The uranium trioxide powder is mechanically conveyed to a temporary storage bin, then to a hammer mill where it is pulverized. The uranium trioxide is then stored until the next process step is taken.

- Reduction

The pulverized uranium trioxide is chemically reduced to uranium dioxide in one of two sets of fluidized bed reactors operating at about 538°C (1000°F). Each set consists of two fluidized beds in series to prevent short circuiting of feed powder to the product discharge without reduction. The reducing gas also serves as the fluidizing gas and

consists of hydrogen and nitrogen formed in the plant by dissociation of ammonia. The uranium dioxide product is carried with the outlet gases from the reactors to a collection hopper. This hopper is vented through sintered metal filters that are periodically pulsed with a nitrogen backflow to dislodge uranium dioxide powder that drops into the hopper.

- Hydrofluorination

Uranium dioxide produced in the reduction reactors is converted to uranium tetrafluoride by reaction with anhydrous hydrogen fluoride at an operating temperature of 343°C (650°F) to 538°C (1000°F). The uranium dioxide is fed into the first of a series of two chemical reactors fluidized by the anhydrous hydrogen fluoride. The partially reacted powder from the first reactor discharges into an intermediate hopper that feeds the second reactor of the series. The fluorinated product from the second reactor discharges to a product hopper. Two parallel sets of two reactors in series perform these functions.

- Fluorination

The uranium tetrafluoride product and other compounds (UO_2F_2 and UO_2) from the hydrofluorination step are converted to uranium hexafluoride by reaction with elemental fluorine gas. The uranium tetrafluoride is charged to one of five primary fluorination towers (flame reactors) where elemental fluorine continuously reacts with uranium tetrafluoride to produce uranium hexafluoride.

Much of the exhaust gas from the primary towers is recycled back to the primary towers through a series of two sintered metal filters and a cold trap. A bleed stream taken from the main exhaust gas, following the cold trap, is fed to two cleanup towers, which are used to react the unreacted fluorine in the bleed stream with excess uranium tetrafluoride. The unreacted uranium tetrafluoride from the cleanup towers is recycled to the primary towers.

- Collection of Uranium Hexafluoride

The gaseous uranium hexafluoride product leaving the primary fluorination towers is cooled in primary (2°C) and secondary (-59°C) cooling chambers (cold traps) to recover the uranium hexafluoride as a solid.

- Interim Storage and Load-Out of Uranium Hexafluoride

Periodically the cold traps are heated above the melting point of uranium hexafluoride and the UF_6 is drained into cylinders for storage and shipping.

Auxiliary processes for the production of elemental fluorine, for nitric acid recovery and reuse, and for hydrogen fluoride recovery and reuse are described below.

- Fluorine Production

Fluorine is produced onsite as needed by the electrolysis of anhydrous hydrogen fluoride dissolved in a fused salt bath of potassium fluoride-hydrogen fluoride. This electrolytic process is carried out in medium temperature (88°C) electrolyte cells. The fluorine gas is then filtered to remove entrained electrolyte, compressed, cooled to condense out anhydrous hydrogen fluoride,^(4, p. III-4) and fed to the fluorination process.

- Nitric Acid Recovery and Reuse

The nitric acid recovery process is shown later in Figure 8-5, as it is associated with the airborne effluent treatment. Nitric acid is recovered for reuse from several process off-gas streams. The off gas from the single effect uranium evaporator discharges into a condenser where nitric acid vapors are condensed for reuse. The noncondensable off gas from this condenser is joined by off gas from the second stage uranium concentrator tanks and from the denitrators. This combined off gas is scrubbed with 40 wt% nitric acid and reused.

The scrubbed off gas is cooled to condense additional nitric acid vapors for reuse, and the noncondensable off gas is joined by off gas from the digester tanks. This combined off gas is discharged to a nitric acid absorption column where additional nitric acid is formed by oxidation and absorption of nitrogen oxide gases. The unabsorbed gases eventually flow to the main plant stack. Most of the nitric acid produced by the absorption column is reused, but any excess acid is discharged to liquid waste treatment. The recovered nitric acid that is to be reused is mixed with fresh 60% nitric acid to obtain the 40% acid used in the digesters.

- Hydrogen Fluoride Recovery and Reuse

Hydrogen fluoride is recovered from the fluorine gas stream by condensation and reused in the fluorine production process. Aqueous hydrogen fluoride is recovered from the hydrofluorination reactor off gas by condensation and sent to the anhydrous hydrogen fluoride supplier for removal of water and reuse.

8.2.2 Waste Management

The waste materials generated in the reference uranium conversion facility are radioactive liquid wastes and radioactive and nonradioactive solid wastes. The radioactive liquid wastes are of greatest concern in this step of the uranium fuel cycle. Figure 8-3 shows waste management methods; the methods of waste management are discussed in the following sections.

- Radioactive Liquid Wastes

The radioactive liquid waste stream from the solvent extraction system, known as raffinate, is primarily composed of ammonium nitrate, nitric acid, metallic salt impurities from the yellowcake feed, minute quantities of uranium, and radioactive daughter products of normal uranium decay. The raffinate is combined with spent sodium hydroxide from the solvent purification system and the miscellaneous digester

FIGURE 8-3. Overall Waste Management Processes for the Reference Uranium "Wet" Conversion Facility

off-gas scrubber and with excess recovered weak acid from the nitric acid absorber.^(5, p. 4) This combined stream (raffinate stream) is neutralized with ammonia, which precipitates most of the contained radioactive elements and other heavy metal impurities. The resulting slurry is confined in storage ponds having sealed bottoms.^(6, p. 3) The evaporating liquid becomes an airborne effluent.

Another liquid stream produced in the facility, the fluoride stream, might be considered either a waste or an effluent. It is assumed that the fluoride stream is an effluent because part of this stream discharges to the environment. Treatment of this stream is discussed in Section 8.3.

- Radioactive Solid Wastes

The solid wastes generated by the precipitation treatments of both the raffinate stream and fluoride stream are confined to their respective storage ponds. In the future the solid wastes in the raffinate storage ponds may be reprocessed to recover the residual uranium, and the solid wastes in the fluoride storage ponds may be buried onsite according to 10 CFR 20.304, or possibly treated and/or disposed of another way.

Other solid wastes that are only slightly contaminated with uranium, such as shipping drums, sludges, and other solids are buried onsite without packaging, in accordance with 10 CFR 20.304.

- Nonradioactive Solid Wastes

Nonradioactive combustible solid wastes such as boxes, crates, paper and rags are burned in an open-pit incinerator. Other combustible solid wastes not suitable for open-pit incineration are burned in an enclosed incinerator that discharges its off gas to the main plant stack.

8.3 EFFLUENT CONTROL PROCESS DESCRIPTIONS FOR URANIUM CONVERSION

Control of emissions of uranium and its daughters, and chemicals such as fluorides and nitrogen oxides must be done to limit effluents to acceptable amounts. These materials can be present in both the aqueous and airborne effluents.

8.3.1 Liquid Effluents

Figure 8-4 shows the liquid effluent treatment system. The fluoride-containing liquid stream (considered as an effluent rather than a waste) consists of several streams combined prior to treatment. The major part of the fluoride stream is weak hydrofluoric acid from the off-gas scrubber system serving the hydrofluorination processes, ^(5, p.5) fluorination processes, and emergency vent off-gas system from process vessels and storage tanks. Added to this weak hydrofluoric acid stream are laboratory wastes, fluorine cell rework sludges (sodium carbonate solutions) and liquids ^(5, p. 5) from the anhydrous hydrogen fluoride vaporizer sump. All these streams combine to form the fluoride effluent stream, which is treated with slaked lime (calcium hydroxide) to neutralize the acid and raise the pH to 12. This resultant slurry flows to a fluoride sludge pond where the bulk of the excess lime and calcium fluoride precipitate settles out. The overflow from the sludge pond is neutralized to a pH of about 7 by adding sulfuric acid. The resulting solution is fed to a clarifying pond where most of the remaining suspended calcium fluoride and calcium sulfate settle out. All ponds have sealed bottoms.

The overflow from the clarifying pond is combined with "clean" effluent water and sewage lagoon overflow. These combined streams are mixed, sampled and discharged from the facility to the receiving river.

8.3.2 Airborne Effluents

The treatment of airborne effluents from the facility is shown schematically in Figure 8-5. Treatment consists mainly of filtration and scrubbing by various systems.

The miscellaneous digester off gas is scrubbed with sodium hydroxide, and the scrub solution is discharged to the liquid waste treatment system. The remaining off gas from the caustic scrubber is joined by the off gas from the primary digester before entering the nitric acid absorption column. The single effect uranium evaporator off gases pass through a condenser, are joined by off gases from the second stage uranium concentrator tanks and

FIGURE 8-4. Process Flow Diagram - Liquid Effluent Treatment System for Reference Uranium "Wet" Conversion Facility

denitrators, and together these off gases are scrubbed with 40% nitric acid and cooled prior to entering the nitric acid absorption column. The off gas from absorption is assumed to be bag filtered before release to the main plant stack.

The reduction reactor off gas is filtered through sintered metal filters and bag filtered (assumed) prior to being burned. The exhaust from the burner is released to the main plant stack.

The hydrofluorination reactor off gas is filtered through sintered metal filters, bag filtered (assumed), cooled in a condenser, and released to the hydrofluoric acid scrubber. The vent off gas from process vessels and storage tanks is released directly to the hydrofluoric acid scrubber. The fluorination cleanup reactor off gas is filtered through sintered metal filters, bag filtered (assumed), cooled in a cold trap, and released to a waste gas burner. The preceding off gas is joined, before entering the burner, by the hydrogen off-gas stream from fluorine production, which has been bag filtered and cooled in a condenser. The two off-gas streams entering the waste burner are mixed with air, burned, and released to the hydrofluoric acid scrubber. The exhaust from this scrubber is discharged to the main plant stack.

Combustion off gas from steam boilers and from the enclosed incinerator (after assumed filtration) are released directly to the main plant stack. The off gas from dust control and pneumatic conveyance systems passes through cyclone separators and bag filters prior to release to the main plant stack.

Uncondensed hexane vapor from the solvent purification still is released directly to the atmosphere. Fluorine from the fluorine cell rework area and the fluorine emergency vent is also released directly to the atmosphere.

Evaporated water from the cooling tower is an airborne effluent.

8.4 FACILITY AND SITE DESCRIPTION

This section summarizes the descriptions of the site and facility and its hardware. This information will be the primary basis for capital cost estimates and serve as background for plant performance analyses.

8.4.1 Site

The reference uranium conversion facility is assumed to lie on the 4.7 km² Site B described in Section 5. The facility itself (within the restricted area fence) requires an area of 0.30 km² within the larger plant site.⁽⁴⁾ The facility layout assumes a well-labeled perimeter fence exists around the total site to exclude the public. Another fence, with a security entrance, surrounds the smaller restricted area.

The liquid effluents from the plant are assumed to be discharged onsite into the river that flows through Site B. The airborne effluents are assumed to be discharged 1 km away from three sides of the rectangular generic site.

8.4.2 Facility Descriptions

The reference facility, shown in Figure 8-6, consists primarily of three buildings (main process building, solvent extraction building, and warehouse building) and the following auxiliary areas: three raffinate stream ponds, three fluoride stream ponds, UF₆ cylinder storage area, chemical tank farm, electrical substation, cooling tower, fuel oil storage area, and a burial ground.

The main process building, occupying about 6,400 m² (69,000 ft²), contains the administrative offices, laboratory, sampling plant, major processing and fluorine generation facilities, and the utility and maintenance areas. This building's maximum height is 18.3 m (60 ft) over the sampling plant area, while most of the roof above the manufacturing area is 12.2 m (40 ft) above ground. The roof height of the 45.7 m wide by 57.9 m deep (150 ft by 190 ft) east wing of the building is about 4.9 m (16 ft). The main plant stack lies near the northwest corner of the building and rises 45.7 m (150 ft) above ground level.

FIGURE 8-6. Layout of the Reference Uranium "Wet" Conversion Facility

The solvent extraction building occupies 372 m² (4000 ft²) with a 9.1 m (30 ft) high roof.

The one-story warehouse is used for the storage of spare mechanical parts.

The lifetime of the facility is assumed to be 40 years.

The summary of the major process area descriptions is given in Table 8-1 and that for major process equipment in Table 8-2.

8.5 EFFLUENT CONTROL PERFORMANCE

The overall effluent control performance for radioactive material is indicated by the input/output information in Table 8-3. Approximately 0.15% of the uranium supplied to the reference facility ends up in either the airborne and liquid effluents or the liquid and solid wastes. Table 8-4 gives the overall input of nonradioactive materials, and Table 8-5 gives the output of nonradioactive airborne and liquid effluents. The output of radioactive and nonradioactive solid and liquid wastes is given in Table 8-6.

A significant amount of additional information is required to complete these tables in this section, to determine the important effluents. Additional information is required to determine the performance of the individual effluent treatment steps for the important effluents.

8.6 FACTORS FOR OPERATING COST INFORMATION

The available basic plant operational requirements are presented to enable later estimation of direct operating costs.

8.6.1 Labor Requirements

The reference facility is assumed to operate 24 hr/day and 365 days/yr. The work force for the reference facility is assumed to include the following:

Management and professional	15 (10%)
Nonmanagement and nonprofessional	140 (90%)
	155 (1, p. 31)

TABLE 8-1. Major Process and Auxiliaries Areas Description -
Reference Uranium "Wet" Conversion Facility

<u>Process Area</u>	<u>Overall Dimensions L x W x H, m^(a)</u>
Main Process Building	104 x 70 x (5,12,18)
Administrative Offices	15 x 12 x NA
Laboratory	24 x 12 x NA
Sampling Plant	NA
Major Process Area	58 x 58 x 12
Fluorine Generation Area	45 x 18 x 5
Utility Area	NA
Maintenance Area	NA
Solvent Extraction Building	24 x 15 x 9
Warehouse (spare parts)	12 x 12 x NA
Auxiliary Areas	
Raffinate Ponds	(1) 129 x 51 x NA (2) 129 x 115 x NA (3) 226 x 98 x NA
Fluoride Ponds	(1) 80 x 35 x NA (2) 64 x 31 x NA (3) 64 x 31 x NA
UF ₆ Cylinder Storage Area	100 x 22 x NA
Chemical Tank Farm	(1) 38 x 21 x NA (2) 15 x 15 x NA
Electrical Substation	68 x 66 x NA
Cooling Tower	27 x 11 x NA
Fuel Oil Storage Area	20 x 12 x NA 3.2E6 l Capacity

^(a) Values in this column are mainly estimates from drawings.

NA = Not available at this time

TABLE 8-2. Major Process Equipment Descriptions -
Reference Uranium "Wet" Conversion Facility

<u>Equipment</u>	<u>No.</u>	<u>Size, m L x W x H</u>	<u>Process Duty or Capacity (ea)</u>	<u>Other Features</u>
Digestion:				
Digesters	3	NA	15,140 ℓ	Operating Temp. 90° to 105°C
Adjustment Tanks	2 ^(a)	NA	NA	NA
Solvent Extraction:				
Pumper Decanters	6 ^(a)	1.2 diameter 1.8 high	NA	NA
Mixer Settlers	2 ^(a)	0.76 diameter 7.6 contacting height	NA	NA
Raffinate Holding Tanks	3	4.7 diameter 2.7 high	17,032 ℓ	NA
Concentration:				
Single Effect Evaporator	1	NA	12,301 ℓ /hr(in) 2,574 ℓ /hr(out)	NA NA
Boildown Tanks	3	3.0 diameter 3.0 high	22,710 ℓ	NA
Denitration:				
Denitrator	3	NA	NA	Trough-type 274°C Op. Temp.
UO ₃ 8in	1	NA	160,000 kg UO ₃	NA
Reduction:				
Reduction Reactors	4	0.46 diameter	886 kg UO ₃ /hr	Fluidized Bed Reactors 538°C Op. Temp.
Hydrofluorination:				
Hydrofluorinator Reactors	4	0.76 diameter	NA	Fluidized Bed Reactors 343° to 538°C Op. Temp.
Fluorination:				
Fluorination Towers				
A. Primary	5	NA	NA	Flame Towers
B. Cleanup	2	NA	NA	Flame Towers
Fluorine Generation:				
Fluorine Cells	68 ^(b)	NA	~100 kg/F ₂ /day	6000 amps ~10 volts/cell
Cold Trap Treatment:				
Cold Traps	6	NA	9091 kg UF ₆	NA
Refrigeration Units	2	NA	NA	Glycol Systems
Steam Chests	3	NA	NA	NA

NA = Not available at this time

(a) Assumed values from schematic drawing.

(b) 60 cells are production cells and 8 cells are being rebuilt, based on Reference 1, page 14 and 15.

TABLE 8-3. Overall Radioactive Materials Input/Output for Reference Uranium "Wet" Conversion Facility

Material	Total Material ^(a)		U ^(a) kg/day	Form		Fraction ^(b) of U Input
	kg/day	l/day		Chemical	Phase	
<u>Input to Plant</u>						
Yellowcake (Ammonium Diuranate)	3.3E4 ^(c)	NA	2.485E4 ^(c)	(NH ₄) ₂ U ₂ O ₇	S	(1.0)
<u>Output From Plant</u>						
Solid Uranium Hexafluoride	3.7E4 ^(c)	NA	2.481E4 ^(c)	UF ₆	S	(0.999)
Airborne Effluents	1.1E6 ^{(d)(e)}	NA ^(d)	8.7E-2 ^(f)	NA	S,G	3.5E-6
Liquid Effluents	1.4E7 ^(d)	NA ^(d)	27 ^(g)	NA	S,L	1.1E-3
Liquid and Solid Wastes (raffinate ponds)	8.3E4 ^(d)	NA ^(d)	3.3 ^(f)	NA	S,L	(1.3E-4)
Solid Wastes (fluoride ponds)	2.0E3 ^(d)	NA ^(d)	7.6 ^(f)	NA	S	(3.1E-4)
Solid Wastes (other)	NA ^(d)	NA ^(d)	NA	NA	S	(NA)

(a) Values based upon one day operating at 100% capacity.

(b) Numbers in parentheses are not released to the environment.

(c) Based on Table 1 in Reference 1, page 23.

(d) Value indicates total of radioactive and nonradioactive sources.

(e) Includes the assumption that 1314 MT natural gas/mo are burned in stoichiometric air and are included in the airborne effluent total.

(f) Based on Table 2 in Reference 1, page 24.

(g) Based on Reference 7, page 3.

KEY: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

TABLE 8-4. Overall Nonradioactive Materials Input to Reference Uranium "Wet" Conversion Facility

Material	Total Material (a) kg/day	Form		
		Chemical	Phase	Other
Nitric Acid	22,332 ^(b)	HNO ₃	L	60%
Anhydrous Ammonia	6,096 ^(b)	NH ₃	L	Compressed
Lime	12,427 ^(c)	CaO	S	NA
Anhydrous Hydrogen Fluoride	14,615 ^(b)	HF	G	NA
Nitrogen	NA	N ₂	L	Compressed & Cooled
Hexane	>460 ^(d)	C ₆ H ₁₄	L	NA
Tributyl Phosphate	273 ^(c)	[CH ₃ (CH ₂) ₃ O] ₃ PO	L	NA
Sulfuric Acid	NA	H ₂ SO ₄	L	NA
Soda Ash	NA	Na ₂ CO ₃	S	NA
Aluminum Hydroxide	NA	Al(OH) ₃	S	NA
Sodium Hydroxide	NA	NaOH	S	NA
Potassium Bifluoride	221 ^(b)	KF-HF	S	NA
Lithium Fluoride		LiF	S	NA
Ammonium Sulfate	1,076 ^(b)	(NH ₄) ₂ SO ₄	S	NA
Carbon Anodes	NA	C	S	NA
Natural Gas	NA	CH ₄ , etc.	G	NA
Oil	NA	NA	L	NA
Phosphoric Acid ⁽²⁾	NA	H ₃ PO ₄	L	NA
Iron Solution ⁽²⁾	NA	NA	L	NA

(a) Value based upon one day operating at 100% capacity.

(b) Based on Table I, Reference 1, page 23.

(c) Based on Reference 8.

(d) Based on Table II, Reference 1, page 24.

KEY: S = Solid

L = Liquid

G = Gas

NA = Not available at this time.

TABLE 8-5. Overall Nonradioactive Airborne and Liquid Effluents from the Reference Uranium Conversion Facility

Material	Form		Output ^(a)
	Chemical	Phase	kg/day
Airborne Effluents			
Carbon Monoxide	CO	G	17
Fluorine	F ₂	G	0.36 ^(b)
Hexane	C ₆ H ₁₄	G	4.6E2 ^(b)
Hydrocarbons	H _x C _y	G	3
Hydrogen Fluoride	HF	G	6.6
Hydrogen Sulfide	H ₂ S	G	NA
Nitrogen Oxides	NO _x	G	5.9E2
Nonradioactive Particulates	NA	S	18
Sulfur Oxide	SO _x	G	1.4E2
Water	H ₂ O	G	NA
Liquid Effluents			
Calcium	Ca ⁺	L,S	1.7E2
Fluorides	F ⁻	L,S	10
Nitrates	NO ₃ ⁻	L	18
Sulfates	SO ₄ ⁻²	L,S	2.0E2
Chlorides	Cl ⁻	L	6.8E2
Aluminum	NA	NA	5.5
Barium	NA	NA	1.7
Copper	NA	NA	1.2
Iron	NA	na	14
Sodium	NA	NA	4.8E2
Zinc	NA	NA	0.54

(a) Value based upon plant operating at 100% capacity.

(b) Based on Table II, Reference 1, page 24.

(c) This material does not enter the plant in this chemical form.

KEY: S = Solid
L = Liquid
G = Gas
NA = Not available at this time.

TABLE 8-6. Overall Solid and Liquid Wastes from the Reference Uranium Conversion Facility

Waste Material	Form	Package	Total ^(a) kg/day	U Content ^(a) kg/day	Fraction of U Plant Input
Uranium-Contaminated					
Raffinate Liquid Wastes ^(d)	Nitric Acid-nitrate liquid	Confined in ponds	~82,800 ^(b)	NA	NA
Raffinate Solid Wastes	Precipitate	Confined in ponds	NA	~3.3 ^(c)	1.3×10^{-4}
Fluoride Solid Wastes	Mainly CaF_2	Settled out	~1,900 ^(c)	~7.6 ^(b)	3.1×10^{-4}
Contaminated Drums	Steel	None	NA	NA	NA
Sludges	NA	None	NA	NA	NA
Other Solids	NA	None	NA	NA	NA
Nonuranium-Contaminated					
Combustibles	Paper, boxes, crates	Incinerated (open-pit)	NA	0	0
Combustibles	NA	Incinerated (enclosed)	NA	0	0
Incinerator Ash	NA	None	NA	0	0
Noncombustibles	NA	NA	NA	0	0

NA = Not available at this time.

(a) Value based upon one day operating at 100% capacity.

(b) Based on Table II, Reference 1, page 24.

(c) Based on Table I, Reference 1, page 23.

(d) These wastes are all converted to solid wastes and airborne effluents.

8.6.2 Material Requirements

The routine material requirements for the reference facility consist of those materials given as inputs in Tables 8.3 and 8.4 and packaging materials for solid waste disposal. Miscellaneous materials such as office materials, office furniture, routine maintenance supplies, etc. are also required.

8.6.3 Unusual Maintenance Requirements

Most of the equipment is assumed to last 20 years. A total of 8 of the 68 fluorine cells will be rebuilt per month. Unusual maintenance on the fluorine cell off-gas lines is required because of buildup of solidified electrolyte deposited during hydrogen-fluorine recombination reactions. This maintenance is assumed to cost the equivalent of replacing these off-gas lines about once every 2 years. The maintenance of other process-contacting equipment is assumed to cost the equivalent of replacing the equipment every 20 years.

8.6.4 Utility Requirements

Total estimated utility requirements for the reference facility for each day of operation at 100% capacity are:

- water NA
- electricity NA
- natural gas NA

8.6.5 Transportation Requirements

All the plant input materials listed in Tables 8.3 and 8.4 and plant output materials such as containers of uranium hexafluoride must be transported to or from the facility. Typical transport distances for these materials are not within the scope of this report.

8.6.6 Waste Disposal Requirements

The solid wastes listed in Table 8.3 are managed in either of two ways. The solid wastes in the raffinate ponds and the solid wastes in the fluoride ponds are retained indefinitely. The other solid wastes are buried onsite.

The solid wastes listed in Table 8-5 are either burned in an open-pit incinerator or in an enclosed incinerator. The ashes from the incinerators are buried onsite without containers.

8.6.7 Other Operating Cost Elements

Other major operating cost elements are those tasks performed by outside contractors. A contractor transports materials into the facility and uranium hexafluoride out of the facility. Other known special operating cost elements are for licensing and insuring the operation of such a nuclear materials processing facility.

8.7 ENVIRONMENTAL IMPACT FACTORS

Table 8-7 summarizes the overall direct environmental impact factors for the reference facility.

TABLE 8-7. Overall Environmental Impacts - Reference
Uranium "Wet" Conversion Facility

	<u>Quantity</u>	<u>Remarks</u>
Total Land Committed	4.7 km ²	Fenced-in site area
Land Actually Used for Facility	0.3 km ²	Restricted area
Water Used	NA	
Water Discharged as Liquid Effluent	1.4E7 kg/day	
Total Materials Added to Liquid Effluents	NA	
Air Used	NA	
Water Discharged as Airborne Effluent	NA	
Total Other Airborne Effluents	NA	
Electrical Energy Consumption	NA	
Thermal Effluent Equivalent	NA	
Resource Use	See Tables 8.3 and 8.4	

8.8 LIMITATIONS AND UNCERTAINTIES IN THE STUDY INFORMATION

Detailed information on the uranium conversion facility is not presently available. Some of this information can be developed or inferred from available existing information but gaps in this information may still exist. Much of the information on effluents and wastes and some process step descriptions are not well known publicly.

8.9 RESEARCH AND DEVELOPMENT NEEDS

More detailed information on the reference facility is needed, especially on the facility description, the chemical inputs, the effluents, the wastes, and the utility requirements. Facility description and chemical inputs are needed for a reasonable basis for cost estimation. Process information is needed to reliably estimate the input to the effluent control processes and to estimate the effluent control performance. Information on quantities, physical forms, and chemical forms is needed to characterize the wastes and effluents as well as aid in determining effluent control performance.

SECTION 8.0: REFERENCES

1. W. J. Shelley, Kerr-McGee Nuclear Corporation, Oklahoma City, Oklahoma, letter and attachment to Richard B. Chitwood, Nuclear Regulatory Commission, Washington, D.C., dated June 27, 1975.
2. Applicants Environmental Report, Supplement #1, AEC Docket No. 40-8027-10, Kerr-McGee Corporation, Oklahoma City, Oklahoma, December 1972.
3. Applicants Environmental Report, Supplement #2, AEC Docket 40-8027-10, Kerr-McGee Corporation, Oklahoma City, Oklahoma, December 1972.
4. Final Environmental Statement Related to the Sequoyah Uranium Hexafluoride Plant, NUREG-75/007, Nuclear Regulatory Commission, Washington, DC, February 1975.
5. Applicants Environmental Report, Revised, AEC Docket No. 40-8027-4, Kerr-McGee Corporation, Oklahoma City, Oklahoma, November 1971.
6. W. J. Shelley, Kerr-McGee Nuclear Corporation, Oklahoma City, Oklahoma, letter to Harold L. Price, United States Atomic Energy Commission, Washington, DC, dated October 15, 1971.
7. W. J. Shelley, Kerr-McGee Nuclear Corporation, Oklahoma City, Oklahoma, letter and attachment to Richard B. Chitwood, Nuclear Regulatory Commission, Washington, DC, dated June 5, 1975.
8. J. M. Costello, Capital and Operating Costs for the Production of Uranium Hexafluoride, paper IX AAEC Symposium on Uranium Processing, AAEC/E 238, September 1972.

ENRICHMENT

9.0 ENRICHMENT

9.A. GASEOUS DIFFUSION ENRICHMENT

A reference gaseous diffusion uranium enrichment facility representative of current technology for commercial scale plants is defined in this section. This reference facility is partly conceptual. It is a full-scale, "stand-alone" plant designed to furnish complete uranium enrichment services for commercial LWRs only without assistance from any other gaseous diffusion plant. It receives natural enrichment uranium hexafluoride (UF_6) and enriches this UF_6 up to any level required for a commercial PWR or BWR. It is based primarily on the gaseous diffusion uranium enrichment plant described in Reference 1.

The facility is capable of 8.75 million separative work units (SWU) per year,^(a) using 2,700 MW of electrical power.^(b) This overall capacity can be compared with the three existing gaseous diffusion plants operated for the U.S. Department of Energy (DOE), and located near Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio:

	<u>MWe-yr Power Required</u>	<u>Millions of kg SWU/yr</u>
Oak Ridge	1,164	3.6
Paducah	1,970	6.1
Portsmouth	<u>1,820</u>	5.4
FY 1977 Totals	4,954	15.1

These plants were built to supply enriched uranium for nuclear weapons and now operate primarily to supply enriched uranium for commercial power reactors, both foreign and domestic.^(3, p. 47) Programs currently underway should result in a fully improved and uprated plant capacity of 27.7 million SWU/yr in 1981.^(4, p. 2-6)

(a) Reference 2, bottom of page 2-7.

(b) Reference 2, sub-section 1.5.1, page 1-7.

Although the reference plant is designed to be independent, the overall plant capacity and equipment sizes are such that integrated operation with the three existing plants is possible, if desired, just as integrated operation is now accomplished between the present enrichment plants.^(5, p. 15-16) The Portsmouth "add on" plant was developed with this in mind, but a privately financed independent facility could also accomplish this to a limited extent by contractual agreements. The reference facility is independent of type of financing used.

The overall characteristics of the reference gaseous diffusion facility study include the following:

- There is one facility, natural uranium feed (as UF_6) and one enriched uranium product (UF_6).
- A single reference facility capable of enriching natural uranium to supply enriched fuel for commercial PWRs and BWRs at the rate of 8.75 million SWU/yr is assumed.
- The facility is to receive natural uranium as UF_6 in a solid form, vaporize the UF_6 , pump the UF_6 through the diffusion cascade to enrich the ^{235}U content, purify the product, and cool the product to a solid for shipment.
- The facility is assumed to operate 365 days and 24 hr/day for 40 years.

9.A.1 SUMMARY

The reference "stand alone" gaseous diffusion uranium enrichment facility is designed for a nominal plant capability of 8.75 million kg SWU/yr. It is designed to receive 13,333 MT of 0.711% ^{235}U feed material annually, produce 2,083 MT of 3.2% ^{235}U product with 11,250 MT of 0.25% ^{235}U tails material also withdrawn from the cascades of the plant.

The foregoing quantities are for uranium contained in UF_6 . The product quantities are shipped as UF_6 to uranium fuel fabrication plants where the UF_6 is converted to uranium oxide and used in the manufacture of fuel elements for LWRs. The 0.25% ^{235}U tails material is either stored onsite or shipped offsite. As is accomplished at the existing gaseous diffusion facilities, it is possible to adjust for an infinite variety of assays and throughputs within the limitations of the equipment.

Most of the 2,700 MW of electric power required for the plant is converted to heat in compressing the process gas. Heat exchangers transfer this heat to an evaporative coolant in a secondary loop. This coolant is then run through exchangers cooled by water; the water is then circulated to cooling towers, where the heat is transferred to the atmosphere.

The reference plant is assumed to receive its uranium in the form of UF_6 in transport cylinders ready for direct feed to the diffusion cascades. However, the plant is designed with appropriately located space so that it can be modified later to receive U_3O_8 , UNH or UO_3 , and convert them to UF_6 .

During routine operations nearly all radioactive materials in the effluents result from maintenance of the main process equipment, and from the decontamination fluids used. Recovery of uranium, its radioactive decay daughters and chemical compounds is accomplished, so that very little radioactivity intrudes into the environment from this plant.

Preventive maintenance of the main process equipment has been highly successful at the three existing DOE gaseous diffusion sites, so that major breakdowns with abnormally high release of UF_6 have been extremely rare and are considered to be "accident" cases in this study. The plant design is such that when an event does happen, it occurs within operating cells, and only extremely small amounts of UF_6 or compounds formed by contact with moisture and other contaminants can reach the environment. The UF_6 escaping from the process channels is almost entirely cold trapped or caught within exhaust filters. The uranium is recovered by several process steps in a decontamination and recovery building.

The uranium recovery is accomplished in several general steps. The liquids and solids are collected. Contaminated trash is run through an incinerator, uranium is dissolved from filter materials, and any other necessary steps are taken to put uranium compounds into solution. Scrubber solutions are also added. The uranium-bearing solutions are run through a small chemical separation plant where tributyl phosphate with a hydrocarbon diluent is used (shown later in Figure 9.A-7). The uranyl nitrate hexahydrate is calcined to produce U_3O_8 . This is reduced with hydrogen (H_2) to uranium dioxide (UO_2) which is then hydrofluorinated to uranium tetrafluoride (UF_4). The UF_4 is then fluorinated to UF_6 .^(9, p. 5-1) This UF_6 is collected and placed in cylinders. The UF_6 is then recycled back into the cascades.

A total of about 28.1 million l/day of liquid effluents is discharged from the plant to the nearby river. These effluents contain about 120 kg/day of chemical contaminants (mostly salts of calcium nitrate, ammonia, and fluoride ions) and about 0.37 kg/day of uranium (the latter is about 0.0074 of plant product output).

The airborne effluents contain about 3,800 kg/day of chemical contaminants (mostly ammonia, nitrogen oxides, and some fluorides), and $5.5E-2$ kg uranium/day.

Uranium contaminated waste consists mostly of about 390 l/day of CaF_2 sludge, which is held in lagoons.^(6, p. A-259) Other contaminated wastes shipped as calcined solids offsite amount to slightly over 1800 l/day. Failed or retired process compressor motors are outside of the cells and therefore are not contaminated. Most broken tools can be decontaminated easily. Such items can be sold as scrap.

The plant employs 1400 persons and operates 24 hr/day. The plant facilities occupy a total of 1.62 km² of the reference generic site (4.7 km²). The plant uses 93.8 million l/day of water, and 58 million kWh/day of electricity.

Detailed information on the main process diffusion barriers within the converters and actual compressor suction volumes are classified for national security reasons, so this portion of the study cannot be completed. Significant additional information or development of inferred information on quantitative releases is needed to develop sizes of process and effluent control systems, which in turn would permit detailed cost-benefit analysis.

9.A.2 MAINLINE PROCESS DESCRIPTION OF GASEOUS DIFFUSION

The reference gaseous diffusion facility performs physical and chemical operations in the enrichment of uranium. The facility receives natural uranium as solid UF₆ in cylinders, as shown in the general process flow diagram in Figure 9.A-1. The UF₆ cylinders are weighed, and the contents are sampled and assayed for purity. Following storage of the cylinders, the UF₆ is heated and vaporized and released to the diffusion cascade. Following the enrichment of the UF₆ in the diffusion cascade, the enriched UF₆ is withdrawn from the cascade and cooled to a solid state in cooled cylinders. The solidified enriched UF₆ is shipped in cylinders to the reference fuel fabrication facilities. Uranium is recovered from miscellaneous wastes and effluents by chemical processing for recycle. The uranium tails are desublimed as a solid into cylinders for storage.

9.A.2.1 Description of Process Steps

Figure 9.A-2 gives a more detailed process flow diagram. The following sections discuss the major process steps.

- UF₆ Cylinder Receiving, Storage, and UF₆ Vaporization

The cylinders of UF₆ are weighed and samples of UF₆ are taken from the cylinders to be assayed for purity. After the UF₆ cylinders have been sampled and assayed, they are stored in a cylinder yard until the diffusion plant is ready to accept them.

FIGURE 9.A-1. Overall Reference Mainline Process for Gaseous Diffusion Enrichment

FIGURE 9.A-2. Mainline Process Flow Diagram for the Reference Gaseous Diffusion Plant

The cylinders are then transferred from the cylinder yard to the feed and tails building, where the solid UF_6 is vaporized by heating the cylinders in steam autoclaves. The gaseous UF_6 is then fed into the diffusion cascade.

- Gaseous Diffusion Enrichment

The average velocities of gas molecules at a given temperature depend on their masses. Therefore, in a gas made up of UF_6 molecules containing different uranium isotopes, the molecules containing the ^{235}U isotope will generally move slightly faster than those containing the ^{238}U isotopes, and will come in contact with the containment vessel walls more frequently. The container wall is the inside of a porous tube (barrier) through which the UF_6 molecules diffuse, as shown in Figure 9.A-3. About half the gas diffuses through the barrier; this diffused stream is slightly enriched in ^{235}U concentration and is fed to the next higher enrichment stage. The remaining undiffused stream is depleted to the same degree in ^{235}U concentration and is recycled to the next lower enrichment stage.

The individual gaseous diffusion stages are connected in the cascade as shown in Figure 9.A-4. The UF_6 feed material is pumped by an electric motor-driven axial flow compressor through a large cylindrical vessel, the convertor, containing a gas cooler and the diffusion barrier. Refer to Figure 9.A-5 for a process diagram of the gaseous diffusion stage heat transfer system and to Figure 9.A-6 for a recirculating cooling water flow schematic. The slightly enriched (diffused) stream is at lower pressure and is drawn off through piping to the low pressure inlet of the compressor for the next higher enrichment stage. The slightly depleted (undiffused) stream is also drawn off through separate piping and routed through a control valve to the medium pressure inlet of the compressor for the next lower enrichment stage. The control valve in the undiffused stream assists in obtaining the proper balance of flows.

This basic process is repeated several hundred times to take the initial feed stream of natural uranium up to an enriched concentration of ^{235}U suitable for use in power reactors. Groups of stages are coupled in this way to make up operating units; such groups make up the cascade.

FIGURE 9.A-3. Schematic of Converter for Gaseous Diffusion Stage

FIGURE 9.A-4. Stage Arrangement - Reference Gaseous Diffusion Facility

FIGURE 9.A-5. Gaseous Diffusion Stage Heat Transfer System

FIGURE 9.A-6. Process Recirculating Cooling Water Flow Schematic

The isotopic separation achievable in a single stage is very small. Producing 3.2 wt% ^{235}U enriched uranium for commercial LWRs from natural uranium feed material with 0.25% tails requires approximately 1,350 diffusion stages in series.

Low density contaminants (air, nitrogen, hydrogen fluoride, R-114 primary coolant) are purged from the product stream at the top of the production cascade by a top purge cascade. A side purge cascade located along the main process cascade also reduces the quantities of light gases entrained in the process stream.

- Product Withdrawal

The product UF_6 is withdrawn from the diffusion cascade into cylinders cooled by refrigeration. Secondary liquid nitrogen traps collect product that is not deposited in the product cylinders. A chemical trap containing activated alumina backs up the liquid nitrogen trap to minimize the escape of UF_6 or HF to the environment. The product cylinders are then either shipped out to a customer or held in the cylinder storage area until the customer is ready to receive them.

- Tails Withdrawal

The depleted tails stream of UF_6 is withdrawn from the bottom stages of the production cascade into cylinders. The gaseous UF_6 tails are compressed and cooled to a solid. The cylinders are then taken to storage.

- Uranium Recovery

The uranium recovery system reclaims uranium from decontamination operations, laboratory wastes, alumina traps and other process operations for recycle. Figure 9.A-7 shows the sources and their flow paths through the uranium recovery system. This flow diagram shows how solid wastes are incinerated and then calcined, pulverized, dissolved, flocculated and filtered. The solution then joins the stream from 11 other principal sources collected from various process and maintenance activities. Many uranium compounds and contaminants are carried along in this solution, which then enters a solvent extraction process area.

The feed solution is processed in contactors containing about 20% tributyl phosphate and about 80% Varsol (similar to kerosene) as a diluent. It is a Purex-type process. Two separations process lines are used: one line uses pulse columns for solutions with high uranium concentration and low volumes; the other line uses mixer-settlers for solutions with low uranium concentration and high volumes. Uranyl nitrate hexahydrate (UNH) is extracted, calcined to produce purified uranium oxide, and then pulverized. This U_3O_8 is then fed into a flame tower in the oxide conversion area where it is converted to UF_6 . The UF_6 gas is filtered, passed through magnesium fluoride traps that absorb volatile impurities, and then cold-trapped into product cylinders as solidified UF_6 . It is then taken to the cylinder storage yard for storage and eventual transfer to the feed station where it is introduced into the cascade as feed material.

9.A.2.2 Waste Management

Gaseous diffusion enrichment facilities generate radioactive and nonradioactive solid wastes only. Other unrecovered materials are released to the environment as radioactive and nonradioactive liquid and airborne effluents. Since uranium arrives as UF_6 , uranium and its associated impurities and daughter decay products are the only radioactive constituents of the nonproduct (waste or effluent) streams leaving the plant when natural UF_6 feed is used. Figure 9.A-8 summarizes waste management activities at the reference plant.

Nonradioactive solid wastes are generated by the supporting activities of gaseous diffusion plants. These wastes originate in offices, lunch rooms, nonradioactive shops, and receiving terminals. They include such items as wiping rags, grease, oil, used crating lumber, used packing boxes, used packing materials, plastic sheeting materials, worn out equipment pieces, broken tools, and burned-out electrical equipment. These noncontaminated materials are collected and hauled away by local waste disposal contractors for deposit in approved landfill sites or for salvaging.

Solid waste materials and articles which are, or could be, contaminated with uranium are segregated into combustible and noncombustible categories. Noncombustible wastes include most ventilation filters, pumps, motors, valves,

FIGURE 9.A-8. Overall Waste Management Processes for the Reference Gaseous Diffusion Facility

segments of process piping and the like. After estimating uranium content and feasibility of its recovery, these materials are either chemically processed, or collected in boxes to be buried by a government-licensed waste disposal contractor at an authorized site. Combustible items such as paper, cloth and plastic articles used in equipment decontamination are reduced to ash in a specially designed incinerator. The off gases are water-scrubbed and filtered before being discharged to the atmosphere. The ashes are sampled and analyzed for uranium, and depending on the uranium content, the ashes are either returned to the plant and chemically processed for uranium recovery, or are boxed for burial at an authorized site.

Some of the solid wastes are suspended in liquids and are routed to lagoons where they gradually precipitate to the bottom. They are periodically removed and placed in a designated and recorded part of the contaminated burial ground.

9.A.3 EFFLUENT CONTROL PROCESS DESCRIPTIONS

Effluent treatment systems are included in the reference plant to control the emissions of uranium and radioactive decay daughters and chemicals such as fluorides, nitrates and ammonia. These materials can be present in both the aqueous and the airborne effluents. Radiation doses to adults^(a) at the location of maximum exposure (at the facility boundary about 1000 m from the plant) are estimated to total about 0.3 mrem/yr.^(b)

9.A.3.1 Liquid Effluents

About 28.1 million ℓ /day of liquid effluents are discharged from the plant. These effluents contain about 120 kg/day of chemical contaminants

(a) Table 3.2-2, pages 3.2-25, Final Environment Statement for Expansion of U.S. Uranium Enrichment Capacity", ERDA-1543, April 1976, (Reference 1 of this section) shows a total body dose of 0.3 millirem. On page 3.2-24, Section 3.2.1.2.2, On people, "Table 3.2.2 ... total body and organ doses ... (i.e., at the facility boundary 1200 m from the plant)." Section 5 of this "Analysis of the Nuclear Fuel Cycles" document, "Reference Generic Site", page 5-22, Figure 4-5 shows ground release up to 10 m as approximately linear and the site boundary with a distance from the source, as 1000 m from the plant: {1,200 m/1,000 m} (0.30) - 0.36 mrem/yr.

(b) Reference 1, Table 3.2-2, 3.2-25.

(mostly salts of calcium nitrate, ammonia, and fluoride ions) and about 0.37 kg/day of uranium (about 0.0074% of plant product output). Figure 9.A-9 shows schematically the treatment systems of liquid effluents from the plant.

Most radioactive effluents originate from the equipment decontamination and uranium recovery processes. Nonradioactive effluents are mostly from the sanitary plant water treatment backwash, the steam plant water treatment effluents, and the treated cooling tower blowdown discharge to the primary holding pond. The pond contents are neutralized with lime, and resulting precipitates settle to the bottom. A secondary holding pond provides added settling time and backup during emergencies. The clarified effluent is released to the river.

Prior to discharge to the holding pond, the cooling tower blowdown is treated with sulfuric acid and a reducing agent such as ferrous sulfate, sodium sulfite, or sulfur dioxide to reduce hexavalent chromium to the trivalent form. Next the blowdown is transferred to a neutralization tank where sodium hydroxide or lime is added to raise the pH to approximately eight. Zinc and trivalent chromium precipitate under these conditions and are discharged to the primary holding pond with the remaining blowdown liquid.

Extremely low contamination plant laundry effluents and sanitary sewage discharge to the sanitary sewage treatment facility which is a conventional municipal type of sewage treatment plant with primary and secondary treatment. Eventually the effluents are discharged to the river.

Runoff water from the coal yard and sluiced steam plant fly ash are discharged to the steam plant and pond. Since the runoff from the coal yard is slightly acidic and the fly ash is slightly alkaline, neutralization occurs in the ash pond before discharging the clarified effluent to the river. Settled ash is kept in the pond.

9.A.3.2. Airborne Effluents

The airborne effluents contain about 3,800 kg/day of chemical contaminants (mostly ammonia, nitrogen oxides, and some fluorides), and 5.5×10^{-2} kg U/day. Figure 9.A-10 summarizes the treatment of airborne effluents from the facility.

FIGURE 9.A-9. Process Flow Diagram--Liquid Effluent Treatment System for Reference Gaseous Diffusion Facility

FIGURE 9.A-10. Process Flow Diagram--Airborne Effluent Treatment System for Reference Gaseous Diffusion Facility

The effluents from the top purge cascade pass through a sodium fluoride trap to absorb molybdenum hexafluoride. Next the effluents pass through an alumina trap that removes uranium hexafluoride. A potassium hydroxide scrubber then removes hydrogen fluoride from the effluent stream. Finally, the effluents are discharged to the atmosphere through an air jet exhaust. The trap materials are periodically replaced with fresh filter materials. The exhausted trap materials are rinsed with appropriate solvents to put the uranium compounds into solution, and this solution becomes a feed source for the uranium recovery facility. Some trap materials are initially heated to accomplish direct UF_6 recovery. Rejected residue material from the traps is monitored and packaged for onsite recorded burial, or shipment to an offsite low-level waste commercial burial facility.

The effluents from the side purge cascade pass through an alumina trap to remove uranium hexafluoride and through a potassium hydroxide scrubber to remove hydrogen fluoride. The effluents are then discharged to the atmosphere.

The effluents from the UF_6 receiving building pass through a cold trap and an alumina trap to remove uranium hexafluoride prior to release to the atmosphere.

Several sources of effluents from the decontamination and uranium recovery building exist. The vacuum system used in cleaning disassembled equipment discharges airborne effluents through a HEPA filter to the atmosphere. The first stage calciners discharge their effluents through a packed column scrubber to the atmosphere. The scrubbing solution within the packed column is part of the feed solution that enters the second stage calciners. The effluents from the second stage calciners also go through a packed column scrubber before being vented to the atmosphere. This scrubbing solution is recycled as part of the feed for the second stage calciners.

The flame tower effluent passes through a sintered metal filter, a magnesium fluoride trap, a cold trap and a sodium fluoride trap prior to release to the atmosphere. The sintered metal filter collects particulates in the flame tower effluent and the magnesium fluoride trap absorbs volatile impurities. Both the cold trap and the sodium fluoride trap remove uranium hexafluoride

from the effluent. Materials in these traps are replaced on a regularly scheduled basis. Some of the trap materials are initially subjected to heat to drive off UF_6 for direct recovery. The used-up absorbent materials are then subjected to appropriate solvents and uranium compounds are placed in solutions which become feed stock for the uranium recovery facility. Some of these trap materials are recyclable. The rejected portions become solid waste for disposal either onsite or offsite as appropriate.

The pneumatic material handling system effluents pass through a sintered metal filter and a HEPA filter to the atmosphere. The exhausts from the glovebox enclosures also pass through a sintered metal filter and a HEPA filter before discharge to the atmosphere.

Effluents from the steam plant pass through an electrostatic precipitator that removes over 99% of the airborne particulates. The effluents next pass through a wet lime scrubber to remove sulfur dioxide before being released to the atmosphere.

Effluents from the maintenance building are released directly to the atmosphere without treatment.

Incinerator effluents are water scrubbed and HEPA filtered prior to release to the atmosphere.

9.A.4 FACILITY AND SITE DESCRIPTION

This information will be used later as the primary basis for capital cost estimates and as background for plant performance.

9.A.4.1 Site

The reference gaseous diffusion enrichment facility is assumed to lie on the 4.7 km^2 (1160 acres) Site B described in Section 5. The plant itself requires a fenced area of 1.82 km^2 (450 acres) within the larger plant site. The plant layout provides the maximum practicable distance from airborne effluent sources to the four sides of the rectangular site. A well-labeled perimeter fence is assumed to exist around the total site to exclude the public. Another fence is assumed to surround the smaller plant area, including a security entrance to the plant.

The liquid effluents from the plant are assumed to be discharged onsite into the river flowing through one corner of the site. This river amply provides the year-round requirement for about 94×10^6 l/day of make-up water for the plant. The site has sufficient elevation to prevent flooding of process facilities and effluent lagoons.

9.A.4.2. Facility

The reference facility is largely based on a conceptual design of a 8.75 million SWU/yr stand-alone gaseous diffusion plant.⁽²⁾ Figure 9.A-11 shows the overall layout of the gaseous diffusion plant within the 1.8 km^2 area of the immediate plant.

The major facilities of the reference gaseous diffusion plant are:

- UF_6 receiving building
- Cylinder storage yard
- Feed and tails withdrawal building
- Process buildings (housing the diffusion cascade)
- Purge and product withdrawal building
- Decontamination and uranium recovery building
- Administration building
- Steam plant building
- Coal yard
- Air plant
- Nitrogen plant
- Process equipment assembly and maintenance building
- Cooling tower heat dissipation system
- Holding ponds
- Burial grounds
- Recirculating cooling water systems including water treatment plant

FIGURE 9.A-11. Layout of the Reference 8.75 Million SWU/yr Gaseous Diffusion Facility

- Sanitary water system including water treatment plant
- Sanitary sewage system including sewage treatment plant
- Firewater system
- Storm drainage system
- Laboratory
- Laundry
- Miscellaneous support facilities (i.e., the general shop, computer facility, cafeteria, medical center, fire and guard buildings, garage and the stores building).

Much of the information about such a facility is classified for national security reasons. Thus, complete descriptions of the facility are not available. That information given here is a summary of the pertinent information that is publicly available.

The UF_6 receiving building is designed to minimize accidental releases of UF_6 to the environment. It contains three steam autoclaves, a sampling apparatus, cylinder moving equipment and analytical support facilities.

The feed and tails withdrawal building contains the equipment necessary for vaporization of feed (steam autoclaves, etc.) and tails withdrawal (cooling, compression desublimation units, etc.)

The purge and product withdrawal building contains the purge equipment and the five desublimation cells for product withdrawal and solidification.

The process buildings are single-level structures that contain the gaseous diffusion stages, which are of three sizes and grouped in cells. All the auxiliary equipment necessary for the operation of the stages is included in these buildings. (A stage is made up of one convertor, one compressor, and a motor that drives two compressors.) Coolant drain tanks and related equipment are placed outside the process buildings.

The decontamination and uranium recovery building houses the equipment necessary for decontamination of broken equipment and the equipment for chemical recovery of uranium (Purex process).

The air plant can produce 142 standard cubic meters/minute of compressed air that is filtered and dried in alumina driers.

The nitrogen plant can supply a normal flow of 1.0 standard cubic meters/minute. The liquid nitrogen used in the plant is stored in a cryogenic tank.

The cooling towers are the mechanical draft type. A pumphouse adjacent to the cooling towers provides water circulation to the cooling towers.

The reference facility is expected to operate for 40 years. Table 9.A-1 summarizes the various process area descriptions and Table 9.A-2 summarizes the major process equipment.

9.A.5 EFFLUENT CONTROL PERFORMANCE

Overall radioactive materials input and output from the reference facility are summarized in Table 9.A-3. The only radioactive material routinely available for effluent release is uranium. (Generally an insignificant amount of radioactive decay products of uranium are present.) About 0.00018% of the uranium fed to the plant is present in the airborne effluents, and about 0.0013% of the uranium is in the liquid effluents.

Overall input of nonradioactive materials is given in Table 9.A-4, while the nonradioactive materials in the airborne effluents and the liquid effluents are shown in Tables 9.A-5 and 9.A-6, respectively. Overall output of solid wastes is shown in Table 9.A-7.

A significant amount of additional information is required to complete these tables in this section to determine the important effluents. Additional information is required to determine the performance of the individual effluent treatment steps for the important effluents.

TABLE 9.A-1. Major Process and Auxiliaries Areas Description -
Reference Gaseous Diffusion Facility

Process Area	Overall Dimensions (a) L x W x H, m
UF ₆ Receiving Building	47 x 34 x NA
Cylinder Yard	300 x 300 x NA
Feed and Tails Withdrawal Building	140 x 30 x NA
Process Buildings	520 x 140 x NA
Purge and Product Withdrawal Building	140 x 30 x NA
Decontamination and Uranium Recovery Building	150 x 91 x NA
Administration Building	130 x 66 x NA
Steam Plant Building	120 x 61 x NA
Air Plant	46 x 30 x NA
Nitrogen Plant	30 x 30 x NA
Process Equipment Assembly and Maintenance Building	240 x 180 x NA
General Shop	150 x 56 x NA
Cooling Tower and Holding Basin Area	240 x 130 x NA
Primary Holding Pond	210 x 210 x NA
Secondary Holding Pond	210 x 210 x NA
Steam Plant Ash Pond	210 x 210 x NA
Contamination Burial Ground	76 x 71 x NA
Land Fill Area	140 x 140 x NA
Laundry	46 x 30 x NA
Cafeteria	30 x 20 x NA
Fire Department Building	41 x 30 x NA
Guard Building	41 x 30 x NA
Garage	61 x 30 x NA
Stores Building	150 x 61 x NA
Technical Services Building	130 x 56 x NA
Coal Yard	120 x 61 x NA

(a) Values are estimated from Figure 9.A-11.
NA = Not available

TABLE 9.A-2. Major Process Equipment Descriptions -
Reference Gaseous Diffusion Facility

Equipment	Location	No.	Size, m L x W x H	Process Duty or Capacity	Other Features
Steam Autoclave	URB	3	NA	Able to handle 12.5 metric ton cylinders	Pressure and electrical conductivity controls
Steam Autoclave	FTWB	8	NA	Able to handle 12.5 metric ton cylinders	Pressure and electrical conductivity controls
Diffusion Stages	One of the four PB	~1350	~375--Small(a) ~400--Medium(a) ~575--Large(a)	NA	Stage made up of one convertor, one compressor, and one motor for two compressors
Desublimation Cell	PPWB	5	NA	NA	NA
Compression--Desublimation Systems	FTWB	NA	NA	NA	Each system has two compressor trains having two compressors in series; each compressor has an aftercooler
Incineration Calciner	DURB	1	NA	NA	NA
Continuous Dissolver Calciner	DURB	NA	NA	NA	NA
Flocculating Columns	DURB	NA	NA	NA	NA
Storage Columns	DURB	NA	NA	NA	NA
Measuring Columns	DURB	NA	NA	NA	NA
Extraction Loops	DURB	NA	NA	NA	NA
Calciners	DURB	NA	NA	NA	NA
Flame Tower	DURB	1	NA	NA	NA
Cold Traps	DURB	NA	NA	NA	NA
Steam Boilers	SPB	4	NA	45,000 kg/hr	Coal-fired
Air Compressors	AP	NA	NA	NA	NA
Liquid Nitrogen Tank	NP	1	NA	NA	NA

(a) Actual compression suction volumes are classified.

NA = Not available

URB = UF₆ Receiving Building, PPWB = Purge and Product Withdrawal Building, FTWB = Feed and Tails Withdrawal Building, AP = Air Plant, DURB = Decontamination and Uranium Recovery Building, PB = Process Building, SPB = Steam Plant Building, NP = Nitrogen Plant

TABLE 9.A-3. Overall Radioactive Materials Input/Output for Reference Diffusion Facility

Material	Total (a) Material		kg U/day	Form		Fraction of (b) Plant Input
	kg/day	l/day		Chemical	Phase	
<u>Input to Plant</u>						
Unenriched UF ₆	5.40E4	NA	3.65E4	UF ₆	S	(1)
<u>Output from Plant</u>						
Enriched UF ₆	8.44E3	NA	5.71E3	UF ₆	S	(0.156)
Tails (stored onsite or offsite)	4.56E4	NA	3.08E4	UF ₆	S	(0.844)
Airborne Effluents	NA ^(c)	NA ^(c)	5.5E-2	NA	S,G	1.5E-6
Liquid Effluents	NA ^(c)	NA ^(c)	0.37	NA	L	1.0E-5
Solid Waste	NA ^(c)	NA ^(c)	NA	NA	S	(NA)

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

- (a) Values based upon one day operating at 100% capacity.
(b) Numbers in parentheses are not released to the environment.
(c) Value indicates total of radioactive and nonradioactive sources.

TABLE 9.A-4. Overall Nonradioactive Materials Input for Reference Gaseous Diffusion Uranium Enrichment Plant(a)

Material	Total Material ^(b)		Chemical	Form		kg/day as 100%
	kg/day	g/day		Phase	Other	
Sodium Fluoride ^(c)	NA	NA	NaF	S	A	NA
Alumina ^(c)	NA	NA	Al ₂ O ₃	S	NA	NA
R-114 Cascade Coolant Freon	82	NA	CClF ₂ -CClF ₂	L,G	Pressurized	NA
Trichlorethylene	3.5E2	2.4E2	CHCl-CCl ₂	L	NA	3.5E2
Helium	NA	NA	He	G	Pressurized	NA
Water	9.4E7	9.4E7	H ₂ O	L	NA	9.4E4
Argon	NA	2.9E3	Ar	G	Pressurized	NA
Oxygen, compressed	NA	1.6E4	O ₂	G	Pressurized	NA
Hydrogen	NA	NA	H ₂	G	Pressurized	NA
Nitrogen	NA	NA	N ₂	G	Pressurized	NA
Sodium Carbonate	NA	NA	Na ₂ CO ₃	S	NA	NA
Sulfuric Acid	2.0E3	1.1E+6	H ₂ SO ₄	L	93%	1.9E3
Nitric Acid	3.3E2	2.3E+5	HNO ₃	L	68%	2.2E2
Lime	1.2E4	3.5E+6	CaO	S	NA	NA
Orocol (Betz Labs)	123	NA	NA	S	NA	NA
Aqueous Ammonia	NA	NA	NH ₃ ·H ₂ O	L	28%	NA
Anhydrous Ammonia	NA	NA	NH ₃	G	100%	NA
Acetone	NA	NA	(CH ₃) ₂ CO	L	100%	NA
Hydrochloric Acid	5.1	4.6E3	HCl	L	22%	1.1
Hydrofluoric Acid	NA	NA	HF	L	72%	NA
Caustic Soda	2.0E2	NA	NaOH	L	NA	NA
Chlorine	2.0E2	NA	Cl ₂	L	NA	NA
Process Lubricating Oil	NA	1.7E2	NA	L	NA	NA
Propane	NA	3.0E2	C ₃ H ₈	L,G	NA	NA
Electrical Insulating Oil	NA	44	NA	L	NA	NA
Perchloroethylene	NA	0.41	Cl ₂ C-CCl ₂	L	NA	NA
Gasoline	NA	2.8E3	NA	L	NA	NA
Coal (average)	1.4E5	NA	NA	S	NA	1.4E5
Diesel fuel	NA	2.5E3	NA	L	NA	NA

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

(a) Reference 7, p. 11

(b) values based upon one day operating at 100% capacity, 3.2% ²³⁵U in product, 0.25% ²³⁵U in tails.

(c) Used to trap UF₆ by two chemical traps in series between cold trap and point of discharge into the air; first trap contains sodium fluoride and second trap contains alumina.

TABLE 9.A-5. Overall Nonradioactive Airborne Effluents from Reference Gaseous Diffusion Uranium Enrichment Plant

Material	Form		Output ^(a) kg/day
	Chemical	Phase	
Water vapor (from lagoons and cooling towers)	H ₂ O	G	6.5E7
Gases from all other sources			
Hydrofluoric acid	HF	G	6.5
Fluorides	F, UF _x	G,S	NA
Ammonia	NH ₃	G	0.88
Nitrogen Oxides	NO _x	G	1.5E3
Nitric Acid	HNO ₃	L	NA
Carbon Dioxide	CO ₂	G	NA
Carbon Monoxide	CO	G	2.5E2
Hydrocarbons	H _x C _y	G	42
Sulfuric Acid	H ₂ SO ₄	L	NA
Boric Acid	H ₃ BO ₃	L	NA
Nickel Sulfate	NiSO ₄	L,S	NA
Nickel Chloride	NiCl ₂	L,S	NA
Acetone	(CH ₃) ₂ C	G	3.3
Helium	He	G	NA
Hydrogen	H ₂	G	NA
Nitrogen	N ₂	G	NA
Argon	Ar	G	NA
R-114 Cascade coolant	CClF ₂ -CClF ₂	G	34
Sulfur Oxides	SO _x	G	1.8E3
Ozone	O ₃	G	1.3E-1
Chloroethene (trade name)	NA	G	5.8
Trichloroethylene	CHCl-CCl ₂	G	1.3E2
Xylene	C ₈ H ₁₀	L,G	0.45
Kerosene	NA	L,G	2.9
Particulates	NA	S	90

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

(a) Values based upon one day operating at 100% capacity.

TABLE 9.A-6. Overall Nonradioactive Liquid Effluents from Reference Gaseous Diffusion Uranium Enrichment Plant(a)

Materials	Form		Output(b)		Fraction of (c) Plant Input
	Chemical	Phase	kg/day	l/day	
Water(d)	H ₂ O	L	2.8E7	2.8E7	~0.3
Aluminum(e)	Al ⁺³		0.68	NA	NA
Calcium(e)	Ca ⁺²	L,S	5.1E2	NA	NA
Sodium(e)	Na ⁺	L	7.7E2	NA	NA
Ammonium(e)	NH ₄ ⁺	L	17	NA	NA
Fluoride(e)	F ⁻	L	1.2	NA	NA
Sulfate(e)	SO ₄ ⁻²	L,S	5.1E2	NA	NA
Sulfite(e)	SO ₃ ⁻²	L,S	0.86	NA	NA
Nitrate(e)	NO ₃ ⁻	L	91	NA	NA
Chloride(e)	Cl ⁻	L	7.7E2	NA	NA
Residual Chlorine	Cl ₂	G	4.9	NA	NA
Phosphate(e)	PO ₄ ⁻³	L	12.0	NA	NA
Chromium(e)	Cr ⁺³	L,S	0.80		
Iron(e)	Fe ⁺³	L,S	34	NA	NA
Boron(e)	BO ₃ ⁻³	L	0.86	NA	NA
Nickel(e)	Ni ⁺²	L,S	3.4	NA	NA
Magnesium(e)	Mg ⁺²	L,S	0.86	NA	NA
Molybdenum(e)	Mo ⁺⁶	L,S	0.86	NA	NA
Silver(e)	Ag ⁺	L,S	0.86	NA	NA
Varsol	NA	L	0.51	NA	NA
Manganese(e)	Mn ⁺²	L,S	0.86	NA	NA
Tributyl Phosphate	PO(C ₄ H ₉) ₃		0.17	NA	NA
Water Treatment Chemicals	NA	L	NA	NA	NA
Oil and Grease	NA	L	NA	NA	NA
Sanitary Effluents(f) Mostly	H ₂ O	L,S	3.0E6	3.0E6	~0.32
Zinc(e)	Zn ⁺²	L	8.1	NA	NA
Cadmium	Cd ⁺²	L,S	6.8E-2	NA	NA
Copper	Cu ⁺²	L,S	1.2	NA	NA

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

(a) Reference 1, p. 2.3-146

(b) Value based upon one day operating at 100% capacity.

(c) Some of these materials do not enter the plant in the chemical form given here.

(d) See Figure 9.A-6, Water Inputs and Outputs.

(e) In form of ions; weight of ion only.

(f) Included as part of the return of 28.1×10^6 l/day to the river and ground water.

TABLE 9.A-7. Overall Solid Wastes from the Reference
Gaseous Diffusion Uranium Enrichment Plant

<u>Waste Material</u>	<u>Form</u>	<u>Package</u>	<u>Total lb/day</u>	<u>U Content Form</u>
Uranium-Contaminated				
Incinerator Ash	Powdered Ash	Fiberboard Boxes	NA	UO ₂
Process Equipment	Pipe, Compressors, Convertors and Motors	NA	NA	NA
Process Sludge	CaF ₂ Sludge	Remains in Lagoon	390	U Salts
Contaminated Clothing	Clothing, Towels	208 & Steel Drums	NA	U Salts
Noncombustible Misc.	Metal, Glass	Fiberboard Boxes	NA	U Salts
Filter Trap Materials	NA	NA	NA	NA
Nonuranium Contaminated				
Incinerator Ash	Powered Ash	NA	NA	--
Noncombustible Misc.	Misc.	NA	NA	--
Sanitary/Process Sludge	Misc. Chemical Salts	Remains in Lagoon	NA	--

NA = Not available at this time

9.A.6 FACTORS FOR OPERATING COST INFORMATION

The basic plant operational requirements are presented in this section to enable later estimation of direct operating costs.

9.A.6.1 Labor Requirements

The reference plant is assumed to operate 24 hr/day, 7 days/wk, including holidays. The plant is estimated to employ 1400 people at the steady-state level.^(a,b) The amount of staff labor that may be attributed to effluent control operation is unknown.

^(a) Estimated by M. H. Arndt, January 9, 1978.

^(b) Reference 1, p. 2.5-46.

9.A.6.2 Material Requirements

At design level of operations 13,410,000 kg/yr of uranium containing 0.711% ^{235}U in feed is needed for a total weight of 19,800,000 kg of UF_6 feed material. This is usually received in about 1,600 feed cylinders, each containing up to 12,500 kg (nominally 14 tons each) of UF_6 . Occasionally some feed is received in smaller cylinders.

Peak steam load is estimated at 136,000 kg/hr.^(a) At Site B, 41,000 MT of coal per year are burned, with an average heat content of 6,545 kcal/kg of coal for a total of 268×10^9 kcal/year. This provides process heat to the feed station autoclaves for UF_6 vaporization, steam traces where needed to maintain process UF_6 as a gas, and general space heating for the facility buildings.

The routine material requirements are those identified previously in Table 9.A-4. Packaging materials for disposal of solid wastes (listed in Table 9.A-7) and small amounts of miscellaneous materials such as office materials are also required.

9.A.6.3 Unusual Maintenance Requirements

A complex of three buildings covering approximately 0.03 km^2 (8 acres) is assumed to be needed to house maintenance shops and related facilities. Three major large cascade equipment items that require maintenance facilities are convertors, which contain the barrier and gas cooler, compressors, and compressor motors. The shops provide the capability to perform all required maintenance functions necessary to support plant operations.

The convertors present a special requirement, as they are assembled and maintained in the convertor assembly and maintenance buildings. Approximately 15 to 25 convertors need overhaul each year due to plugged barriers, leaking heat exchanger tubes, or a combination of both. About 10 to 20 axial-flow compressors also need overhaul each year to maintain compressor efficiency.

The failure rate in diffusion cascade equipment has proven to be low. Overhauling convertors each year would be done simply to maintain process

^(a)Reference 1, p. 2.3-177.

efficiency. Failure during operation has been rare and is expected to be less than one unit every four years with the newer equipment designs. The axial-flow compressors are expected to have a higher failure rate, possibly averaging one unit per year, mostly due to bearing failure.

A limited investment is assumed to be made in spare equipment for replacement.

9.A.6.4 Utility Requirements

Total estimated utility requirements for the plant for each day of operation at 100% capacity are:

Water	93,800,000 kg/day
Electricity	2,400 MW-day/day
Coal	143,800 kg/day

9.A.6.5 Transportation Requirements

All the plant input materials listed in Table 9.A-4, the input UF_6 , the output UF_6 , and waste items to be disposed of offsite must be transported to or from the site. Typical distances for transport of these materials are not within the scope of this study.

9.A.6.6 Waste Disposal Requirements

The solid wastes listed in Table 9.A-7 must be removed for ultimate disposition. The uranium-contaminated materials are assumed to be disposed of at a regional burial ground for radioactive wastes. The nonsalvageable nonradioactive wastes are assumed to be taken to a landfill. Salvageable materials are returned to the supplier or others for reuse.

9.A.6.7 Other Operating Cost Elements

Many of the operating cost elements, such as those listed below, cannot be described in detail at this time due to lack of information:

- a. System for removing metallic contaminants from the blowdown of the cooling system
- b. Furnace to melt scrap aluminum
- c. Fluorine manufacturing plant

- d. Radio and telephone communications
- e. Hospital and first aid stations
- f. Security system (fences, alarms, etc.).

Certain major operating cost elements are those tasks performed by outside contractors, such as offsite transportation of materials, disposal of radioactive wastes, and disposal of nonradioactive wastes. Other known special operating cost elements are for licensing and insuring the operation of such a nuclear materials processing facility.

9.A.7 ENVIRONMENTAL IMPACT FACTORS

The overall direct environmental impact factors for the reference facility are summarized in Table 9.A-8. These quantities are those used directly at the plant. Impacts of resources required for material input or output beyond the plant boundary are not included.

The primary release of heat to the atmosphere would result from the evaporation of the 65,000,000 ℓ /day of water by the cooling towers. The plumes generated by this evaporation would be usually expected to extend for no more than 760 m from the tower, with the average plume length being about 230 m. Normally, the height of the plume would be expected to rise to about 230 m.

The rejection of the water vapor by the cooling towers increases the potential for fogging near the cooling towers. Since natural fog is a function of the season of the year, and the time of day, the additional fog produced by the cooling towers would also follow these parameters. The potential would be greater during the fall and winter between the hours of 5:00 and 8:00 AM.^(a) A quantitative description of fogging depends on the meteorological conditions and is site-dependent. At the Oak Ridge Gaseous Diffusion Plant, no more than 300 hours of additional fog would be generated during a year from operation of the cooling towers.

Areas occupied by individual facilities are provided in Table 9.A-9.

^(a) See page 2.3-126 in Reference 1.

TABLE 9.A-8. Overall Environmental Impacts - Reference
Gaseous Diffusion Facility

	<u>Quantity</u>	<u>Remarks</u>
Total Land Committed	4.7 km ²	Fenced-in Area
Land Actually Used for Plant	1.8 km ²	High Security Area
Water Used	9.4E7 kg/day	
Water Discharged as Liquid Effluent	2.8E7 kg/day	
Total Materials Added to Liquid Effluents	1.2E2 kg/day	Includes 0.37 kg U/day
Water Discharged as Airborne Effluent	6.5E7 kg/day	
Total Other Airborne Effluents	3.8E3 kg/day	Includes 5.5 x 10 ⁻² kg U/day
Electrical Energy Consumption	2.4E3 MW-day/day	
Thermal Effluent Equivalent	2.4E3 MW-day/day plus 12 MW-day/day (average) from steam plant stack	
Resource Use	See Table 9.A-4	Also Special Maintenance Requirements Section 9.A.6.3

TABLE 9.A-9. Areas Occupied by Major Plant Facilities of the Reference Gaseous Diffusion Plant

<u>Facility</u>	<u>Completed Area (km²)</u>	<u>Land Affected By Construction, (km²)</u>
Plant Site	1.82	1.82
Permanent Buildings	0.263	0.263
Electric Substations	0.243	0.243
Coal Yard	0.008	0.008
Holding Ponds	0.040	0.049
Steam Plant Ash Pond	0.081	0.093
Burial Ground	0.008	0.008
Sanitary Landfill	0.020	0.024
Roads	0.121	0.121
Railroads	0.040	0.040
Parking Lots and Portals	0.028	0.101
Construction Site		0.405

9.A.8 LIMITATIONS AND UNCERTAINTIES IN THE STUDY INFORMATION

Detailed process and facilities information for large gaseous diffusion uranium enrichment plants is not publicly available. Information pertinent to this study is generally omitted because it is not available directly. Some additional information can be developed or extrapolated from existing available information.

Nearly all the information in this study is based on other studies, which were based on operating experience at Oak Ridge, Paducah and Portsmouth gaseous diffusion facilities. These facilities have experienced up to about 1% of their feed from recycle UF₆, mostly from weapons program fuels. In this reference conceptual facility all UF₆ feed is from freshly mined uranium, so contamination of the uranium with plutonium and other actinides and fission products is not present. Consequently, all of the cobaltous fluoride traps would be eliminated from this conceptual plant. A more detailed study may disclose other differences which are not immediately obvious.

9.A.9 RESEARCH AND DEVELOPMENT NEEDS

Uranium contaminated waste consists mainly of about 400 ℓ /day of CaF_2 sludge containing about 350 to 400 g of uranium.⁽⁶⁾ This settles on the bottom of the sludge lagoon (see Figure 9.A-6). It is periodically removed and placed in the contaminated burial ground. The adequacy of this method of waste disposition needs analysis. Possibly, improved techniques may be desirable, such as an economical way to reprocess CaF_2 sludge to extract enough uranium so that sludge could be returned without restrictions to the public environment. Other alternatives, such as using different waste treatment schemes may be desirable.

Studies may also be desirable to assess the radioactivity and other effluents added to the environment by the steam plant. Most types of coal contain enough radioactive materials so that the coal-fired steam plant that furnishes process and space heating steam could be adding significant radioactivity to the environment compared to the UF_6 cascade process.

Significant additional information or development of inferred information on quantitative releases from various types of breakdowns is needed to develop sizes of effluent control systems, which would permit a detailed cost/benefit analysis. Although the negative environmental effects of the effluents are comparable to those of the three existing sites which have been studied in depth, alternative processes to those used in the reference facility appear to merit some analysis.

Alternative or improved techniques for removing chemical and radioactive materials from the liquid and airborne effluents may also be worthy of investigation. Processes that might use some of the heat now being dumped to the atmosphere by the cooling towers might be beneficial.

9.B GAS CENTRIFUGE ENRICHMENT

A reference gas centrifuge uranium enrichment facility that is representative of current technology is defined in this section.

The reference facility is partly conceptual. It is a full scale, "stand-alone" plant designed to be completely adequate within its own area to furnish complete uranium enrichment services without assistance from any other plant. It receives natural enrichment uranium hexafluoride and could enrich this UF_6 up to any level required for commercial PWRs or BWRs. It is based primarily on the gas centrifuge uranium enrichment plant described in the "Final Environmental Statement for the Portsmouth Gaseous Diffusion Plant Expansion, ERDA-1549".⁽²⁾ A facility capable of 8.8 million kg of SWU/yr is contemplated. This over-all capacity can be placed in perspective by comparison with the three existing gaseous diffusion plants located near Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio. The fiscal year 1977 production for these diffusion plants was:

	<u>MWe-yr Power Required</u>	<u>Millions of kg SWU yr</u>
Oak Ridge	1,164	3.6
Paducah	1,970	6.1
Portsmouth	<u>1,820</u>	<u>5.4</u>
FY 1977 Totals	4,954	15.1

Although built to supply enriched uranium for the weapons program, these plants now are operated primarily to supply enriched uranium for commercial power reactors, both foreign and domestic. Programs currently underway should result in a fully improved and uprated plant capacity of 27.7 million SWU/yr to be reached in 1981.^(a) The 8.8 million SWU/yr of gas centrifuge capacity would then bring the U.S. total to 36.5 million SWU/yr of uranium enrichment capacity in 1986 or 1987.^(b) At the time it was determined to provide additional enrichment capacity (up to 36.5 million SWU/yr), it was

^(a)Reference 8, p. 2-6.

^(b)Reference 2, "Foreword".

thought the demand for such capacity required that it be available by 1985. Upon further review, it now appears that completion by 1986 or 1987 will be adequate, so that gas centrifuge technology can be utilized.^(a)

9.B.1 SUMMARY

The reference 8.8 million kg SWU gas centrifuge uranium enrichment facility, when operating at 100% of design level, produces 2,095 MT of 3.2% ^{235}U enriched uranium product per year.

Uranium hexafluoride (UF_6) containing natural uranium (0.711% of the U is ^{235}U) is received as feed material at the rate of 13,410 MT per year. Tails, containing 0.25% ^{235}U , are either stored onsite or shipped offsite, and are withdrawn at the rate of 11,314 MT per year. All the foregoing figures are for the contained uranium in the form of uranium hexafluoride (UF_6). The product quantities are shipped as UF_6 to uranium fuel fabrication plants where the UF_6 is converted to uranium oxide and used in the manufacture of fuel elements for LWRs.

Facilities for feeding UF_6 to the new centrifuge plant, for removing the product and the tails, and for controlling the flow through the cascade are provided. Most of the 150 MWe of electric power required for the plant is used for cooling tower forced draft fans and pumping of cooling water for the process cascades. This heated water is then circulated to cooling towers, where the heat is transferred to the atmosphere.

Since commercial facilities have been used in the past to convert U_3O_8 , UO_3 and UNH to UF_6 , we assume the reference plant will receive its uranium in the form of UF_6 in transport cylinders ready for direct feed to the cascades. However, the plant is designed with appropriately located space so that it can be modified later to receive U_3O_8 , UNH or UO_3 , and convert them to UF_6 .

During routine operations nearly all radioactive effluents result from maintenance of the main process equipment, and the decontamination fluids used. Recovery of uranium, its daughters and chemical compounds is principally accomplished as described in Section 9.B.3.1, so that very little radioactivity intrudes into the environment from this plant.

^(a)Reference 2, "Foreword".

The plant employs 2450 persons.^(a) The plant facilities occupy about 1.5 km² of the reference generic site (4.7 km²). The plant uses 11.3 million l/day of water, and 3.0 million kWh/day of electricity, and 144 MT/day of coal (average).

The expected operating life of the gas centrifuge plant is 40 years,^(b) and the plant is planned to operate 24 hr/day, 365 days/yr.

9.B.2 MAINLINE PROCESS DESCRIPTION

A volatile compound of uranium must be used in either the gaseous diffusion process or the gas centrifuge process; the hexafluoride (UF₆) is the only known suitable compound. Since UF₆ is solid at room temperature, the process must be operated at temperatures and pressures necessary to maintain the UF₆ in gaseous form. Although it is a stable compound, UF₆ is extremely reactive with water, very corrosive to most common metals, and not compatible with organics such as lubricating oils. This chemical activity dictates the use of process materials which must come into contact with UF₆ such as nickel and aluminum, which resist the corrosiveness of UF₆. This also means that the entire cascade must be leak-tight and clean. The corrosiveness of the process gas imposes added difficulties in the fabrication of the centrifuge rotors and the other parts, valves, piping, heat exchangers, etc.

Gas centrifuges operate somewhat like centrifugal cream separators, since they separate the ²³⁵UF₆ molecules from the ²³⁸UF₆ molecules by their difference in weight. Descriptions of process steps appear in the following sections.

9.B.2.1 Description of Process Steps

A gas centrifuge plant is made up of a large number of centrifuges rotating at a high rate of speed. The UF₆ molecules containing ²³⁸U tend to congregate at the outside wall of the centrifuge, whereas the molecules containing ²³⁵U tend to congregate near the center axis because they are slightly lighter. The feed UF₆ steadily enters the rotor near its middle,

^(a) See Section 9.B.6.1.

^(b) Reference 2, p. 5-24, paragraph 5.1.3.5.3, modified by the authors.

the slightly lighter $^{235}\text{UF}_6$ "product" stream is steadily siphoned off as it rises to the top of the center axis and the ^{238}U heavier "waste" stream is steadily siphoned off the bottom of the outside wall (see Figure 9.B-1).

This separative effect is small and must be repeated in hundreds of centrifuges in series. To achieve the desired quantity, many centrifuges must also be operated in parallel (see Figure 9.B-2).

FIGURE 9.B-1. Schematic of Gas Centrifuge

FIGURE 9.B-2. Evolution of Gas Centrifuge Cascade Configuration

The dotted lines in the upper diagram indicate the minimum interstage flow as calculated. The solid line is derived from empirical experience data and indicates an actual interstage flow that can be achieved, which shows more machines are actually needed than the theoretical calculations would indicate.

The concept of "Centrifuge Building Blocks" is shown in Figure 9.B-3, which is composed of four separate sketches:

- The upper left sketch shows the power and the cooling water being fed into the bottom of a centrifuge. The feed, product and waste (depleted) lines are shown being served from the top, with valves in each line.
- The upper right sketch shows eight centrifuges arranged in a group
- A sketch at the lower left of Figure 9.B-3 shows how groups of centrifuges are placed together to make up a stage. At lower right is shown how stages are interconnected to form a cascade.

FIGURE 9.B-3. Concept of Centrifuge Building Blocks

These piping systems operate below atmospheric pressure. The operating status of each centrifuge is monitored in the building control room.

Routine failure of centrifuge rotors along with other mechanical parts is expected, so that provision is made to handle this condition as a routine process operation. This is described in Section 9.B.6.3, Unusual Maintenance Requirements.

The enrichment process is usually thought of as a large number of gas centrifuges operating in series. However, to achieve sufficient quantity of production, it is also necessary to have many centrifuge unit cascades operating in parallel. Each cascade is connected by process headers into the overall process gas system. The UF_6 feed for each process unit is vaporized at the feed and withdrawal building and piped through feed headers to the centrifuges. The process overview of a gas centrifuge plant is shown in Figure 9.B-4.

Facilities for receiving and handling UF_6 , the vaporization of UF_6 at the feed stations, and the removal, condensing and desubliming by the withdrawal equipment are described in Section 9.B.4.2.

9.B.2.2 Waste Management

Gas centrifuge enrichment facilities generate radioactive and nonradioactive solid wastes only. Other "waste" materials are released to the environment and are therefore radioactive and nonradioactive liquid and airborne effluents. Uranium arrives as UF_6 , so that uranium and its associated impurities are the only radioactive constituent of the waste or effluent streams leaving the plant, when "natural" UF_6 feed is used. A summary of waste management activities at the reference gas centrifuge uranium enrichment plant is given in Figures 9.B-5 and 9.B-6.

Nonradioactive solid wastes are generated by the supporting activities of gas centrifuge plants. These wastes originate in offices, lunch rooms, nonradioactive shops, and receiving terminals. The wastes include paper, wiping rags, grease, oil, used crating lumber, used packing boxes, used packing materials, plastic sheeting materials, worn-out equipment pieces, broken tools, burned-out electrical equipment, and the like. These noncontaminated materials are collected and hauled away by local waste disposal contractors for deposit in approved landfill sites or for salvaging.

FIGURE 9.B-4. Process Overview of a Gas Centrifuge Plant

FIGURE 9.B-5. Overall Waste Management Processes for the Reference Centrifuge Facility

FIGURE 9.B-6. Gas Centrifuge Repair Activity in Recycle and Assembly Building
(Major Contributor to Solid Wastes)

In the gas centrifuge enrichment plant, solid waste materials and articles which are, or could be, contaminated with uranium are segregated into combustible and noncombustible categories. Noncombustible wastes include failed rotors and other failed centrifuge parts, some ventilation filter materials, pumps, motors, valves, segments of process piping and the like. After determining uranium content versus feasibility of recovery, these materials are either chemically cleaned and/or processed, or collected in boxes for ultimate burial by a government-licensed waste disposal contractor at an authorized site. Combustible items such as the paper, cloth, and plastic articles used in equipment decontamination are reduced to ash in a specially design incinerator located in an incinerator building adjacent to the recycle and assembly building. The off gases are water scrubbed and filtered before being discharged to the atmosphere. The ashes are sampled and analyzed for uranium, and depending on the uranium content, the ashes are either returned to the plant and chemically processed for uranium recovery, or are boxed for ultimate burial at an authorized site.

Some of the solid wastes are suspended in liquids and are routed to the primary and secondary holding ponds (also called primary and secondary sludge lagoons) where they gradually precipitate to the bottom. They are periodically removed and placed in a designated and recorded part of the contaminated burial ground (see Figure 9.B-5). About 141.4 m^3 (5000 ft^3) of mildly radioactive wet sludge is dried out and removed each year.

A contaminated burial ground requiring about 12 hectares (30 acres) is provided for disposal of solid radioactive wastes over the 40-year life of the plant. The burial ground is used for disposal of spent absorbates, such as alumina, and contaminated centrifuge parts. Table 9.B-1 lists the total radioactive material buried after 40 years of centrifuge plant operations. (About 0.4 Ci/yr of uranium would be buried in the case of the same size of gaseous diffusion plant.)

After 40 years of operation, the burial ground will contain significant quantities of uranium contaminated process waste material as shown in Table 9.B-2.

TABLE 9.B-1. Total Buried Radioactive Uranium Resulting from Failed Centrifuges After 40 Years of Operations for an 8.8 Million SWU/Yr gas Centrifuge Uranium Enrichment Plant^(a)

<u>Source</u>	<u>Alumina Chemical Traps (Ci)</u>	<u>Miscellaneous Parts (Ci)</u>	<u>Failed Machine Parts (Ci)</u>	<u>Total (Ci)</u>	<u>Total (kg)</u>
^{234}U	12.30	0.382	5.13	17.82	3
^{235}U	0.52	0.016	0.21	0.75	351
^{238}U	<u>11.44</u>	<u>0.355</u>	<u>4.77</u>	<u>16.56</u>	<u>49,264</u>
Total	24.26	0.753	10.11	35.13	49,618

^(a)Reference 2, p. 5-25, adjusted by authors for 40-year plant life at 8.8 million SWU/yr.

TABLE 9.B-2. Predicted Process Waste Materials Accumulated by the 8.8 Million SWU/Yr Gas Centrifuge Enrichment Plant After 40 Years of Operation and Disposed of Onsite^(a)

<u>Material</u>	<u>Quantity</u>
Steel (metric tons)	5.5E4
Aluminum (metric tons)	4.1E4
Iron (metric tons)	1.4E2
Brass (metric tons)	7.0E2
Alnico V (metric tons)	2.1E3
Plastic (metric tons)	3.3E2
Rotor material (metric tons)	9.5E4
Alumina (metric tons)	11.6E3
Diffusion pump oil ^(b) (ℓ)	1.4E5
Damping oil ^(b) (ℓ)	7.5E5
Lubrication oil ^(b) (ℓ)	11.2E5

^(a)Reference 2, p. 5-25, adjusted by authors for 40 years of operation.

^(b)Total oil requirements are listed.

9.B.3 EFFLUENT CONTROL PROCESS DESCRIPTIONS

Without effluent treatment, operation of the gas centrifuge plant would result in effluents containing modest amounts in excess of the limits set for uranium and its radioactive decay daughters and chemicals such as fluorides, nitrates and ammonia. These materials can be present in both the aqueous and the airborne effluents.

9.B.3.1 Liquid Effluents

At a gas centrifuge plant using only virgin natural uranium feed, the radioactive liquid effluents contain only uranium, its daughters, and its compounds. To obtain a clear understanding of radioactive liquid effluents it is useful to look at all of the water inputs and outputs of the reference facility as shown in Figure 9.B-7. This is further clarified by Table 9.B-3, "List of Average Daily Water Use and Effluents by Groups of Facilities." Most waste streams containing uranium compounds originate in the recycle and assembly building due to the decontamination and repair operations which are carried out there. It therefore was more efficient to also provide the uranium recovery systems within the same building. Low-level radioactive liquid effluents are released from the uranium recovery systems and from a number of other systems as described in the following:

- UF_6 drums, when received at the reference site, are placed in an autoclave and a small sample is removed at the Toll Enrichment UF_6 Receiving and Enrichment Building. Also, at each of the two Feed and Withdrawal Buildings, autoclaves heat the UF_6 to vaporize it for entry into the gas centrifuge cascades. Both of these buildings also contain equipment to condense the UF_6 product gas at the product ends of the cascades and desublime it into shipping drums. Also contained is identical equipment to condense and desublime the tails. Although all of this equipment is designed to accomplish these activities with negligible release to the environment, piping, valves and other equipment do sometimes leak or fail. All three buildings have cold traps for the purge and evacuation of UF_6 lines, monitors for all floor drains, a fluoride analyzer in the effluent line, with alarm

FIGURE 9.B-7. River Intake and Water Effluents for an 8.8×10^6 SWU Gas Centrifuge Stand-Alone Enrichment Plant

TABLE 9.B-3. List of Average Daily Water Use and Effluent
by Groups of Facilities

	<u>10⁶ ℓ Input</u>	<u>10⁶ ℓ Output</u>
Toll assay, feed, product and tails stations and contaminated drains from eight process buildings	2.84	2.81
Recycle and Assembly Bldg. (centrifuge repairs and maintenance of service modules)		
Uranium Recovery Facility (located in Recycle and Assembly Bldg.)		
Adjacent Warehouse, Maintenance and Service Bldg.		
Combustible Solid Waste Incinerator (receives 0.03×10^6 ℓpd as decontamin- ation water from Recycle and Assembly activities)		0.03
Laundry, Drinking Water, Showers (0.04×10^6 ℓ/day of this is evaporated from the nonradioactive sludge lagoon and the sewage treatment plant)	1.21	1.17
Blowdown from Cooling Towers (3.82×10^6 ℓ/day is airborne as evaporation and 0.04×10^6 ℓ/day drift which also eventually evaporates)	5.73	1.87
Steam plant make-up (portion of steam, 1.39×10^6 ℓpd, which goes to non- return steam drains plus 0.17×10^6 ℓpd boiler "blow down")	<u>1.56</u>	<u>1.56</u>
Total Input	11.34	7.44
Airborne effluents from cooling towers (3.86×10^6 ℓ/day plus 0.04×10^6 ℓ/day evaporated at nonradioactive sludge lagoon and sewage treatment plant)		<u>3.90</u>
Total Output		11.34

in the central control building, and provision for automatic closure of the drain line.^(a) A hold-up tank is provided, which can be pumped to Uranium Recovery Facility, or otherwise treated as appropriate.

- The eight process buildings are designed so that most of the contamination is contained in the service modules for most types of centrifuge failures. However, monitored floor drains are provided along with hold-up tanks for any wash-down activity which might be needed.
- The 13.7 m (45 ft long) service modules and also the gas centrifuges themselves are reworked, repaired or replaced in the Recycle and Assembly Building. This activity is described in detail in Section 9.B.6.3 "Unusual Maintenance Requirements." Leachates from crushed rotors and other heavily contaminated parts are rich in uranium and its compounds. Most waste streams containing uranium compounds originated in the Recycle and Assembly Building so that for the "stand alone" reference gas centrifuge plant, it is more efficient to locate the Uranium Recovery Facility within the same building. In addition to the leachate solutions, 27,300 ℓ /day (7,200 gal/day)^(b) of decontamination water is pumped from the Recycle and Assembly Building activities to the Uranium Recovery Facility.
- The adjacent Warehouse, Maintenance and Service Building would have nonradioactive effluents comparable to a large commercial garage and machine shop.
- The solid waste incinerator building is located adjacent to the steam plant so that useful heat energy can be conserved by this operation. As is shown on Figure 9.B-5 combustibles are segregated between those that are uranium free and those which are contaminated with uranium. The ashes of U-contaminated combustibles are handled

^(a) Reference 2, p. A-38.

^(b) Reference 2, p. 5-18.

separately and are leached with nitric acid. The leachate becomes part of the feed stock for the uranium recovery facility. The ashes are then dried and then sent to the burial ground as solid waste. The incinerator building stack gases are exhausted through off-gas scrubbers, demister and HEPA filter so that only a small quantity of radioactive material reaches the environment. The scrubbers and demister contribute to uranium recover feed stock. Eventually, the HEPA filter is retired and the uranium leached from it.

- The uranium recovery facility is contained within the recycle and assembly building. Figure 9.B-8 "Uranium Recovery Flow Diagram" contains a list of sources of uranium bearing solution on the left side. Mean Time Between Failures (MTBF) statistics at the Oak Ridge test plant with Set I, Set II and Set III gas centrifuges indicate a considerable effort in decontamination and uranium recovery. Fortunately, the containment features of each module prevent almost all radioactivity from reaching the environment as liquid, gas or particulates. The small amount of UF_6 which can escape from the modules is almost entirely cold trapped or caught within exhaust filter materials. As shown on Figure 9.B-8 the uranium recovery process is divided into two solvent extraction lines, where tributyl phosphate with a diluent is used. The separations process really amounts to two small Purex operations: one uses pulse columns for high uranium concentration/low liquid volume solutions; the other uses mixer settlers for low uranium concentrations/high liquid volume solutions. In either case uranyl nitrate hexahydrate is the product. This is calcined to produce U_3O_8 .

The next step reduces the U_3O_8 with hydrogen (H_2) to uranium dioxide (UO_2), which is then hydrofluorinated to uranium tetrafluoride (UF_4).^(a) The UF_4 is then fluorinated to UF_6 (see flame tower on Figure 9.B-8). This is cleaned in magnesium fluoride traps, cooled and desublimed and placed in cylinders. The UF_6 is

^(a)Reference 9, p. 5.1.

FIGURE 9.B-8. Uranium Recovery Flow Diagram

then ready to be recycled back into the cascades. The resultant liquid wastes are partly of very low concentration of contaminant and are released to the environment through the holding ponds (see Figure 9.B-7). The liquid wastes containing major solids in solution and radioactivity are calcined to solid wastes and disposed of by burial at the burial ground.

- Spill from drinking fountains, water from shift change showers, flushing of toilets and water from the plant laundry are all routed to sanitary sewage treatment plant which has both primary and secondary treatment for an average of 1.17×10^6 l/day of sewage. At the plant laundry, work clothing usually has only a very minor degree of uranium contamination. Occasional heavily contaminated clothing is first rinsed thoroughly, and the rinse water sent to uranium recovery. Biodegradable products are selected for use when possible. The effluent from the laundry equipment passes through a trap for removal of solids before being discharged to the plant's sanitary sewage treatment facility. About 175 g/yr^(a) of uranium reaches the environment (the river) via this pathway (3.53×10^{-4} Ci/yr).
- At the steam plant, waste effluents result from the softening process, boiler blowdown, combustion of coal and disposal of ash. The runoff from the coal yard (adjacent to the steam plant) is slightly acidic. This will be channeled to the steam plant ash pond by a drainage system, where it is neutralized by the sluiced fly ash before being discharged to the river. The most complex effluents are derived from water softening. Hydrogen and sodium zeolite units in parallel are used to soften sanitary water for use in the steam plant. The sodium zeolite softener is regenerated with a strong solution of sodium chloride. Metallic ions removed from the zeolite flow to the primary holding pond as a solution of chloride salts (along with the excess sodium chloride). The hydrogen zeolite softener is regenerated with dilute acid (usually sulfuric acid), and the resulting sulfates and excess acid are

^(a)Reference 2, p. 5-24, subsection 5.1.3.5.2.

discharged to the primary holding pond. The portion of water run through each unit depends on the alkalinity of the influent, the alkalinity of the mixed effluent, and the free mineral acidity of the hydrogen zeolite effluent. After softening, a degasifier removes CO₂ and the water is treated for corrosion control. This reduces the quantity of boiler blowdown needed. Details of the effluent from zeolite regeneration are shown in Table 9.B-4.

The steam plant for an isolated "stand alone" would have to provide 9070 kg/hr (20,000 lb/hr) of steam for process, and 136,080 kg/hr (300,000 lb/hr) of steam for space heating, for a total of 145,150 kg/hr (320,000 lb/hr) to meet winter loads.^(a) Year-round operations result in the burning of 52,000 MT/yr of coal and the quantities of effluents are shown in Tables 9.B-4 and 9.B-5.

- There are two holding ponds (also referred to as "lagoons"), each 40,000 m². They are provided: 1) to prevent accidental discharge of harmful chemicals to the environment and 2) to allow settling of low solubility solids. Adjustable weirs permit emergency containment of pond contents.

The primary holding pond is provided to receive all liquid chemical wastes from the plant including those containing residual amounts of uranium. Neutralization or other treatment of this pond is possible, but treatment of the individual source streams will generally minimize or obviate this requirement. Waste water from decontamination and uranium recovery operations in the centrifuge equipment recycle/assembly facilities, cooling tower blowdown, water treatment backwash and the steam plant flow into the primary pond. The effluent from the primary pond is monitored to maintain water quality within allowable environmental limits.

A secondary holding pond for aqueous discharge streams from the plant is provided to receive water streams that would normally

^(a)Reference 1, pp. 2.3-16, 2.3-19 and 2.3-21.

TABLE 9.B-4. Suspended/Dissolved Solid Effluents and Zeolite Softening Regenerates from Reference Gas Centrifuge Uranium Enrichment Steam Plant^(d)

Constituent	Quantity
Suspended solids, ppm	
Calcium as CaO	45
Magnesium as MgO	30
Phosphate as P ₂ O ₅	60
Silica as SiO ₂	45
Iron as Fe ₂ O ₃	60
Loss on ignition ^(a)	60
Total	300
Dissolved solids, ppm	
Sodium and potassium salts of chloride, sulfate, silica, sulfite, and orthophosphates	NA
Calcium and magnesium complexes of phosphate or chelant	NA
Soluble or colloidal organics and silica	NA
Total	2030
Zeolite softening - excess regenerates ^(b)	
	Max Normal max Av
60°B ^(c) H ₂ SO ₄ , kg/day	60.9 45.7 18.2
NaCl, kg/day	31.6 23.7 9.5
Flow, m ³ /day	215,500 163,900 65,500

^(a) Comprises lignins, tonnins, water of hydration, and unidentified organics.

^(b) Assumes that the flow through the hydrogen zeolite softener is three times the flow through the sodium zeolite softener, and that sulfates and chlorides will be present in the regenerate.

^(c) Degrees Baumé.

^(d) Blowdown rate is 174,200 liters/day (46,000 gpd) at maximum rate.

TABLE 9.B-5. Principal Radioactive Liquid Effluents from the Reference 8.8 Million SWU/Yr Gas Centrifuge Enrichment Plant^(a)

Contaminant	Flow Rate	Ci/yr
Uranium (total)	166 kg/yr	0.335
Uranium-234	43.2 g/yr	0.267
Uranium-235	5.53 kg/yr	0.012
Uranium-236	26.6 g/yr	0.002
Uranium-238	160.3 kg/yr	0.054
Technetium-99	0	0
Thorium-234	1.79E-5 g/yr	0.415
Protactinium-234	6.00E-10 g/yr	0.415

^(a) Reference 2, subsection 5.1.3.5.2, p. 5-24 and Table 2.3-18, p. 2-79 with minor correction by authors of obvious typographical errors.

be discharged to the environment, but have been in the process area and could possibly be contaminated. These include such streams as the discharge from potentially contaminated storm drains and condensate from steam-heated process equipment. Under normal circumstances the primary pond achieves sufficiently low contaminant concentrations to deliver its effluent stream directly to the river. It is possible, however, to discharge the primary pond effluent through the secondary pond if additional retention time is desired.

Some sludge formation and settlement normally occurs in the primary pond, but this effect will be minimal in the secondary pond. Both ponds have oil skimmers at the pond inlet that should retain and remove virtually all oil from accidental oil spills within the plant. A secondary skimmer at the outlet of each pond should prevent all but traces of oil from being discharged to the environment.

The sludge from the water clarifiers will be pumped into a sludge basin at the water treatment plant as a slurry. The settlement of sludge from the slurry will give rise to an effluent stream of water which will be retained for clarification in the primary pond prior to discharge (see Figure 9.B-7). About 141 m^3 (5000 ft^3) of radioactive wet sludge settle out in the holding ponds each year.^(a) Periodically, this is removed, dried out, and placed in recorded areas of the burial grounds.

As a result of the effluent control processes, less than two (2) curies/yr of radioactive substances are carried by liquids to the environment (the adjacent river) as is shown in Table 9.B-5.

9.B.3.2 Airborne Effluents

Airborne radioactive effluents in a gas centrifuge plant originate as follows:

1. Purge cascade
2. Equipment breakdown within the process cells

^(a)Reference 2, p. 2-80.

3. Feed receiving and assaying
4. Feed gasification
5. Product withdrawal and solidification
6. Tails withdrawal and solidification
7. Recycle and assembly building (service module and centrifuge repair or replacement)
8. Uranium recovery facility
9. Laboratory
10. Incineration of burnable contaminated solid wastes
11. Burning of coal at steam plant

Locations 1 through 10 above have water scrubbers and/or HEPA (high efficiency particulate air) filtration of the off-gas streams which are highly effective.^(a) In addition to the sodium fluoride traps which capture the uranium, the purge cascade off-gas stream has caustic scrubbers utilizing potassium hydroxide to remove the hydrofluoric acid gas.

Cobaltous fluoride traps are not provided, since this stand-alone plant will only process UF_6 made from newly mined U_3O_8 . This means there will be no plutonium or other actinides to remove from the gaseous effluents. However, space is provided in the plant design so that cobaltous fluoride traps can be added if in the future it is found desirable to process recycle material. Some airborne effluents are the result of maintenance operations using liquids which eventually become a gas. Converters, compressors, and other equipment exposed to the UF_6 process stream require decontamination to remove small residual surface amounts of uranium after removal from the cascade and before performance of maintenance work. A decontamination facility is included in the maintenance area together with chemical cleaning and rinse tanks and degreasers for cleaning components as required. Cleaning solutions generated which contain significant amounts of uranium are processed for recovery of the metal. The chemical traps chiefly contain alumina that will remove all but insignificant traces of uranium before discharge of the gas stream to the atmosphere. The reaction with alumina is nonreversible, and

^(a) Reference 1, Sections 2.3.3.18.1 Gaseous Wastes, p. 2.3-140, 2.3.1.17.1 Gaseous Wastes, p. 2.3-47, and Table 2.3-11, p. 2.3-50.

uranium recovery from most of the alumina is accomplished by leaching of the alumina with nitric acid in the decontamination and recovery facility. The greatest gaseous radioactive releases stem from purging during cold trapping operations.

The radioactive gas releases from Location 1 to 10 above are included in Table 9.B-6.

The burning of coal to provide steam for process and space heating also results in the release of radioactive gaseous effluents as indicated in Table 9.B-7.

TABLE 9.B-6. Maximum Radioactive Gaseous Releases for 8.8 Million^(a) SWU Gas Centrifuge Plant

<u>Radionuclide</u>	<u>Grams/year</u>	<u>Ci/year</u>
^{234}U	5.82	3.6E-2
^{235}U	654	1.4E-3
^{238}U	19,000	6.4E-3
U-Total	19,700	4.38E-2

^(a)Reference 2, p. 5-24.

A major contributor to the airborne nonradioactive effluents is the coal-fired steam plant, which provides process steam and space heat. The primary airborne emissions due to the combustion of coal are particulates, carbon dioxide, water vapor, sulfur dioxide, and oxides of nitrogen. Smaller quantities of carbon monoxide, hydrocarbons, and aldehydes are also present in the stack effluent. Electrostatic precipitators remove over 99% of the particulates from the stack effluents; the fly ash and bottom ash are collected in a slurry and pumped or sluiced to the steam ash pond.

TABLE 9.B-7. Gaseous Effluents from the Coal-Fired Steam Plant^(a)

Effluent	Rate				
	Metric tons/ hr (max)	Metric tons/ year (av)	Btu/hr (max)	Btu/year (av)	Ci/year
Particulates	0.010	36.0	--	--	--
SO ₂	0.200	724	--	--	--
NO _x	0.160	552	--	--	--
CO	0.003	10.5	--	--	--
Hydrocarbons	0.002	5.3	--	--	--
Heat to stack	--	--	80E6	350E9	--
U-238 and daughters	--	--	--	--	4.6E-4
Th-232 and daughters	--	--	--	--	2.2E-3

(a) Bases of calculations:

Coal Basis

Heat content, Btu/lb coal		Sulfur, lb/lb coal	0.0250
to steam	10,000		
to stack	3,000	SO ₂ equivalent,	
Total	13,000	lb/lb coal	
		to air	0.0125
Ash, lb/lb coal		to sludge	0.0375
to particulates	0.0006	Total	0.0500
to recovered			
fly ash	0.0634	sludge	0.138
to bottom ash	0.0160		
Total	0.0800	Gaseous effluents,	
		lb/lb coal	
		NO _x	0.0100
		CO _x	0.0002
		Hydrocarbons	0.0001

Steam Plant Basis

lb/hr (max)	320,000	metric tons/hr (max)	16
Steam lb/hr (av)	120,000	Coal metric tons/hr (av)	6
lb/year (av)	1.05E9	metric tons/year (av)	52,500

Sulfur dioxide is removed using the wet lime or limestone method or the best available technology. The wet lime and limestone processes generate a large volume of sludge, which is disposed of in the steam plant ash pond. The pond is sized to store the fly ash and sludge, and to provide an effluent conforming with existing EPA guidelines. The principal nonradioactive gaseous effluents are listed in Table 9.B-8.

TABLE 9.B-8. Nonradioactive Gaseous Effluents for the Reference 8.8 Million SWU/Yr Gas Centrifuge Plant(a)

<u>Constituent</u>	<u>Process and Support Facilities (10⁵ g/year)</u>	<u>Steam Plant Share (10⁵ g/year)</u>	<u>Total for Plant (10⁵ g/year)</u>	<u>Source</u>
HF	5	24	29	Process Buildings
NO _x	20	5,500	5,550	Steam Plant
Particulates	2	360	362	Steam Plant
SO ₂	1	7,230	7,240	Steam Plant

(a) Reference 2, p. 5-26.

The cooling towers cool the 382 million liters/day of recirculating cooling water; this water in turn removes the excess process heat from the process cascades. To accomplish this, the cooling towers evaporate 3.82 million liters of water per day into the atmosphere. In addition, wind usually carries away spray, or drift, at the rate of 38,200 liters/day, which eventually evaporates into the atmosphere. All of this evaporation tends to increase the concentration of impurities in the recirculating cooling water. To offset this, 1.87 million liters/day of "blowdown" is bled off, and eventually gets back to the river (see Figure 9.B-7).

Hydrogen fluoride gas is of concern because of its potential for vegetation damage. Plants vary in their sensitivity to HF. Sensitive plants are injured by as little as 0.2 µg/m³, while more resistant plants may withstand 15 µg/m³ without injury. Hydrogen fluoride is also accumulated by plants

and can cause fluorosis in livestock feeding on forage that has accumulated over 30 to 50 ppm fluorides.^(a)

Nitrogen gas, which is used for purging and as a liquid in some of the cold traps, eventually is all released to the atmosphere.

9.B.3.3 Biocidal Effluent Systems

Biocides are used to control the growth of algae and bacteria in the plant's water systems, vegetation around fences, railroads, parking lots, etc., and insects in and around various buildings. Chlorine residuals are maintained at about 1.0 ppm in the sanitary water system, between 0.1 and 0.5 ppm in the sanitary sewage effluent, and between 0.2 and 0.5 ppm in the recirculating water system. The herbicides used for vegetation control as well as the pesticides used for insect control are EPA-approved. The expected annual use of biocides is estimated (in kilograms):^(b)

Sodium pentachlorophenate	1361
Simazine 80W weed killer	227
Strychnine-treated corn	23
D-con rat and mouse poison	2.3
Chlorine	7711

9.B.4 FACILITY AND SITE DESCRIPTION

This section summarizes the description of the site, the facility and its hardware. This information will be used as the primary basis for capital cost estimates, and as background for plant performance.^(c) Operating life of the plant is planned to be 40 years. The resources needed for such a plant are shown in Table 9.B-9.

(a) Reference 2, p. 5-5.

(b) Reference 2, p. 2-81.

(c) Capital cost and construction time are estimated in Reference 2, p. 5-38 for the gas centrifuge plant at Portsmouth, Ohio.

TABLE 9.B-9. Summary of the Resources Required for a
Stand-Alone 8.8 Million kg SWU Gas
Centrifuge Enrichment Plant

	<u>Construction</u>	<u>Steady-state Operation (avg)</u>
Employment number	5,100 max	2,600
Natural resource use		
Land, 4.7 km ²		
committed to plant		
Disturbed (within security fence)	1.5	1.50
Undisturbed	3.20	3.20
Land (km ²) committed to landfill disposal/(through the year 2025)		
Of uranium-contaminated material	0	0.06
Of uncontaminated material	~0.012	0.06
Water		
Total required, l/day	570,000	11.34E6 ^(a)
Discharged to air		
Cooling towers, l/day	0	3.86E6
Steam plant, (make-up) l/day	0	1.56E6
Discharge to streams		
Enrichment plant operations, l/day ^(b)	0	7.44E6
Sanitary sewage, l/day ^(c)	1.48E6	1.17E6
Energy requirements		
Coal (for heating and process steam), metric tons/year	35,000	52,500
Electric power, MWe	15	120
Gasoline and diesel fuel, l/year	1,400,000	500,000

(a) A water reserve capable of 40,000 l/min for 4 hr is also necessary for fire protection.

(b) Includes cooling tower blow-down.

(c) Includes shift-change showers and laundry for operations.

9.B.4.1 Site

The reference gas centrifuge enrichment facility is assumed to be located on the 4.7 km² (1160 acres) generic Site B described in Section 5 of this report. The plant itself requires a fenced area of 1.5 km² (450 acres) within the larger plant site. The layout of the plant, shown in Figure 9.B-9, is such that maximum practicable distance is provided from airborne effluents sources to the four sides of the 4.7 km² rectangular site. It is assumed that a well-labeled perimeter fence exists around the total site to exclude the public. It is also assumed that another fence surrounds the smaller plant area and includes a security entrance to the plant. The liquid effluents from the plant are assumed to be discharged into the river that flows through one corner of the site.

The medium size river is amply capable of providing the year-around requirement for about 12×10^6 l/day of make-up water for the plant.^(a) The site has sufficient elevation to prevent flooding of process facilities and effluent lagoons. About 150 MWe of reliable electric power from a nearby utility are available.

9.B.4.2 Facility

The general layout of the reference gas centrifuge facility is shown in Figure 9.B-9. Based on conceptual studies to date, the facilities required for a new stand-alone 8.8 million SWU/year gas centrifuge plant include:

- Production buildings (housing the centrifuge cascades)
- Central control building
- Receiving and shipping building
- Feed and withdrawal buildings
- Centrifuge recycle and assembly building (includes facility for equipment decontamination and uranium recovery)
- Laboratory

^(a) See Figure 9.B-7 River Intake and Water Effluents for Reference 8.8 x 10⁶ SWU Gas Centrifuge Stand-Alone Plant

FIGURE 9.B-9. Site Layout for Reference 8.8 Million SWU Stand-Alone Gas Centrifuge Plant

- Nitrogen and air plant
- Recirculating cooling water (RCW) systems, cooling towers and water treatment
- Steam plant, ash pond and coal yard
- Incinerator plant
- River pump facility filtration plant and sanitary water system
- Sewage treatment plant
- High voltage electrical sub-station
- Emergency diesel electric generator
- Changehouses
- Fire and security building
- Storage for water to extinguish fires
- Administration building
- Laundry
- Storm drain system
- Holding ponds (also called "sludge lagoons")
- Burial grounds for radioactive solid waste
- Garage, motor pool, vehicle and mobile equipment maintenance and warehouse building

Table 9.B-10 "Dimensions of Major Structures" provided a summary of sizes for the foregoing items.

The production facilities are contained in eight process buildings. Each process building is approximately 130 m wide by 200 m long (425 ft wide by 660 ft long) and is separated into four 26 m high (85 ft high) crane bays. The building is a noncombustible structure with steel frame, prefinished metal siding, and metal deck with built-up roof. All of the eight buildings are used for enrichment of product to 3.2% ^{235}U assay. The feed for the process buildings is 0.711% ^{235}U assay, and the tails would be 0.25% ^{235}U assay.

TABLE 9.B-10. Dimensions of Major Structures

Overall Site	4.7 km ²	4.7 x 10 ⁶ m ²
Within Security Fence	1.5 km ²	1.5 x 10 ⁶ m ²
8 Production Buildings		200 m x 130 m x 26 m
Central Control Building		25 m x 25 m x 7 m
Receiving and Shipping Building		31 m x 31 m x 8 m
2 Feed Stations, Product and Tails Withdrawal Bldgs., Each		60 m x 38 m x 5 m
Recycle/Assembly Building		210 m x 150 m x 26 m
Uranium Recovery Facility (Shares a common wall with R/A)		150 m x 100 m x 30 m
Laboratory Building		120 m x 30 m x 8 m
Nitrogen and Air Plant		40 m x 30 m x 8 m
RCW Cooling Towers		46 m x 7 m x 10 m
RCW Water Treatment and Pump House		8 m x 5 m x 5 m
Steam Plant		50 m x 40 m x 12 m
Incinerator Plant		20 m x 15 m x 9 m
River Pump Structure		15 m x 10 m x 6 m
Filtration Plant Building		20 m x 15 m x 5 m
Outdoor Concrete Filtration Basins		75 m x 50 m x 8 m
Sewage Treatment Plant (2 Biofilters 100 m dia.)		20 m x 15 m x 7 m
High Voltage Electrical Substation		75 m x 50 m
Emergency Diesel Electric Facility		100 m x 35 m x 8 m
2 Change Houses, Each		100 m x 30 m x 5 m
Fire and Security Building		40 m x 20 m x 10 m
Elevated Water Storage Tanks (3), Each 20 m dia., for Fire Administration Building		150 m x 20 m x 8 m
Laundry		50 m x 50 m x 8 m
2 Holding Ponds (Sludge Lagoons), @40,000 m ² Each		200 m x 200 m each
Contaminated Burial Ground, 8 Hectares		400 m x 300 m
Warehouse, Maintenance and Service Building		200 m x 150 m x 15 m

The services required for each centrifuge are feed, product and tails piping connections, vacuum systems, electrical connections, cooling water, and instrumentation. All centrifuges in a stage are connected by feed, product, and tails process piping. These piping systems operate below atmospheric pressure. The operating status of each centrifuge is monitored in the control room.

Each of the crane bays contains two basic areas: 1) the cascade area contains the centrifuges and service modules; and 2) the equipment area, located at both ends of the cascade area, contains auxiliary equipment such as vacuum pumps, electrical gear, and ventilation equipment. Operational functions are accomplished in a basement near the center of the building, which contains the building control room, assay instrumentation room, operations offices, rest rooms, and a lunchroom. Two relatively small structures attached to each side of the building provide a maintenance and storage area. A corridor across the width of the building at the center is provided for storage and movement of damaged and replacement centrifuges. More detailed descriptions of the centrifuge cascades are contained in Subsection 9.B.2, Mainline Process Description.

The central control building is centrally located with regard to the eight process buildings (see Figure 9.B-10). It is 25 x 25 x 7 m, noncombustible, with steel frame, prefinished metal siding, and metal deck with built-up roof.

The receiving and shipping building does not have to be large since UF_6 shipping containers are usually stored outdoors. The building is a noncombustible structure approximately 31 x 31 x 8 m. It is equipped with three autoclaves to permit assaying incoming and outgoing shipping cylinders, and a crane system designed to handle 12.7 metric ton (14 short ton) shipping cylinders for incoming "natural" UF_6 . Those would be stored on concrete pads in the adjacent storage yard until needed by the centrifuge cascade. Product cylinders and any tails cylinders shipped offsite are also handled by this facility. The adjacent fenced-in storage yard has about 200,000 m^2 of storage area.

The feed station and product and tails withdrawal facility are contained in two buildings, each of which serves four process buildings. Each feed and withdrawal building contains four autoclaves for liquefying and vaporizing UF_6 feed; a tails withdrawal compression-liquefaction system consisting of two compressor trains of four compressor in series; and a product withdrawal station consisting of condensing and refrigeration equipment for desublimation of the gas stream. Each feed and product and tails withdrawal building contains approximately 2280 m^2 ($24,700 \text{ ft}^2$) of floor space, of which about $1,970 \text{ m}^2$ ($21,200 \text{ ft}^2$) are process area and 325 m^2 (3500 ft^2) are offices, rest rooms, a control room, and laboratory.

The recycle-assembly building provides all the facilities necessary to accomplish a twofold purpose. First, machine subassemblies are assembled during the construction phase; second, disabled machines from the enrichment areas are accepted for performing fault-detecting diagnostic operations, reclaiming the machines (whenever possible) for return to normal operation, and for decontamination and scrap processing, as required. The facility is a multilevel building with about $31,500 \text{ m}^2$ ($340,000 \text{ ft}^2$) of enclosed floor area, plus about $10,200 \text{ m}^2$ ($110,000 \text{ ft}^2$) of open area for receiving and storage. A sketch of the centrifuges to be assembled in the building is shown in Figure 9.B-1.

The uranium recovery facility is described in Section 9.B.2.1. It shares a common wall with the $210 \text{ m} \times 150 \text{ m}$, $31,500 \text{ m}^2$ Recycle Assembly Building. The uranium recovery facility has an additional $15,000 \text{ m}^2$ and has a height of 30 m for a third of this area and about 20 m for two thirds of the area.

The laboratory has two missions. One is to perform supporting laboratory work for the eight main process buildings, the receiving and shipment building, the feed and withdrawal facilities and the various utilities onsite. The other mission is to perform physical and chemical research and development aimed toward improving the process. The laboratory building is noncombustible, two story, 120 m long $\times$ 30 m wide.

The nitrogen and air plant is about 40 m $30 \text{ m} \times 8 \text{ m}$ high, of noncombustible construction. About 600 m^2 is used for cryogenic equipment to

liquefy nitrogen from the atmosphere. Some of this liquid nitrogen is used as a liquid in cold traps to solidify UF_6 . Large quantities of nitrogen are used for purging of the cascades. About 600 m^2 is used to prepare dry air which is also used in the cascades.

Excess heat from the cascades is transferred to the atmosphere via the recirculating cooling water (RCW) system, cooling towers and the RCW system blowdown. The RCW system has its own, additional water treatment. For details see subsection 9.B.2.1 "Description of Process Steps" and Figure 9.B-7, "River Intake and Water Effluents for Reference 8.8×10^6 SWU Gas Centrifuge Stand-Alone Plant". The cooling tower consists of eight cells, with a total installed capacity of $303,000 \text{ l/min}$ ($80,000 \text{ gal/min}$) or $436 \times 10^6 \text{ l/day}$ ($115 \times 10^6 \text{ gal/day}$). This provides a spare cell, so that seven cells can normally be available while one cell is out of service for maintenance. Normal operation would be designed for $265,000 \text{ l/min}$ or $381.5 \times 10^6 \text{ l/day}$ for a cooling range of 35°C to 29.44°C (95° to 85°F) at a design wet-bulb temperature of 25°C (77°F).^(a) The cooling tower is $46 \text{ m} \times 7 \text{ m} \times 10 \text{ m}$ high. The adjacent RCW water treatment and pump house is $8 \text{ m} \times 5 \text{ m} \times 5 \text{ m}$ high.

The steam plant serving a stand-alone gas centrifuge facility must have sufficient capacity to restart the entire facility on a cold winter day. Steam traces must keep all UF_6 pipes, valves and fittings at a temperature that will maintain the UF_6 in its gaseous state. This would require three coal-fired boilers each producing $50,000 \text{ kg}$ of steam per hour with another $50,000 \text{ kg/hr}$ boiler as a spare. Steam is furnished at 7 kg/cm^2 (100 psig). The steam plant building is noncombustible, steel frame, transite siding, built-up roof, $50 \text{ m} \times 40 \text{ m} \times 12 \text{ m}$ high.

The incinerator plant is located adjacent to the steam plant and designed to produce steam at 7 kg/cm^2 (100 psig) to save fuel at the steam plant. Interconnection by piping and valving makes this possible. The incinerator plant burns all combustible trash from all gas centrifuge facility operations (see Figures 9.B-5 and 9.B-8). Its smoke stack contains a scrubber system to remove most of the radioactive particulates from the gaseous effluents.

^(a)Reference 2, pp. 2-77 and 5-23.

The scrubber fluids become part of the feed for the uranium recovery system. The building is noncombustible, 20 m x 15 m x 9 m high.

The river pump facility is capable of lifting 15 million liters per day from the river under fire emergency conditions, with the river at lowest recorded level. Under average conditions it can pump 11 million liters per day to the filtration plant. The pumps, motors and switchgear are all outdoor equipment requiring no housing structure.

The filtration plant is a standard municipal type facility with the same equipment as would be provided for a small factory town of 2450 people. The structure is 15 m x 10 m and 6 m high, noncombustible. The outdoor concrete filtration basins would be, overall, 75 m x 50 m x 8 m high.

The sewage treatment plant has 2 biofilters, each 100 m in diameter processing 1.2 million ℓ /day. The building is 20 m x 15 m x 7 m high, noncombustible.

The high-voltage electrical substation consists of the necessary dead-end tower, bus-work, transformers and switchgear to supply 150 MWe for the process and supporting facilities. The outdoor equipment is contained in a fenced area 75 m x 50 m. The control console is contained in the structure for the adjacent building housing the emergency diesel electric generators.

In addition to the 105 MWe needed for basic process work, a stand-alone plant would require another 45 MWe for the addition of a uranium recovery plant, water pumping, street lighting and electrically powered heat traces for the UF_6 process lines to maintain production in case the steam plant has difficulties. However, when the steam plant is completely available, 120 MWe would suffice to maintain production if there were an outage on the high voltage electrical supply. Therefore, six 20,000 diesel-electric generators are provided. These are housed in separate concrete cubicles so that fire on one diesel will not affect the other five. The complete 120 MWe diesel-electric facility is of noncombustible reinforced concrete construction with built-up roof, 100 m x 35 m x 8 m high.

A large portion of the 2450 plant workers must pass through change houses to leave their street clothes and dress in plant-supplied work clothes.

At the end of their shift, they shower and change back to their street clothes. If their work involves heavy contamination, they may be required to change during their shift, particularly before eating. Two change houses are provided in opposite corners of the plant. They are noncombustible, 100 m x 30 m x 5 m high.

The fire and security building contains the fire fighting equipment plus security guard offices. It is noncombustible, 40 m x 20 m x 10 m high with a 30 m training and hose drying tower.

Three elevated steel water tanks, 4 million l each, 20 m diameter, are provided for fire protection.

The administration building provides office space for overall management, engineering and administrative people. It contains a first aid and medical center, a computer facility, rooms for instruction and conference, plus a small cafeteria (there is a small lunch room in the basement of each of the process buildings). The administration building is noncombustible, two stories, covering an area 150 m long and 20 m wide.

The laundry processes the work clothes discarded in the two change houses, towels from the shower rooms, laboratory coats and head coverings. Heavily contaminated clothing is rinsed in special solutions to recover uranium compounds for uranium recovery. The clothing is eventually burned in the incinerator building and the ashes are leached with nitric acid to recover most of the remaining uranium. The ashes are packaged and placed in the burial ground. The laundry is a noncombustible building 50 m x 50 m x 8 m high.

The storm drainage system merely drains rain, melting ice and snow runoff. Normal operations do not put radioactive substances into it. Accidents are immediately cleaned up so that almost no radioactivity should reach the environment by this route.

Two holding ponds (sludge lagoons) 40,000 m² each are provided 1) to prevent accidental discharge of harmful chemicals to the environment and 2) to allow settlement of low solubility solids. Adjustable weirs permit emergency containment of pond contents. A skimmer can remove surface oil

and floating materials. The effluent will be visually monitored for oil, silt, etc., and automatically monitored for conductivity, pH, dissolved oxygen, fluorides, and chromates.

A new contaminated burial ground requiring about 12 hectares (30 acres) is provided for disposal of solid radioactive wastes over the 40-year life of the plant. The burial ground will be used for disposal of spent absorbates, such as alumina, contaminated centrifuge parts and other discarded contaminated equipment. Table 9.B-1 lists the total radioactive uranium buried after 40 years of operations. Table 9.B-2 lists other contaminated materials placed in the burial ground over 40 years.

A warehouse to serve the entire project, plus maintenance and service for plant autos, trucks and various types of mobile equipment, would be housed in a noncombustible structure 200 m x 150 m x 15 m high.

Table 9.B-11 lists basic construction materials needed for the reference facility.

TABLE 9.B-11. Basic Construction Materials
Needed, Preliminary Estimate^(a)

	<u>Metric Tons</u>	<u>Short Tons</u>
Steel	253,000	230,000
Aluminum	24,000	22,000
Copper	4,700	4,300
Zinc	200	185
Transformer cooling oil	310	280
Concrete	183,000	240,000 (yd ³)

^(a)Reference 2, p. 5-22.

Much of the information about such a facility is classified for national security reasons. Thus, complete descriptions of the facility are not available. The information given here is a summary of the pertinent information that is publicly available, plus our own rough estimates of the added

utilities and facilities needed to make this a stand-alone, self-sufficient plant.

9.B.5 EFFLUENT CONTROL PERFORMANCE

Overall radioactive materials input and output from the reference facility are summarized in Table 9.B-12. The only radioactive material routinely available for effluent release is uranium. (Generally an insignificant amount of radioactive decay products of uranium are present.) About 0.00015% of the uranium fed to the plant is present in the airborne effluents, and about 0.0012% of the uranium is in the liquid effluents. About 0.0093% of the uranium is lost in solid forms, but is retained onsite in the burial ground.

TABLE 9.B-12. Overall Radioactive Materials Input/Output for Reference Gas Centrifuge Facility

Material	Total UF ₆ Material(a)		kg U/day	Form		Fraction of Plant Input(b)
	kg/day	l/day		Chemical	Phase	
<u>Input to Plant</u>						
Unenriched UF ₆ (0.711% ²³⁵ U)	5.43E4	NA	3.67E4	UF ₆	S	(1)
<u>Output from Plant</u>						
Enriched UF ₆	8.48E3	NA	5.74E3	UF ₆	S	(0.156)
0.25% UF ₆ Tails (stored on-site or off-site)	4.59E4	NA	3.10E4	UF ₆	S	(0.844)
Airborne Effluents	NA	NA	0.054 ^(c)	NA	S,G	1.5E-6
Liquid Effluents	NA	NA	0.455 ^(d)	NA	L	1.25E-5
Solid Waste	NA	NA	3.398 ^(e)	NA	S	(9.30E-5)

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

- (a) Values based upon one day operating at 100% capacity.
 (b) Numbers in parentheses are not released to the environment.
 (c) From Table 9.B-6.
 (d) From Table 9.B-5.
 (e) From Table 9.B-1.

Pathways to the environment for liquid effluents can be deduced from Figure 9.B-7.

A significant amount of additional information is required to complete the tables referenced in this section to determine the important effluents. Also, additional information is required to determine the performance of the individual effluent treatment steps for the important effluents.

9.B.6 FACTORS FOR OPERATING COST INFORMATION

The basic plant operational requirements are presented in this section to enable later estimation of direct operating costs.

9.B.6.1 Labor Requirements

The reference plant is assumed to operate 24 hr/day, 7 days/week, including holidays, for its planned 40 year operating life. The add-on 8.8 million SWU plant at Portsmouth is estimated to employ 2300 people at the steady-state level.^(a) This breaks down as follows:

	<u>Workers</u>
General and administrative	230
Enrichment buildings, cooling tower, pump house, air and nitrogen plant	310
Recycle and assembly building	550
Maintenance	<u>1210</u>
Total for add-on gas centrifuge plant	2300

As indicated in Figure 9.B-10 a number of additional facilities are needed to permit the 8.8 million SWU gas centrifuge facility to operate on an isolated site completely independently (as a "stand alone" facility, as it is usually called). We estimate the number of workers for each of the added facilities to be approximately as follows:

^(a)Reference 2, pages 1-7 and 5-9.

	<u>Workers</u>
Uranium recovery addition to the recycle and assembly building	30
Steam plant, coal fired 200,000 kg/hr, and incinerator	18
River pumping and filtration plants	16
Sewage treatment plant	16
Fire fighting equipment and water storage	10
Holding ponds, burial grounds and storm drainage	6
Security and guard service	10
Laundry	14
Stand-by diesel generation and high voltage switchyard	6
Nitrogen and air plant	8
Warehousing, garage, mobile equipment maintenance	<u>16</u>
Added workers to permit stand-alone operation	150
"Add-on" plant workers	<u>2300</u>
Total workers required to operate the reference facility	2450

The amount of staff labor that may be attributed to effluent control operation is unknown.

9.B.6.2 Material Requirements

At design level of operations 19,831 MT/yr of uranium hexafluoride (UF_6) would be needed as feed material. This would contain 13,410 MT/yr of "natural" 0.711% of ^{235}U uranium. This would be received in slightly less than 1,610 shipping cylinders, each containing up to 12,500 kg (nominally 14 short tons each) of UF_6 . Occasionally some feed is received in smaller cylinders.

Steam is required to heat the feed station autoclaves for UF_6 vaporization, for steam traces along UF_6 process lines to insure that the UF_6 remains a gas throughout the process, and to provide space heating for the facility buildings. Peak steam load is estimated at 145,000 kg/hr. During an average year 52,500 MT of coal per year are burned, with an average heat content of 6,545 kcal/kg of coal, for a total of 344E9 kcal/yr.

The electrical peak load is expected to be between 115 MWe and 150 MWe, with an average of approximately 125 MWe.

Specific material requirements are not known at this time. A large portion of the material requirements will be dependent on the centrifuge MTBF factor (mean time between failure) and will also depend on how the individual centrifuges fail.

9.B.6.3 Unusual Maintenance Requirements

The expected high rate of gas centrifuge machine failures make it economical to have an onsite recycle/assembly building where failed centrifuges can be disassembled, the difficulty diagnosed, failed parts replaced, the centrifuge reassembled, tested and stored until needed. It is expected that rotors and other centrifuge parts will be purchased commercially and will be manufactured offsite. This is shown in Figure 9.B-4. Figure 9.B-6 shows flow of damaged centrifuges and other process equipment in relation to offsite renewal parts, their integration, and their environmentally related discards. A flowchart of the assembly process is presented in Figure 9.B-10.

The disabled machines are received from the enrichment facility and unloaded by crane. Centrifuges that return from the cascade areas are diverted into two disassembly areas, one for selective repair and one for full disassembly. Most of the UF_6 inventory in the centrifuges is removed in the cascade, except for those machines having a completely wrecked rotor.

The disassembled subassemblies are cycled through decontamination to the diagnostic centers. If the subassemblies are defective, they are repaired, inspected, and returned to inventory. The subassemblies that pass diagnostic testing are returned directly to inventory and, along with the repaired units, are used in either final assembly or selective repair. The repaired machines and newly assembled units undergo a final conditioning and inspection. Failed centrifuge parts are buried at approved burial sites after recovery of as much uranium as practicable.

The wash water (sanitary water) used during decontamination of the subassemblies and component parts is collected in always-safe tanks and pumped to the uranium recovery section of the recycle/assembly building.

The recycle and assembly building is an unusual maintenance facility. It is an assembly and testing plant to provide new gas centrifuges as needed

FIGURE 9.B-10. Flowchart for Gas Centrifuge Assembly and Repair Process in Recycle and Assembly Building

and also serves as a repair station for centrifuges and other process equipment which can be repaired.

9.B.6.4 Utility Requirements

Total estimated utility requirements for the plant for each day of operation at 100% capacity are:

Water	11,340,000 l/day
Electricity	125 MW-day/day
Coal	144,000 kg/day

9.B.6.5 Transportation Requirements

All of the plant materials we have discussed must be transported to or from the site. Typical distances for transport of these materials are not within the scope of this study.

9.B.6.6 Waste Disposal Requirements

The solid wastes listed in Table 9.B-2 are disposed of in the burial ground onsite. The nonsalvageable nonradioactive wastes are assumed to be taken to a landfill. Salvageable materials are returned to the supplier or others for reuse.

9.B.6.7 Other Operating Cost Elements

Many of the operating cost elements, such as those listed below, cannot be described in detail at this time due to lack of information:

- Operating requirements of recycle/assembly building
- System for removing metallic contaminants from the blowdown of the RCW cooling system
- Furnace to melt scrap aluminum
- Radio and telephone communications
- Hospital and first aid stations
- Security system (fences, alarms, etc.)

9.B.7 ENVIRONMENTAL IMPACT FACTORS

The overall direct environmental impact factors for the reference facility are summarized in Table 9.B.13. These quantities are those used directly at the plant. Impacts of resources required for material input or output beyond the plant boundary are not included.

TABLE 9.B-13. Overall Environmental Impacts - Reference Gas Centrifuge Enrichment Facility

	Quantity	Remarks
Total Land Committed	4.7 km ²	Fenced-in area
Land Actually Used for Plant	1.5 km ²	High security area
Water Pumped from River	11.34E6 l/day	
Water Discharged as Liquid Effluent	7.44E6 l/day	
Uranium Carried in Liquid Effluent	0.455 kg/day	Contained in a number of compounds
Water Discharged as Airborne Effluent	3.86E6 l/day	
Loss to Underground Water or Evaporation	0.04E6 l/day	
Uranium in Airborne Effluents	0.054 kg/day	Contained in a number of compounds
Electrical Energy Consumption	125 MW-day/day	
Thermal Effluent Equivalent	125 MW-day/day plus 9.42E8 kilocalories/day from the steam plant	

9.B.8 LIMITATIONS AND UNCERTAINTIES IN THE STUDY INFORMATION

Detailed process and facilities information for gas centrifuge plants is nonexistent, since the United States is just about to start design and construction of its first gas centrifuge plant.

SECTION 9: REFERENCES

1. Final Environmental Statement - Expansion of the U.S. Uranium Enrichment Capacity. ERDA-1543, April 1976.
2. Final Environmental Statement - Portsmouth Gaseous Diffusion Plant Expansion, Piketon, Ohio. ERDA-1549, September 1977.
3. The Nuclear Industry, 1973. WASH-1174-74, U.S. Atomic Energy Commission, 1974.
4. Draft Environmental Impact Statement - Portsmouth Gaseous Diffusion Plant. Volume 1, ERDA-1555-D, February 1977.
5. AEC Diffusion Plant Operation. ORO-684, U.S. Atomic Energy Commission, January 1972.
6. Draft Environmental Statement - Portsmouth Gaseous Diffusion Plant Expansion, Piketon, Ohio. Volumes 1 and 2, ERDA-1549, June 1976.
7. Environmental Effects of Construction and Operation of a Gaseous Diffusion Plant. ORO-725, Goodyear Atomic Corporation, Portsmouth, OH, July 1973.
8. ERDA-1555-D. Volumes 1 and 2.
9. "Controlling Airborne Effluents from Fuel Cycle Plants". Proceedings of topical meeting by A.N.S. and A.I.Ch.E., Sun Valley, ID, August 5-6, 1976.

FUEL FABRICATION

10.0 FUEL FABRICATION

Two reference nuclear fuel fabrication facilities are described: a uranium fuel fabrication facility in Section 10.A, and a mixed oxide fuel fabrication facility in Section 10.B.

10.A URANIUM FUEL FABRICATION

A reference UO_2 fuel fabrication facility representative of current technology for commercial scale plants was defined for this study. The facility is partly conceptual and is based primarily on the Westinghouse Nuclear Fuel Plant - Columbia Site⁽¹⁾ (W NFCS), designed to fabricate low-enriched UO_2 (U with ≤ 5.0 wt% ^{235}U) fuel assemblies. It had an initial design capacity of 400 MTU/yr^(a) and is expandable to 1600 MTU/yr.^(1, p. 3.2-13) In September 1974, the W NFCS was operating at about double the initial design capacity.⁽²⁾

The overall characteristics of the reference UO_2 fuel fabrication facility include:

- One facility, uranium feed with multiple enrichment mixtures, and two basic uranium fuel products (UO_2 fuel assemblies for PWRs and BWRs). The facility also assembles mixed oxide fuel assemblies for PWRs and BWRs.
- A single reference facility is assumed that is capable of producing and shipping PWR and BWR fuel assemblies to large, modern reactors at the rate of 4.38 MTM/day (1600 MTM/yr).^(a)
- The facility is assumed to operate 365 day/yr and 24 hr/day for 40 years.

^(a) MTU = metric ton of uranium; MTM = metric ton of heavy metal (i.e., uranium and/or plutonium).

- The facility is to receive UF_6 in solid form and hermetically-sealed UO_2 - PuO_2 fuel rods,^(a) fabricate UO_2 fuel rods, ship UO_2 powder,^(b) and produce and ship UO_2 and UO_2 - PuO_2 fuel assemblies. All fuel rods contain pellet fuel and have Zircaloy cladding. The UF_6 is converted to UO_2 powder by the ammonium diuranate (ADU) process.
- The reference facility is set up to accommodate fuels with the highest expected ^{235}U and plutonium enrichments. It is assumed that no process changes would be made if lower enrichment fuels were used.
- With respect to space and equipment needs, the reference facility is set up for PWR fuel rods and assemblies. The same weight of UO_2 is assumed to yield 1.714 PWR fuel rods or one BWR fuel rod.

10.A.1 SUMMARY

The reference UO_2 fuel fabrication facility produces and ships fuel assemblies for large, modern PWRs and BWRs at the rate of 4.38 MTM/day (1600 MTM/yr). A PWR assembly contains 0.46 MTM in the Zircaloy-clad UO_2 or UO_2 - PuO_2 fuel rods and a BWR assembly contains 0.19 MTM in the UO_2 or UO_2 plus UO_2 - PuO_2 fuel rods.^(5, p. 2.32) The facility receives prefabricated and hermetically sealed mixed oxide fuel rods, and completes the assembly of these fuel elements.

The reference facility receives uranium as UF_6 and first converts the uranium to UO_2 using the aqueous ammonium diuranate (ADU) process. The UO_2 is calcined, formed into pellets and loaded into prefabricated Zircaloy tubing. The fuel-containing rods are sealed and fabricated into fuel assemblies using mostly prefabricated external hardware. Clean uranium scrap is recycled to appropriate points in the process, while dirty uranium scrap (i.e., contaminated with extraneous materials) is purified by ADU precipitation before being recycled to the product stream.

^(a) The UO_2 - PuO_2 fuel rods come from the reference mixed oxide fuel fabrication facility (see Section 10.B) which is assumed to be offsite.

^(b) The UO_2 powder is assumed to be shipped to the reference UO_2 - PuO_2 fuel fabrication facility in 208 l (55-gal) drums.

The ADU conversion process is responsible for most of the chemical effluents from the plant. A total of about 0.73 million ℓ /day of liquid effluents is discharged from the plant. These effluents contain about 4000 kg/day of chemical contaminants (mostly salts of calcium nitrate, ammonia, and fluoride ions) and about 0.0005 kg/day of uranium (the latter is about 0.00001% of plant throughput). The airborne effluents contain about 1000 kg/day of chemical contaminants (mostly ammonia, nitrogen oxides, and some fluorides), and about 0.005 kg/day of uranium (mostly from the sintering furnace exhaust), or about 10 times that in the liquid effluents.

Uranium-contaminated waste consists mostly of about 50,000 ℓ /day of CaF_2 sludge held in lagoons. Other contaminated wastes shipped offsite amount to slightly over 1000 ℓ /day. Total contaminated wastes contain about 0.2% of the uranium fed to the plant. Some of the nonuranium-contaminated waste is scrap fuel assembly materials which are returned to suppliers as scrap or released for scavenging. Most of this nonuranium-contaminated waste is deposited in an approved local landfill.^(a)

The plant employs a total of 1850 persons.^(b) The plant facilities^(c) occupy a total of 0.24 km^2 of Site B, the reference generic site of 4.7 km^2 . The plant uses 1,300,000 kg/day of water, 8,800 kW-day/day of electricity, and 110,000 ℓ /day of natural gas.

Detailed process and facilities information for large UO_2 fuel fabrication plants is not publicly available. Therefore, much information desired for this study is not complete. Significant additional information or development of inferred information on effluent control systems, process, and facility, is needed to perform a detailed cost-benefit analysis. Although the negative environmental effects of the reference plant effluents have not been investigated, alternative processes to the reference process appear to merit some analysis. In particular, the direct conversion process (UF_6 to UO_2) should

^(a) Reference 1, pp. 3.3-20 and 7.2-18.

^(b) Reference 1, pp. 3.1-4 and 8.3-2.

^(c) Reference 1, pp. 3.1-2, 3.1-3 and 4.1-1.

be considered. In addition, alternative or improved techniques for removing chemical and radioactive materials from the liquid and airborne effluents appear to be worthy of investigation.

10.A.2 MAINLINE PROCESS DESCRIPTION OF THE REFERENCE URANIUM FUEL FABRICATION FACILITY

The reference UO_2 fuel fabrication facility performs chemical and mechanical operations in the manufacture of fuel assemblies. The facility receives low-enriched^(a) uranium hexafluoride (UF_6) and hermetically-sealed, Zircaloy-clad UO_2 - PuO_2 fuel rods^(b) as shown in the general process flow diagram in Figure 10.A-1. The low-enriched uranium is to be the only radioactive material present in the reference facility in unsealed container form.

Three basic operations are performed in the facility: 1) chemical conversion of the UF_6 to UO_2 powder by the ammonium diuranate (ADU) process; 2) mechanical processing including preparation of UO_2 pellets by cold pressing and sintering, fabrication of Zircaloy-clad UO_2 (the fuel rods or tubes are loaded with finished pellets, fitted with end plugs, and welded), and manufacture of UO_2 and UO_2 - PuO_2 fuel assemblies (PWR and BWR type); and 3) recovery of uranium from off-specification and scrap material. The final assemblies are shipped to appropriate light water commercial power reactors.

Model UO_2 fuel fabrication plants in WASH-1248^(6, p. E-1) and the ORNL study^(3, p. 1) employ the wet ADU process for the conversion of UF_6 to UO_2 ; this is the current dominant industry practice. The dry direct conversion (DC) process was also considered for a second model plant in the ORNL study^(3, p. 1) and is being considered for the use in the W NFCS.^(1, p. 3.2-5) In comparison to other conversion processes in use or being developed, the greatest waste management problems appear to be associated with the ADU process.^(6, p.E-8)

(a) The U contains 2 to $\leq$ 5.0 wt% ^{235}U .⁽¹⁾

(b) The mixed oxide rods come from the reference UO_2 - PuO_2 fuel fabrication facility.

FIGURE 10.A-1. Overall Reference Fabrication Process for UO₂ Fuels

10.A.2.1 Description of Mainline Process Steps

A more detailed process flow diagram is shown in Figure 10.A-2. The major process steps are discussed below.

- UO₂-PuO₂ Fuel Rod Receiving

Hermetically-sealed, Zircaloy-clad UO₂-PuO₂ (4.5 wt% PuO₂, typical) fuel rods are shipped from the reference UO₂-PuO₂ fuel fabrication facility to this facility in a licensed shipping container holding approximately 750 PWR fuel rods^(7, p. 3.8-1) or about 438 BWR rods. The two shipping boxes inside the container are assumed to be removed and stored until the rods are needed for insertion into fuel assemblies. The empty shipping container and, later, the empty shipping boxes are returned to the reference UO₂-PuO₂ fuel fabrication facility.

- Chemical Conversion to UO₂

The UF₆ is solid at ambient temperature and is shipped in Model OR-30 series shipping containers; as indicated in Department of Transportation regulations, the incoming UF₆ is shipped in Model 30A or 30B pressurized cylinders with overpack.^(a) Heat is added to vaporize the UF₆ and the gaseous UF₆ is fed to the ammonium diuranate (ADU) line. Eight ADU conversion lines are needed. As Figure A.2 shows, the ADU process for converting UF₆ to UO₂ involves: hydrolyzing the UF₆ in water to form uranyl fluoride (UO₂F₂) plus hydrofluoric acid (HF); reacting the UO₂F₂ with ammonium hydroxide (NH₄OH) to precipitate ADU [(NH₄)₂U₂O₇]; and mechanical separation followed by heating (calcining) the ADU in the presence of steam and hydrogen to form UO₂.^(1, p. 3.2-1)

The calcined UO₂ product is transferred to the comminution (pulverizing) station. Solid UF₆ heels and empty cylinders are shipped to the gaseous diffusion enrichment plant in Model 30A or 30B cylinders.^(b) If the UF₆ heel in a cylinder weighs less than 11.3 kg (25 lb), it can be shipped without overpack.

^(a) Reference 1, pp. 4.2-19 and 5.2-6.

^(b) Reference 1, pp. 4.2-22 and 5.2-6.

FIGURE 10.A-2. Mainline Process Flow Diagram for the Reference UO₂ Fuel Fabrication Facility

- Comminution, Blending and packaging

The UO_2 from the calcination step is comminuted (pulverized) in a hammer mill,⁽⁸⁾ collected into batches for blending, and acceptable UO_2 powder is packaged in polyethylene canisters^(a) for transfer to the pellet area. Rejected UO_2 is recycled by returning it to the calcination step in the conversion area. The UO_2 powder moves to the blender by means of a pneumatic transfer line (flexible hose).^(a)

- Pelletizing

UO_2 powder from the chemical conversion or scrap recovery area is received in the pellet area where it is prepared for slugging (low-pressure pressing) into a shape that resembles a medium-sized coin⁽⁹⁾ (i.e., a nickel). Negative atmospheric pressure is provided at the slug press feed hopper opening to preclude dusting when the UO_2 powder is added.^(1, p. 3.2-11) After densifying the UO_2 powder in the slug pressing operation, the slugs are granulated and screened to obtain the proper fuel particle size distribution. A binder-lubricant is added to the acceptable granular material and blended into it; the fuel material is then transferred to the pellet pressing station.

Clean scrap from these steps is sent through a second granulation step and recycled back through the powder preparation step. Dirty scrap (fuel material contaminated with foreign material) is transferred to the dirty scrap recovery area.

At the pelleting station, the granulated, densified UO_2 powder is pressed into green (unsintered) pellets by high speed presses.⁽⁸⁾ Negative atmospheric pressure present at the pellet press feed hopper minimizes dusting when the UO_2 powder is added.^(1, p. 3.2-11) Acceptable green pellets are transferred to the sintering furnace station. Clean scrap is sent through a granulation step before it is returned to the powder preparation step for reuse.

^(a)Reference 1, pp. 5.1-3 and 5.1-5.

Sintering boats (i.e., metal trays) loaded with acceptable green pellets come to the sintering furnace station and are fed through a furnace on a continuous train.⁽⁸⁾ A single furnace can contain as much as 510 kg (1125 lb) of UO_2 pellets.^(a)

The furnaces are electrically heated and have a hydrogen atmosphere. If the hydrogen pressure gets too low, the furnaces automatically shift to an inert nitrogen atmosphere. The hydrogen is piped into the furnaces from storage tanks located outside the manufacturing building. All exit of hydrogen is controlled; a natural gas curtain burns the hydrogen that escapes from the furnace.^(b) The furnace is also purged with nitrogen before it is operated.

Rejected material (e.g., overfired pellets, broken pellets, pellet chips) is recycled as clean scrap since it is essentially free of nonfuel impurities. The rejected material is transported to the oxidation and reduction station where it is modified to obtain the required oxidation state and/or physical state. It then returns to the process stream at the powder preparation station. Acceptable sintered pellets are transferred to the grinding station. Underfired pellets are assumed to be recycled back through the sintering furnace.

Centerless grinding is used to obtain precise pellet diameters. It is assumed that a recirculating water coolant system is used.^(c) The material ground off the pellets is collected and recycled;⁽⁸⁾ a grinder sludge separator is assumed to be used and the dried sludge handled as clean scrap. Rejected ground pellets are also handled as clean scrap, sent to the oxidation and reduction station, and rejoin the process stream at the powder preparation station. Acceptable ground pellets are loaded into trays for transfer to the drying station.

(a) Reference 1, pp. 5.1-20 and 5.1-22.

(b) Reference 1, p. 5.1-20 and 5.1-22.

(c) The grinder coolant system is not described in Reference 1; however, a drying oven is used to remove moisture from ground pellets.

The loaded trays of ground pellets are placed in a drying oven to evaporate the moisture (the moisture could originate from the grinder coolant or from a pellet washing and cleaning step).⁽¹⁰⁾ Dried pellets are stored until required for subsequent process steps. When fuel is needed for production, the trays of dried pellets are transferred to the rod area.

- Rod Loading and Finishing

Trays of dried UO_2 pellets are unloaded and the pellets are placed in the fuel rod mockup channels at the rod loading station, inclined so pellets can easily move down into the tubes. The PWR tubes (25 at a time) are manually loaded with pellets before either end plug is fitted.⁽⁸⁾ Pellets are loaded into BWR tubes after one end has been fitted with a welded end plug.^(10, p. 3-3) An automatic rotary Tungsten-Inert-Gas (TIG, using helium shielding gas) welding machine is used to weld the bottom and top plugs to the loaded tubes. Before the top plug is fitted, a spring is inserted.

It is assumed that BWR fuel rods are not pressurized, whereas PWR fuel rods are pressurized; the pressurization is obtained by performing the final end-plug weld in a chamber containing helium at the required pressure (typically about $3.5 \times 10^5 \text{ kg/m}^2$, 25 atmospheres, or about 500 psig).

Welded rods are then subjected to a series of examinations including visual and dimensional inspection, radiography, gamma scanning, and helium leak testing. Acceptable fuel rods are stored on racks in the fuel assembly area. Fuel rods failing these examinations are assumed to be sent to the rod repair and dismantling station where they are repaired or rejected. Repairable rods would typically have flaws in the plug welds or improperly loaded pellets. Rejected rods are those considered to be beyond repair.

Uranium-contaminated scrap metal from repaired rods or from dismantling of rejected rods and other miscellaneous waste (e.g., swabs,

decontamination reagents) are collected as waste for disposal. Damaged pellets are transferred to the oxidation and reduction station, and acceptable pellets returned to the process stream at the pellet nick inspection step (i.e., after the grinding station).

- Fuel Assembly

Finished UO_2 (or $\text{UO}_2\text{-PuO}_2$) fuel rods are unloaded from storage racks or containers and inserted into appropriate fuel assemblies. The final assembly area for UO_2 fuel assemblies is near the mixed oxide fuel assembly area. In general (and assuming no plutonium becomes airborne,^(1, p. 3.3-1), manufacturing fuel assemblies is common to fuel fabrication plants handling UO_2 and/or $\text{UO}_2\text{-PuO}_2$ fuel rods.

There are several differences between PWR and BWR fuel assemblies; for example:

- PWR fuel assemblies have control rod guide tubes and about 1/3 of these assemblies can be fitted with control rod clusters^(a)
- BWR fuel assemblies can contain some poison rods (i.e., rods loaded with $\text{UO}_2\text{-Gd}_2\text{O}_3$ pellets)
- In mixed oxide PWR fuel assemblies, all fuel rods (a real design is not available yet) probably contain $\text{UO}_2\text{-PuO}_2$ fuel pellets
- In mixed oxide BWR fuel assemblies, part of the fuel rods (possibly 10 to 15 in the interior, though a real design is not yet available) will contain $\text{UO}_2\text{-PuO}_2$ fuel pellets and the remaining rods will contain UO_2 fuel pellets.

The finished fuel rods are inserted into a structural framework typically set up in a horizontal position, involving spacer grid assemblies, the lower end fitting (tie plate or nozzle), and other components. Fuel rods are loaded into a fuel assembly by inserting them through the spacer grid assemblies. In some cases,^(8,11) a fine water

^(a) A control rod cluster is composed of a multifingered spider from which are suspended stainless steel-clad cadmium-silver-indium (Cd-15% Ag-5% In), boron carbide, or hafnium control rods.⁽⁸⁾

spray is used on the rods during insertion to give some lubrication; in other cases,⁽⁹⁾ a thin notched loading strip is used. An upper end fitting (tie plate or nozzle) and other components are added to complete the fuel assembly. With some fuel assemblies, a shielded arc welding operation is used to attach the top end fitting to the fuel assembly. Unacceptable fuel assemblies are assumed to be transferred to a fuel assembly repair and dismantling station and acceptable fuel assemblies are transferred to a cleaning station. At the cleaning station, the fuel assemblies are immersed in a series of tanks that contain solutions that are not strongly corrosive.⁽⁸⁾

It is assumed that the fuel assembly and dismantling station processes unacceptable fuel assemblies that originate at the fuel assembly inspection, storage and shipping stations. Such fuel assemblies may also originate at the reactor (unirradiated fuel assemblies could be returned because of quality control/quality assurance reasons). Some fuel assemblies would need only cleaning of a greasy surface or correcting an improper weld, while others would need to be dismantled so components could be rechecked (e.g., for cross-mixing of pellets) or replaced (e.g., because of cracked end fittings) and reconstituted.

Repaired fuel assemblies return to the process stream at the inspection step. Unacceptable fuel rods are transferred to the rod repair and dismantling station. Solid waste (e.g., scrap metal) and miscellaneous waste are collected for disposal.

The completed, clean, acceptable fuel assemblies are hung vertically in specially constructed racks⁽⁸⁾ and held in storage until they are loaded into shipping containers for delivery to the reactor. The PWR fuel assemblies are assumed to be shipped in Model RCC-1 containers, which can accommodate 3.55 m (12 ft long) fuel rods and assemblies.^(a) The BWR fuel assemblies are assumed to be shipped in Model RA-1 shipping packages.^(10, p. 5-19)

^(a)Reference 1, pp. 4.2-21 and 5.2-6.

- Scrap Recovery

Scrap in various forms is sent to the recovery process operation where it is handled on a batch basis.^(a) Relatively clean uranium-containing scrap from which uranium of acceptable quality can be recovered by a modest amount of processing (i.e., without solvent extraction) is treated in the scrap recovery operation in the reference plant. Dirty scrap requiring more processing is either packaged and stored for later processing or shipped as waste.

Initial steps in scrap recovery involve concentration and conversion of the scrap into forms that can be readily processed into U_3O_8 powder. The basic sequence of this process involves: dissolution of solid forms in nitric acid, conversion to slurry form by precipitating ADU from the solution, dewatering the slurry form by wet mechanical separation, calcining the resulting sludge in natural or controlled atmosphere furnaces, and packaging and storing the resulting product.

Some scrap, however, does not require processing through the entire sequence. Acceptable product is recycled by returning it to the powder preparation step in the pellet area. Unacceptable product is transferred to the pH adjustment or the calcination station in the conversion area.

Solid waste is collected for disposal, and liquid effluents held in the quarantine tanks are transferred to the waste treatment building when they do not exceed the specified release levels.^(a)

- Other Components for Fuel Rods and Fuel Assemblies

The Zircaloy tubes and plugs, the springs and other components (e.g., getters, insulators) for the fuel rods are received, inspected, cleaned and stored until needed. Other nonradioactive parts besides fuel rods are required for fuel assembly construction, including upper and lower end fittings, spacer grid assemblies, springs and other components (e.g., guide tubes). Such parts are common to uranium oxide

^(a)Reference 1, pp. 3.2-9 and 10.

and mixed oxide fuel assemblies. It is assumed^(a) that the upper and lower end fittings (rigid, heavy components made of stainless steel) and Zircaloy guide (thimble) tubes are also received, inspected, cleaned and stored until required in the fabrication process. Rejected components and solid wastes (e.g., shipping boxes or crates) are either returned to the supplier or discarded as nonradioactive wastes.

The grid spacers are fabricated in the reference facility. Grid spacers for PWR fuel assemblies use nickel plated Inconel 718,⁽⁸⁾ and those for BWR fuel assemblies can use a Zircaloy grid structure with Inconel-X springs. Manufacturing PWR grid spacers includes press stamping, machining, (e.g., spark erosion is one method used), spot welding, pickling, bead blasting, plating and brazing.^(b)

Rejected solid materials are either returned to the supplier or discarded as nonradioactive waste. Acceptable grid spacers are stored until needed in the fuel assembly area.

- Analytical Services

The chemical laboratory area receives small samples taken throughout the fabrication process for chemical, radiochemical, physical or metallographic analysis.^(c) A typical analytical system involves weighing, dissolving (or pretreating in some fashion), and measuring a small sample for a specific characteristic. Operations involving radioactive materials in unsealed physical forms are limited to low-enriched uranium. Examined samples are assumed to go to the scrap recovery area, and liquid waste generated in the analytical services area is assumed to enter the process drain line.

(a) It is not clear in the reports (see Reference 1, p. 3.1-1, 3 and 9) whether components (e.g., fuel rod end plugs, fuel assembly and fittings) other than grid spacer parts are prepared in the machining area of the Westinghouse Nuclear Fuel Plant.

(b) Reference 1, pp. 3.2-9, and 12.

(c) Reference 1, pp. 3.3-19 to 21, 5.1-7, 5.2-6.

10.A.2.2 Waste Management

Fuel fabrication facilities generate radioactive and nonradioactive solid wastes only. Other "waste" materials are released to the environment as radioactive and nonradioactive liquid and airborne effluents. Waste management practices differ between fuel fabrication facilities depending upon whether a facility is fabricating UO_2 or UO_2 - PuO_2 fuel rods. However, since the UO_2 - PuO_2 fuel rods are received pre-fabricated in this reference facility, uranium and its associated impurities are the only radioactive constituents of the nonproduct (or waste or effluent) streams leaving the plant.

Nonradioactive solid wastes are generated by the supporting activities and originate in offices, lunch rooms, nonradioactive shops and receiving terminals. They include paper, wiping rags, grease, oil, used crating lumber, used packing boxes, used packing materials, plastic sheeting materials, worn out equipment pieces, damaged input materials (e.g., Zircaloy), etc. These noncontaminated materials are collected and hauled away by local waste disposal contractors for deposit in approved landfill sites or for salvage.

Solid waste materials and articles that are, or could be, contaminated with uranium are segregated into combustible and noncombustible categories. Noncombustible wastes include ventilation filters, pumps, motors, valves, segments of process piping, etc. After determining approximate uranium content versus feasibility of recovery, these materials are either chemically processed or collected in boxes for burial at a government licensed waste disposal site. Buried wastes contain less than $177g\ U/m^3$.^(a)

Combustible items such as paper, cloth, and plastic articles used in equipment decontamination are reduced to ash in a specially designed incinerator. The ashes are sampled and analyzed for uranium. Depending on the uranium content, the ashes are either returned to the plant and chemically processed for uranium recovery, or are boxed for ultimate burial at an authorized site. The off gases are water scrubbed and filtered before being discharged to the atmosphere.

^(a)Reference 1, pp. 3.3-19 to 21, 5.1-7, and 5.2-6.

The solid waste precipitates resulting from treatment of the liquid process effluents of the plant are routed to lagoons and stored there. When lagoons fill with sediment, they are covered over with soil and new lagoons are built. It is not currently known whether additional disposition of these wastes will eventually be required.

A summary of waste management activities at the reference uranium fuel fabrication facility is given in Figure 10.A-3.

10.A.3 EFFLUENT CONTROL PROCESS DESCRIPTIONS

Control of emissions of uranium and its radioactive decay daughters, and chemicals such as fluorides, nitrates, and ammonia must be done to limit effluents to acceptable amounts. These materials can be present in both aqueous and the airborne wastes.

10.A.3.1 Liquid Effluents

The treatment of liquid effluents from the reference facility is shown in Figure 10.A-4. The primary aqueous process effluent (from the ADU conversion process) is cleaned of ADU solids in the mainline process by two stages of centrifugation. Then it is treated in the effluent treatment system by ion exchange to remove additional uranium and other cationic impurities. The supernatant liquid is then processed through cartridge filters before being routed to tanks where lime is added to precipitate the fluoride as CaF_2 . This slurry is sent to a distillation column to remove about 75% of the ammonia for reuse in the plant's ADU process. The liquid effluents from scrap recovery operations and contaminated sump solutions are also routed to the ammonia still. The remaining unrecovered ammonia is assumed to be vented to the atmosphere.

The ammonia still bottoms, which contain concentrated salts and solids, are routed to the first holding lagoon (lined pond) to allow the solids to settle. This lagoon also receives liquid effluents from most process scrubbers (they use water as the scrub solution). The supernatant liquid from the first lagoon is routed to a second lagoon for additional solids settling. The supernatant liquid from the second lagoon is then pumped to

FIGURE 10.A-3. Overall Waste Management Operations for Reference UO_2 Fuel Fabrication Plant

FIGURE 10.A-4. Process Flow Diagram - Liquid Effluent Treatment System for the Reference UO₂ Fuel Fabrication Facility

the nearby river in combination with the sanitary effluent (which also includes water deionizer regeneration solutions and flushes, steam boiler blowdown, and chemicals for developing x-ray film in the laboratory). The water bleed stream from the closed-loop cooling tower is pumped to the sanitary effluent lagoon. A significant amount of the water in these liquid effluents evaporates into the atmosphere.

10.A.3.2 Airborne Effluents

The treatment of airborne effluents at the plant is shown schematically in Figure 10.A-5. In cases where potential for radioactive materials or significant chemicals exist, treatment consists of water scrubbers and/or HEPA (high efficient particulate air) filtration.

All process gases from the aqueous processing and scrap recovery systems are water scrubbed and followed by one stage of HEPA filtration. Fifteen scrubbers are used, including 10 for the mainline calciners (one for each calciner). The water scrub solutions from the latter scrubbing (which removes much of the fluoride as hydrofluoric acid) are recycled to the first stage centrifuge of the mainline ADU process. The scrub water from the other scrubbers is routed to a quarantine (hold-up) tank before transfer to the first holding lagoon. The off gases from dissolution of scrap uranium are condensed to return much of the nitrogen oxides and condensable vapors to the dissolver before the noncondensable gases are routed to the scrubbers.

Many of the solids handling processes are dusty operations that require filtration of the off gas before atmospheric release. The pellet drying operations are HEPA filtered at the air exhaust point of their respective hoods. (Although some of the other process steps may not have filtration in their immediate exhaust, such filtration is assumed at this time.) Ventilation exhausts from process building rooms that have potential for containing uranium (i.e., process steps through fuel rod loading and sealing) are also routed through a bank of HEPA filters. Filtered air from the solids handling process steps is assumed to be routed to this latter bank of HEPA filters.

FIGURE 10.A-5 PROCESS FLOW DIAGRAM-AIRBORNE EFFLUENT TREATMENT SYSTEM FOR THE REFERENCE UO₂ FUEL FABRICATION FACILITY

FIGURE 10.A-5. Process Flow Diagram - Airborne Effluent Treatment System for the Reference UO₂ Fuel Fabrication Facility

The off gases from the waste incinerator are water scrubbed before HEPA filtration. The scrub water is filtered and then routed to the contaminated sump for final effluent treatment.

Ventilation from other in-plant activities or areas is exhausted directly to the atmosphere without treatment. These exhausts result from:

- Steam boiler combustion gases
- Chemical and health physics laboratory ventilation
- Calcliner combustion gases
- Plating and rinse hoods exhaust gases
- Pre-etch exhaust gases
- Pickling exhaust gases
- Grid plating room ventilation
- Air compressor ventilation
- Chemical storage ventilation
- Nonradioactive personnel area ventilation

10.A.4 FACILITY AND SITE DESCRIPTION

The following description of the UO_2 fuel fabrication site and facility and its hardware will be used as the primary basis for capital cost estimates, and as background for plant performance analyses.

10.A.4.1 Site

The reference facility is assumed to lie on the generic site described in Section 5 B. The plant itself requires an area of 0.24 km^2 within the larger plant site. The plant layout allows airborne effluents to emanate equidistant and 1 km away from three sides of the rectangular site. A well-labeled perimeter fence is assumed to exist around the total site to exclude the public, and another fence, including a security entrance, surrounds the smaller plant area. The liquid effluents are assumed to be discharged onsite into the river that flows through one corner of the site.

10.A.4.2 Facility

The reference facility is largely based on the Westinghouse Nuclear Fuel Columbia Plant, with an expanded design capacity of 1600 MTU/yr.^(a) Construction of the facility was begun in 1968 and completed in 1969. The plant was operated at about 800 MTU/yr in 1974,^(b) and is expected to be operating at the capacity used in this study--1600 MTU/yr eventually. The reference facility lies on already disturbed rural land. Within the 4.7 km² (1158 acre) site, the developed area represents about 0.24 km² or 60 acres. This developed area contains the fuel manufacturing building, chemical storage area, machining area, waste ponds, offices, parking lot, and other outside equipment. Figure 10.A-6 shows the facility's layout.^(d) The main plant building uses about 22,300 m² (240,000 ft²); about 81% is used for fuel manufacture and about 19% for offices, laboratories, and service areas.^(e) The proposed separate building (4,645 m² or 50,000 ft²), which will fabricate machined components, is assumed to be built on a concrete slab. The other expansion of production equipment, using another 4,645 m² (50,000 ft²) in the main process building, is assumed to be complete. Besides these two buildings, the buildings, the major parts in the developed area of the site are the chemical storage area and the waste treatment area (including four chemical settling lagoons and one sanitary effluent pond).

Except for the office/cafeteria wing, the reference facility is a two-to-three story, windowless, steel or prefabricated concrete slab structure with associated service and office buildings.^(6,1,8) The building has long, simple lines of rectangular interconnecting areas. The manufacturing plant and the offices are fully air conditioned.^(1, p. 3.1-4)

(a) Reference 1, pp. 1.2-5, 2.2-17 and 3.2-13.

(b) Reference 2, pp. 42-43.

(c) Reference 1, pp. 3.1-2, 3 and 4.1-1.

(d) Reference 1, Figures 3.1-1,2 and 3.3-1,2

(e) Reference 1, pp. 3.1-1, 8.

FIGURE 10.A-6. Layout of the Reference UO₂ Fuel Fabrication Facility

Figure 10.A-7 shows the general floor plan of the main building, which is divided into four major functional areas:

- Office and cafeteria area
- Controlled process area (where uranium is handled before encapsulation and sealing in fuel rods)
- General purpose area (where no uranium is handled or where uranium is handled after encapsulation)
- Mixed oxide fuel assembly area

These areas are separated by dividing walls and by different ventilation systems.

A total of eight ADU processing lines is required for the production capacity of the reference plant. Each line processes uranium of a single enrichment at any given time. All processing operations in the controlled process areas are assumed to be conducted in hoods or glove boxes or other enclosures and to be surrounded by operating areas. These separate process areas are generally served by individual (filtered) ventilation systems, as the locations of the multiple small process stacks indicate (shown in Figure 10.A-8). Total ventilation flow for the facility is $6.5E9$ l/day (160,000 cfm).

The facility is expected to operate for 40 years.

10.A.5 EFFLUENT CONTROL PERFORMANCE

The overall effluent control performance for radioactive effluents from the reference facility is summarized in Table 10.A-1. The only radioactive material available for routine effluent release is uranium. Basically, about 0.0001% of the uranium fed to the plant is present in the airborne effluents, and about 0.00001% is present in the liquid effluents. About 0.5% of the uranium feed ends up in packaged wastes or materials returned to the source.

FIGURE 10.A-7. Main Building Floor Plan for the Reference UO₂ Fuel Fabrication Facility

FIGURE 10.A-8. Roof Plan and Process Stack Locations for the Reference UO₂ Fuel Fabrication Facility

TABLE 10.A-1. Overall Radioactive Materials Input/Output for
Reference UO₂ Fuel Fabrication Facility

Material	Total Material ^(a)		U ^{(a)(c)}	Form		Fraction of ^(b)
	kg/day	l/day	kg/day	Chemical	Phase	Plant Input
<u>Input to Plant</u>						
Enriched UF ₆	6.5E3	1.4E3	4.40E3	UF ₆	S	(1)
<u>Output from Plant</u>						
Product Fuel Assemblies	6.4E3 ^(d)	NA ^(d)	4.38E3	UO ₂	S	(0.995)
UF ₆ Shipping Heels	19	4.2	13	UF ₆	S	(2.9E-3)
Airborne Effluents	1.3E7 ^{(c)(d)}	1.0E10 ^{(c)(d)}	5.1E-3	UO ₂	S	1.2E-6
Liquid Effluents	7.3E5 ^{(c)(d)}	7.3E5 ^{(c)(d)}	5.3E-4	NA	L	1.2E-7
Solid Waste	NA ^{(c)(d)}	5E4 ^{(c)(d)}	9	UO ₂	S	(2.0E-3)

S = Solid

L = Liquid

G = Gas

NA = Not available at this time

(a) Values are based upon one day operating at 100% capacity for PWR fuels.

(b) Numbers in parentheses are not released to the environment.

(c) Sealed fuel rods containing plutonium received and assembled at the plant and shipped out are not covered in this table. No routine radioactive effluents result from this material.

(d) Value indicates total of radioactive and nonradioactive sources.

The only other radioactive material received at the plant is hermetically sealed plutonium dioxide or plutonium dioxide-uranium dioxide in hermetically sealed fuel rods. There are no routine radioactive effluents from these sealed fuel rods.

The overall effluent treatment performance on nonradioactive materials for the reference plant is not well known at this time, primarily because of the proprietary nature of this information. The overall input of nonradioactive materials is given in Table 10.A-2. The nonradioactive materials in the airborne effluents, the liquid effluents, and the solid wastes from the plant are given in Tables 10.A-3, 10.A-4, and 10.A-5, respectively.

In general, many of the gaseous and liquid materials fed to or generated within the plant are included in the plant effluents. Notable exceptions are: the fluoride removed from the liquid effluents by precipitation to a calcium fluoride waste; the ammonia, which is approximately 75% recovered for reuse; and selected metal ions removed from the liquid effluents by precipitation as relatively insoluble sulfate salt wastes.

A significant amount of additional information is required to complete these tables to determine the critical effluents. More information will also be required to determine the performance of the individual effluent treatment steps for the critical effluents.

Most of the information in this section is developed in Reference 1. Additional information was obtained from References 3, 6 and 12.

10.A.6 FACTORS FOR OPERATING COST INFORMATION

The basic plant operational requirements are presented to enable later estimation of direct operating costs.

10.A.6.1 Labor Requirements

The reference plant is assumed to operate 24 hr/day, 7 days/week (including holidays) for its entire operating life. The plant is estimated to require a staff of about 1850 persons to perform all onsite operations.⁽¹⁾

TABLE 10.A-2. Overall Nonradioactive Materials Input to the Reference UO₂ Fuel Fabrication Facility

Material	Total Material (a)		Chemical	Form		kg/day as 100%
	kg/day	g/day		Phase	Other	
Fuel Tubes, End Caps	1296	NA	Zry-4	S	Tubes/plugs	1296
Fuel Assembly Nozzles	97	NA	304 SS	S	NA	97
Grid Spacers	53	NA	Inconel 718	S	Plate Stock	53
Plenum Springs	2.9	NA	304 SS	S	Springs	2.9
Helium	>0.2	NA	He	G	Pressurized	70.2
Water	1.3E6	1.3E6	H ₂ O	L	NA	1.3E6
Natural Gas	NA	1.1E5	Natural Gas	L	Pressurized	NA
Argon	NA	NA	Ar	G	Pressurized	NA
Hydrogen	NA	NA	H ₂	G	Pressurized	NA
Nitrogen	NA	NA	N ₂	L	Pressurized	NA
Sodium Carbonate	NA	NA	Na ₂ CO ₃	S	NA	NA
Nickel Sulfate	NA	NA	NiSO ₄ ·6H ₂ O	S	NA	NA
Sulfuric Acid	NA	NA	H ₂ SO ₄	L	93%	NA
Sodium Hydroxide	NA	NA	NaOH	L	50%	NA
Nitric Acid	NA	NA	HNO ₃	L	68%	NA
Lime	NA	NA	CaO	S	NA	NA
Aqueous Ammonia	NA	NA	NH ₄ OH	L	28%	NA
Anhydrous Ammonia	NA	NA	NH ₃	G	100%	NA
Acetone	NA	NA	(CH ₃) ₂ CO	L	100%	NA
Hydrochloric Acid	NA	NA	HCl	L	22%	NA
Zinc Stearate	NA	NA	Zn(C ₁₈ H ₃₅ O ₂) ₂	S	100%	NA
Hydrofluoric Acid	NA	NA	HF	L	72%	NA
Boric Acid	NA	NA	H ₃ BO ₃	S	100%	NA
Water Treatment Chemicals	NA	NA	NA	NA	NA	NA
Oil and Grease	NA	NA	NA	L,S	NA	NA

Key: S = Solids
L = Liquids
G = Gas
NA = Not available at this time

(a) Value based upon one day operating at 100% capacity for PWR fuels.

TABLE 10.A-3. Overall Nonradioactive Airborne Effluents
from the Reference UO₂ Fuel Fabrication Facility

Material	Form		Output ^(a)		Fraction of Plant Input
	Chemical	Phase	kg/day	l/day	
Water Vapor (from Lagoons and Cooling Towers)	H ₂ O	L,G	6E5	6E5	0.46
Fluorides	HF, NH ₄ F	L,G	0.97	NA	NA
Ammonia	NH ₃	G	7.9E2	NA	NA
Nitrogen Oxides	NO _x	G	10	NA	-(b)
Nitric Acid	HNO ₃	L,G	24	NA	NA
Carbon Monoxide	CO	G	3.0E-2	NA	-(b)
Hydrocarbons	H _x C _y	G	5.2E-3	NA	-(b)
Sulfuric Acid	H ₂ SO ₄	L	NA	NA	NA
Boric Acid	H ₃ BO ₃	L	NA	NA	NA
Nickel Sulfate	NiSO ₄	S	NA	NA	NA
Nickel Chloride	NiCl ₂	S	NA	NA	NA
Acetone	(CH ₃) ₂ CO	G	NA	NA	NA
Helium	He	G	NA	NA	NA
Hydrogen	H ₂	G	NA	NA	NA
Nitrogen	N ₂	G	NA	NA	NA
Argon	Ar	G	NA	NA	NA
Sulfur Oxides	SO _x	G	1.0E-3	NA	NA
Nonradioactive Particulates	NA	S	3.1E-2	NA	NA
Zirconium	NA	NA	24	NA	NA
Xylol	C ₈ H ₁₀	NA	5.6	NA	NA
Butanol	C ₄ H ₁₀ O	NA	6.4	NA	NA
Methyl Butyl Ketone	C ₆ H ₁₂ O	NA	4.0	NA	NA
Glycol Ethyl Ether	NA	NA	3.2	NA	NA
Isopropyl Alcohol	C ₃ H ₈ O	NA	20	NA	NA

(a) Value based upon one day operating at 100% capacity for PWR fuels.

(b) This material does not enter the plant in this chemical form.

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

TABLE 10.A-4. Overall Nonradioactive Liquid Effluents from the Reference UO₂ Fuel Fabrication Facility

Materials	Form		Output ^(a) kg/day
	Chemical	Phase	
Calcium Salts	Ca ⁺²	L,S	1.7E3
Sodium Salts	Na ⁺	L	1.0E2
Ammonium Salts	NH ₄ ⁺	L	6.8
Fluoride Salts	F ⁻	L	11
Sulfate Salts	SO ₄ ⁻²	L,S	1.3E2
Sulfite Salts	SO ₃ ⁻²	L	1.7
Nitrate Salts	NO ₃ ⁻	L	37
Chloride Salts	Cl ⁻	L	77
Phosphate Salts	PO ₄ ⁻³	L	6.2
Iron Salts	Fe ⁺³	L	1.5
Boron Salts	BO ₃ ⁻³	L	6.6
Nickel Salts	Ni ⁺²	L	0.7
Magnesium Salts	Mg ⁺²	L	3.9
Molybdenum Salts	Mo ⁺⁶	L,S	0.33
Silver Salts	Ag ⁺	L	0.25
Manganese Salts	Mn ⁺²	L	7.3E-2
Water Treatment Chemicals	NA	L	NA
Oil and Grease	NA	L	5.7
Sanitary Effluents	H ₂ O ^(c)	L,S	3E5
Zinc Salts	Zn ⁺²	L	NA
Copper Salts	Cu ⁺²	L	4.8E-2
Chromium Salts	NA	L	0.45

(a) Value based upon one day operating at 100% capacity for PWR fuels.

(b) Some of these materials do not enter the plant in the chemical form given here.

(c) Mostly H₂O

TABLE 10.A-5. Overall Solid Waste From the Reference UO_2 Fuel Fabrication Facility

Waste Material	Form	Package	Total ^(a)		U Content ^(a)		Fraction of Plant Input
			ℓ/day	kg/day	kg/day	Form	
<u>Uranium Contaminated</u>							
Incinerator Ash	Powdered Ash	Fiberboard Boxes	NA	NA	4.3	UO ₂	0.001
Zircaloy Scrap	Zry-4 Tubes, Plugs	Fiberboard Boxes	0.5	3.5	NA	UO ₂	NA
Process Sludge	CaF ₂ Sludge	Remains in Lagoon	<52,000	NA	5.1	U Salts	0.0012
Contaminated Clothing	Clothing, Towels	208 ℓ Steel Drums	NA	NA	NA	U Salts	NA
Noncombustible Misc.	Metal, Glass	Fiberboard	1050		<0.2	U	<5E-5
<u>Non-Uranium Contaminated</u>							
Incinerator Ash	Powdered Ash	NA	NA	NA	~0	--	~0
Zircaloy Scrap ^(b)	Zry-4 Tubes, Plugs	Boxes	10	61	~0	--	~0
Scrap Fuel Nozzles ^(b)	304 SS	Boxes	0.3	2	~0	--	~0
Scrap Fuel Spacers ^(b)	Inconel Sheet	Boxes	0.2	1	~0	--	~0
Scrap Fuel Springs ^(b)	304 SS Spring	Boxes	0.06	0.06	~0	--	~0
Noncombustible Misc.	Miscellaneous	NA	NA	NA	~0	--	~0
Sanitary/Process Sludge	Misc. Chemical Salts	Remains in Lagoon	NA	NA	~0	--	~0

^(a)Value based upon one day operating at 100% capacity for PWR Fuels.

^(b)Returned to vendor for salvage.

NA = Not available at this time

About 360 of this crew are management, supervisory or professional staff and about 1490 employees are skilled or unskilled labor. The amount of this staff labor that may be attributed to effluent control operations is unknown.

10.A.6.2 Material Requirements

The routine material requirements are those identified previously in Table 10.A-2. Packaging materials for offsite disposal of solid wastes listed in Table 10.A-5 are required, and small amounts of miscellaneous materials such as office materials, routine maintenance materials, etc, are also required.

10.A.6.3 Unusual Maintenance Requirements

Some equipment will require replacement and/or major repairs fairly often where the service is relatively severe. These special requirements are currently unknown, but for this study are assumed to be equivalent to replacement of all major equipment every 15 years. It is also assumed that all HEPA and roughing filters are replaced every year, and one new large lagoon with a capacity of 5,700,000 ℓ (1,500,000 gal.) must be built every year.

10.A.6.4 Utility Requirements

Total estimated utility requirements for the plant for each day of operation at 100% capacity are:

- Water 1,300,000 kg/day
- Electricity 8,800 kW-day/day
- Natural Gas 110,000 ℓ /day

10.A.6.5 Transportation Requirements

All plant input materials listed in Table 10.A-2 the finished fuel assemblies, and the output waste items listed in Table 10.A-5 must be transported to or from the site. Typical transport distances are not within the scope of this report.

10.A.6.6 Waste Disposal Requirements

The solid wastes listed in Table 10.A-5 must be removed for ultimate disposition. The uranium contaminated materials are assumed to be disposed of at a regional burial ground for radioactive wastes. The nonsalvageable nonradioactive wastes are assumed to be taken to a nearby landfill. Salvageable materials are returned to the supplier or others for reuse.

10.A.6.7 Other Operating Cost Elements

Other major operating cost elements are those tasks performed by outside contractors. Laundering of noncontaminated and radioactively contaminated work clothing is assumed to be contracted. The quantity of this laundry is currently unknown. Other activities assumed to be performed through contractors are transportation of materials and disposal of radioactive and nonradioactive wastes.

Other known special operating cost elements are licensing and insuring the operation of such a nuclear materials processing facility.

10.A.7 ENVIRONMENTAL IMPACT FACTORS

A summary of the overall direct environmental impact factors for the reference facility is given in Table 10.A-6. These quantities are those used directly at the plant. Impacts of resources required for material input or output beyond the plant boundary are not included.

10.A.8 LIMITATIONS AND UNCERTAINTIES IN THE STUDY INFORMATION

Detailed process and facilities information for large fuel fabrication plants designed to fabricate LWR fuel assemblies is publicly unavailable. Some additional information can be developed or extrapolated from existing available information. However, including that information will still leave gaps in the desired information. Even some of the data reported here relating to effluent quantities from the reference facility (taken almost entirely from one applicant's report) are questionable and require verification; they appear to be on the low side, based on the author's judgment.

TABLE 10.A-6. Overall Environmental Impacts - Reference UO₂ Fuel Fabrication Facility

	Quantity	Remarks
Total Land Committed	4.7 km ²	Fenced-in Area
Land Actually Used for Plant	0.24 km ²	High-Security Area
Water Used	1.3E6 kg/day	
Water Discharged as Liquid Effluent	7.5E5 kg/day	
Total Materials Added to Liquid Effluents	~2.0E3 kg/day	Includes 5.3E-4 kg U
Air Used	9.0E6 kg/day	6.5E9 l/day
Water Discharged as Airborne Effluent	5.5E5 kg/day	
Total Other Airborne Effluents	~3.0E3 kg/day	Includes 5.1E-3 kg of U
Electrical Energy Consumption	8.8E3 kW-day/day	
Natural Gas Consumption	1.1E5 l/day	
Thermal Effluent Equivalent	1.9E4 kW-day/day	
Resource Use	See Table 10.A-2	Also Special Maintenance requirements

Information on the design of mixed oxide fuel assemblies for large, modern LWRs is largely proprietary. PWRs were assumed to use mixed oxide fuel in separate and distinct fuel assemblies. For BWRs, it was assumed that of the 63 fuel rods in an assembly, about 10 to 15 in the inner region might be mixed oxide fuel rods and the rest UO₂ fuel rods. No pertinent data on poison rod fabrication was found.

10.A.9 RESEARCH AND DEVELOPMENT NEEDS

Considerable additional information is needed on the reference UO₂ fuel fabrication plant in two major areas: 1) facility and hardware and 2) process flowsheets. Plant and facility information is needed to provide a basis for approximate cost estimates, for reliable estimates on the source terms to effluent cleanup systems, and for estimates on effluent cleanup system performance. Process flowsheets are needed to provide design or experience

factors for mainline plant and effluent control systems, and to provide reasonable estimates of the characteristics of the materials in the effluents.

Alternative processes to some of those in the reference facility appear to merit some study. The direct conversion process (UF_6 to UO_2) is strongly being considered as the next generation process and has been installed in some newer plants. This process could be investigated as an alternative to the reference process studied here. Effluent and waste control needs are considerably different for the two processes. Additional study on nitrate removal processes, fluoride recovery systems for recycle, and possibly variations in ammonia recovery also appear to be worth pursuing.

10.B URANIUM AND PLUTONIUM MIXED OXIDE FUEL FABRICATION

The reference $\text{UO}_2\text{-PuO}_2$ fuel fabrication facility selected for this study is representative of current technology and is primarily modeled on the Westinghouse Recycle Fuels Plant (RFP), a proposed large-scale [0.55 to 1.1 MT of $(\text{UO}_2\text{-PuO}_2)/\text{day}$ or 200 to 400 MT of $(\text{UO}_2\text{-PuO}_2)/\text{year}$] plant.^(7,13) No sizable $\text{UO}_2\text{-PuO}_2$ production operation exists at this time.^(4, p. 7) Although the Recycle Fuels Plant had been scheduled for operation in 1979,^(a) action on the RFP presently depends on the outcome of the pending national decision on plutonium recycle.

The overall characteristics of the reference mixed oxide fuel fabrication facility (partly conceptual) include the following:

- One facility, a plutonium feed and a natural uranium feed, and two basic products ($\text{UO}_2\text{-PuO}_2$ fuel rods for PWRs and BWRs).
- A single reference facility is assumed that is capable of producing and shipping PWR and BWR, Zircaloy-clad, $\text{UO}_2\text{-PuO}_2$ fuel rods at the rate of 1.1 MT $(\text{UO}_2\text{-PuO}_2)/\text{day}$ [400 MT $(\text{UO}_2\text{-PuO}_2)/\text{year} \sim 352.6 \text{ MTM/year}$]. The hermetically-sealed fuel rods are to be shipped offsite to the reference uranium fuel fabrication facility (see Section 10.A) for insertion into appropriate fuel assemblies for large, commercial reactors.
- The facility is to receive PuO_2 powder from another source and UO_2 powder from the reference uranium fuel fabrication facility. The facility will not receive plutonium nitrate solution and convert it to PuO_2 powder.
- The reference facility is assumed to accommodate fuels with the highest expected ^{235}U and plutonium enrichments and no process changes would be made if lower enrichments were used.
- With respect to space and equipment needs, the reference facility is set up for producing PWR fuel rods. It is assumed that the same weight of $\text{UO}_2\text{-PuO}_2$ fuel yields 1.714 PWR fuel rods or one BWR fuel rod.

^(a)Reference 14, p. 4.3-1.

- Finished nonradioactive fuel rod components are assumed to be received from a supplier.
- The reference facility is assumed at this time to have no recovery operation for dirty scrap (fuel materials contaminated with extraneous materials).⁽⁷⁾ Dirty scrap is stored onsite for future recovery of product values.

10.B.1 SUMMARY

The reference mixed-oxide fuel fabrication facility is designed to produce and ship mixed oxide Zircaloy-clad fuel rods for PWRs and BWRs to the reference UO_2 fuel fabrication facility for assembly. The proposed production rate of the reference facility is 1.1 MT ($\text{UO}_2\text{-PuO}_2$)/day [400 MT $\text{UO}_2\text{-PuO}_2$].

The reference facility is designed to receive uranium oxide powder (from the reference UO_2 fabrication facility) and plutonium oxide powder. The powders are mechanically blended along with recycled $\text{UO}_2\text{-PuO}_2$ powder from other process steps in the facility. The blended powder is cold-pressed and sintered to yield $\text{UO}_2\text{-PuO}_2$ pellets that are loaded into Zircaloy tubes to produce the $\text{UO}_2\text{-PuO}_2$ fuel rods.

A total of about 1.3×10^9 l/day of air and airborne effluents is released to the environment containing about 1200 kg/day of chemical effluents (sulfur oxides and nitrogen oxides, excluding nitrogen and water vapor) and 1.4×10^{-8} kg U/day and 6.4×10^{-10} kg Pu/day. The liquid effluent discharge totals about 78,000 l/day and includes about 5 kg/day of chemical constituents and about 1.5×10^{-7} kg U/day and 6.9×10^{-9} kg Pu/day.

The contaminated solid wastes contain about 7 kg U/day and about 0.33 kg Pu/day. The contaminated solid wastes are to be either stored onsite (i.e., dirty scrap) or disposed of offsite to an authorized waste repository.

The plant will employ about 260 persons. The plant facilities (within the inner security fence) occupy a total of 0.073 km^2 of the total reference generic site of 4.7 km^2 . The plant uses 212,000 kg/day of water and 2,740 kW-day/day of electricity.

Detailed process and facility information for large mixed oxide fuel fabrication plants is not publicly available. Therefore, much information desired for this study is not complete.

Significant additional information or development of inferred information on effluent control processes, mainline processes, and facility description is needed to perform a detailed cost-benefit analysis.

10.B.2 MAINLINE PROCESS DESCRIPTION OF THE REFERENCE MIXED OXIDE FUEL FABRICATION FACILITY

The reference $\text{UO}_2\text{-PuO}_2$ fuel fabrication facility receives UO_2 (natural U) and PuO_2 powder as shown in the overall process diagram in Figure 10.B-1. The UO_2 and PuO_2 are mechanically blended with recycled $\text{UO}_2\text{-PuO}_2$ powders from other process steps in the facility. The blended mixture is cold-pressed and sintered to yield $\text{UO}_2\text{-PuO}_2$ pellets that are loaded into tubes to produce PWR- and BWR-type, Zircaloy-clad, $\text{UO}_2\text{-PuO}_2$ fuel rods. The welded and inspected fuel rods are shipped to the reference UO_2 fuel fabrication facility for incorporation into appropriate fuel assemblies.

The reference $\text{UO}_2\text{-PuO}_2$ fuel fabrication facility contains equipment in "canyon" type areas where mixed oxide pellets are fabricated on a remote and continuous basis. Some process steps (e.g., loading of pellets into tubes, welding of loaded fuel rods) are performed in gloveboxes. By contrast, the smaller present-day plants employ batch-type operations and semi remote (glove box) methods for all the steps up through the final welding on the fuel rod. Mixed oxide fuel is currently prepared by dry (mechanical blending) or wet (coprecipitation) processes; however, in near-future commercial-scale production plants the dry technique is currently the most likely to be used in the pelletization process.

10.B.2.1 Description of Mainline Process Steps

A more detailed process flow diagram is given in Figure 10.B-2. The major process steps are discussed below.

FIGURE 10.B-1. Overall Reference for Mixed Oxide Fuels Fabrication Process

FIGURE 10.B-2. Mainline Process Flow Diagram for the Reference Mixed Oxide Fuel Fabrication Facility

- PuO₂ Powder Receiving, Unloading and Storage

L-10 containers, holding 4.5 kg of PuO₂, arrive at the site by truck. They are stored in the PuO₂ storage area in the manufacturing building.

The L-10 containers are opened inside a ventilated enclosure; the inner cans are then opened and sampled, and the PuO₂ powder is transferred, by a pipe-type conveyor that employs an air jet system, to one of three storage vessels in the restricted access area in the manufacturing building. One vessel at a time supplies powder to the process lines. The PuO₂ samples are transferred in vials by "rabbit" tube carrier to the analytical services facility.

Cleaned empty inner cans are compressed by a small compactor and transferred to a lined drum, which is subsequently sealed and sent to the drum scanning station in the miscellaneous waste treatment area.^(a) Other solid wastes (spent filters, defective equipment, defective gloves, and combustibles) are also sealed in drums and sent to miscellaneous waste treatment. Empty noncontaminated L-10 containers are assumed to be returned to the PuO₂ supplier.

- UO₂ Receiving, Unloading and Storage

The UO₂ powder is received from the reference uranium fuel fabrication facility (see Section 10.A) in 208 L (55 gal) drums. The drums are stored in the UO₂ storage and unloading area in the manufacturing building. A mechanized drum tilting device in a controlled air flow enclosure is used to pour the UO₂ from the drums; a pneumatic conveyor transports the material to a UO₂ transfer hopper. The empty (noncontaminated) drums are assumed to be reused, and drum liners go to the miscellaneous waste treatment area. UO₂ particles from the filter vessel in the off-gas header are returned to the dump enclosure for reuse.

^(a)Reference 13, p. 5.3-4.5.

- Powder Blending

Natural UO_2 , PuO_2 and recycled UO_2 - PuO_2 powder (from the clean scrap recovery system) are blended in batch increments and transported to the blender by pneumatic conveyors. The materials come from transfer vessels (UO_2) or storage vessels (PuO_2 and recycle UO_2 - PuO_2) and pass through feed hoppers and weight hoppers before entering the V-blender. Rejected UO_2 (>1% moisture) goes to clean scrap storage, rejected PuO_2 (>1% moisture) goes to clean scrap storage, rejected PuO_2 (>1% moisture) goes to PuO_2 storage for drying, and rejected recycle UO_2 - PuO_2 goes to clean scrap recovery for drying.

- Mixed Oxide Powder Storage

A batch of mixed oxide is transferred from the blender to a particle-size reduction mill by the mechanical mill feeder drive. The discharged milled powder is then transported by pneumatic conveyor^(a) to one of nine mixed oxide silos for storage. Rejected batches of mixed oxide in the storage silos are transported to clean scrap recovery for analysis. Sub-blend samples of mixed oxide are accumulated from the size-reduction mill and sent to the analytical services facility.

- Compaction, Granulated, Pelletizing, Boat Loading, and Green Pellet Storage

Mixed oxide powder is transferred by the pneumatic conveyor from a silo to the slug press where it is compacted into slugs, which are then granulated and classified. Acceptable granules are sent to the pelletizing press; oversize granules (indicates broken classifier screen) are considered dirty scrap and transported to miscellaneous waste treatment; and undersize granules are directly recycled back to the slug press. A mechanical conveyor moves acceptable green (i.e., unsintered) pellets from the pelletizing press to boats (i.e., trays) placed in green pellet storage. Rejected green pellets are collected as clean scrap and sent to clean scrap recovery.

^(a)Reference 13, p. 5.6-3.

Both the slug press and the pelletizing presses use dies. The normal die lubricant addition is about 0.1 wt%; this amounts to about 0.95 ℓ (1 qt) of the low viscosity organic die lubricant per day per press for 3-shift operation.^(a) The presses operate hydraulically and the hydraulic fluid is contained in a sealed system within the presses.

- Sintering, Boat Conveyance, and Pellet Storage

The boats of green pellets are moved by shuttle car to one of the six sintering furnaces, which use forming gas (about 6% hydrogen and 94% nitrogen).^(b) The boats of pellets pass through the furnaces to the hydrogen and density inspection station where samples are taken and sent to the analytical services facility. Acceptable pellets are sent to sintered pellet boat storage; underfired pellets are recycled back through the furnace; overfired pellets are sent to clean scrap recovery.

- Pellet Grinding, Inspection and Storage

Boats of sintered pellets from storage are transferred by mechanical conveyor to one of the two independent lines involved with the next processing steps. The pellets are mechanically unloaded and conveyed single-file through a centerless grinder for surface grinding (using a water coolant). Broken pellets and chips from unloaded boats are transferred in clean scrap cans to clean scrap recovery. A high-velocity air stream (from nozzles) then passes over the ground pellets and dries them.

Next, the ground pellets are inspected for diameter. Acceptable pellets go to the nick inspection station; undersize pellets are transferred to clean scrap recovery; and oversize pellets are sent back for regrinding. From the nick inspection station, acceptable pellets are mechanically conveyed single-file to a tray loader and rejected pellets are sent to clean scrap recovery. The loaded trays are mechanically conveyed through a heated-air drier. The trays are then mechanically conveyed to the pellet storage units, which receive air from the restricted access area cooling system and discharge warm air to the restricted access area atmosphere.

^(a)Reference 13, pp. 5.7-8,9.

^(b)Reference 13, pp. 5.8-2, 5, 12.

The two processing lines interconnect at the pellet storage units by a mechanical cross conveyor and share a single inspection and sampling station.^(a) Before pellets are released from the storage units for insertion into tubes at the loading station, selected trays of pellets are conveyed to the inspection and sampling station where 1) sample pellets are singly analyzed for moisture and then transferred to miscellaneous waste treatment, and 2) other sample pellets are transported to the analytical services facility for other analyses. Trays of acceptable pellets are then moved mechanically from the storage units to the loading station, and rejected pellets are unloaded into scrap transfer cans. This rejected fuel ultimately enters the clean scrap feed hopper.

- Receiving, Cleaning and Storage of Tubes, Plugs and Springs

The Zircaloy tubes are inspected and accepted at the supplier's site, packaged in shipping boxes, shipped to the reference facility and sent to the tube receiving station in the rod inspection building. Acceptable boxes of tubes are placed in tube storage racks, while rejected boxes are either returned to the supplier or discarded as nonradioactive solid waste.

The tubes are uncrated from accepted boxes and inspected; the empty crates are disposed of as nonradioactive waste; and the inspected tubes are cleaned (using acetone followed by blowing nitrogen through the tubes)^(b) and sent to the bottom plug press station. Discarded materials from the cleaning operation are handled as nonradioactive wastes, which include felt plugs, acetone, wipes, polyethylene end caps,^(c) plastic sheeting and gloves.^(d)

Top plugs, bottom plugs, and repair plugs are inspected and accepted at the supplier's site, packaged in cardboard boxes, shipped to the rod inspection building, and sent to the plug receiving and storage area. Rejected boxes of plugs are returned to the supplier or discarded as nonradioactive

^(a)Reference 13, pp. 5.9-6, 10.

^(b)Apparently, felt plugs are forced through the tubes by the nitrogen.

^(c)Most of these are probably discarded at later stations.

^(d)Reference 13, Figure 5.10-2.

solid waste. Accepted boxes of plugs are unpacked and the plugs stamped, then sent to the spring and plug cleaning station. Empty boxes and rejected stamped plugs are considered as nonradioactive waste.

Springs are inspected and accepted at the supplier's site, packaged in cardboard boxes, shipped to the rod inspection building, and sent to the spring receiving and storage station. Rejected boxes of springs are returned to the supplier or are discarded as nonradioactive solid waste. Accepted boxes of springs are unpacked, subjected to a compression test, and sent to the spring and plug cleaning station. Springs rejected at the test are disposed of in the same manner as the rejected boxes of springs.

Consumable materials from offsite suppliers are received in the rod inspection building where they are unpacked. These materials include: 1) varsol, 2) acetone, 3) gloves, 4) wipes, 5) felt plugs, 6) polyethylene end caps, 7) plastic sheeting, 8) gloves (for glove boxes), 9) swabs, 10) cleaning agents, and 11) others. The empty cardboard boxes and containers are discarded as nonradioactive waste and the consumable materials are stored in a rack. Items 1 through 4 are used at the spring and plug cleaning station, items 2 through 7 are used in the tube cleaning station, and a number of the items are used in the fuel fabrication area.

The spring and plug cleaning station in the rod inspection building uses the consumable materials, two ultrasonic cleaners, a water rinse unit, and a hot air drying unit. Discarded materials are handled as nonradioactive solid or liquid wastes. Clean, dry plugs and springs are placed on portable storage racks.

At the bottom plug press station in the rod inspection building, a machine is used to press a bottom end plug (force fit used) into a tube. A girth weld (in an inert atmosphere) is then made to join the plug to the tube. The welded tubes are then stored in a rack to await x-ray examination. After x-ray inspection, tubes are held in post x-ray storage. Accepted tubes are visually inspected and then pass through the air lock (between the rod inspection and the manufacturing buildings) and into the empty tube storage

station. Rejected tubes are returned for reweld or are sent to the rework storage and bottom plug cut-off station. The cut-off bottom plugs are discarded as nonradioactive solid waste and the reworked tubes are recycled through the bottom plug press.

- Fuel Rod Loading

The fuel rod loading station in each of the two processing lines in the manufacturing building is in a glove box and has a mechanical device to load pellets into the fuel tubes (or rods). Loaded tubes are removed from a port seal and moved to a decontamination station that uses a limited amount of solvent. The solid waste (combustible) is sent to miscellaneous waste treatment.

The open ends of rejected rods are sealed with a plastic bag and tape and the rods are transferred to the rod repair and dismantling station. Acceptable rods are moved to the spring loading and top plug press station where a spring is inserted into the rod and the top and plug are pressed into place. The assembled rod is transferred to the welding enclosure.

The two process lines merge into one line on entering the welding enclosure; a single process line is used for all subsequent processing steps. At the inert-gas-blanketed welding enclosure, a girth weld is made to join the top plug to the tube. Rejected rods are sent to the rod repair and dismantling station. Acceptable rods (PWR type only) are moved to the pressure welding chamber where the inside of the rods are pressurized with helium and seal welded.^(a) The rods are taken to post-weld storage, and then to the air lock (between the manufacturing and rod inspection buildings) and to preinspection storage.

- Rod Repair and Dismantling

The rod repair and dismantling station consists of two adjacent glove boxes. In one, the rods are depressurized (PWR only) and cut open for repair or dismantling, and the repaired rods with new springs and repair

^(a)Top plugs for PWR fuel rods have a small opening that is sealed at this welding step. Top plugs for BWR fuel rods have no such opening.

plugs are decontaminated. In the second glove box, the decontaminated rods are welded within an inert atmosphere; PWR rods are also pressurized with helium and seal welded.

This station handles repairable and rejected fuel rods in batches of 12 to 25 PWR rods. Repairable rods typically have defects in the girth weld at the top plug or in the seal weld, or are improperly filled with pellets. Rejected rods are those judged to be beyond repair.

Repaired rods are transported to the air lock and preinspection storage station where they rejoin the main process stream. Scrap metal (e.g., tubes, plugs, springs, chips from tube cutting and reaming) and other miscellaneous waste (e.g., swabs, decontamination reagents) are collected in containers and sent to miscellaneous waste treatment. Damaged pellets are transported to the clean scrap recovery system. Acceptable pellets are transferred to the nick inspection station in the restricted access area and rejoin the process stream.

- Rod Testing, Inspection, Storage and Shipping

Fuel rods pass from the manufacturing building through the air lock and preinspection storage station to the rod inspection building where they are tested and inspected. The tests and inspections include: helium leak test, rod assay inspection, x-ray inspection, and individual inspections for straightness, visual weld quality, diameter, weight, and surface flaws or imperfections.^(a) Leaky rods^(a) are transferred to the rod repair and dismantling station.

Acceptable rods are individually gamma scanned at the rod assay station to verify pellet composition and to assure that no pellets are missing. Rejected rods^(b) are sent to the rod repair and dismantling station. Trays of acceptable rods are moved to the pre-x-ray storage unit.

^(a)Reference 13, p. 5.13-1, and Figure 5.10-1.

^(b)The rods are moved in shielded carriers.

At the x-ray inspection station, weld radiographs are taken on fuel rods, which are then moved to post-x-ray storage and to the physical inspection and weighing station. Rods rejected^(a) because of the x-ray or physical inspections are sent to the rod repair and dismantling station. Acceptable rods are transferred to the post inspection storage unit. When released by quality control, rods are moved by shielded carriers and mechanically stacked in the inspected rod storage vault where ventilation air removes the autogenous heat.^(b)

When rods are to be shipped, they are mechanically unstacked from the vault, transported again by the shielded carriers and loaded into shielded shipping boxes. Loaded boxes are moved by bridge crane and placed in shipping casks that are then transferred onto trucks (in the truck well). The hermetically-sealed fuel rods are then transported to the uranium fuel fabrication facility for incorporation into fuel assemblies.

- Clean Scrap Recovery

The clean scrap recovery system processes clean scrap in batches. This clean scrap is mixed oxide material that is essentially free of impurities but needs modification of physical state and/or oxidation state, and blending and analytical certification before it can rejoin the production lines.^(c) The scrap received includes: off-density green pellets, off-fired pellets (incorrect metal-to-oxygen ratio), and dried grinder sludge.^(d)

First the scrap fuel is reduced in particle size in a totally enclosed roll crusher; a dust collection shroud is attached to the scrap container/crusher interconnection to collect oxide dust that might be released when these equipment items are separated. The crushed material is then subjected to multiple oxidation-reduction steps to attain the required physical or

(a) The rods are moved in shielding carriers.

(b) Reference 13, p. 5.13-3.

(c) Reference 13, p. 5.14-1.

(d) In Reference 7, grinder sludge is classed as clean scrap. In the ORNL study,⁽⁴⁾ grinder sludge is handled as dirty scrap.

oxidation state. Preheated air is fed to the first reaction vessel to initially oxidize the UO_2 to U_3O_8 ; the PuO_2 remains chemically unaltered at this step. The mixed oxide is then pneumatically transferred to one of the two reduction-oxidation-reduction (R-O-R) vessels; these are essentially duplicates of the initial vessel, where preheated forming gas (6% H_2 - 94% N_2) is introduced to reduce the U_3O_8 to UO_2 . The temperature is then lowered to aid the oxidation cycle. Another reduction cycle follows (identical to the first); the material is then transferred pneumatically using nitrogen to one of the three clean scrap storage vessels.^(a) One vessel supplies the process line, one is filled and awaiting quality certification, and one is being filled.

Nitrogen is used to transfer the hot product from the R-O-R reaction vessels and for mixing operations to prevent reoxidation.^(b) A recirculating nitrogen system is used, since quite large flow rates of nitrogen gas are needed to blend the product in the storage vessels and transfer it from R-O-R reaction vessels to the storage vessels. The recirculating system has filters and a cooler; the cooler removes residual heat from the product as it leaves the reaction vessels and removes the autogenous heat from the plutonium while in storage.

A blended batch of mixed oxide may sometimes be classed as overrun material or be rejected (e.g., because of enrichment). This material is pneumatically transferred to an available clean scrap storage vessel for mixing with processed scrap and made ready for re-use.

- Analytical Services

The analytical services facility is used to provide all analyses^(c) of feed materials, process streams, and fuel materials that are needed to support production. Samples in sealed containers are pneumatically conveyed by "rabbit" tube carrier to the analytical services facility. Transfers

(a) Reference 13, p. 5.14-15 and Figure 5.14-9.

(b) Reference 13, p. 5.14-6.

(c) All samples are processed in the analytical services facility, except for the liquid effluent treatment samples, which are processed in the health physics laboratory. (see Reference 13, pp. 5.15-1, 2, 3.)

between areas in the facility are made pneumatically, except for liquid waste. Excess clean PuO_2 is transported to the PuO_2 bulk storage area, other excess sample material, scrap and dry waste are transferred to miscellaneous waste treatment via glove box, and liquid waste is transferred directly to miscellaneous waste treatment. Of the fissile material processed in the analytical services facility, about 60% is returned (as PuO_2) to the PuO_2 bulk storage area, 20% goes to miscellaneous waste treatment as miscellaneous scrap and 20% is transferred to miscellaneous waste as liquid waste.

- Other Systems

Other systems in the manufacturing building support the reference facility production and operation, including decontamination and hot repair cell, and dirty scrap storage. These are briefly described below:

- 1) Decontamination and Repair Cell

Decontamination, maintenance, repair or disposal of process equipment are normally performed remotely in this cell. Compressed air and vacuum cleaners are used for operations where dry cleaning is adequate. For decontamination operations that require spraying, washing or flushing, steam from an independent steam generation system and a circulating water flushing system (with provision for addition of nonflammable reagents, degreasers, etc.) are provided. Two tanks are used for the recirculating flushing system. Liquids from flushing or washing operations drain to a cell floor sump; they are then pumped through cartridge filters to remove oxide solids and returned to the tanks. Liquid wastes are sampled and analyzed for plutonium before they are transferred to the liquid waste treatment system. Loaded filter cartridges are transported to the miscellaneous waste treatment system.

After decontamination, components are repaired in the adjacent repair area or bagged out for offsite disposal. The repair area has machine shop equipment and other tools, and vacuum cleaning equipment available for dry cleaning, but the area normally does not contain liquids.

Flammable materials in the cell are limited to substances for swabbing or wiping; solvents used in the cell are nonflammable. Chemical oxidants (e.g., nitric acid) are not normally used for cell operations. Discarded materials are sent to the miscellaneous waste treatment system.

2) Dirty Scrap Storage

Dirty scrap is fuel material scrap that is contaminated with foreign matter, and cannot be returned to the manufacturing process without chemical purification. Separation, concentration, and packaging of the dirty scrap is done in the miscellaneous waste treatment system before it is sent to this storage area. This shielded concrete storage area can accommodate the total quantity of dirty scrap generated during the first three years of plant operation.

Ventilation air is provided to the storage unit to dissipate the decay heat generated by the stored scrap.^(a) A fan draws room air and forces it through the storage unit; the air is cooled and discharged back into the room.

This dirty scrap is stored until it can be recycled through a plutonium recovery process. The reference facility does not have such a scrap recovery processing operation (though space is provided for it).^(b)

10.B.2.2 Waste Management

The radioactive contamination of greatest concern in waste materials is plutonium contamination. The waste management process schemes at the reference facility are summarized in Figure 10.B.3. Radioactive waste materials and articles are those contaminated with plutonium or uranium that are not planned to be recovered.

(a) Reference 13, pp. 10.5-2,3.

(b) Reference 13, Figure 6.3-4.

FIGURE 10.B-3. Overall Waste Management Operations for the Reference Mixed Oxide Fuel Fabrication Facility

- Radioactive Waste

Radioactive waste materials and articles are handled in either of two processes as discussed below.

- 1) Liquid Waste Treatment

The liquid wastes may come from either the liquid effluent treatment process or the miscellaneous waste treatment process. Most contaminated liquid wastes come from the miscellaneous waste treatment scrap recovery operations.

Wastes are received alternately in one of the two waste receiving tanks. When one tank is full, the incoming stream is diverted to the other tank. Contents of the full tank are mixed, sampled and assayed to verify plutonium and uranium concentration and then batch-transferred to the cement mixing operation. The mixed liquid-cement slurry (batch size is 98.4 l or 26 gal. of liquid) is transferred to a 208-l (55-gal.) drum. After the slurry cures to a solid, the drums are mechanically sealed, surveyed for contamination and transferred to onsite storage for eventual shipment to offsite disposal facilities. About 70 drums/yr are anticipated.

- 2) Miscellaneous Waste Treatment

The miscellaneous waste treatment process treats solid and liquid wastes containing recoverable and nonrecoverable plutonium and uranium. Waste to be treated includes: gloves (from glove boxes); plastic bags, bottles, tubing, and sheet materials; swabs, wipes, rags and paper; metallographic mounts, grinding and polishing waste; filter elements for air and liquid streams; absorption bed cartridges; surgical gloves; discarded protective clothing; solvents and spent lubricants; and scrap hardware (tools and equipment).

The plutonium content of such materials can range from trace quantities to significant amounts. All incoming material is gamma scanned to approximate the plutonium content. It is then categorized as non-recoverable (i.e., judged to be disposable) or potentially recoverable.

The material categorized as waste is next scanned by a precision gamma scanner and transferred to the drumming station where it is loaded into a 208 l (55-gal.) drum. The waste is compacted (if compressible) and the drum is sealed. Hardware and other noncompressible materials are packed into drums separately and the drums are sealed. Loaded and sealed drums are inspected and gamma surveyed to assure that external contamination is below allowable limits. These drums are then transported to the loading dock for offsite disposal at an authorized site.

The miscellaneous waste treatment system also handles the "waste" materials with potentially recoverable product (dirty scrap), which include: impure fuel material (e.g., mixed oxide and PuO_2 powder, oversize granules, pellets and chips); sweepings (e.g., from glove boxes); analytical or quality assurance samples; liquid wastes from the analytical services facility; and filter elements from the systems for contaminated liquid waste treatment and potentially contaminated liquid effluent treatment.

Dirty scrap is examined with a neutron counter to obtain a more accurate estimate of plutonium content. After being sorted according to physical types, the materials are transferred to appropriate glove boxes for separation and concentration. Treatments available include roasting, shredding, washing, precipitation and filtering, calcination, and mechanical separation. Some materials require several treatments.

The resulting plutonium concentrate from dirty scrap is crushed, mixed, assayed for plutonium content, and loaded into 1-liter metal cans, sealed and sent to dirty scrap storage. The low-level solid waste (e.g., residue, shredded plastics, gloves) is sent to the drumming station and drummed with other disposable waste. Low-level aqueous waste created during processing of the dirty scrap is pumped to the liquid waste treatment system for solidification. The small amount of organic liquids requiring disposal is filtered, collected, sampled and transferred to 208 l (55-gal.) drums (containing an absorbent), which are prepared for eventual shipment to offsite disposal.

The reference facility has the capability to store all the dirty scrap generated during the first three years of operation. Over that period, about 3 MT (3000 kg) of mixed oxide are estimated to be generated as dirty scrap. About 1 m³ of storage volume is required, assuming an average density of 3 g/cm³ for such material.

- Nonradioactive Solid Wastes

Nonradioactive solid wastes are generated by the supporting activities of the fuel fabrication facility. These wastes originate in offices, lunch rooms, nonradioactive shops, and receiving terminals. The wastes include paper, wiping rags, grease, oil, used crating lumber, used cardboard packing boxes, used packing materials, worn out equipment pieces, rejected fuel rod springs, tubes, plugs, and the like. These noncontaminated materials are collected and hauled away by local waste disposal contractors for deposit in approved land fill sites or for salvaging.

10.B.3 EFFLUENT CONTROL PROCESS DESCRIPTIONS

The control of plutonium and its radioactive decay daughters is the major concern, and control of uranium is secondary, in the effluents from the reference mixed oxide fuel fabrication facility. The control of plutonium as well as americium, thorium and uranium involves both liquid and airborne effluent control. Some nonradioactive effluents are also controlled to some degree.

10.B.3.1 Liquid Effluents

The processing of liquid effluents in the reference facility is shown in Figure 10.B-4, excluding the sanitary effluent controls. Separate collection and pretreatment of janitorial wash water is provided because of potentially contaminated dirt and sediment in this water. The wash water is drained to alternate mop water hold tanks (40 & or 10 gal.). While the contents of one tank are sampled and analyzed, the other tank serves as a receiving vessel. Janitorial wash water is not normally contaminated with alpha radio activity and is pumped through a filter to a potentially contaminated quarantine tank (3800 & or 1000 gal.). Provision is made, however,

FIGURE 10.B-4. Process Flow Diagram - Liquid Effluent Treatment System for the Reference Mixed Oxide Fuel Fabrication Facility

to pump the wash water through a filter back to the smaller potentially contaminated sump tank (800 l or 200 gal.) if slight alpha contamination is detected.

All other potentially contaminated effluents are collected in one of the two sump tanks located in the basement. The smaller tank (800 l or 200 gal.) provides retention capacity while the contents of the larger tank (2300 l or 600 gal.) are being mixed, sampled, and analyzed for radioactivity and pH. If the alpha radioactivity is within the permissible discharge limit and the liquid has a near-neutral pH, it is pumped through a filter into one of the two quarantine tanks (3800 l or 1000 gal.) for discharge to the sanitary treatment system and eventual discharge to the river.

If the alpha radioactivity exceeds the maximum permissible discharge limit, the liquid is transferred from the larger sump tank to a treatment tank (2300 l or 600 gal.) where it is neutralized with caustic, if necessary. The treated liquid is mixed and then pumped through filters into a deactivation feed tank (3800 l or 1000 gal.) for deactivation treatment. The filters are mounted inside an alpha enclosure to collect particulates that may be present. Spent filter cartridges are transferred to the miscellaneous waste treatment system.

Deactivation treatment, a proprietary process, is accomplished by passing the contaminated solution through absorption-adsorption ion exchange beds at a controlled flow rate to a deactivation product tank (3800 l or 1000 gal.). If product analysis shows that the deactivation treatment successfully reduced the contamination level within maximum permissible release limits, the product is discharged to the sanitary treatment system and eventually to the river. If the deactivation process is ineffective, the liquid may be returned for retreatment or is transferred to the liquid waste treatment system for solidification in drums.

10.B.3.2 Airborne Effluents

The treatment of airborne effluents from the mainline processes in the reference facility is shown schematically in Figure 10.B-5.

FIGURE 10.B-5. Process Flow Diagram - Airborne Effluent Treatment System of the Mainline Process for the Reference Mixed Oxide Fuel Fabrication Facility

The following paragraphs discuss airborne effluent control for individual mainline process steps:

- PuO₂ Unloading and Storage

The exhaust air from the pneumatic conveying system filters through a sintered metal filter within the storage vessel and then discharges to a common off-gas header. Pulses of reverse-flow air are used to clean the sintered metal filters. In the off-gas header, the exhaust air filters through another bank of sintered metal filters, prefilters, and HEPA filters before discharging to the plant exhaust system. The exhaust air from air-jet mixing and aerating operations follows this same process pathway.

- UO₂ Unloading

The air from the UO₂ drum dump enclosure passes through a filter (assumed to be a sintered metal filter) a prefilter, a HEPA filter and discharges to the restricted access area.

- Blending Process

The exhaust air from the UO₂ pneumatic conveying system passes through a filter (assumed to be a sintered metal filter) and then discharges through the same system as the exhaust air from the UO₂ drum dump enclosure, beginning with the initial sintered metal filter as a backup. The exhaust air from the PuO₂ pneumatic conveying system is first filtered through a sintered metal filter and then discharges to the PuO₂ unloading exhaust air system beginning with the second sintered metal filter as a backup. The exhaust air from the recycle UO₂-PuO₂ pneumatic conveying system is filtered through a sintered metal filter (within the storage vessel), a backup sintered metal filter (in common off-gas header), a prefilter, a HEPA filter, and then discharges to the plant exhaust system. (This could be the same control system as the PuO₂ unloading exhaust air system, but reference facility information is not clear.) Vent air from the UO₂ transfer hopper is pre-filtered, HEPA-filtered and discharged to the normal access area atmosphere. Vent air from the UO₂ feed and weigh hoppers, the PuO₂ feed and weigh hoppers, the UO₂-PuO₂ feed and weigh hoppers and the blender is prefiltered, HEPA-filtered and discharged to the restricted access area atmosphere.

- Mixed Oxide Powder Storage

The exhaust air from each of nine pneumatic conveying systems is first filtered through a sintered metal filter and then discharges to the $\text{UO}_2\text{-PuO}_2$ pneumatic conveying system exhaust for further filtration.

- Compaction, Granulation, Pelletization, and Green Pellet Storage

The exhaust air from the three conveying systems follows the same path as the mixed oxide powder storage exhaust air. The vent air from the slug press and the pelletizing press is prefiltered, HEPA-filtered, and discharged to the dust collection system in the restricted access area. The dust collection system is assumed to be the atmosphere air recirculation system for the restricted access area since no description is available. The vent air from the granulator is prefiltered, HEPA-filtered, and discharged to the plant exhaust system.

- Sintering, Boat Conveyance and Pellet Storage

The forming gas from each of the five furnaces is filtered through a sintered metal filter, a prefilter, a HEPA filter and discharges to the plant exhaust system.

- Pellet Grinding, Inspection and Storage

Part of the vent air from the sludge dryer is prefiltered, HEPA-filtered, and discharged to the plant exhaust system; the other part is prefiltered, HEPA-filtered, and discharged to the atmosphere dust collection system for the restricted access area. The vent air from the pellet dryer is prefiltered, HEPA-filtered, and discharged to the restricted access area atmosphere.

- Rod Testing, Inspection, Storage and Shipping

The vent gas from the helium leak test chamber is prefiltered, HEPA-filtered, and discharged to the plant exhaust system.

- Clean Scrap Recovery

The reactor off gas from each of the two reduction-oxidation-reduction reactors is filtered through a sintered metal filter, a backup sintered

a prefilter, a HEPA filter and discharges to the plant exhaust system. All air exhausted from the manufacturing building passes through a minimum of two filters (assumed to be HEPA filters) before discharge to the environment.

To minimize and restrict radioactive contamination within the reference facility three zones of confinement are provided. The outer zone, the normal access area has the lowest potential for contamination and is the normal work area for personnel. Outside air is drawn in, filtered, humidified, either heated or cooled for human comfort, and distributed to the NAA. The second zone, the limited access zone areas, is used only for sampling and maintenance access to the third zone. The third zone, the restricted access area, includes glove box interiors, decontamination and repair cell interiors, process lines and powder fabrication equipment. These latter areas possess the highest level of potential contamination because of their direct exposure to plutonium and uranium. Air from the normal access areas is drawn into the limited access areas for ventilation purposes, and air from the limited access areas is drawn into the restricted access areas to remove process heat and humidity. Most of the air in each area is recirculated after filtration to lower the quantity of gaseous effluent released to the environs. Recirculation of air in the normal access area amounts to about 1.1×10^9 l/day (27,000 cfm), in the limited access area about 2.4×10^8 l/day (6,000 cfm), and in the restricted access area, about 2.9×10^8 l/day (7,000 cfm).

The interior normal access area is at a negative pressure relative to the outside. The limited access area is controlled at a more negative pressure, and the restricted access area has the lowest pressure. Thus, the air flows from a zone of lower contamination level to one of higher contamination level, thus directing the ventilation flow toward the zones with the more extensive treatment systems.

Exhaust ventilation consists of two parallel systems, each containing two HEPA filters in series. The two systems operate at 50% of rated capacity, so if one fails, the other can handle the exhaust from the entire facility.

The support systems airborne effluent control system is shown in Figure 10.B-6. The caustic gas scrubber scrubs out contaminants in the airborne releases from two fume hoods, various glovebox vents, oven and furnace off-gases from the miscellaneous waste treatment roasting glovebox, and an acid tank vent.

10.B.4 FACILITY AND SITE DESCRIPTION

This section summarizes the description of the site and the facility and its hardware. This information will be used as the primary basis for capital cost estimates, and as background for plant performance.

10.B.4.1 Site

The reference facility is assumed to lie on the 4.7 km² generic site described in Section 5.B. The facility itself (within the inner security fence) requires an area of 0.073 km² within the larger plant site.^(a) The facility layout assumes a well-labeled perimeter fence exists around the total site to exclude the public. Another fence surrounds the smaller facility area and includes a security entrance. The liquid effluents from the plant are assumed to be discharged onsite into the river that flows through the generic site.

10.B.4.2 Facility

The reference mixed oxide fuel fabrication facility is principally modeled after the proposed Westinghouse Recycle Fuels Plant.^(7,13) The reference facility is capable of producing mixed oxide BWR and PWR fuel rods at 400 MT (UO₂-PuO₂)/yr at fully expanded production. The reference facility is generally representative of currently proposed designs for commercial plants where mixed oxide pellets are fabricated using the mechanical (dry) blending process and Zircaloy-clad mixed oxide fuel rods are to be produced.^(4, p. 1)

^(a)Reference 13, p. 4.2-1.

HEATING, VENTILATING, AND AIR CONDITIONING SYSTEM

LIQUID EFFLUENT TREATMENT SYSTEM

VENT AIR FROM:

- POTENTIALLY CONTAMINATED SUMP TANKS
- POTENTIALLY CONTAMINATED TANK
- MOP WATER HOLD TANKS
- POTENTIALLY CONTAMINATED QUARANTINE TANKS
- DEACTIVATION FEED TANK
- DEACTIVATION PRODUCT TANK

VENT AIR FROM ACID SOLUTION HEAD TANK

ANALYTICAL SERVICES SYSTEM

EXHAUST AIR FROM TWO FUME HOODS

MISCELLANEOUS WASTE TREATMENT SYSTEM

VENT AIR FROM:

- PRECIPITATION TANK
- CHEMICAL ADDITION STORAGE TANK

OFF GAS FROM:

- OVEN
- FURNACE

GLOVEBOX OFF-GAS

LIQUID WASTE TREATMENT SYSTEM

VENT AIR FROM:

- SOLIDIFICATION FEED TANKS
- SOLIDIFICATION FEED HEAD TANK

OFF-GAS FROM THE CEMENT MIXER

DECONTAMINATION AND HOT CELL REPAIR SYSTEM

VENT AIR FROM:

- WATER TANK
- DETERGENT TANK

FIGURE 10.B-6. Process Flow Diagram - Airborne Effluent Treatment System for the Supporting Process for the Reference Mixed Oxide Fuel Fabrication Facility

The reference facility contains approximately 11,150 m² (120,000 ft²) of buildings area.^(15, p. 499) The permanent physical structures, including the buildings, parking lots, and roads occupy about 0.032 km² (8 acres); an access road requires about 0.02 km² (5 acres); and the landscaped area involving grass, shrubs, and trees occupies about 0.065 km² (16 acres).^(a)

The facility consists of a main manufacturing plant, an office arrangement, and conventional support and maintenance services as shown in Figure 10.B-7.^(b) The main structures associated with the fuel fabrication process are shown in Figures 10.B-8, 10.B-9 and 10.B-10^(c) and include four reinforced concrete buildings: the manufacturing building, the rod inspection building, the feed materials and personnel control building, and the electro-mechanical equipment building. The manufacturing building has a total floor area of 6466 m² (69,600 ft²) and is the only building that houses dispersible forms (i.e., nonpelletized PuO₂).^(d) Concrete thicknesses in the manufacturing building are (in cm): ground floor, 15.2; first floor, 20.3; ceiling, 50.8; and walls, 50.8. Concrete wall thicknesses in the other three main buildings are 30.5 cm. Common walls or air locks interconnect these four buildings.

The manufacturing building is a) basically an "L" shaped, two-level building; b) structurally separated from the other main buildings; and c) contains special nuclear materials storage, fuel blending and fabrication, waste treatment, laboratories, filter rooms, liquid effluent treatment, the physical isolated emergency power areas and emergency control center.^(e)

The rod inspection building is a single-level building.^(f) It contains facilities for cleaning tubes and for inspecting loaded, sealed fuel rods; offices; and a storage/shipping area.

(a) Reference 7, p. 4.3-1.

(b) Reference 13, Figure 4.2-1.

(c) Reference 13, Figures 4.4-1,2,3.

(d) Reference 13, p. 3.8-1.

(e) Reference 13, p. 3.1-4.

(f) Reference 13, p. 4.2-5.

FIGURE 10.B-7. Layout of the Reference Mixed Oxide Fuel Fabrication Facility

FIGURE 10.B-8. Floor Plan⁽³⁰⁾ for Basement of Reference UO₂-PuO₂ Manufacturing Building

^a REQUIRED PRODUCING 400 MT OF MIXED OXIDE/YEAR

FIGURE 10.B-9. Floor Plan (39) for First Floor of Reference UO₂-PuO₂ Manufacturing Building

^a REQUIRED FOR PRODUCING 400 MT OF MIXED OXIDE/YEAR

FIGURE 10.B-10. Floor Plan for Second Floor of Reference Mixed Oxide Manufacturing Building⁽¹³⁾

The feed materials and personnel control building is a rectangular two-level structure.^(a) The first floor contains rooms for personnel lockers, showers, medical-bioassay, health physics, personnel decontamination, a monitoring station, and an emergency control center. The second floor contains areas for the feed material truck dock and for storage of nonplutonium process materials.

The electro-mechanical equipment building houses electrical switchgear, mechanical equipment, shops and maintenance storage.^(b) It also provides an area (in filter room no. 1) for the intake air system. The cooling tower is outside, on the roof of the mechanical equipment room.

The administration building, a linear, two-story building, contains the administrative offices and warehousing, reception, and employee food service areas.^(c)

The forming gas facility consists of permanent cylinders for hydrogen, trailer-mounted hydrogen cylinders, and the cryogenic nitrogen supply tank.^(d)

The reference facility is expected to operate for 40 years.

The process area descriptions and major process equipment descriptions are summarized in Tables 10.B-1 and 10.B-2, respectively.

10.B.5 EFFLUENT CONTROL PERFORMANCE

The overall effluent control performance for radioactive material from the reference facility is indicated by the input/output information in Table 10.B-3. Approximately $1.5 \times 10^{-9}\%$ and $1.6 \times 10^{-8}\%$ of the uranium supplied to the reference facility are released in the airborne and liquid effluents, respectively. About $1.4 \times 10^{-8}\%$ and $1.6 \times 10^{-8}\%$ of the plutonium supplied to the reference facility are released in the airborne and liquid effluents, respectively. About 0.75% of the uranium and the plutonium supplied to the facility end up in the solid wastes.

(a) Reference 13, p. 4.2-5.

(b) Reference 13, p. 4.2-6.

(c) Reference 13, p. 4.2-4.

(d) Reference 13, p. 4.2-7

Process Area	Overall Dimensions, L x W x H, m	Perimeter Construction		Equipment Enclosures				
		Material	Description	No.(a)	Overall Dimensions, L x W x H, m	Description	Other Features	
Manufacturing Building								
Basement	31 x 17 x 5.5	Reinforced concrete walls	NA	(20 cm thick concrete roof slab, 30 cm thick concrete floor slab, 46 cm thick walls)				NA
Bagged, decontaminated equipment storage	23 x 17 x 5.5 (320 m ²)	NA	NA	(1)	L = 5.5, W = 1.5	NA	NA	
Liquid effluent treatment	16 x 9.1 x 5.5 (140 m ²)	NA	NA	(1)-2 (2)-1 (3)-1 (4)-1 (5)-4 (6)-1	L = 3.1, W = 1.2 L = 1.5, W = 1.2 L = 1.5, W = 0.61 Dia = 0.70 Dia = 1.5, H = 3.1 Dia = 0.61, H = 2.4	NA NA NA NA NA NA	NA	
Elevator machine room	3.1 x 2.4 x 5.5 (7.4 m ²)	NA	NA	NA	NA	NA	NA	
1st Floor	68 x 55 x 6.1 (3000 m ²)	Reinforced concrete walls	NA	(46 cm thick walls, 15 cm thick floor slabs)				NA
Fuel fab. area	18 x 12 x 6.1	8-12 gauge SS	NA	NA	NA	NA	NA	
Furnace area	21 x 12x 6.1	NA	NA	(1)-5	Dia = 1.5, H = 1.5	Electrically heated furnaces		
Hot repair	14 x 5.8 x 6.1	NA	NA	NA	NA	NA	NA	
Decontamination	5.5 x 4.9 x 6.1	NA	NA	NA	NA	NA	NA	
Emergency control center	11 x 7.6 x 6.1	NA	Shielded wall	NA	NA	NA	NA	
Lounge	7.6 x 2.7 x 6.1	NA	NA	NA	NA	NA	NA	
Rest rooms (2)	7.6 x 7.6 x 6.1	NA	NA	NA	NA	NA	NA	
Records storage	7.0 x 6.4 x 6.1 (32 m ²)	NA	NA	NA	NA	NA	NA	
Dark room	3.4 x 3.1 x 6.1 (10 m ²)	NA	NA	NA	NA	NA	NA	
Metal lab	12 x 6.4 x 6.1	NA	NA	(1)-1 (2)-2 (3)-3	2.7 x 0.91 x 1.8 1.8 x 1.2 x NA 1.2 x 0.61 x NA	Hood Glove boxes Glove boxes	NA	
Office	5.2 x 4.3 x 6.1	NA	NA	NA	NA	NA	NA	
ASF storage	4.3 x 3.4 x 6.1	NA	NA	NA	NA	NA	NA	
Mass spec. lab	14 x 6.1 x 6.1 (75 m ²)	NA	NA	(1)-1	1.2 x 0.91 x 1.2	Hood	NA	
Low level alpha lab	7.6 x 6.1 x 6.1	NA	NA	(1)-4 (2)-1	1.5 x 1.2 x 1.8 1.2 x 0.91 x NA	Hood Glove box	NA	
Radiochem lab	6.1 x 6.1 x 6.1	NA	NA	NA	NA	NA	NA	
Emission spec. lab	15 x 12 x 6.1	NA	NA	(1)-5 (2)-1	2.1 x 0.91 x NA 1.2 x 1.2 x NA	Glove boxes Glove box	NA	
Chem analysis lab	16 x 15 x 6.1	NA	NA	(1)-6 (2)-1 (3)-10 (4)-2 (5)-1	1.5 x 0.91 x 1.8 2.4 x 0.91 x 2.4 2.1 x 0.91 x NA 1.2 x 0.61 x NA 3.1 x 0.61 x NA	Hoods Hood Glove boxes Glove boxes Glove box	NA	
Fan room #2	18 x 6.7 x 6.1	NA	NA	NA	NA	NA	NA	
Fan room #3	9.1 x 6.7 x 6.1	NA	NA	NA	NA	NA	NA	
2nd Floor	68 x 55 x 6.1 (3000 m ²)	Reinforced concrete walls	NA	(46 cm thick walls, 20 cm thick floor slab)				NA
PuO ₂ storage	23 x 7.9 x 8.8	NA	NA	NA	NA	NA	NA	
Powder storage and scrap recovery	41 x 11 x 8.8	8-12 gauge SS	NA	NA	NA	NA	NA	
Lounge	9.1 x 7.6 x 5.8 (45 m ²)	NA	NA	NA	NA	NA	NA	
Rest rooms (2)	7.6 x 4.9 x 5.8	NA	NA	NA	NA	NA	NA	
Switch gear room	7.6 x 4.3 x 5.8	NA	NA	NA	NA	NA	NA	
Battery room	6.1 x 3.7 x 5.8	NA	NA	NA	NA	NA	NA	
Emergency generator rooms (2)	7.6 x 3.7 x 5.8 (each)	NA	NA	NA	NA	NA	NA	
Liquid waste drumming station	4.3 x 3.1 x 5.8	NA	NA	NA	NA	NA	NA	
Shielded office	4.3 x 3.1 x 5.8	NA	NA	NA	NA	NA	NA	
Miscellaneous waste treatment lab	31 x 18 x 5.8 (520 m ²)	NA	NA	NA	NA	Various pieces of equipment	NA	
Filter room #1	31 x 8.8 x 5.8	NA	NA	(1)-1 (2)-4 (3)-2	4.9 x 4.3 x NA 6.1 x 1.5 x NA (each) 1.5 x 0.61 x NA (each)	Spray chamber Filter enclosures	NA	
Filter room #2	31 x 8.8 x 5.8	NA	NA	Same as for Room # 1				NA
Feed Materials and Personnel Control Building								
1st Floor	41 x 39 x (4.9,6.1) (1200 m ²)	NA	NA	NA	NA	NA	NA	
Health physics room	16 x 7.6 x 6.1	NA	NA	NA	NA	NA	NA	
Emergency decontamination room	7.3 x 4.6 x 6.1	NA	NA	NA	NA	NA	NA	
Personnel air lock	7.3 x 3.1 x 6.1	NA	NA	NA	NA	NA	NA	
Monitor station	8.2 x 4.9 x 6.1	NA	NA	NA	NA	NA	NA	
Medical bioassay room	12 x 6.1 x 4.9	NA	NA	NA	NA	NA	NA	
Showers (2)	11 x 5.5 x 6.1 (each)	NA	NA	NA	NA	NA	NA	
Locker rooms (2)	19 x 8.8 x (4.9,6.1) (140 m ² each)	NA	NA	NA	NA	NA	NA	
Rest rooms (2)	5.5 x 3.7 x 4.9 (each)	NA	NA	NA	NA	NA	NA	
Change rooms (2)	5.5 x 3.7 x 4.9 (each)	NA	NA	NA	NA	NA	NA	
2nd Floor	40 x 24 x (5.8, 7.0)	NA	NA	NA	NA	NA	NA	
UO ₂ storage	15 x 8.2 x 5.8	NA	NA	NA	NA	NA	NA	
Cold chemical storage	16 x 8.2 x 5.8	NA	NA	NA	NA	NA	NA	
Equipment air lock	4.9 x 3.7 x 5.8	NA	NA	NA	NA	NA	NA	
Office	4.9 x 3.7 x 5.8	NA	NA	NA	NA	NA	NA	
Feed material receiving room	40 x 24 x (5.8,7.0) (670 m ²)	NA	NA	NA	NA	NA	NA	
Rod Inspection Building								
1st Floor	65 x 53 x 3.4 (1700 m ²)	NA	NA	NA	NA	NA	NA	
Truck dock	46 x 7.9 x 3.4	NA	NA	NA	NA	NA	NA	
Storage area	7.9 x 7.6 x 3.4	NA	NA	NA	NA	NA	NA	
Rod inspection room	57 x 23 x 3.4	NA	NA	(1)-28 (2)-1 (3)-3 (4)-2 (5)-1 (6)-1	NA 9.8 x 3.7 x 3.4 4.6 x 2.7 x 3.4 (each) 6.1 x 3.1 x 3.4 (each) 4.9 x 4.3 x 3.4 4.3 x 3.1 x 3.4	Various stations Rod storage Gage & x-ray rooms Rest rooms Fan room Office	NA	
2nd Floor	65 x 53 x 2.7 (1700 m ²)	NA	NA	NA	NA	NA	NA	
Observation gallery	65 x 7.6 x 2.7	NA	NA	NA	NA	NA	NA	
Upper rod inspection room	NA	NA	NA	NA	NA	NA	NA	
Electron-Mechanical Equipment Building								
1st Floor	45 x 29 x 6.1	NA	NA	NA	NA	NA	NA	
Electrical switchgear	29 x 17 x 6.1	NA	NA	NA	NA	NA	NA	
Mechanical equipment room	20 x 15 x 6.1	NA	NA	(1)-1	5.8 x 1.5 x NA	Secondary cooling water system area	NA	
Fan room #1	15 x 9.1 x 6.1	NA	NA	NA	NA	NA	NA	
Maintenance storage	14 x 12 x 6.1	NA	NA	NA	NA	NA	NA	
Garage	15 x 12 x 6.1	NA	NA	NA	NA	NA	NA	
2nd Floor	45 x 29 x 5.8 (some is roof)	NA	NA	NA	NA	NA	NA	
Shops	29 x 23 x 5.8	NA	NA	NA	NA	NA	NA	
Cooling tower	7.6 x 2.7 x NA	NA	NA	NA	NA	NA	NA	
Fresh air intake	6.7 x 2.7 x NA	NA	NA	NA	NA	NA	NA	
Administration Building								
1st Floor	62 x 52 x NA (880 m ²)	NA	NA	(1)-11 (2)-1 (3)-1	NA NA NA	Various rooms Kitchen Warehouse	NA	
2nd Floor	65 x 52 x NA (880 m ²)	NA	NA	(1)-17 (2)-1 (3)-1	NA NA NA	Various rooms Cafeteria Terrace	NA	

^(a)Numbers in () indicate types of enclosures and numbers following indicate quantity.
NA = Not available at this time.

TABLE 10.B-1. Major Process Area Descriptions -- Reference UO₂-PuO₂ Fuel Facility

Equipment	Location	No.	Size, m LxWxH (each)	Material	Others	Process Duty or Capacity (each)	Other Factors
<u>PuO₂ Unloading:</u>							
Glovebox enclosures	NA	NA	NA	NA	NA	NA	NA
Dolly for L-10 container	NA	NA	NA	NA	NA	NA	NA
Transfer piping between box & RAA	NA	NA	NA	NA	NA	NA	NA
<u>PuO₂ Storage:</u>							
PuO ₂ storage vessel	NA	3	NA	NA	NA	170 kg Pu	NA
Transfer Piping	NA	NA	NA	NA	NA	NA	NA
<u>Powder Blending & UO₂ Unloading:</u>							
UO ₂ drum weighing & dump station	Feed material receiving & storage	1	NA	NA	NA	NA	Can handle 208 liter drums
UO ₂ pneumatic conveyors	NA	NA	NA	NA	NA	NA	Air filtered - SMF (sintered metal filter)
UO ₂ transfer hoppers	NAA	1	NA	NA	NA	1.4 m ³	Dust-tight, remotely activated
Double sequencing isolation valve	At RAA barrier	1	NA	NA	NA	NA	Two valves in series
UO ₂ feed hopper	RAA	1	NA	Stainless Steel (SS)	NA	0.14 m ³	Dust-tight
UO ₂ rate feeder	RAA	1	NA		NA	NA	Two speed electric
UO ₂ weigh hopper	RAA	1	NA		NA	0.13 m ³	Dust-tight
PuO ₂ pneumatic conveyor	NA	NA	NA	SS	NA	NA	Air filtered - SMF
PuO ₂ feed hopper	RAA	1	8.9 cm dia	SS	NA	NA	Dust-tight
PuO ₂ rate feeder	RAA	1	NA	NA	NA	NA	Two speed electric
PuO ₂ weigh hopper	RAA	1	8.9 cm dia	SS	NA	NA	Dust-tight
Mixed-oxide (MOX) pneumatic conveyor	NA	NA	NA	NA	NA	NA	Air filtered - SMF
MOX feed hopper	RAA	1	20.3 cm dia	SS	NA	NA	Dust-tight
MOX rate feeder	RAA	1	NA	NA	NA	NA	Two speed electric
MOX weigh hopper	RAA	1	20.3 cm dia	SS	NA	NA	Dust-tight
“V” blender	RAA	1	NA	NA	NA	0.14 m ³ 225 kg	NA
<u>MOX Powder Storage:</u>							
Reduction mill	RAA	1	NA	NA	NA	NA	Pulverizing machine
MOX pneumatic conveyors	RAA	9	NA	NA	NA	NA	Air filtered - SMF
MOX powder sampler	RAA	1	NA	NA	NA	NA	NA
MOX storage silos	RAA	9	45.7 cm dia	SS	NA	0.14 m ³ 225 kg	Dust-tight
<u>Compaction, Granulation, Pelletization, Boat Loading and Green Pellet Storage:</u>							
Slug press	RAA	1	NA	NA	NA	NA	Motor driven, automatic press
Granulator	RAA	1	NA	NA	NA	NA	Motor driven, automatic press
Classifier	RAA	1	NA	SS	NA	NA	NA
Slug conveyor	RAA	1	NA	NA	NA	NA	Belt conveyor
Pneumatic granule conveyor	RAA	1	NA	NA	NA	NA	Pipe system
Pelletizing press	RAA	1	NA	NA	NA	NA	Automatic, motor driven
Pellet conveyor	RAA	1	NA	NA	NA	NA	Belt conveyor
Boat loader	RAA	1	NA	NA	NA	NA	NA
Pellet boats	NA	NA	22.9 cm x 22.9 cm x 7.6 cm	Molybdenum	NA	NA	NA
Green pellet boat stacking and retrieving machine	RAA	NA	NA	NA	NA	NA	NA
Green pellet storage unit	RAA	1	NA	NA	NA	675 kg	NA
<u>Sintering Furnace, Boat Conveyors and Pellet Storage:</u>							
Shuttle car 1	RAA	NA	NA	NA	NA	NA	NA
Sintering furnaces	RAA	5	NA	NA	NA	3 loaded pellet boats (150 kg MOX)	Molybdenum heating elements
Rejected pellet boat dumper	RAA	1	NA	NA	NA	1 pellet boat	NA
Sintered pellet boat stacking and retrieving machine	RAA	1	NA	NA	NA	1 pellet boat	NA
Sintered boat pellet storage	RAA	1	NA	NA	NA	135 loaded pellet boats	NA
<u>Pellet Grinding Inspection and Storage:</u>							
Bridge cane	RAA	1	NA	NA	NA	4545 kg	NA
Reclinear manipulator	RAA	1	NA	NA	NA	NA	NA
Boat transfer mechanism	RAA	5	NA	NA	NA	NA	NA
Boat unloaders	RAA	2	NA	NA	NA	NA	Transparent cover serves as dust containment
Pellet conveyor system	RAA	2	NA	NA	NA	NA	Centerless grinder
Pellet grinder	RAA	2	NA	NA	NA	NA	NA
Sludge collector and dryer	RAA	1	Settling tank max. width 8.9 cm	NA	NA	28 kg/day (MOX)	Mechanical device, checks pellet diameters
Dimensional inspection device	RAA	2	NA	NA	NA	NA	Mechanical device, checks pellet diameters
Nick inspection device	RAA	2	NA	NA	NA	NA	Optical scan
Tray loading device	RAA	2	NA	NA	NA	9.6 kg	NA
Trays	RAA	NA	NA	NA	NA	9.6 kg	Hot air dryer
Pellet dryer	RAA	2	NA	NA	NA	NA	NA
Pellet storage unit	RAA	2	NA	NA	NA	4000 kg MOX pellets	In glovebox
Moisture analysis	RAA	1	NA	NA	NA	1 pellet	NA
Pellet vacuum drying system	RAA	2	NA	NA	NA	NA	NA
<u>Receiving, Cleaning and Storage of Tubes, Plugs and Springs:</u>							
Tube storage racks	Rod insp bldg	NA	NA	NA	NA	17,000 PWR tubes (min)	NA
Top plug storage area	Rod insp bldg	NA	NA	NA	NA	1670	NA
Bottom plug storage area	Rod insp bldg	NA	NA	NA	NA	1730	NA
Bottom plug press	Rod insp bldg	1	NA	NA	NA	NA	NA
Bottom plug welder	Rod insp bldg	1	NA	NA	NA	NA	NA
Pre X-ray storage	Rod insp bldg	1	NA	NA	NA	250 tubes	NA
X-ray inspection	Rod insp bldg	1	NA	NA	NA	25 tubes	NA
Post X-ray storage	Rod insp bldg	1	NA	NA	NA	250 tubes	NA
Quality Check (QC) bottom plug weld inspection	Rod insp bldg	1	NA	NA	NA	NA	NA
Airlock and empty tube storage	Rod insp. manufac-turing bldg	NA	NA	NA	NA	1500 tubes	
Spring storage area	Rod insp bldg	NA	NA	NA	NA	19,200 (min)	NA
Rework storage area	NA	NA	NA	NA	NA	100 tubes & plugs	NA
<u>Fuel Rod Loading:</u>							
Loading station	RAA	2	NA	NA	NA	For combination of 1 loading, 1 decontamination and 1 spring loading and top plug press station 8 fuel rods - MOX at any one time	NA
Decontamination unit	RAA	2	NA	NA	NA	NA	NA
Spring loading and top plug press	RAA	1	NA	NA	NA	NA	NA
Plug welding station	RAA	1	NA	NA	NA	10-25 PWR rods	NA
<u>Rod Repair and Dismantling:</u>							
Depressurizing and end plug cut-off station	Glovebox in NAA	1	NA	NA	NA	10-25 PWR rods	NA
Spring removal and rod end ream station	Glovebox in NAA	1	NA	NA	NA	10-25 PWR rods	NA
Decontamination, spring insertion and top plug pressing station	Glovebox in NAA	1	NA	NA	NA	NA	NA
Girth weld station	Glovebox in NAA	1	NA	NA	NA	NA	NA
Helium pressurization and pressure welding station		1	NA	NA	NA	NA	NA
Pellet removal station	Glovebox in NAA	1	NA	NA	NA	NA	NA
Tube cut-up station	Glovebox in NAA	1	NA	NA	NA	NA	NA
<u>Rod Testing, Inspection, Storage and Shipping:</u>							
Air lock and preinspection storage	Manufacturing, rod insp bldg	1	NA	NA	NA	200 PWR rods	Shielded, pass-through air lock
Helium leak testing equipment	Rod insp bldg	1	NA	NA	NA	NA	2 vacuum chambers, vacuum pump, mass spec leak detector
Helium leak test storage area	NA	NA	NA	NA	NA	100 PWR rods	NA
Rod assay and gamma scan	Rod insp bldg	1	NA	NA	NA	NA	NA
Pre X-ray storage	Rod insp bldg	1	NA	NA	NA	100 PWR rods	Shielded enclosure
X-ray inspection	Rod insp bldg	1	NA	NA	NA	25 PWR rods	NA
Post X-ray storage	Rod insp bldg	1	NA	NA	NA	250 PWR rods	Shielded enclosure
Physical inspection and weighing	Rod insp bldg	1	NA	NA	NA	1 PWR rod at a time	Table, gauges, magnification, lens, scale
Rejected rod shielded carrier	Rod insp bldg	1	NA	NA	NA	50 PWR rods	Shielded
Shielded carriers	Rod insp bldg	1	NA	NA	NA	225 PWR rods	NA
Post inspection storage	Rod insp bldg	1	NA	NA	NA	250 PWR rods	Shielded
Inspected rod storage	Rod insp bldg	1	NA	NA	NA	20,000 PWR rods	Shielded enclosure
Inspected rod stacker	Rod insp bldg	1	NA	NA	NA	NA	4 compartments
Motorized transfer dolly	Rod insp bldg	1	NA	NA	NA	225 rod in box	NA
Bridge crane	Rod insp bldg	1	NA	NA	NA	9091 kg	NA
<u>Clean Scrap Recovery:</u>							
Collection containers	Various locations	NA	20.3 cm dia	NA	NA	NA	Lid closure, bottom valve
Roll crusher	RAA	1	NA	NA	NA	NA	Dust shroud around connection between collection container and crusher
Oxidation reactor	RAA	1	NA	Iconel	NA	20 kg	Sintered metal tilter
Reduction-oxidation-reduction reactors	RAA	2	NA	Iconel	NA	20 kg	SMF
Storage vessels	RAA	3	NA	NA	NA	720 kg	NA

TABLE 10.B-2. Major Process Equipment Descriptions - Reference UO₂-PuO₂ Fuel Fabrication Facility

TABLE 10.B-3. Overall Radioactive Materials Input/Output for Reference Mixed Oxide Fuel Fabrication Facility

Material	Total Material ^(a)		(U) or (Pu) ^(a) kg/day	Form Chemicals ⁽ⁱ⁾	Phase	Fraction of ^(b) Plant Input	
	kg/day	ℓ/day				U	Pu
<u>Input to Plant</u>							
Uranium Dioxide	1.1E3	1.1E3 ^(c)	930(U)	UO ₂	S	(1.0)	(1.0)
Plutonium Dioxide	50	15 ^(d)	44(Pu)	PuO ₂	S		
<u>Output from Plant</u>							
<u>Product Fuel Rods</u>							
PWR Fuel Rods {	{	1.4E3 ^{(e)(f)}	1.5E2 ^{(e)(g)}	923(U)	UO ₂ , UO ₂ -PuO ₂	S	(0.9925) (0.9773)
BWR Fuel Rods {		1.5E3 ^{(e)(f)}	1.6E2 ^{(e)(g)}	43(Pu)	PuO ₂ , UO ₂ -PuO ₂	S	
Airborne Effluents		NA ^(e)	1.3E9 ^(e)	1.4E-8(U)	UO ₂ , UO ₂ -PuO ₂	S	1.5E-11 1.5E-11
			6.5E-10(Pu)	PuO ₂ , UO ₂ -PuO ₂	S		
Liquid Effluents		NA ^(e)	7.8E4 ^(e)	1.5E-7(U)	NA	L	1.6E-10 1.6E-10
			6.9E-9(Pu)	NA	L		
Solid Wastes		NA ^(e)	7.0(U) ^(h)	UO ₂ , UO ₂ -PuO ₂	S	(7.5E-3)	(7.5E-3)
			3.3E-1(Pu) ^(h)	PuO ₂ , UO ₂ -PuO ₂	S		

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

- (a) Values based upon one day operating at 100% capacity.
(b) Numbers in parentheses are not released to the environment.
(c) Assumes density of UO₂ powder is 1.0 kg/ℓ.
(d) Assumes density of PuO₂ powder is 3.25 kg/ℓ.
(e) Value indicates total of radioactive and nonradioactive sources.
(f) This value consists of the weight of UO₂-PuO₂ (1096 kg/day) and weight of the fuel rod tubes.
(g) This value consists of the volume of UO₂-PuO₂ (105 ℓ/day) as part of the total volume of the fuel rods.
(h) This value includes dirty scrap stored onsite.
(i) For UO₂-PuO₂, assumes $\frac{\text{Pu}}{\text{U+Pu}} = 4.5\%$ by weight.

The overall input of nonradioactive materials, the output of nonradioactive airborne and liquid effluents, and solid wastes are given in Tables 10.B-4, 10.B-5, and 10.B-6, respectively.

A significant amount of additional information is required to complete these tables to determine the critical effluents. More information will also be required to determine the performance of the individual effluent treatment steps for the critical effluents.

Most of the information in this section is developed in Reference 13.

10.B.6 FACTORS FOR OPERATING COST INFORMATION

The basic plant operational requirements are presented to enable later estimation of direct operating costs.

10.B.6.1 Labor Requirements

The reference facility is assumed to operate 24 hr/day and 365 days/yr. The work force is assumed to include the following.^(7,13)

Management and professional ^(a)	76	(29%)
Nonmanagement and nonprofessional	<u>184</u>	(71%)
	260	

^(a) The ratio of management and professional to nonmanagement and nonprofessional staff members is based on information used for the reference uranium fuel fabrication facility (see Section 10.A.6.1).

Based on the data in GESMO,⁽¹²⁾ the total manpower need could be nearer to 280 than 260. The amount of this work force involved in effluent control operations is unknown.

10.B.6.2 Material Requirements

The routine material requirements for the facility consist of those materials given as inputs in Tables 10.B-3 and 10.B-4 and packaging materials for solid waste disposal. Miscellaneous materials such as office materials, office furniture, routine maintenance supplies, etc., are also required.

TABLE 10.B-4. Overall Nonradioactive Materials Input to the Reference Mixed Oxide Fuel Fabrication Facility

Material	Total Material (a)		Form		
	kg/day	lb/day	Chemical	Phase	Other
Fuel Rod Tubes	2.78E2	4.3E1	Zircaloy-4	S	Tubes
Fuel Rod Plugs	6.6	1.0	Zircaloy-4	S	Plugs
Fuel Rod Springs	6.4E-1	8.1E-2	304 SS	S	Springs
Helium	>4.4E-2	>2.7E1	He	L	Pressurized
Water	2.1E5	2.1E5	H ₂ O	L	NA
Fuel Oil	NA	NA	NA	L	NA
Die Lubricant	NA	1.9	NA	L	NA
Hydraulic Fluid	NA	NA	NA	L	NA
Forming Gas (N ₂ -H ₂)	NA	NA	N ₂ -H ₂	G	N ₂ -6.0Vol% H ₂
Nitrogen	>1.8E3	NA	N ₂	L	NA
Nitrogen	NA	NA	N ₂	G	Compressed
Hydrogen	>8.4	NA	H ₂	G	Compressed
Inert Gas	NA	NA	Ar/He	G	NA
Nitric Acid	NA	NA	HNO ₃	L	NA
Caustic	NA	NA	NaOH	L	NA
Caustic	NA	NA	NA	L	NA
Ammonium Hydroxide	NA	NA	NH ₄ OH	L	NA
Organic Solvents	NA	NA	NA	L	NA
Detergent	NA	NA	NA	L	NA
Nonflammable reagents	NA	NA	NA	L	NA
Ethyl Alcohol	NA	NA	NA	L	NA
Solvents	NA	NA	NA	L	NA
Degreasers	NA	NA	NA	L	NA
Cement	NA	NA	NA	S	NA
Butane	NA	NA	(CH ₃) ₂ (CH ₂) ₂	G	NA
Halon 1301	NA	NA	CBrF ₃	L	Compressed Gas
Gloves	NA	NA	NA	S	Neoprene, Butyl, PVC, Latex
Swabs	NA	776	NA	S	Rags and Paper
Wipes	NA		NA	S	
Cleaning Agents	NA		NA	L	
Varsol	NA		NA	L	NA
Acetone	NA		CH ₃ COCH ₃	L	NA
Felt Plugs	NA		NA	S	NA
End Caps	NA		NA	S	NA
Plastic Sheetting	NA		NA	S	NA
Plastic	NA		NA	S	Bags, Bottles, Tubing
Dessicant	NA		NA	S	NA
Cellulosic Gasketing	NA		NA	S	NA
DOP	NA		Diocetyl Phthalate (C ₆ H ₄ -1,2-[COO(CH ₂) ₇ CH ₃] ₂)	L	NA
Metallographic Mounts	NA		NA	S	NA
Grinding and Polishing Material	NA		NA	S	NA
Filter Elements	NA		NA	S	Air and Liquid Elements
Absorption Bed Cartridges	NA	NA	NA	S	NA
Blotter Paper	NA		NA	S	NA
Protective Clothing	NA		NA	S	NA
Hydrochloric Acid	NA		HCl	L	NA
Sulfuric Acid	NA		H ₂ SO ₄	L	NA
Steel Drums	NA		Steel	S	NA
Metal Containers and Boxes	NA		NA	S	NA

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

(a) Values based upon one day operating at 100% capacity for PWR fuels

TABLE 10.B-5. Overall Nonradioactive Airborne and Liquid Effluents from Reference Mixed Oxide Fuel Fabrication

Material	Form		Output ^(a)		Fraction of Plant Input
	Chemical	Phase	kg/day	l/day	
Airborne					
Sulfur Oxides	SO _x	G,L	1.1E-2	5.7E-3	(b)
Nitrogen Oxides	NO _x	G	0.10	7.0E-2	(b)
Nitrogen	N ₂	G	>1.8E3	1.5E6	~1
Hydrogen	H ₂	G	>8.4	9.3E4	~1
Helium	He	G	NA	NA	NA
Water	H ₂ O	G,L	1.3E5	1.3E5	.63
Hydrocarbons	H _x C _y	G	1.2	NA	NA
Liquids					
Phosphates	PO ₄ ⁻³	L,S	8.2E-2	NA	NA
Nitrate	NO ₃ ⁻¹	L,S	2.8	NA	NA
Sodium	NA ⁺¹	L	1.4	NA	NA
Chlorides	Cl ⁻	L	1.8E-2	NA	NA
Sulfates	SO ₄ ⁻²	L	6.2E-2	NA	NA

(a) Value based upon one day operating at 100% capacity for PWR fuels.

(b) This material does not enter the plant in this chemical form.

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

TABLE 10.B-6. Overall Solid Wastes from the Reference Mixed Oxide Fuel Fabrication Facility

Waste Material	Form	Package	Total ^(a)		U and/or Pu Content		
			l/day	kg/day	kg/day	Form	Fraction of Plant Input
<u>Pu and U Contaminated</u>							
Compactible Solid Waste	Plastics, paper, etc.	208 l drums	1.3E2	NA	2.5(U)	UO ₂	0.0027
					1.2E-1(Pu)	PuO ₂	0.0027
Noncompactible Solid Waste	Hardware, Equipment, etc.	208 l drums	7.4E1	NA	1.4(U)	UO ₂	0.0015
					6.5E-3(Pu)	PuO ₂	0.0015
Solidified Waste	Cement	208 l drums	3.8E1	NA	7.5E-1(U) 3.5E-2(Pu)	NA	0.0008 0.0008
Organic Liquid Plus Absorbent	Absorbent	208 l drums	NA	NA	NA	NA	NA
<u>Uncontaminated</u>							
Combustible	Shipping boxes, carboys	NA	NA	NA	--	--	--
Noncombustible	NA	NA	NA	NA	--	--	--
Zircaloy-4 Scrap	Metal	NA	2.1	1.3E-1	--	--	--
Stainless Steel Springs	Metal	NA	1.5E-3	1.2E-2	--	--	--

(a) Value based upon one day operating at 100% capacity for PWR fuels.

NA = Not available at this time

10.B.6.3 Unusual Maintenance Requirements

Some equipment will require replacement and/or major repairs fairly often where the service is relatively severe. It is estimated that most of the equipment will last 15 years or more. Some items (such as conveyor systems, transfer equipment, and combustible waste incinerator) are assumed to last about 10 years and other items such as mills and screens are assumed to last only 5 years. All HEPA and prefilters are assumed to be replaced once every year.

10.B.6.4 Utility Requirements

Total estimated utility requirements for each day of operation at 100% capacity are:

Water	212,000 kg/day
Electricity	2,740 kW-day/day

10.B.6.5 Transportation Requirements

All plant input materials listed in Tables 10.B-3 and 10.B-4 and plant output materials, such as finished fuel assemblies and solid wastes, must be transported to or from the facility. Typical transport distances are not within the scope of this report.

10.B.6.6 Waste Disposal Requirements

The solid wastes listed in Table 10.B-6 must be removed for ultimate deposition. The uranium and plutonium contaminated materials are assumed to be disposed of at an authorized repository for radioactive wastes, while nonradioactive wastes are to be taken to a nearby landfill.

10.B.6.7 Other Operating Cost Elements

Other major operating cost elements are those tasks performed by outside contractors. Since the reference facility has no laundry unit, this service is assumed to be contracted. The quantity of this laundry is unknown at this time. Other activities already identified are assumed to be performed through contractors: transportation of materials and disposal of radioactive and nonradioactive wastes.

Other known special operating cost elements are licensing and insuring the operation of such a nuclear materials processing facility.

10.B.7 ENVIRONMENTAL IMPACT FACTORS

The overall direct environmental impact factors for the reference facility are summarized in Table 10.B-7.

TABLE 10.B-7. Overall Environmental Impacts - Reference Mixed Oxide Fuel Fabrication Facility

	<u>Quantity</u>	<u>Remarks</u>
Total Land Committed	4.7 km ²	Fenced in area
Land Actually Used for Facility	0.073 km ²	High-security area
Water Used	2.1E5 kg/day	
Water Discharged as Liquid Effluent	7.8E4 kg/day	
Total Materials Added to Liquid Effluents	~5 kg/day	
Air Used	1.7E6 kg/day	1.3E9 l/day
Water Discharged as Airborne Effluent	1.3E5 kg/day	
Total Other Airborne Effluents	~3.0E3 kg/day	
Electrical Energy Consumption	2.7E3 kW-day/day	
Thermal Effluent Equivalent	NA	
Resource Use	See Table 10.B-4	

NA - Not available at this time

These quantities are those used directly at the plant. Impact of resources required for material input or output beyond the plant boundary are not included.

10.B.8 LIMITATIONS AND UNCERTAINTIES IN THE STUDY INFORMATION

Detailed information on a large plant designed to fabricate PWR and BWR mixed oxide fuel is not publicly available. Much of the information that is missing in previous tables and descriptions is not available directly. Some of this information can be developed or extrapolated from available existing information, but information gaps will still exist. Much of the information on effluents and wastes as well as some process step descriptions is not well known to the public. There is also a scarcity of data on the chemical forms of effluents available in the literature.

Since much of the information presented is from estimates from one applicant's reports, there is uncertainty as to the final numbers when a plant is completely designed and operating.

10.B.9 RESEARCH AND DEVELOPMENT NEEDS

More detailed information on large scale mixed oxide fuel fabrication facilities is needed. In particular, details are needed on the facility, the processes, wastes and effluents. Facility information is needed to provide a better basis for cost estimation. Process information is needed to reliably estimate the input to the effluent control processes and to estimate the effluent control performance. Information such as quantities, physical forms, and chemical forms is needed to characterize the wastes and effluents as well as to aid in determination of effluent control performance.

Confirmatory data as to the generation rate of particulates of radioactive materials (such as plutonium) from mixed oxide plants is needed because present information is derived largely from observations in enriched uranium fuel fabrication facilities.⁽⁴⁾ These data are needed because plutonium radionuclides account for about 95% of the radiation dose by inhalation of mixed oxide dusts.

More experimental information from large installations that use systems of HEPA and other filters in series would be useful in determining effluent control performance.

SECTION 10: REFERENCES

1. Environmental Evaluation for Westinghouse Nuclear Fuel Division, Columbia, South Carolina, Westinghouse Electric Corporation, March 1975. [W NFCS].
2. Nuclear Industry, 21:42-43, September 1974. (The plant was operating at 700-800 tons/yr; had a nominal capacity of 1000 tons/yr, but had not yet achieved that; and has a planned eventual capacity of 1000-1500 tons/yr.)
3. W. H. Pechin, et al., Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low As Practicable" Guides - Fabrication of Light-Water Reactor Fuel from Enriched Uranium Dioxide, US AEC Report ORNL-TM-4902 , p. 11, May 1975.
4. W. S. Groenier, et al., Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "As Low As Practicable" Guides - Fabrication of Light-Water Reactor Fuels Containing Plutonium, US AEC Report ORNL-TM-4904, Oak Ridge, Tennessee, p. 24, May 1975.
5. Alternatives for Managing Wastes from Reactors and Post Fission Operations in the LWR Fuel Cycle, Energy Research and Development Administration, Report ERDA-76-43, April 1976.
6. Environmental Survey of the Uranium Fuel Cycle, WASH-1248, U.S. Atomic Energy Commission, Fuels and Materials, Directorate of Licensing, April 1974.
7. Westinghouse Recycle Fuels Plant Environmental Report, (WRFP, ER), 1-3:3.8-1, July 1973.
8. L. D. Smith, "Columbia Fuel Manufacturing Plant", Nuclear Engineering International, 15(172)817-821, October 1970.
9. "Industrial Notes - Where Does the B&W PWR Stand Now", Nuclear Engineering International, pp. 586-587, July 1971.
10. General Electric Company, Environmental Report, General Electric Nuclear Facility, Wilmington, North Carolina, Report NED0-20197, Docket 70-01113, January 1974.
11. "Nuclear-Fuel Suppliers Build for Peak Demand", Electrical World, pp. 60-61, November 15, 1970.
12. Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Reactors, US NRC Report NUREG-0002, August 1976.

13. Westinghouse Electric Company, Nuclear Fuels Division, Westinghouse Recycle Fuels Plant License Application, (W RFP, LA), Docket Numbers 701432-1 -2, -3, and -4, July 1973.
14. Proposed Final Environmental Statement, Liquid Metal Fast Breeder Reactor Program, WASH-1535, US AEC, Volume 2, December 1974.
15. "Industrial Notes: Westinghouse Recycle Fuels Plant", Nuclear Engineering International, Volume 18, July 1973.

11.0 LIGHT WATER REACTORS

Two reference light water reactor facilities are described: a pressurized water reactor (PWR) in Section 11.A, and a boiling water reactor (BWR) in Section 11.B.

11.A PRESSURIZED WATER REACTOR

A reference pressurized water reactor (PWR) facility representative of current technology for commercial scale facilities was chosen for this study. The reference PWR is based primarily on Portland General Electric Company's Trojan Nuclear Plant.⁽¹⁻⁵⁾ This facility is located 7.2 km (4.5 miles) upstream from Rainier, Oregon on the Columbia River.

The overall characteristics of the reference PWR facility include the following:

- One facility, one feed (slightly enriched uranium as UO_2 in fuel assemblies), and two basic products (electrical energy and spent fuel assemblies).
- A single reference PWR capable of a net electrical capacity of 1130 MWe is assumed.
- The facility receives the fuel assemblies made from enriched natural uranium, uses the fuel assemblies in the reactor core to heat water to produce steam, generates electricity using the steam produced, and stores spent fuel assemblies before shipping to the reference fuel reprocessing facility.
- The facility is assumed to operate 292 days/yr and 24 hr/day for 40 years.

11.A.1 SUMMARY

The reference pressurized water reactor facility produces 1178 MW (gross) and 1130 MW (net) of electricity at a nominal full reactor core power of 3411 Mwt.

The reactor core is composed of 193 fuel assemblies that contain 264 UO_2 rods per assembly. A total of 101,033 kg (222,739 lb) of slightly enriched UO_2 is in the core in the form of ceramic pellets housed in slightly cold-worked Zircaloy-4 tubes from the reference uranium fuel fabrication plant.

The reactor core is the ultimate source of radioactive effluents and wastes that are discharged from the facility. A total of about 47.5 M ℓ /day of liquid effluents are discharged from the plant. These effluents contain maximum amounts of about 7300 kg/day of chemical contaminants and also about 3.5 Ci/day of radionuclides including tritium. The airborne effluents total about 47 billion ℓ /day and represent the principal release mechanism for radioactive noble gases. These noble gases constitute about 94% of the airborne radioactivity in Curies, and exit the plant at the average rate of about 17 Ci/day. In addition, 1.0 Ci/day of ^3H (tritium) and ^{14}C combined are released in the airborne effluents. The total liquid and gaseous radionuclide releases contain only a small portion (<1%) of the total Curie content of radionuclides that are produced in the core. The major amounts of radionuclides remain with the spent fuel which is shipped offsite.

Contaminated solid wastes, shipped offsite for burial, amount to just over 270 ℓ /day.

Nonradioactive airborne effluents in the form of water evaporation and drift are ejected from the cooling tower to the atmosphere at a heat rejection rate of 2.3 M thermal kW-hr/hr.

The plant employs 210 persons, and the facilities occupy a total of 0.08 km^2 of the 4.7 km^2 generic site.⁽²⁾ Utilities required for plant operation include 158 M kg of make-up water/day and 40,000 kW-days of electricity/day.

11.A.2 MAINLINE PROCESS DESCRIPTION OF THE REFERENCE PWR FACILITY

The reference pressurized water reactor facility receives slightly enriched uranium fuel assemblies and uses these fuel assemblies to sustain a controlled nuclear fission reaction. The heat produced by the nuclear fission reaction is removed from the reactor core through a pressurized water system. The pressurized hot water transfers heat through a heat exchanger to boil water in a secondary water system. The steam produced in the secondary water system is passed through a turbine that drives a generator to produce electricity. All other processes are auxiliary to this main process.

An overall process flow diagram for the reference PWR is shown in Figure 11.A-1. Each portion of this process is described in the sections that follow.

11.A.2.1 Description of Mainline Process Steps

The following sections discuss the major process steps:

- New Fuel Storage and Handling

Figure 11.A-2 is a simplified diagram of the major steps in new fuel storage and handling. This system provides a way to store, transport and handle nuclear fuel from the time it reaches the facility in an unirradiated condition until it is loaded into the reactor. The new fuel assemblies are received, unloaded and stored dry in the fuel storage facility, which can store 1/3 of the reactor core fuel assemblies and control rods in a subcritical array so that a k_{eff} (effective neutron multiplication constant) of less than 0.95 is maintained. During refueling operations the fuel assemblies are transferred from the storage facility and loaded into the reactor.

- Reactor Cooling

Figure 11.A-3 gives an overview of the reactor primary coolant flow. The cooling system consists of four similar heat transfer loops connected in parallel to the reactor pressure vessel. Each loop

FIGURE 11.A-1. Overall Process Flow Diagram for the Reference Pressurized Water Reactor Facility

contains a reactor primary coolant pump, steam generator and associated piping and valves. The system also includes a pressurizer, a pressurizer relief tank, interconnecting piping and instrumentation necessary for operational control. The entire cooling system is located in the containment building.

FIGURE 11.A-2. New Fuel Storage for Reference Pressurized Water Reactor Facility

FIGURE 11.A-3. Reactor Primary Coolant System Overall Flow Diagram (Typical Except Pressurizer System for Four Loops)

During operation, the reactor cooling system transfers the heat generated in the core to the steam generators where steam is produced to drive the turbine generator. Borated demineralized water circulates in the reactor cooling system at a flow rate and temperature consistent with achieving the reactor core thermal-hydraulic performance. The water also acts as a neutron moderator and reflector and as a solvent for the neutron absorber used to aid in control of the nuclear reactions.

The primary cooling system is contained independently to provide a barrier against the release of radioactivity generated within the reactor.

Reactor cooling system pressure is controlled by using the pressurizer. Here water and steam are maintained in equilibrium by electrical heaters or water sprays. Steam can be formed by the heaters or condensed by the water spray to minimize pressure variations due to contraction and expansion of the reactor coolant. Spring-loaded safety valves and power-operated relief valves are mounted on the pressurizer and discharged to the pressure relief tank, where any steam discharged from overpressurization is condensed and cooled by mixing with water.

The reactor cooling system is composed of:

- the reactor vessel, including control rod drive mechanism housings
- the reactor coolant side of the steam generators
- reactor coolant pumps
- a pressurizer attached to one of the four reactor coolant loops
- safety and relief valves
- the interconnecting piping, valves and fittings between the principal components listed above
- the piping, fittings and valves that lead to connecting auxiliary or support systems up to and including the second isolation valve (from the high pressure side) on each line.

- Steam and Power Conversion

Figure 11.A-4 is a simplified flow diagram for steam and power conversion. Steam from each of the four steam generators is carried in a separate carbon steel pipe through a flowmeter, three flow control valves and then to the high-pressure turbine.

Steam leaving the high-pressure turbine passes through moisture separator reheaters and combined intermediate stop and intercept valves to the inlets of the three low-pressure turbines. After passing through the low-pressure turbines, the expanded steam discharges to the main condenser beneath the turbines. From there the condensate is pumped through the feedwater heaters and then back to the steam generators.

Steam is supplied to the turbines of the steam generator feedwater pumps, the single stage reheat of the moisture separator reheaters, the turbine gland sealing system, and the auxiliary system.

FIGURE 11.A-4. Overall Flow Diagram of Steam and Power Conversion for Reference Pressurized Water Reactor Facility

- Chemical and Volume Control for Primary Coolant

Figure 11.A-5 shows the chemical and volume control system process flow.

The chemical and volume control system maintains the coolant inventory in the reactor cooling system within the allowable pressurizer level range for all normal modes of operation including startup from cold shutdown, full power operation and plant cooldown. This system also has sufficient makeup water capacity to maintain the minimum required inventory in the event of minor reactor cooling system leaks.

The filter and demineralizer units in the system remove fission products, activation products, and corrosion products from the reactor coolant during reactor operation. The system can also remove excess lithium from the reactor coolant, keeping the lithium concentration within the desired limit for pH control.

FIGURE 11.A-5. Chemical and Volume Control Diagram for Primary Coolant System in Reference Pressurized Water Reactor Facility

The system regulates the concentration of chemical neutron absorber (boric acid) in the reactor coolant to control reactivity changes that result from the change in reactor coolant temperature between cold shutdown and hot full-power operation, burnup of fuel and burnable poisons, and xenon transients. The system can add boric acid through either one of two flow paths and from either one of two boric acid sources.

- Spent Fuel Storage and Handling

Figure 11.A-6 shows a simplified diagram of the spent fuel storage and handling process. This involves under-water storage, transport and handling of spent nuclear fuel from the time it is removed from the reactor until it is shipped from the facility after postirradiation cooling. Shipping is to a reprocessing plant in this study, but could also be to a spent fuel repository.

From the reactor, the spent fuel is transferred to the spent fuel storage area, which is designed to prevent fuel assembly damage and/or potential fission release under normal and postulated accident conditions.

FIGURE 11.A-6. Diagram of Spent Fuel Storage and Handling for the Reference Pressurized Water Reactor Facility

The system provides confinement of contaminants and filtration of water in the storage area. The spent fuel pool cooling and cleanup system removes the decay heat from the spent fuel elements in the spent fuel pool and purifies the system water inventory continuously. The decay heat is removed by circulating the pool water through heat exchangers. Purification is accomplished by a demineralizer and filter.

11.A.2.2 Waste Management

The PWR facility generates radioactive and nonradioactive solid wastes.

Nonradioactive solid wastes are generated by the supporting activities of the PWR facility. They originate in offices, lunch rooms, nonradioactive shops, and receiving terminals and include paper, rags, grease, oil, used crating lumber, packing boxes, packing materials, worn-out equipment pieces, damaged stock items, etc. Local waste disposal contractors collect and haul the materials away for salvage or deposit in approved landfill sites.

The radioactive solid waste system provides for storage and processing for disposal of radioactive solid wastes generated by reactor plant operation and maintenance. The wastes are packaged at this facility and shipped offsite for disposal at an authorized site. The solid waste system receives the following input streams for processing and disposal:

- spent demineralizer resins that have been used to process potentially radioactive liquid,
- concentrated evaporator bottoms from the clean radioactive effluent evaporator and two chemical volume control system boric acid evaporators,
- expended filter cartridges that have been used to process potentially radioactive liquid, and
- miscellaneous solid wastes that are potentially contaminated, such as rags and clothing, sampling planchets and swipe paper, expended ventilation filters and other wastes.

Unacceptable demineralizer effluent water quality indicates depletion of potentially radioactive demineralizer resins. Transfer of resins from these demineralizer vessels to the spent resin storage tank is effected by

resin slurry flow using primary makeup water. The resin is then solidified using a solidifying agent and catalyst. The resin is solidified along with the evaporator concentrates in 1416 ℓ (50 ft³) containers.

Effluent evaporator concentrates from the clean radioactive effluent evaporator are pumped in solution by the evaporator concentrate pumps to the waste concentrate holding tanks. The waste is pumped as generated, at a concentration necessary for proper evaporator operation. Should the radioactivity of concentrated boric acid from the chemical volume control system boric acid evaporators exceed 0.01 $\mu\text{Ci/g}$, it is rejected to the waste concentrate holding tanks also. These wastes are solidified as described above.

Filters are replaced when filters become clogged or when radioactivity levels reach limiting values for shielding design. Filters are either incorporated with the resins and evaporator concentrates when they are solidified or they are baled into 208 ℓ (55 gal) drums.

Miscellaneous solid wastes potentially containing low levels of radioactive contamination are collected in polyethylene or similar type containers. These wastes are stored in interim low-level storage areas until they are processed by the solid waste hydraulic baler. These wastes are compressed by the baler into 208 ℓ (55 gal) drums.

Figure 11.A-7 summarizes waste management activities at the reference PWR facility.

FIGURE 11.A-7. Overall Waste Management Operations for the Reference Pressurized Water Reactor Facility

11.A.3 EFFLUENT CONTROL PROCESS DESCRIPTIONS

Control of emissions of radionuclides (from fuel leaks into and neutron activation of the reactor cooling system) and emissions of chemicals such as sulfates, chlorine and sodium, must be done to limit effluents to acceptable amounts. These materials enter the environment via the liquid and airborne effluent systems, while excess heat is discharged through the heat dissipation system.

11.A.3.1 Liquid Effluents

Liquid effluents in the reference PWR are divided into three categories: clean, dirty, and chemical. Clean effluents (such as reactor coolant, spent-fuel pool water, equipment drains, or resin transfer sluice water) are those that may have important concentrations of radioactivity or chemicals but are generally low in particulates. Dirty effluents (such as those from floor drains) are those that usually are high in particulate content but low in concentration of chemicals and radioactivity. The dirty radioactive effluent treatment system also receives overflows and relief valve discharges from the clean radioactive effluent treatment system. Chemical effluents are

nonradioactive effluents (such as from the circulating water system) that may contain important quantities of nonradioactive chemicals.

Liquids containing radioactive materials that are releasable to the environment are piped to the discharge and dilution structure before discharge to the river. Table 11.A-1 lists the flows associated with radioactive liquid effluents.

- Clean Radioactive Effluent Treatment System

The clean radioactive effluent treatment system (Figure 11.A-8) is designed to process effluent with a radioactivity level assuming 1% of the fuel develops leaks. Liquid effluents from several sources are piped to this system for processing. One source is reactor coolant letdown and assorted drains that empty into the reactor coolant drain tank located within the containment. From there the liquid is pumped, with the liquid collected in the auxiliary building drain tank, through a filter to the clean effluent receiver tanks. Here it joins liquid from the chemical drain tanks, primary water-storage overflow, fuel pool overflow, and other assorted drains, and is pumped through the clean effluent filter to remove particulates and then into the effluent evaporator where it is concentrated on a batch basis.

TABLE 11.A-1. Clean and Dirty Liquid Radioactive Effluent Treatment Systems in Reference Pressurized Water Reactor Plant

System	Source	Influent L/day	Influent Isotope Concentration
Clean Radioactive Effluent System	Auxiliary Building Sump	760	0.1 x PCA ^(a)
	Containment Sump	150	1 x PCA
	Sample Drains	130	1 x PCA
	Miscellaneous	760	0.01 x PCA
	Total	1800	0.204 μ Ci/g
Dirty Radioactive Effluent System	Decontamination and Showers	950	
	Lab Drains	1510	0.002 x PCA
	Miscellaneous	1890	0.01 x PCA
	Total	3400 ^(b)	0.00644 μ Ci/g

(a) PCA = Primary Coolant Activity

(b) Excludes decontamination solutions and shower water

The evaporator bottoms containing the concentrated chemicals and radioactive materials discharge to the concentrate tank and are ultimately pumped to the solid waste system. The evaporator distillate passes through one or two clean effluent monitor tanks. After one tank is filled, it is isolated for analysis and possible reuse, discharge or further processing; and the second tank is placed in service. If analysis indicates the condensate is acceptable, it can be pumped either to the primary water storage tank for reuse or pumped to the plant liquid effluent discharge to the river. If the condensate is not acceptable for discharge or recycle, it can be returned to the clean effluent receiver tanks for further decay and/or additional processing. The clean radioactive effluent system is also designed to process certain secondary coolant system effluents such as steam generator blowdown if a primary-to-secondary coolant leak occurs in a steam generator.

- Dirty Radioactive Effluent Treatment System

The dirty radioactive effluent treatment system (Figure 11.A-9) processes effluents with low radioactivity concentrations and significant nonradioactive particulate material (dirt). Liquids from various sumps collect in the dirty effluent drain tanks, are filtered to remove particulates, and are collected in the dirty effluent monitor tanks. The monitor tank is divided to provide two independent tanks. When one side is filled, it is isolated for analysis and the other tank placed in service. If analysis indicates that the liquid is acceptable for dilution and discharge to the environment, it is pumped to the plant liquid effluent discharge line. If the radioactivity or chemical concentration is too high for discharge, the liquid is transferred to the clean effluent receiver tanks for additional processing.

FIGURE 11.A-9. Flow Diagram - Dirty Radioactive Effluent Treatment System for the Reference Pressurized Water Reactor

- Chemical Effluent System

River water in the reference PWR is used principally in the cooling systems. Small amounts of neutralizing and inhibiting chemicals are used in these cooling systems to control clogging of equipment with scale, sediment and organic growths.

The plant design incorporates, as much as practicable, the closed system approach, which ensures that the water in the system is reused continuously and, therefore, fewer chemical additives are required. The chemical additives required for treating the circulating water systems include sulfuric acid to overcome the scaling properties of the river water and chlorine to reduce biological fouling, such as from algae slimes.

Chlorine can be injected into the cooling system at two points: 1) the intake structure downstream of the traveling screens, and 2) downstream of the cooling tower circulating water lines. During normal plant operation, gaseous chlorine is injected in slug amounts [approximately 172 kg (380 lb) per injection] which are timed to occur every 24 hours, resulting in a concentration of 1.5 ppm chlorine in the circulating water system for a few hours each day. No residual chlorine

in excess of 0.05 ppm is discharged to the river. If the free chlorine exceeds this concentration, sodium bisulfite is added to the effluent stream to reduce the chlorine concentration by chemical reaction. The sodium bisulfite injection takes place in the discharge and dilution structure.

Sulfuric acid is injected into the circulating water to neutralize alkalinity of the river water. When released, it is in the same form as the naturally occurring sodium, calcium, or magnesium sulfates in the river that are considered harmless. The pH of the discharge will be essentially neutral. The chemicals contained in the blowdown stream are further diluted by the time they reach the surface of the river.

Liquid effluents from the plant's makeup and drainage systems are handled in one of two ways. If the effluents indicate a pH below 6.5 or above 8.5, they are discharged first to the neutralizing tank where the pH is adjusted to the correct range. If the effluent indicates a pH between 6.5 and 8.5, it is discharged to the dilution structure.

The following effluent streams contribute to the discharge system:

- drain desludge and overflow from clarifier,
- overflow and drain from condensate storage tank,
- discharge from blowdown tank,
- storm drain from reactor building area,
- drain from chemical tank area,
- storm drain from diesel oil tank area, and
- drain from the cooling tower and blowdown.

These effluents are monitored, diluted with river water, and then discharged to the river through the outfall structure.

Figure 11.A-10 presents an overall plant water use diagram.

11.A.3.2 Airborne Effluents

The principal sources of gas received by the radioactive airborne effluent system (Figure 11.A-11) are: cover gas displaced from the chemical volume control system (CVCS) holdup tanks during normal operation, and air displaced

FIGURE 11.A-10. Chemical and Water Flow Diagram - Reference Pressurized Water Reactor Facility

FIGURE 11.A-11. Overall Process Flow Diagram - Radioactive Airborne Effluent System for Reference Pressurized Water Reactor Facility

from the radioactive liquid effluent tanks as they are filled with liquid and from degasification of the primary system for refueling. Since the cover gas must be replaced when the CVCS tanks are emptied, facilities are provided to recycle the gas that was collected and stored to minimize releases. The gases from tanks using nitrogen as a cover and from those containing liquids with hydrogen are kept separate from tanks and equipment that contain air or aerated liquids.

- Gas Collection Header

The gas displaced in the CVCS holdup tanks and discharged from the gas strippers passes through the gas collection header and is collected in the effluent gas surge tank. The plant operator then can select the effluent gas decay tank to be used for storing the compressed gas and a backup tank. Generally, the last tank to receive gas is used to return gas to the CVCS tanks. This permits stored gas to decay for discharge without adding additional radioactivity. A minimum decay period of 45 days is available, in addition to the decay that takes place during filling (approximately 60 days during normal operations). This is achieved by isolating the tank from the system and allowing the gas to decay without radioactivity being added. Gas vented to the atmosphere from the gas decay tanks discharges through high-efficiency filters to the auxiliary building vent.

- Vent Collection Header

The vents from the tanks and equipment containing air or aerated liquids discharge into the vent collection header. These vent gases are routed through a HEPA filter to the auxiliary building vent without any holdup provisions. The equipment and tanks that vent into this header contain liquids with no appreciable content of volatile materials.

- Other Effluent Release Points

Release points exist in various plant systems that have the potential for discharging radioactive noble gases, radioactive iodine, and radioactive material in particulate form. These potential release points, some of which do not constitute gas processing systems, can discharge

effluents with gaseous contamination resulting either from reactor cooling system leakage or from primary-to-secondary steam generator leakage.

The containment purge exhaust removes potentially contaminated gases from within the containment and exhausts the gases to the environs through the containment building roof vent. Exhaust flow is created by two fans, each rated for 708 m³/min (25,000 cfm) flow, which evacuate the containment through a common prefilter and HEPA filter.

The fuel and auxiliary building ventilation exhaust provides ventilation exhaust flow for all building structures housing reactor coolant and reactor auxiliary system components outside the containment. These components represent potential sources for the release of gaseous and particulate activities and are (in addition to the drainage sumps, tanks, and equipment) purged by the vent collection or gas collection headers. The exhaust is directed to the top of the containment building before environmental release.

A portion of the total fuel building ventilation air is drawn from spaces that contain CVCS equipment located between the reactor cooling system and the letdown heat exchanger. This is the only equipment outside the containment that processes thermally hot, unpurified reactor coolant and presents an increased airborne radioactivity potential. Ventilation exhaust from these spaces is drawn by a separate booster fan through a filtration unit consisting of a prefilter, HEPA filter, deep bed charcoal filter, and after HEPA filter. The exhaust is then directed to normal building exhaust plenums.

The condenser air ejector exhaust provides a discharge path to the environs for radioactive noncondensable gases and particulates in air evacuated from the condenser during plant startup and normal plant operation. It also provides a discharge path for the steam generator blowdown tank vent. Three air ejectors are used during startup to establish system vacuum and to discharge the working steam and entrained air to the environs at a point above the turbine building roof.

Two two-stage air ejectors, one of which will normally operate, evacuate noncondensable gases from the condenser during normal operation. The gases, along with any noncondensed steam, are released to the environs at a point above the turbine building roof. A filtration unit in the exhaust piping consists of a prefilter, HEPA filter, deep bed charcoal filter, final HEPA filter and exhaust booster fan. This equipment is bypassed unless steam generator tube leakage exists.

The steam packing exhaust blower discharge provides a release path to the environs for potentially radioactive materials in the gland exhaust from the high-pressure and three low-pressure turbine gland seals. The system discharges to a release point above the turbine building roof.

The turbine building ventilation exhaust provides a release path to the environs for potentially radioactive gaseous and air particulate activity generated by steam leakage, equipment vents, packing leakage, and other secondary system losses within the turbine building. The turbine building volume is exhausted by a 31,500 m³/min (1,111,500 cfm) continuous low profile gravity vent directed out the turbine building roof vent.

Table 11.A-2 lists the air flows from the environmental release points for airborne effluents which are shown on a site plot plan in Figure 11.A-12 and on an elevational plan in Figure 11.A-13.

TABLE 11.A-2. Total Air Flow from each Airborne Effluent Discharge Point in the Reference Pressurized Water Reactor Plant

<u>Release Point</u>	<u>Air Flow (m³/d)</u>
Gas Collection Header	<1.0E3
Vent Collection Header	4.1E3
Fuel and Auxiliary Building Vent Exhaust	~4.3E6
Containment Purge Exhaust	2.0E6
Turbine Building Vent Exhaust	~4.1E7
Air Ejector Vent Exhaust	2.4E3
Steam Packing Exhauster	<u>5.0E4</u>
TOTAL	~4.7E7

- ① GAS COLLECTION SYSTEM
- ① VENT COLLECTION SYSTEM
- ① CONTAINMENT PURGE EXHAUST
- ① FUEL AND AUXILIARY BUILDING VENTILATION EXHAUST
- ② MAIN STEAM RELIEF VALVE DISCHARGE
- ④ CONDENSER AIR EJECTOR EXHAUST
- ⑤ STEAM PACKING EXHAUSTER BLOWER DISCH.
- ⑥ FEEDWATER HEATER RELIEF VALVE DISCH.
- ⑦ TURBINE BLDG. VENTILATION EXHAUST

FIGURE 11.A-12. Location of Airborne Effluent Release Points for Reference Pressurized Water Reactor Facility

- ① GAS COLLECTION SYSTEM
- ① VENT COLLECTION SYSTEM
- ① CONTAINMENT PURGE EXHAUST
- ① FUEL AND AUXILIARY BUILDING VENTILATION EXHAUST
- ② MAIN STEAM RELIEF VALVE DISCHARGE
- ④ CONDENSER AIR EJECTOR EXHAUST
- ⑤ STEAM PACKING EXHAUSTER BLOWER DISCHARGE
- ⑥ FEEDWATER HEATER RELIEF VALVE DISCHARGE
- ⑦ TURBINE BUILDING VENTILATION EXHAUST

FIGURE 11.A-13. Elevational View of Airborne Effluent Release Points for Reference Pressurized Water Reactor Facility

Other sources of miscellaneous airborne releases are the radioactive waste cover system, generator cooling system, and reactor cooling system. The radwaste cover system uses and exhausts to the atmosphere a total amount of 2718 std m³ (96,000 standard cubic feet (scf)) of nitrogen annually. An annual 6343 std m³ (224,000 scf) of hydrogen is also used and emitted during operation of the generator cooling and reactor coolant system. Purging of the generator requires 1417 kg (3125 lb) of liquid carbon dioxide once every 3 years.

- Heat Dissipation System

The reference plant uses a natural-draft counter-flow cooling tower to dissipate over 99.7% of the effluent heat that would have discharged to the river had once-through cooling been used. The cooling tower is part of the closed-cycle secondary cooling water system. The main condenser of the plant transfers heat from exhaust steam of the turbine to the secondary cooling water. The water passes to the cooling tower where heat added by the condenser is transferred to the atmosphere by evaporation of part of the water. The cooled water is then pumped back through the secondary cooling system. Figure 11.A-14 schematically shows this cooling system.

FIGURE 11.A-14. Heat Dissipation System Flow Diagram for Reference Pressurized Water Reactor Facility

11.A.4 FACILITY AND SITE DESCRIPTION

This section summarizes the description of the site and the facility and its hardware. This information will be used as the basis for capital cost estimates and as background for plant performance.

11.A.4.1 Site

The reference PWR plant is assumed to lie on the generic site (Site B) described in Section 5. The plant itself requires an area of 0.08 km^2 within the larger plant site. The plant layout allows airborne effluents to emanate equidistant and 1 km away from three sides of the rectangular site. It is assumed that a well-labeled perimeter fence exists around the total site to exclude the public, and another fence surrounds the smaller plant area, including a security entrance to the plant. The liquid effluents from the plant are assumed to be discharged onsite into the river flowing through one corner of the site.

11.A.4.2 PWR Facility

The reference facility is based primarily on the Portland General Electric - Trojan Nuclear Plant, with a net electrical output capacity of 1130 MWe. The Trojan plant is presently in operation.

The facility occupies about 0.08 km^2 of the 4.7 km^2 Site B. The structures on the facility grounds include the reactor containment building, the turbine building, the auxiliary building, the fuel building, the control building, the cooling tower, the shop, and the office area. These are shown in the reference facility layout, Figure 11.A-15.

The main ventilation system for the reactor containment building handles $2.0\text{E}6 \text{ } \ell/\text{day}$ (50,000 cfm) flow into and out of the building. To enter and exit the building, this air passes through systems containing an 80% efficient roll-type prefilter, a bank of HEPA filters, and two fans in parallel, each with a capacity of $2.0\text{E}6 \text{ } \ell/\text{day}$ (50,000 cfm).

The main ventilation system for the turbine building handles a maximum airflow of $4.5\text{E}7 \text{ } \ell/\text{day}$ (1,111,500 cfm). Thirteen fans handle $2.3\text{E}6 \text{ } \ell/\text{day}$ (57,300 cfm) each and another thirteen fans handle $1.2\text{E}6 \text{ } \ell/\text{day}$ (28,200 cfm) each. The turbine building ventilation air is not filtered before discharge.

FIGURE 11.A-15. Layout of the Reference Pressurized Water Reactor Facility

The auxiliary and fuel building heating and ventilation system consists of a single air supply system and two exhaust systems. The supply system handles about $3.4E6$ ℓ /day (83,380 cfm). The air enters through an 85% efficient automatic roll filter, electric heating coil, and two parallel fans each with 50% capacity.

The exhaust system that serves the spent fuel storage area consists of two parallel exhaust air plenums that can exhaust $7.9E5$ ℓ /day (19,375 cfm). Each plenum contains an exhaust fan, a bank of carbon adsorbers, two banks of HEPA filters, and an 85% efficient automatic roll filter. One plenum operates while the other plenum is on standby.

The exhaust system for the remaining auxiliary and fuel buildings consists of four parallel plenums that can each exhaust about $1.1E6$ ℓ /day (28,157 cfm). Each plenum contains a bank of HEPA filters and an automatic roll filter. Three of the four exhaust plenums operate while the fourth plenum serves as a standby.

The control building has several ventilation supply and exhaust systems. The control room emergency ventilation system consists of two parallel plenums that can each handle about $1.3E5$ (3200 cfm). Each plenum consists of a 60% efficient flat filter, two banks of HEPA filters, a bank of carbon adsorbers and a supply fan. The control room air conditioning supply system consists of two parallel fans that can each supply about $9.0E5$ ℓ /day (22,000 cfm). Two separate control building supply systems handle a total of about $9.5E5$ ℓ /day (23,400 cfm) to $3.6E5$ ℓ /day through one fan, and $5.9E5$ ℓ /day through another fan. Two control building exhaust systems handle a total of about $9.8E5$ ℓ /day (24,000 cfm).

The PWR facility is expected to operate for 40 years.

Tables 11.A-3 and 11.A-4 summarize the various process area descriptions and major equipment, respectively.

TABLE 11.A-3. Major Process Areas Description - Reference Pressurized Water Reactor Facility

<u>Process Area</u>	<u>Overall Dimensions L x W x H</u>	<u>Perimeter Construction Material</u>	<u>Other Features</u>
Reactor Containment Building	43 dia. x 64 H Concrete, Steel Lined Interior	Reinforced	NA
Turbine Building	NA	Steel Frame, Reinforced Concrete Floors	2-Story Building Rectangular
Auxiliary Building	NA	Reinforced Concrete-Below Grade, Steel Frame-Above Grade	2-Story Below Grade, 4-Story Above Grade
Fuel Building	NA	Precast Concrete, Corrugated Metal	4-Story Above Grade
Control Building	NA	Structural Steel	4-Story Above Grade
Cooling Tower	117 dia. x 152 H, base 71 m dia, Throat 76 m dia.	Cement-asbestos sheets with Concrete Supports	NA
Shop and Warehouse	NA	Steel Frame	1-Story
Office	NA	Steel Frame	2-Story

NA = Not available at this time

TABLE 11.A-4. Major Process Equipment Descriptions - Reference
Pressurized Water Reactor Facility

Equipment	Location	No.	Size, m (each) L x W x H	Process Duty or Capacity	Other Features
Reactor Pressure Vessel	RCB	1	5 dia. x 13 H	NA	NA
Steam Generators	RCB	4	21 H	NA	Vertical Shell, U-Tube Evaporator
Reactor Coolant Pumps	RCB	4	9 H	3.35E5 2/min	Vertical, Single Stage, Centrifugal Pump
Pressurizer	RCB	1	NA	NA	Vertical, Cylindrical Vessel
Pressurizer Relief Tank	RCB	1	3 dia. x 8 L		Horizontal, Cylindrical Vessel
Turbine-Generator	TB	1	NA	NA	1800 RPM, 96 cm last-stage blades
Moisture Separation - Steam Reheater Assemblies	TB	2	NA	NA	NA
Feed Water Heaters	TB	NA	NA	NA	NA
Main Condenser	TB	1	NA	NA	NA
Steam Packing Exhauster	TB	1	NA	NA	NA
Mixed Bed Demineralizer	AB	2	1 dia. x 2 H	NA	NA
Cation Bed Demineralizer	AB	1	1 dia. x 2 H	NA	NA
Volume Control Tank	AB	1	2 dia. x 3 H	NA	NA
Holdup Tank	FB	3	10 H	NA	NA
Boric Acid Tank	FB	2	4 dia. x 10 H	NA	NA
Boric Acid Batching Tank	FB	1	1 dia. x 2 H	NA	NA
Primary Water Storage Tank	NA	NA	NA	NA	NA
Monitor Tanks	FB	2	6 dia. x 3 H	NA	NA
Boric Acid Evaporator and Gas Stripper	AB	1	5 x 3 x 3	NA	NA
Spent Fuel Pool	FB	1	NA	NA	NA
Spent Fuel Pool Cooling Pumps	AB	2	2 x 0.5 x 0.6	NA	NA
Spent Fuel Pool Cooling Water Heat Exchanger	FB	2	0.5 dia. x 6 L	NA	NA
Spent Fuel Pool Purification Pump	AB	1	2 x 0.5 x 0.6	NA	NA
Spent Fuel Pool Purification Filter	NA	1	0.3 dia. x 1 L	NA	NA
Fuel Pool Demineralizer	NA	1	3 H	NA	NA
Spent Fuel Pool Demineralizer After-Filter	NA	1	0.3 dia. x 1 H	NA	NA
Spent Resin Storage Tank	AB	1	3 dia. x 3 H	NA	NA
Waste Concentration Holding Tank	FB	1	2 dia. x 2 H	NA	NA
Mechanical Baler	NA	NA	NA	NA	NA

TABLE 11.A-4. (cont'd)

Equipment	Location	No.	Size, m (each) L x W x H	Process Duty or Capacity	Other Features
Auxiliary Building Drain Tank	FB	1	2 dia. x 2 H	NA	NA
Chemical Effluent Drain Tank	AB	1	3 dia. x 2 H	NA	NA
Reactor Coolant Drain Tank	RCB	1	1 dia. x 2 H	NA	NA
Reactor Coolant Drain Tank Pumps	AB	2	1 x 0.3 x 0.6	NA	NA
Clean Effluent Receiver Tanks	AB	2	3 dia. x 9 H	NA	NA
Clean Effluent Receiver Tank Pump	NA	2	1 x 0.3 x 0.6	NA	NA
Clean Effluent Evaporator	AB	1	6 x 3 x 4	NA	NA
Clean Effluent Evaporator Condenser	NA	1	NA	NA	Electrically Heated
Absorption Tower	NA	1	NA	NA	NA
Distillate Cooler	NA	1	NA	NA	NA
Vent Condenser	NA	1	NA	NA	NA
Treated Effluent Monitor Tank	AB	2	3 dia. x 5 H	NA	NA
Waste Concentrates	FB	2	2 dia. x 3 H	NA	NA
Containment Building Sump Pump	RCB	2	2 L	NA	NA
Auxiliary Building Sump Pump	AB	2	5 L	NA	NA
Dirty Effluent Drain Tank	AB	1	3 dia. x 4 H	NA	NA
Dirty Effluent Monitor Tank	AB	1	3 dia. x 4 H	NA	NA
Dirty Effluent Filter	AB	2	0.2 dia x 1 L	NA	NA
Effluent Gas Surge Tank	AB	1	1 dia. x 2 L	NA	NA
Effluent Gas Compressor	AB	2	3 x 1 x 2	NA	NA
Effluent Gas Aftercooler	AB	2	NA	NA	NA
Effluent Gas Moisture Separator	AB	2	NA	NA	NA
Effluent Gas Decay Tanks	AB	4	3 dia. x 5 L	NA	NA
Circulating Water Pumps	NA	2	NA	8.04E5 l/min	NA
Cooling Tower Condenser	NA	1	NA	1.01E5 l/min	Single pass, three shell deareating type; each shell has two fuel bundles

Key: RCB = Reactor containment building
 TB = Turbine building
 AB = Auxiliary building
 FB = Fuel building
 SS = Stainless steel
 CS = Carbon steel
 Aus S = Austenitic steel

11.A.5 EFFLUENT CONTROL PERFORMANCE

The overall effluent control performance for radioactive effluents from the reference PWR facility is summarized in Table 11.A-5. In the airborne effluents, the largest number of Curies of radionuclides result from ^{85}Kr and ^{133}Xe . Tritium contributes most of the radioactivity in the liquid effluents. The major assumption for the releases given in Table 11.A-5 is that there are 0.12% leaking fuel rods.⁽⁴⁾

Table 11.A-6 gives the overall input of nonradioactive materials. These are primarily the materials used to treat the circulating water and the service water.

The only nonradioactive effluents discharged from the PWR facility are liquid effluents except for airborne effluents emitted by the diesel generators during emergency power generation. The nonradioactive liquid effluents are summarized in Table 11.A-7.

The overall solid wastes from the reference facility are summarized in Table 11.A-8. The spent filters are packaged in the same containers as the spent resin or the evaporator concentrates or in 208-l drums.

11.A.6 FACTORS FOR OPERATING COST ESTIMATION

The basic plant operational requirements are given to provide information for a later estimation of direct operating costs. The operating costs are not estimated in this report.

11.A.6.1 Labor Requirements

The reference PWR plant is assumed to operate 24 hr/day, 7 days/wk for 292 days/yr. There are approximately 210^(a) full-time employees functioning in four main groups: operations, maintenance, technical support, and quality assurance. About 35 of this labor force are management, supervisory or professional personnel and about 185 employees are skilled or unskilled labor.

^(a) Number based on information received by phone call to Chuck Heming at the Trojan Nuclear Plant on December 21, 1977.

TABLE 11.A-5. Overall Radioactive Materials Input/Output for Reference Pressurized Water Reactor Facility

Material	Total Material ^{(a)(h)}		Form		Fraction of ^(b) Plant Input
	kg/day	Ci/day	Chemical	Phase	
<u>Input to Plant</u>					
Uranium ^(c) in Fuel Assemblies	102	0.14	UO ₂	S	(1)
<u>Output from Plant</u>					
Spent Fuel in Fuel Assemblies	~102	NA	--	S,G	(~1)
<u>Airborne Effluents^(d)</u>					
⁴¹ Ar	2.1E-12	8.6E-2	Ar	G	Footnote (e), (e) All Cases
^{83m} Kr	1.4E-13	2.8E-3	Kr	G	
^{85m} Kr	1.7E-12	1.4E-2	Kr	G	
⁸⁵ Kr	6.0E-6	2.3	Kr	G	
⁸⁷ Kr	2.8E-13	7.9E-3	Kr	G	
⁸⁸ Kr	2.1E-12	2.7E-2	Kr	G	
⁸⁹ Kr	9.9E-16	6.5E-4	Kr	G	
^{131m} Xe	1.2E-8	1.0	Xe	G	
^{133m} Xe	1.4E-10	6.1E-2	Xe	G	
¹³³ Xe	6.8E-8	1.3E+1	Xe	G	
^{135m} Xe	1.8E-14	1.6E-3	Xe	G	
¹³⁵ Xe	2.1E-11	5.4E-2	Xe	G	
¹³⁷ Xe	3.3E-15	1.2E-3	Xe	G	
¹³⁸ Xe	6.9E-14	5.6E-3	Xe	G	
⁸⁶ Rb	8.3E-16	6.8E-8	NA	S	
⁸⁸ Rb	1.1E-15	1.3E-4	NA	S	
¹³⁴ Cs	4.3E-12	5.6E-6	NA	S	
¹³⁶ Cs	1.4E-13	1.0E-5	NA	S	
¹³⁷ Cs	6.7E-11	5.8E-6	NA	S	
⁸³ Br	5.6E-17	8.8E-7	NA	S,G	
⁸⁴ Br	6.5E-18	4.6E-7	NA	S,G	
⁸⁵ Br	7.4E-20	5.4E-8	NA	S,G	

TABLE 11.A-5. (cont'd)

Material	Total Material ^(a) (h)		Form		Fraction of ^(b) Plant Input
	kg/day	Ci/day	Chemical	Phase	
¹³⁰ I	2.0E-16	4.0E-7	NA	S,G	
¹³¹ I	4.8E-13	5.9E-5	NA	S,G	
¹³² I	1.9E-15	1.9E-5	NA	S,G	
¹³³ I	5.9E-14	6.7E-5	NA	S,G	
¹³⁴ I	3.1E-16	8.4E-6	NA	S,G	
¹³⁵ I	1.0E-14	3.6E-5	NA	S,G	
⁵¹ Cr	1.6E-14	1.4E-6	NA	S	
⁵⁴ Mn	1.8E-13	1.5E-6	NA	S	
⁵⁵ Fe	4.6E-13	1.2E-6	NA	S	
⁵⁹ Fe	1.2E-14	6.1E-7	NA	S	
⁵⁸ Co	2.1E-13	6.6E-6	NA	S	
⁶⁰ Co	2.1E-12	2.4E-6	NA	S	
⁸⁹ Sr	3.9E-15	1.1E-7	NA	S	
⁹⁰ Sr	1.3E-13	1.9E-8	NA	S	
⁹¹ Sr	1.2E-16	4.2E-7	NA	S	
⁹⁰ Y	2.1E-17	1.2E-8	NA	S	
^{91m} Y	6.1E-18	2.5E-7	NA	S	
⁹¹ Y	5.9E-14	1.4E-6	NA	S	
⁹³ Y	2.5E-17	8.3E-8	NA	S	
⁹⁵ Zr	2.2E-15	4.7E-8	NA	S	
⁹⁵ Nb	1.0E-15	4.0E-8	NA	S	
⁹⁹ Mo	6.1E-13	2.9E-4	NA	S	
^{99m} Tc	4.9E-14	2.6E-4	NA	S	
¹⁰³ Ru	9.9E-16	3.2E-8	NA	S	
¹⁰⁶ Ru	2.0E-15	6.8E-9	NA	S	
^{103m} Rh	9.8E-19	3.1E-8	NA	S	
¹⁰⁶ Rh	2.2E-19	7.8E-7	NA	S	
^{125m} Te	1.1E-15	1.9E-8	NA	S	
^{127m} Te	2.0E-14	1.9E-7	NA	S	

TABLE 11.A-5. (cont'd)

Material	Total Material (a)(h)		Form		Fraction of (b) Plant Input
	kg/day	Ci/day	Chemical	Phase	
^{127}Te	2.2E-16	5.8E-7	NA	S	
$^{129\text{m}}\text{Te}$	3.1E-14	9.3E-7	NA	S	
^{129}Te	5.1E-17	1.1E-6	NA	S	
$^{131\text{m}}\text{Te}$	2.2E-15	1.7E-6	NA	S	
^{131}Te	1.3E-17	7.2E-7	NA	S	
^{132}Te	6.0E-14	1.8E-5	NA	S	
$^{137\text{m}}\text{Ba}$	2.3E-17	1.2E-5	NA	S	
^{140}Ba	2.2E-15	1.6E-7	NA	S	
^{140}La	2.0E-16	1.1E-7	NA	S	
^{141}Ce	1.8E-15	5.0E-8	NA	S	
^{143}Ce	4.0E-17	2.7E-8	NA	S	
^{144}Ce	7.8E-15	2.5E-8	NA	S	
^{143}Pr	5.3E-16	3.5E-8	NA	S	
^{144}Pr	3.3E-19	2.5E-8	NA	S	
^{239}Np	3.5E-15	8.2E-7	NA	S	
^3H	1.0E-7	9.9E-1	$^3\text{H}_2, ^3\text{H}_2\text{O}$	L, G	
^{14}C	6.8E-6	3.0E-2 ^(f)	NA	G	
<u>Liquid Effluents</u>					
^{83}Br	2.4E-16	3.8E-6	NA	NA	
^{84}Br	1.8E-18	1.3E-7	NA	NA	
^{85}Br	1.2E-22	8.6E-11	NA	NA	
^{130}I	4.9E-15	9.7E-6	NA	NA	
^{131}I	3.1E-11	3.8E-3	NA	NA	
^{132}I	4.0E-14	4.1E-4	NA	NA	
^{133}I	2.4E-12	2.7E-3	NA	NA	
^{134}I	2.6E-16	6.9E-6	NA	NA	
^{135}I	1.4E-13	4.8E-4	NA	NA	
^{86}Rb	1.7E-14	1.3E-6	NA	NA	
^{88}Rb	1.3E-17	1.6E-6	NA	NA	
^{134}Cs	3.4E-10	4.5E-4	NA	NA	

TABLE 11.A-5. (cont'd)

Material	Total Material (a)(h)		Form		Fraction of (b) Plant Input
	kg/day	Ci/day	Chemical	Phase	
¹³⁶ Cs	2.9E-12	2.1E-4	NA	NA	
¹³⁷ Cs	4.0E-9	3.4E-4	NA	NA	
⁵¹ Cr	3.4E-13	3.1E-5	NA	NA	
⁵⁴ Mn	9.1E-13	7.2E-6	NA	NA	
⁵⁵ Fe	1.0E-11	2.6E-5	NA	NA	
⁵⁹ Fe	3.2E-13	1.6E-5	NA	NA	
⁵⁸ Co	8.3E-12	2.6E-4	NA	NA	
⁶⁰ Co	4.6E-11	5.2E-5	NA	NA	
⁸⁹ Sr	2.0E-13	5.5E-6	NA	NA	
⁹⁰ Sr	1.1E-12	1.6E-7	NA	NA	
⁹¹ Sr	7.0E-16	2.5E-6	NA	NA	
⁹⁰ Y	4.7E-16	2.6E-7	NA	NA	
^{91m} Y	3.8E-17	1.6E-6	NA	NA	
⁹¹ Y	1.4E-12	3.3E-5	NA	NA	
⁹³ Y	1.7E-16	5.5E-7	NA	NA	
⁹⁵ Zr	1.8E-13	3.8E-6	NA	NA	
⁹⁵ Nb	1.2E-13	4.8E-6	NA	NA	
⁹⁹ Mo	1.2E-11	5.5E-3	NA	NA	
¹⁰³ Ru	3.1E-14	1.0E-6	NA	NA	
¹⁰⁶ Ru	4.8E-14	1.6E-7	NA	NA	
^{103m} Rh	2.3E-17	7.2E-7	NA	NA	
¹⁰⁶ Rh	1.3E-18	4.5E-6	NA	NA	
^{110m} Ag	1.8E-13	8.6E-7	NA	NA	
^{125m} Te	2.7E-14	4.8E-7	NA	NA	
^{127m} Te	5.1E-13	4.8E-6	NA	NA	
¹²⁷ Te	2.6E-15	6.9E-6	NA	NA	
^{129m} Te	7.4E-13	2.2E-5	NA	NA	
¹²⁹ Te	6.9E-16	1.4E-5	NA	NA	
^{131m} Te	2.8E-14	2.2E-5	NA	NA	
¹³¹ Te	7.2E-17	4.1E-6	NA	NA	

TABLE 11.A-5. (cont'd)

Material	Total Material ^{(a)(h)}		Form		Fraction of ^(b) Plant Input
	kg/day	Ci/day	Chemical	Phase	
¹³² Te	1.1E-12	3.4E-4	NA	NA	
^{137m} Ba	7.1E-20	3.8E-8	NA	NA	
¹⁴⁰ Ba	4.7E-14	3.4E-6	NA	NA	
¹⁴⁰ La	5.3E-15	2.9E-6	NA	NA	
¹⁴¹ Ce	3.9E-14	1.1E-6	NA	NA	
¹⁴³ Ce	5.7E-16	3.8E-7	NA	NA	
¹⁴⁴ Ce	3.3E-12	1.0E-5	NA	NA	
¹⁴³ Pr	1.2E-14	8.3E-7	NA	NA	
¹⁴⁴ Pr	7.3E-18	5.5E-7	NA	NA	
²³⁹ Np	5.9E-14	1.4E-5	NA	NA	
³ H	3.6E-7	3.5	³ H ₂ O	L	
<u>Solid Wastes</u> ^(g)					
⁵⁴ Mn	3.3E-8	2.6E-1	NA	S	
⁵⁹ Fe	2.2E-10	1.1E-2	NA	S	
⁵⁸ Co	3.5E-8	1.1	NA	S	
⁶⁰ Co	4.6E-7	5.2E-1	NA	S	
⁸⁹ Sr	2.9E-9	8.1E-2	NA	S	
⁹⁰ Sr	8.5E-7	1.2E-1	NA	S	
⁹⁰ Y	2.2E-10	1.2E-1	NA	S	
⁹¹ Y	9.8E-10	2.4E-2	NA	S	
⁹⁵ Zr	1.6E-9	3.4E-2	NA	S	
⁹⁵ Nb	1.6E-9	6.3E-2	NA	S	
⁹⁹ Mo	1.3E-11	6.0E-3	NA	S	
¹³² Te	2.8E-12	8.6E-4	NA	S	
¹³¹ I	3.0E-9	3.7E-1	NA	S	
¹³² I	8.5E-14	8.8E-4	NA	S	
¹³³ I	1.2E-14	1.4E-5	NA	S	
¹³⁴ I	3.1E-18	8.2E-8	NA	S	
¹³⁵ I	6.9E-16	2.4E-6	NA	S	

TABLE 11.A-5. (cont'd)

Material	Total Material (a)(h)		Form		Fraction of (b) Plant Input
	kg/day	Ci/day	Chemical	Phase	
¹³⁴ Cs	1.1E-5	1.4E+1	NA	S	
¹³⁵ Cs	5.7E-9	6.6E-9	NA	S	
¹³⁶ Cs	8.4E-10	6.2E-2	NA	S	
¹³⁷ Cs	9.5E-4	8.2E+1	NA	S	
¹⁴⁰ Ba	2.3E-11	1.7E-3	NA	S	
¹⁴⁴ Ce	3.8E-8	1.2E-1	NA	S	
¹⁴⁴ Pr	1.6E-12	1.2E-1	NA	S	

(a) Values based upon one day operating at 100% capacity (including anticipated operation occurrences).

(b) Numbers in parentheses are not released to the environment.

(c) Uranium is enriched to 3.2% ²³⁵U.

(d) Airborne and liquid effluent numbers come from Reference 4.

(e) This material does not enter the plant in this chemical form, all cases.

(f) ¹⁴C number is calculated based on information from References 6 and 7.

(g) Solid waste numbers from Reference 4.

(h) These are the numbers that are presently reported but they are tentative and could be significantly in error. If the values for ¹³⁷Cs were known to be reasonably accurate, then a calculation for losses of plutonium and uranium could be performed as was done for the BWR (see Table 11.B-7).

TABLE 11.A-6. Overall Nonradioactive Materials Input to the Reference Pressurized Water Reactor Facility

Material	Total Material ^(a)		Chemical	Form		Other	kg/day at 100%	Purpose
	kg/day	ℓ/day		Phase	Density			
Sulfuric Acid	4.4E3	NA	H ₂ SO ₄	L	NA	93%	NA	To control pH in cooling water and make-up water demineralizers
Chlorine	3.1E2	9.5E4	Cl ₂	G	3.2 g/ℓ		3.1E2	Prevention of biological growth
Ammonium Hydroxide	NA	NA	NH ₄ OH	L	NA		NA	NA
Volatile Amines	1.1	NA	.	L	NA		NA	pH control and oxygen elimination in secondary steam-feedwater systems
Sodium Orthophosphate	2.3	NA	NA	NA	NA		NA	Scale prevention
Boric Acid	0.90	NA	H ₃ BO ₃	L	NA		NA	Chemical shim in primary coolant
Sodium Hydroxide	77	NA	NaOH	NA	NA		NA	Make-up water demineralizer
Alum	22	NA	NA	NA	NA		NA	Clarification of river water
Sodium Bisulfite	0.8	NA	NaHSO ₃	NA	NA		NA	Reduction of total residual chlorine

Key: S = Solid
 L = Liquid
 G = Gas
 NA = Not available at this time

(a) Values based upon one day operating at 100% capacity.

TABLE 11.A-7. Overall Nonradioactive Liquid Effluents from the Reference Pressurized Water Reactor Facility

Materials	Form		Output ^{(a)(b)} kg/day
	Chemical	Phase	
Sulfate	SO ₄ ⁻²	L	6.6E3
Volatile Amines	NA	L	9.1E-2
Boron	B ⁺³	L	0.6
Sodium	Na ⁺¹	L	7.0E2
Sulfite	SO ₃ ⁻²	L	7.0E-3
Chlorine	Cl ₂	G,L	4.8E-1
Phosphates	PO ₄ ⁻³	L	2.3
Lithium	Li	L	4.3E-1

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

(a) Values based upon one day operating at 100% capacity.

(b) Includes chemicals already in the make-up water.

TABLE 11.A-8. Overall Solid Wastes from the Reference Pressurized Water Reactor Facility

Waste Material	Form	Package	Total ^(a) ℓ/day
<u>Radioactive</u>			
Spent Resins	Solidified Slurry	1416 ℓ Shipping Container	33
Evaporator Concentrates	Solidified Liquid	1416 ℓ Shipping Container	53
Spent Filters	Filter Elements	1416 ℓ Shipping Container	(b)
Miscellaneous Waste	Clothing, Rags, Towels, Lab Equipment, Small Tools	208 ℓ Drum	72
<u>Nonradioactive</u>			
Miscellaneous Waste	Paper, Rags, Grease Oil, Lumber, Boxes, etc.	NA	NA

NA = Not available at this time

(a) Values based upon one day operating at 100% capacity.

(b) Spent filter elements are packaged with either the spent resins or evaporator concentrates, so amounts are included under those respective headings.

11.A.6.2 Material Requirements

The chemical material requirements for the reference PWR plant are those identified previously in Table 11.A-6. Packaging materials for offsite waste disposal of solid wastes listed in Table 11.A-8 are required. Small amounts of miscellaneous materials such as office materials, routine maintenance materials, etc., are also required.

11.A.6.3 Unusual Maintenance Requirements

Some equipment will require replacement and/or major repairs periodically. These special requirements are currently unknown. These special requirements are assumed to be equivalent to a replacement of a steam generator every 10 yr. HEPA, roughing, and charcoal filters are assumed to be replaced every 2 yr.

11.A.6.4 Utility Requirements

Total estimated requirements for the PWR plant operating at full capacity are:

- Water 1.6E8 kg/day
- Electricity 4.0E4 kW-day/day

11.A.6.5 Transportation Requirements

All the plant input materials, fuel assemblies, and output waste items must be transported to and/or from the site. Typical transport distances are not within the scope of this study.

11.A.6.6 Waste Disposal Requirements

In this study the spent fuel is removed from the reactor and after interim storage, shipped to the fuel reprocessing plant. The solid wastes must be transported offsite for ultimate disposition. The nonsalvagable materials are shipped offsite for reuse.

11.A.6.7 Other Operating Cost Elements

Certain major operating cost elements are assumed to be performed by outside contractors. Laundering of noncontaminated and radioactive work clothing is assumed to be contracted. Also, transporting materials, disposal of radioactive wastes and disposal of nonradioactive wastes are assumed to be performed by outside contractors.

Other known special operating cost elements are the licensing and insurance costs associated with operating the reference reactor.

11.A.7 ENVIRONMENTAL IMPACT FACTORS

A summary of the overall direct environmental impact factors for the reference PWR facility is given in Table 11.A-9. These quantities are those used directly at the plant. Impacts of resources required for material input or output beyond the plant boundary are not included.

TABLE 11.A-9. Overall Environmental Impacts - Reference Pressurized Water Reactor Facility

	<u>Quantity</u>	<u>Remarks</u>
Total Land Committed	4.7 km ²	Fenced-in area
Land Actually Used for Plant	0.08 km ²	High-security area
Water Used	1.6E8 kg/day	
Water Discharged as Liquid Effluent	4.8E7 kg/day	
Total Materials added to Liquid Effluents	4.8E3 kg/day	
Air used	5.8E7 kg/day	
Water Discharged as Airborne Effluents	6.2E7 kg/day	
Total Other Airborne Effluents	~0 kg/day	
Electrical Energy Consumption	4.0E4 kW-day/day	
Thermal Effluent Equivalent	2.3E6 kW-day/day	
Resource use	See Table 11.A-8	See also special Maintenance Requirements Section 11.A.7.3

11.A.8 LIMITATIONS AND UNCERTAINTIES IN THE STUDY INFORMATION

Pertinent information concerning the overall effluent treatment system performance has not yet been obtained in usable format. Final performance evaluations for the gaseous and liquid effluent treatment systems were not made due to the lack of input and output information, respectively. The information in this report is presented primarily in readily available documents for licensing purposes; extrapolation of the data from this format is necessary for completeness in this study. Other data sources are also likely to be available.

11.A.9 RESEARCH AND DEVELOPMENT NEEDS

Additional operational and descriptive information would be helpful to get a realistic analysis of the important effluents.

In addition, alternative control processes for reducing the emission of krypton, xenon, iodine, and tritium may need to be evaluated to provide for cost-benefit analysis of these processes.

11.B BOILING WATER REACTOR

A reference boiling water reactor (BWR) plant representative of current technology for commercial scale plants was chosen for this study, based primarily on the Washington Public Power Supply system (WPPSS) Nuclear Project No. 2 (WNP-2) located on DOE's Hanford Reservation approximately 12 miles north of Richland, Washington.^(8,9) WNP-2 is a single unit nuclear electric generating plant having a nominal net electric power output of 1100 MWe. The plant consists of a boiling water reactor, turbine-generator, evaporative cooling tower system, a pumphouse that takes makeup water from the Columbia River, a 500-kV transmission line, and other facilities required to generate electric power and handle nuclear wastes.

The overall characteristics of the reference boiling water reactor facility study include the following:

- One facility, one feed (slightly enriched uranium in fuel assemblies), two basic products (electricity and spent fuel assemblies).
- A single reference facility is assumed that is capable of producing 1100 MWe net electric power.
- The facility receives the fuel assemblies containing slightly enriched uranium dioxide and achieves nuclear fission within the assemblies in the reactor core to boil water and produce steam. The steam is used to produce electricity in a turbine generator. Spent fuel assemblies are stored onsite until shipment.
- The reference facility is assumed to operate 292 days/yr and 24 hr/day for 40 years.

11.B.1 SUMMARY

The reference boiling water reactor produces 1150 MW of electricity (gross) and 1100 MW (net) at a full reactor core power of 3323 MWt.

The reactor core is composed of 764 fuel assemblies, each containing 63 fuel rods containing UO_2 fuel and one water rod. This inventory amounts to 139,344 kg (307,202 lb) of slightly enriched uranium in ceramic uranium dioxide pellets clad in Zircaloy.

All radioactive effluents and wastes from the facility come from the reactor core. An average total of about 14.1 million ℓ /day of liquid effluents are discharged from the plant. Contained in these daily effluents are approximately 3500 kg of chemical additives (primarily water treatment chemicals) and about 0.04 Ci of radionuclides including tritium. The airborne effluents total 18.1 trillion ℓ /day and contain about 23 Ci of radioactive noble gases, 0.007 Ci of radioactive iodine, 0.2 Ci of tritium, and 0.03 Ci of ^{14}C . Solid wastes shipped offsite average about 960 ℓ /day of high-radioactivity wastes and 180 ℓ /day of low-radioactivity wastes.

Nonradioactive airborne effluents in the form of water evaporation and drift are emitted from the cooling towers at the rate of 70.2 million ℓ /day and carry into the atmosphere 2.2 million kW-days of heat daily.

The plant employs about 170 persons, and occupies a total of 0.12 km^2 of the 4.7 km^2 reference generic site. It uses 84.3 million kg of water and 50,000 kW-days of electricity for daily operation.

11.B.2 MAINLINE PROCESS DESCRIPTION OF THE REFERENCE BWR FACILITY

The reference boiling water reactor uses slightly enriched uranium fuel assemblies to sustain a controlled nuclear fission reaction for the purpose of boiling water to produce steam. The steam is passed through a turbine which drives a generator to produce electricity. All other processes are auxiliary to this main process.

An overall process flow diagram for the reference boiling water reactor is shown in Figure 11.B-1. Each portion of this process is described in the sections that follow excepting the effluent treatment systems which are described in Section 11.B.3.

11.B.2.1 Description of Mainline Process Steps

The following sections discuss the major process steps.

FIGURE 11.B-1. Overall Process Flow Diagram for the Reference Boiling Water Reactor Facility

- New Fuel Storage and Handling

The new fuel storage and handling process, shown in Figure 11.B-2, provides a means to store, transport and handle nuclear fuel from the time it reaches the facility in an unirradiated condition until it is loaded into the reactor.

FIGURE 11.B-2. Storage and Handling of New Fuel in the Reference BWR

The new fuel assemblies are unloaded and stored dry in the fuel storage facility, which can store up to 30% of the reactor core fuel assemblies. The fuel is stored in a subcritical array so that the

effective neutron multiplication factor (k_{eff}) is less than 0.90. When the reactor is ready for refueling, the fuel assemblies are transferred from the storage facility and loaded into the reactor core.

- Steam Production Process

Nuclear fission of the fuel in the reactor core provides the heat source used to boil water to produce the steam necessary for electricity. The core contains nuclear fuel assemblies, control rods and instrumentation to maintain controlled nuclear fission. The control rods are withdrawn from the bottom of the core to allow the nuclear fission reaction to occur. The reactor cooling water flows upwards through the core and is heated to boiling. Conductive and convective heat transfer to the water cools the zirconium-sheathed fuel rods.

- Reactor Cooling

The reactor cooling process, Figure 11.8-3, provides coolant flow through the reactor core. Adjusting the core coolant flow rate changes reactor heat output, thus providing a way to follow plant load demand without adjusting the control rods.

FIGURE 11.8-3. Reactor Coolant System for the Reference Boiling Water Reactor Facility

The water recirculates through the core using jet pumps located in the peripheral area around the core inside the reactor vessel. The pumps are powered from two externally located electrically-driven centrifugal pumps that draw a fraction of the reactor water from the vessel and return it, with increased pressure to the jet pumps.

The reactor water cleanup system recirculates a portion of the reactor coolant through a filter-demineralizer to remove particulates and dissolved ionic impurities from the coolant. Excess coolant is pumped to storage tanks for later recycle.

- Steam and Power Conversion

Steam produced in the reactor core is separated from the reactor water and dried by hot metal plates in the top of the reactor vessel before leaving the vessel. The saturated steam leaves the vessel in four steam lines and passes through the high-pressure turbine where it is expanded and then exhausted to two parallel moisture separator/reheaters (two reheat stages). The moisture separators remove the moisture content of the steam and superheat the steam before it enters the low-pressure turbines where the steam expands further.

Steam for the first-stage reheater is taken from the first extraction point of the high-pressure turbine, while steam for the second-stage reheater is taken from the main steam header. From the low-pressure turbines the steam is exhausted into the main condenser where it is condensed and deaerated. The condensate pumps take suction from the condenser hotwell and deliver the condensate through a gland seal steam condenser, a steam-jet air ejector condenser, an off-gas condenser, and condensate demineralizers to the condensate booster pump suction. The condensate booster pumps then discharge through the low-pressure feedwater heater trains to the reactor feedwater pumps, which supply feedwater through the high-pressure feedwater heaters to maintain the water level in the reactor vessel. Turbine extractions supply steam for heating the feedwater in the heating cycle. The drains from the feedwater heaters, the reheaters, and the moisture separators are cascaded to the next lower pressure feedwater heater and finally discharged to the condenser.

Figure 11.B-4 shows a flow diagram of the steam and power conversion system.

FIGURE 11.B-4. Steam and Power Conversion Process for Reference Boiling Water Reactor Facility

- Spent Fuel Storage and Handling

Figure 11.B-5 shows the spent fuel storage and handling process, which provides a means to store, transport and handle spent nuclear fuel from the time it is removed from the reactor until it leaves the facility after postirradiation cooling.

FIGURE 11.B-5. Spent Fuel Storage and Handling Process for Reference Boiling Water Reactor Facility

Following irradiation in the reactor, the spent fuel is removed from the reactor and transferred to the spent fuel storage area, which is designed to prevent fuel assembly damage and/or potential fission product release under normal and postulated accident conditions. The facility is designed to ensure the confinement and filtration of the atmosphere within the facility and the particulate contaminants present in that atmosphere.

The fuel pool cooling and cleanup system removes the decay heat from the spent fuel elements in the spent fuel pool and purifies the system water inventory continuously. Decay heat is removed by circulating the pool water through heat exchangers. Purification is accomplished by filter demineralizers. After postirradiation cooling the fuel is shipped offsite, assumed to a fuel reprocessing plant in this study.

11.B.2.2 Waste Management

The BWR facility generates radioactive and nonradioactive solid wastes.

Nonradioactive solid wastes generated in a BWR facility resemble those of any other large industrial plant. Solid nonradioactive wastes include paper, rags, grease, oil, used crating lumber, packing boxes and packing materials, worn-out equipment pieces, damaged stock items, and the like. Outside contractors collect and haul these materials away for salvaging or deposit in approved landfill sites.

The solid waste processing system processes both wet and dry radioactive solid wastes. Wet solid radioactive wastes include backwash sludge and spent resins from the reactor water cleanup system, the condensate filter demineralizer system, the fuel pool filter demineralizer, the waste demineralizer, the decontamination solution concentrator and the distillate polishing demineralizer. Dry solid radioactive wastes include rags, paper, small equipment parts, solid laboratory wastes, air filters, etc.

The solid radioactive waste system collects, monitors, processes, packages and provides temporary storage facilities for radioactive solid wastes before offsite shipment and ultimate disposal.

Wet solid radioactive wastes are collected in solid-liquid phase separators where they are allowed to settle, and the resulting clarified liquid is sent to the liquid effluent system for further treatment. Before packaging the sludge into drums, much of the residual water is removed in a centrifuge. The dewatered solid wastes are put into 1400 l (50 ft³) containers for ultimate disposal offsite.

Dry solid radioactive wastes are segregated into compressible and noncompressible wastes, packaged in 208 l (55 gal) steel drums, and stored for eventual offsite disposal.

Figure 11.B-6 summarizes waste management activities at the reference BWR facility.

FIGURE 11.B-6. Overall Waste Management Operations for the Reference Boiling Water Reactor Facility

11.B.3 EFFLUENT CONTROL PROCESS DESCRIPTIONS

Operating the reference BWR requires controls of radionuclide emissions to the environment to limit the effluents to acceptable amounts. The reactor core is the source of all radioactive effluents and wastes discharged from the plant. Small amounts of radioactive materials are transferred to the coolant through leaks in the fuel assemblies or from irradiated tramp uranium remaining on the outside of the fuel rods from the fuel fabrication process. System corrosion products and coolant additives also become

radioactive by irradiation from the core, thus increasing the radioactivity potentially available for release to the environs. Chemicals and heat are ejected from the water coolant by the heat dissipation system. Figure 11.B-7 presents a plant water use diagram.

11.B.3.1 Liquid Effluents

The liquid effluent management system is composed of a group of subsystems designed to collect, treat, and recycle different categories of effluent water. These subsystems are designated as the equipment drain, floor drain and chemical effluent systems. A process flow diagram is presented in Figure 11.B-8 and process decontamination data are presented in Table 11.B-1. The radionuclide distribution of liquid radioactive effluent system influents is assumed to be the same as in the reactor coolant.

TABLE 11.B-1. Decontamination Factors for Liquid Effluent Equipment in the Reference Boiling Water Reactor Facility⁽⁸⁾

<u>Equipment</u>	<u>Decontamination Factor</u>	
Deep Bed Demineralizers		
Radioactivity	Soluble	100
	Insoluble	50
Precoat Filters		
Suspended Solids	Equipment Drains	20
	Floor Drains	100
Radioactivity	Soluble	1
	Insoluble	2
Evaporators		
Concentration (input:bottoms) Ratio = 2:25		
Radioactivity		1000

NOTE: NUMBERS SHOWN ARE ESTIMATED FLOWS IN LITERS PER DAY (GALLONS PER MINUTE), AND REPRESENT NORMAL OPERATING CONDITIONS

FIGURE 11.B-7. Water Use Diagram for the Reference Boiling Water Reactor Plant

FIGURE 11.B-8. Liquid Effluent Process Flow Diagram for the Reference Boiling Water Reactor Facility

All radioactive liquid effluent process streams terminate in one of the sample or distillate tanks. Since the liquid management system operates on a batch basis, each treated batch is sampled and analyzed. If the sample indicates that the processed liquid is substandard in purity, equipment is provided to either recycle the batch through the same treatment or through a subsystem providing a higher degree of treatment. If the sample indicates that the radioactivity level is within acceptable discharge limits and the processed liquid is in excess of inventory capacity, the processed liquid is discharged to the river.

- Equipment Drain System

High purity (low solid content) liquid effluents are collected in the effluent collector tank from the following sources: drywell equipment drain sump, reactor building equipment drain sump, radioactive waste building equipment drain sump, turbine generator building equipment drain sump, reactor water cleanup system, residual heat removal (RHR) system, cleanup phase separators (decant water), condensate phase separators (decant water), and fuel pool seal rupture drains. The quantities of these effluents are summarized in Table 11.B-2. Since these effluents can contain large amounts of primary reactor cooling water, the radioactive concentration could be moderately high (on the order of $0.2 \mu\text{Ci/l}$).

The equipment drain subsystem treatment consists of filtration and demineralization. This treatment is sufficient to purify the process water so that it may be returned to the condensate storage tank for reuse. Normally, the treated effluent will be totally recycled to the condensate storage tank for reuse within the plant. When condensate storage capacity is unavailable, the purified water is sampled, analyzed and, if acceptable for release, is routed to the blowdown line for discharge to the river. Liquid effluent that is unacceptable for discharge is reprocessed.

TABLE 11.B-2. Equipment Drain System Sources for the Reference Boiling Water Reactor Facility⁽⁸⁾

Source	Startup Flows (ℓ/day)	Regular Daily Flows (ℓ/day)	Irregular Flows (ℓ/day)	Maximum Flows (ℓ/day)
Equipment Drains				
Drywell	14,000	14,000		109,000
Reactor Building	14,000	14,000		55,000
Turbine Generation Building	22,000	22,000		22,000
Radwaste Building	3,800	3,800		3,800
Reactor Hydrotest and Thermal Expansion Water	214,000	0		0
Suppression Pool Drain	43,000	0	43,000 ^(a)	0
RHR System Flush Water			15,000 ^(b)	0
Condensate Demineralizer Backwash	102,000		51,000 ^(c)	153,000 ^(d)
Cleanup Demineralizer Backwash	9,100		9,100 ^(e)	
Water Inleakage to Condenser	<u>0</u>	<u>0</u>		<u>54,000</u>
Rounded Totals	423,000	54,000		397,000

(a) Once every 30 days during testing of the reactor emergency core coolant system.

(b) Occurs every shutdown prior to placing the residual heat removal system in operation for shutdown cooling.

(c) Under normal operating conditions, one condensate filter demineralizer is precoated every four days.

(d) The maximum daily flow is based on a condenser inleakage of 54,000 ℓ/day, which corresponds to two condensate demineralizer regenerations daily and maximum leak and drain inflows. Higher condenser inleakage rates can be accommodated up to a maximum of 196,000 ℓ/day. This requires precoating of one condensate demineralizer every 3 hours. This leakage rate would result in overloading the equipment drain subsystem but could be tolerated for short periods of time during location and repair of the leak.

(e) Under normal operating conditions each cleanup demineralizer is precoated every 3.4 days.

- Floor Drain System

Intermediate purity liquid effluent is collected in the floor drain collector tank from the following sources: drywell floor drain sump, reactor building floor drain sumps, radioactive waste building floor drain sumps, turbine generator building floor drain sump, and waste sludge phase separator. The quantities of these effluents are summarized in Table 11.B-3. These are normally of intermediate purity (50 $\mu\text{mho/cm}$ and higher) and radioactive concentration (0.03 to 0.2 $\mu\text{Ci/ml}$).

Processing consists of filtration, demineralization, and transfer to the floor drain sample tank for sampling and analysis. High purity water is routed to condensate storage for reuse in the plant, or, if condensate storage capacity is exceeded and the water meets acceptable discharge limits, the water is discharged to the river via the blowdown line. Unacceptable water is returned for reprocessing.

TABLE 11.B-3. Floor Drain System Sources for Reference
Boiling Water Reactor Facility(8)

<u>Source</u>	<u>Regular Daily Flows (ℓ/day)</u>	<u>Irregular Flows (ℓ/day)</u>	<u>Maximum Daily Flows (ℓ/day)</u>
Floor Drains			
Drywell	2,700		27,000
Reactor Building	7,600		45,000
Radioactive Waste Building	3,800		3,800
Turbine Generator Building	7,600		7,600
Water Sludge Phase			
Separator Decant		<u>32,000</u> ^(a)	<u>32,000</u>
Rounded Totals	22,000	32,000	116,000

^(a) Under normal operating conditions the waste sludge phase separator tank is decanted every 3.4 days.

- Chemical Effluent System

Chemical effluents collected in the chemical effluent tank are from the following sources: detergent drains, maintenance shop

decontamination solutions, reactor and turbine building decontamination drains, low purity effluents from either the equipment or floor drain subsystems, filter demineralizer element chemical cleaning solution, battery room drains, chemical system overflows and tank drains, and laboratory drains. The estimated quantities of these effluents are shown in Table 11.B-4. These chemical effluents are of such high conductivity as to preclude treatment by ion exchange and the radioactivity concentrations are variable.

TABLE 11.B-4. Chemical Liquid Effluent System Sources from the Reference Boiling Water Reactor Facility⁽⁸⁾

<u>Source</u>	<u>Regular Daily Flow (ℓ/day)</u>	<u>Irregular Daily Flow (ℓ/day)</u>	<u>Maximum Flow (ℓ/day)</u>
Detergent Drains			
Shop Decontamination Solutions	3,800		7,600
Laboratory Drains	1,500		1,500
Decontamination Drains			
Reactor and Turbine Generator Buildings		3,800	3,800
Floor Drain or Equipment Drain Subsystem		76,000	76,000
Filter Demineralizer Chemical Cleaning Solutions		Infrequent 7,600	7,600
Battery Room Drains		Infrequent 380	380
Chemical System Overflow and Tank Drains			
Rounded Totals	5,300		97,000

Because of the moderately high chemical content of these effluents, they are first processed through an effluent concentrator (evaporator). The evaporator concentrates are sent to the solid radioactive waste system, and the distillate is routed to a distillate sample tank. After analysis, the distillate is routed through a polishing demineralizer to further reduce impurities, and if acceptable sent to the condensate storage

for plant reuse. If not acceptable, they are reprocessed through the evaporator. As with the other systems, when storage capacity of high purity water is exceeded, some liquid may be discharged to the river via the blowdown line.

- Detergent Effluents

Detergent effluents are primarily laboratory and decontamination solutions that contain detergents and low radioactivity concentrations. Because of a tendency to foul ion exchange resins, these liquids are collected separately in the detergent drain tanks. They are then filtered through the detergent drain filter before routing to the chemical effluent system where they are further processed by distillation for reuse.

- Liquid Effluent Release Point and Dilution

Releases of liquid effluents from these other sources are directed to the cooling water blowdown pipe at a nominal rate of about 19 ℓ /min (5 gal/min) where they are diluted by the cooling tower blowdown of about 9,500 ℓ /min (2,580 gal/min) average flow. The circulating water blowdown line terminates in the river.

11.B.3.2 Airborne Effluent System

The airborne effluent system is divided into three systems: condenser off-gas treatment system, building ventilation, and heat dissipation system. These systems are discussed below.

- Condenser Off-Gas Treatment System

The off gas from the main condenser steam-jet air ejector in the reactor coolant system is first sent through a catalytic recombiner to chemically recombine the hydrogen and oxygen that has been formed by radiolytical dissociation of the water. After cooling to approximately 54°C (130°F) to remove the condensable vapors and reduce the gas volume, the remaining noncondensables (principally air with traces of krypton and xenon) are held for 10 minutes in a tank system. The gas is then cooled to 7°C (45°F), filtered through a HEPA filter, passed

through a desiccant dryer that removes moisture to a dewpoint of approximately -68°C (-90°F), and then chilled to about -18°C (0°F). Charcoal adsorption beds, operating in a refrigerated vault at about -18°C (0°F), adsorb the fission product nuclides of xenon and krypton from the bulk carrier gas (principally dry air). The gas again passes through a HEPA filter and discharges to the environment through the reactor building vent. The short-lived radionuclides of xenon and krypton decay to other elements which desorb and join the dry gas flow to the environment. A simplified process flow diagram is shown in Figure 11.B-9.

FIGURE 11.B-9. Condenser Off-Gas Treatment Process Flow Diagram for Reference Boiling Water Reactor Facility

- Building Ventilation

The reactor, radioactive waste, and turbine buildings have separate heating, ventilation, and air conditioning (HVAC) systems. Each system has supply and exhaust fans (a push-pull system) that provide once-through air flow with no recirculation during normal operation. Each

has the potential of releasing radioactive effluents. Release point data and locations are contained in Table 11.B-5 and in Figure 11.B-10.

TABLE 11.B-5. Airborne Effluent Release Point Data for Reference Boiling Water Reactor Facility

	<u>Reactor Building</u>	<u>Radioactive Waste Building</u>	<u>Turbine Generator Building</u>
Height of Release Point Above Grade, Meters	70.3	19.8	32.6
Average Air Release Rate, ℓ/min	2,690,000	2,320,000	7,530,000
Type and Size of Release Point, M	Duct 1.1 x 3.1 (cross sectional area)	3 Louver Houses 1.4 x 2.4 x 0.8	4 Exhaust Fan Ducts 1.5 x 2.0 (cross sectional area)

FIGURE 11.B-10. Plot Plan of Airborne Effluent Release Points from Reference Boiling Water Reactor Facility

A heating and ventilation unit, containing a roughing filter, a steam heating coil, an air washer and two supply fans (one standby) in that order, supplies outside air through distribution ductwork to the various reactor building areas. The sump vent exhaust filter system exhausts air from the equipment and/or floor drain system sumps and drain headers through a filter system prior to the main reactor building exhaust system. This filter system consists of a moisture separator, an electric heater, a prefilter, a HEPA filter, a charcoal adsorber, and a fan. The exhaust system, consisting of two full-capacity fans with one on standby, draws air from all areas with potential for radioactive contamination and discharges it to an elevated release point located on the reactor building roof.

The radioactive waste building air supply uses the same process as the reactor building. The exhaust system consists of three 50% capacity exhaust filter units each with a roughing filter, a HEPA filter and an exhaust fan. Only two of these units operate at any one time. The release point is located on the radwaste building roof.

The turbine generator building supply air system is composed of four supply ventilation units and distribution ductwork. The units, each composed of a roughing filter, a heating coil, a spray wash and one supply fan, operate in pairs. One pair discharges into a common supply duct system servicing the west side of the building, and the other pair supplies the east side. The sample room hood exhausts through a filter unit prior to discharge into the main turbine building exhaust system. The filter unit consists of a prefilter, a HEPA filter, and a fan. The exhaust system consists of four roof-mounted fans that draw air from a central exhaust duct system. One exhaust fan is on standby.

Each of the two control room supply systems consists of a filter, two water coils in series, an electric heater, and a fan. Each of two emergency filter system units, normally on standby, consists of a prefilter, a HEPA filter, a carbon adsorber filter, and a fan. Air is exhausted from the control room area by a single fan.

- Heat Dissipation System

The reference BWR uses circular mechanical draft cooling towers to dissipate the effluent heat. The cooling tower system is part of the closed-cycle cooling water system. The heat from the turbine exhaust steam is transferred to the closed cycle cooling water in the main condenser. The heated water passes to the cooling towers where the heat is transferred to the atmosphere by partial evaporation. This water, plus make-up water, is returned to the condenser.

11.B.4 BWR FACILITY AND SITE DESCRIPTION

This section summarizes the description of the site and the facility and its hardware. This information will be used as the primary basis for capital cost estimates, and as background for plant performance.

11.B.4.1 Site

The reference BWR plant is assumed to lie on the generic Site B described in Section 5. The plant itself requires an area of 0.12 km^2 within the larger plant site. The plant layout, shown in Figure 11.B-11, allows airborne effluents to emanate equidistant and 1 km away from three sides of the total rectangular site. It is assumed that a well-labeled perimeter fence exists around the total site to exclude the public, and another fence surrounds the smaller plant area, including a security entrance to the plant. The liquid effluents from the plant are assumed to be discharged onsite into the river flowing through one corner of the site.

11.B.4.2 BWR Facility

The reference facility is primarily based on the Washington Public Power Supply System (WPPSS) Nuclear Project No. 2 (WNP-2) with a net electrical output capacity of 1100 MWe. Construction of the facility began in 1973 and is expected to be completed in late 1979. Commercial operation is scheduled for 1980.

The reference facility requires about 0.12 km² (30 acres) of the total generic site for the structures and auxiliary facilities. These structures and facilities include the reactor building, radwaste building, turbine generator building, service building, diesel generator building, cooling tower system, spray ponds, condensate storage tanks, offices, parking lots and other outside equipment. The plant layout is shown in Figure 11.B-11.

The main complex of buildings contains the necessary equipment for generating electricity. Although the reactor building, radwaste building, diesel generator building, turbine generator building and service building are near each other, they are supported on separate concrete foundation mats, and are physically separated above and below grade for seismic and thermal considerations.

The BWR facility is expected to operate for 40 years.

The various process area descriptions are summarized in Table 11.B-6, and descriptions of the major process equipment are summarized in Table 11.B-7.

11.B.5 EFFLUENT CONTROL PERFORMANCE

The overall effluent control performance for radioactive effluents from the reference BWR facility is summarized in Table 11.B-8. Argon, krypton, xenon, iodine radioisotopes, and tritium and ¹⁴C comprise most of the radioactive airborne effluents. Tritium is the major radionuclide in liquid effluents. The basis for the noble gas releases given in Table 11.B-8 is a 30-min holdup and decay time yielding an overall release rate of 10⁵ μCi/sec.

The overall input of nonradioactive materials is given in Table 11.B-9. These are the materials used to treat the circulating water and service water.

The only nonradioactive effluents discharged from the powered facility are liquid effluents except for emission of airborne effluents from the diesel generators during emergency power generation. The airborne effluents are summarized in Table 11.B-10. The nonradioactive liquid effluents are summarized in Table 11.B-11.

The overall solid wastes from the reference facility are summarized in Table 11.B-12.

FIGURE 11.B-11. Layout of the Reference Boiling Water Reactor Facility

TABLE 11.B-6. Major Process Description - Reference
Boiling Water Reactor Facility

<u>Process Area</u>	<u>Approximate Overall Dimensions L x W x H, m</u>	<u>Perimeter Construction Material</u>	<u>Other Features</u>
Reactor Building	45 x 40 x 70	RC, SS	Seismic Cat. I
Radwaste Building	64 x 49 x 32	RC, SS	Seismic Cat. I (Partial)
Turbine Generator Building	91 x 58 x 42	RC, SS	Seismic Cat. I (Modified)
Service Building	84 x 25 x 10	RC, PC	NA
Diesel Generator Building	41 x 24 x 11	RC	Seismic Cat. I
Cooling Towers	61 dia. x 18 H	PC	6 towers
Circulating Water Pump House	NA	SS	NA
Electrical Building	12 x 15 x 5	SS	2 Buildings
Standby Service	18 x 9 x 8	RC	2 Pump Houses
Spray Ponds	76 x 76 x 5	RC	2 Ponds, Seismic Cat. I
Gas Bottle Storage Building	8 x 8 x 4	RC	NA
Condensate Storage Tank	12.6 dia. x 12 H	CS	2 each 1.5E6 l tanks, surrounded by 3.0E6 l concrete dike (Seismic Cat. I)
Guard House	18 x 15 x 5	SS	NA
Office Building	30 x 21 x 4	SS	NA
Warehouse	60 x 30 x 5	SS	NA

NA = Not available at this time

RC = Reinforced Concrete

SS = Structural Steel Frame with Metal Wall Panels

PC = Precast Concrete

CS = Carbon Steel

TABLE 11.B-7. Major Process Equipment Description -
Reference Boiling Water

Equipment	Location	No.	Size, m (each) L x W x H	Construction		Process Duty or Capacity	Other Features
				Material	Other		
Reactor Vessel	RB	1	22 m H, 6.4 m dia.	LAS	Clad inter- nally with SS	NA	Designed for 83 ATMg Contains Core, Steam Separator and Dryer, Jet Pumps
Dry Well	RB	1	30 m H	NA	NA	NA	NA
Suppression Chamber	RB	1	22 m H	NA	NA	NA	NA
Primary Containment Vessel	RB	1	26 m dia. at Base of Cone, 12 m dia. at Top of Cone	NA	NA	NA	Ellipsoidal Bottom Head inside height 6.6 m, Ellipsoidal Top Closure Head Inside Height 4.7 m
Spent Fuel Pool	RB	1	NA	NA	NA	NA	NA
Recirculation Pumps	RB	2	NA	NA	NA	178,700 ℓ /m @ 245 m TDH 11 MWe	NA
Turbine-Generator	TGB	1	NA	NA	NA	NA	NA
Moisture Separator and Reheaters (2-Stage Reheaters)	TGB	2	NA	NA	NA	NA	NA
Main Condenser	TGB	1	NA	NA	NA	NA	NA
Condensate Pumps	TGB	3	NA	NA	NA	NA	NA
Gland Seal Steam Condenser	TGB	1	NA	NA	NA	NA	NA
Steam-Jet Air Ejector	TGB	2	NA	NA	NA	18,800 ℓ /min @ 21°C 2.5 cm Hg	NA
Off-Gas Condenser	TGB	1	NA	NA	NA	NA	NA
Condensate Demineralizers	RWB	6	NA	NA	NA	NA	NA
Condensate Booster Pumps	TGB	3	NA	NA	NA	NA	NA
Feed Water Heaters	TGB	16	NA	NA	NA	NA	NA
Feed Water Pumps	TGB	2	NA	NA	NA	NA	NA
Circulating Water Pumps	CWP	3	NA	NA	NA	7.04E5 ℓ /min @ 29 m TDH	NA
Service Water Pumps	CWP	2	NA	NA	NA	79,500 ℓ /min @ 72 m TDH	NA
Effluent Collector Tank	RWB	1	NA	CS	NA	75,700 ℓ	NA
Effluent Collector Pump	RWB	1	NA	CI	NA	720 ℓ /min @ 47 m TDH	NA
Effluent Sample Tank	RWB	2	NA	CS	NA	75,700 ℓ	NA
Effluent Sample Pump	RWB	2	NA	CI	NA	720 ℓ /min @ 30 m TDH	NA
Effluent Surge Tank	RWB	1	NA	CS	NA	284,000 ℓ	NA
Effluent Surge Pump	TWB	1	NA	CI	NA	720 ℓ /min	NA
Floor Drain Collector Tank	RWB	1	NA	CS	NA	75,500 ℓ	NA
Floor Drain	RWB	1	NA	CI	NA	720	

TABLE 11.B-7. (cont'd)

Equipment	Location	No.	Size, m (each) L x W x H	Construction		Process Duty or Capacity	Other Features
				Material	Other		
Floor Drain Collector Pump	RWB	1	NA	CI	NA	720 l/min @ 47 m TDH	NA
Floor Drain Sample Tank	RWB	1	NA	CS	NA	75,700 l	NA
Floor Drain Sample Pump	RWB	1	NA	CI	NA	720 l/min @ 30 m TDH	NA
Detergent Drain Tank	TWB	2	NA	CS	NA	6060 l	NA
Detergent Effluent Pump	RWB	2	NA	CI	NA	102 l/min @ 27 m TDH	NA
Chemical Effluent Tank	RWB	2	NA	SS	NA	56,800 l	NA
Chemical Effluent Pump	RWB	2	NA	SS	NA	1080 l/min @ 61 m TDH	NA
Distillate Tank	RWB	2	NA	SS	NA	56,800 l	NA
Distillate Pump	RWB	2	NA	SS	NA	540 l/min @ 70 m TDH	NA
Effluent Collector Filter	RWB	1	NA	CS	NA	17 m ² of Filter Area	NA
Effluent col- lector Demineralizer	RWB	1	NA	CS	NA	1.8 m ³ resin bed	NA
Floor Drain Filter	RWB	1	NA	CS	NA	17 m ² of Filter Area	NA
Floor Drain Demineralizer	RWB	1	NA	CS	NA	1.8 m ³ Resin Bed	NA
Detergent Drain Filter	RWB	1	NA	CS	NA	95 l/min	NA
Decontamination Solution Concentrator	RWB	2	NA	SS/CS	NA	38 l/min	NA
Off-Gas Preheater	RWB	2	NA	SS Tubes	NA	NA	24 ATMg Shell 68 MTMg Tube 204°C Shell 302 °C Tube
Catalytic Recombiners	RWB	2	NA	CS	NA	NA	24 ATMg 482°C
Off-Gas Condenser	RWB	1	NA	LAS Shell	NA	NA	24 ATMg Shell 17 ATMg Tube 482°C
Water Separator	RWB	1	NA	CS Shell SS Wire Mesh	NA	NA	24 ATMg 121°C
10-Minute Holdup Piping	RWB	1	NA	CS	NA	NA	24 ATMg, with ends and Elbows 71 ATMg 54°C
Cooler-Condensers	RWB	2	NA	CS or SS Shell SS Tubes	NA	NA	7 ATMg Tube 24 ATMg Shell 66°C Tube 0°C/66°C Shell
Moisture Separators	RWB	2	NA	CS Shell SS Wire Mesh	NA	NA	24 ATMg 0°C/66°C
Desiccant Dryers	RWB	4	NA	CS	NA	NA	24 ATMg 0°C/260°C
Desiccant Regenera- tion Skids	RWB	2	NA	NA	NA	NA	NA

TABLE 11.B-7. (cont'd)

Equipment	Location	No.	Size, m (each) L x W x H	Construction		Process Duty or Capacity	Other Features
				Material	Other		
Glycol Cooled Gas Chillers	RWB	2	NA	CS Shell SS Tubes	NA	NA	3.4 ATMg 0°C/260°C
Gas Blowers	RWB	2	NA	NA	NA	NA	3.4 ATMg
Gas Heaters	RWB	2	NA	NA	NA	NA	3.4 ATMg
Gas Coolers	RWB	4	NA	CS	NA	NA	71 ATMg
Glycol Cooler Skid	RWB	1	NA	NA	NA	NA	NA
Glycol Storage Tank	RWB	1	NA	CS	NA	11,400 L	0°C
Glycol Solution Refrigerator and Motor Drive	RWB	3	NA	NA	NA	NA	NA
Glycol Pump and Motor Drive	RWB	3	NA	CI	NA	NA	-18°C
Prefilters and After Filters	RWB	2 of Each Type	NA	CS Shell Moisture-Resistant Filter Element		NA	24 ATMg -46°C/66°C
Carbon Bed Adsorbers	RWB	8 Beds	1.2 dia. 6.4 H	CS	NA	2700 kg 8-14 mesh Activated Carbon (5.7 m ³)	24 ATMg -46°C/121°C
Charcoal Vault Refrigeration Units	RWB	2	NA	NA	NA	1.3E + 8 Cal/hr	-40°C

Key: RB = Reactor building
 TGB = Turbine generator building
 CWP = Circulating water pumphouse
 RWB = Radwaste building
 LAS = Low-alloy steel
 CS = Carbon steel
 CI = Cast iron
 TDH = Total dynamic heat
 NA = Not available at this time

TABLE 11.B-8. Overall Radioactive Materials Input/Output
for the Reference Boiling Water Reactor
Facility

Material	Total Material ^(b)		Form		Fraction of ^(d) Plant Input
	Elemental kg/day	Ci/day	Chemical	Phase	
<u>Input to Plant</u>					
Uranium ^(a) in Fuel Assemblies	84	.11	UO ₂	S	(1)
<u>Output from Plant</u>					
Spent Fuel in Fuel Assemblies	NA	NA	NA	S,G	(1)
<u>Airborne Effluents</u>					
⁴¹ Ar	2.0E-12	8.6E-2	Ar	G	(c)
^{83m} Kr	1.7E-12	3.4E-3	Kr	G	(c)
^{85m} Kr	3.1E-11	2.6E-1	Kr	G	(c)
⁸⁵ Kr	2.4E-6	9.2E-1	Kr	G	(c)
⁸⁷ Kr	2.4E-11	6.8E-1	Kr	G	(c)
⁸⁸ Kr	6.5E-11	8.2E-1	Kr	G	(c)
⁸⁹ Kr	5.2E-15	3.4E-3	Kr	G	(c)
^{131m} Xe	2.0E-10	1.7E-2	Xe	G	(c)
^{133m} Xe	7.9E-11	3.4E-3	Xe	G	(c)
¹³³ Xe	5.0E-8	9.2	Xe	G	(c)
^{135m} Xe	2.8E-11	2.6	Xe	G	(c)
¹³⁵ Xe	1.5E-9	3.8	Xe	G	(c)
¹³⁷ Xe	9.7E-15	3.4E-3	Xe	G	(c)
¹³⁸ Xe	6.0E-11	4.8	Xe	G	(c)
¹³¹ I	1.3E-11	1.6E-3	I	S	(c)
¹³³ I	5.2E-12	5.8E-3	I	S	(c)
⁵¹ Cr	4.8E-13	4.5E-5	NA	S	(c)
⁵⁴ Mn	1.8E-12	1.4E-5	NA	S	(c)
⁵⁹ Fe	7.7E-14	3.8E-6	NA	S	(c)
⁵⁸ Co	1.4E-13	4.5E-6	NA	S	(c)
⁶⁰ Co	3.9E-11	4.5E-5	NA	S	(c)
⁶⁵ Zn	9.1E-13	7.5E-6	NA	S	(c)

TABLE 11.B-8. (cont'd)

Material	Total Material ^(b)		Form		Fraction of ^(d) Plant Input
	Elemental kg/day	Ci/day	Chemical	Phase	
<u>Airborne Effluents</u>					
⁸⁹ Sr	7.4E-13	2.1E-5	NA	S	(c)
⁹⁰ Sr	6.8E-13	9.6E-8	NA	S	(c)
⁹⁵ Zr	8.1E-14	1.7E-6	NA	S	(c)
¹²⁴ Sb	9.8E-14	1.7E-6	NA	S	(c)
¹³⁴ Cs	1.2E-11	1.5E-5	NA	S	(c)
¹³⁶ Cs	1.7E-14	1.2E-6	NA	S	(c)
¹³⁷ Cs	2.5E-10	2.2E-5	NA	S	(c)
¹⁴⁰ Ba	5.2E-13	3.8E-5	NA	S	(c)
¹⁴¹ Ce	9.3E-14	2.6E-6	NA	S	(c)
³ H	2.4E-8	2.3E-1	NA	G,L	(c)
¹⁴ C	7.0E-6	3.1E-2	NA	G	(c)
<u>Liquid Effluents</u>					
²⁴ Na	2.9E-16	2.6E-6	NA	NA	(c)
³² P	3.6E-16	1.0E-7	NA	NA	(c)
⁵¹ Cr	2.9E-14	2.6E-6	NA	NA	(c)
⁵⁴ Mn	3.9E-15	3.1E-8	NA	NA	(c)
⁵⁶ Mn	1.3E-16	2.8E-6	NA	NA	(c)
⁵⁵ Fe	2.2E-13	5.5E-7	NA	NA	(c)
⁵⁹ Fe	3.2E-16	1.6E-8	NA	NA	(c)
⁵⁸ Co	3.4E-15	1.1E-7	NA	NA	(c)
⁶⁰ Co	1.9E-13	2.2E-7	NA	NA	(c)
⁶⁵ Ni	8.2E-19	1.6E-8	NA	NA	(c)
⁶⁴ Cu	2.1E-15	7.9E-6	NA	NA	(c)
⁶⁵ Zn	1.3E-14	1.1E-7	NA	NA	(c)
^{69m} Zn	1.7E-16	5.5E-7	NA	NA	(c)
⁶⁹ Zn	1.2E-17	5.8E-7	NA	NA	(c)

TABLE 11.B-8. (cont'd)

Material	Total Material ^(b)		Form		Fraction of ^(d) Plant Input
	Elemental kg/day	Ci/day	Chemical	Phase	
<u>Liquid Effluents</u>					
¹⁸⁷ W	1.5E-16	1.1E-7	NA	NA	(c)
²³⁹ Np	1.3E-14	3.1E-6	NA	NA	(c)
⁸³ Br	9.2E-18	1.4E-7	NA	NA	(c)
⁸⁴ Br	1.7E-19	1.2E-8	NA	NA	(c)
⁸⁹ Rb	6.0E-19	8.2E-8	NA	NA	(c)
⁸⁹ Sr	1.9E-15	5.5E-8	NA	NA	(c)
⁹¹ Sr	2.4E-16	8.6E-7	NA	NA	(c)
⁹² Sr	4.6E-17	5.8E-7	NA	NA	(c)
^{91m} Y	1.3E-17	5.5E-7	NA	NA	(c)
⁹¹ Y	1.1E-15	2.7E-8	NA	NA	(c)
⁹² Y	1.3E-16	1.2E-6	NA	NA	(c)
⁹³ Y	2.7E-16	8.9E-7	NA	NA	(c)
⁹⁸ Nb	8.0E-19	3.1E-8	NA	NA	(c)
⁹⁹ Mo	1.9E-15	9.2E-7	NA	NA	(c)
^{93m} Tc	6.5E-16	3.4E-6	NA	NA	(c)
¹⁰¹ Tc	5.9E-20	7.9E-9	NA	NA	(c)
¹⁰⁴ Tc	2.3E-19	2.3E-8	NA	NA	(c)
¹⁰³ Ru	3.6E-16	1.2E-8	NA	NA	(c)
¹⁰⁵ Ru	3.2E-17	2.2E-7	NA	NA	(c)
^{103m} Rh	3.6E-19	1.2E-8	NA	NA	(c)
^{105m} Rh	9.2E-20	2.2E-7	NA	NA	(c)
¹⁰⁵ Rh	8.6E-17	7.2E-8	NA	NA	(c)
^{129m} Te	6.6E-16	2.0E-8	NA	NA	(c)
¹²⁹ Te	5.5E-19	1.2E-8	NA	NA	(c)
^{131m} Te	4.7E-17	3.8E-8	NA	NA	(c)
¹³¹ Te	1.4E-19	7.9E-9	NA	NA	(c)

TABLE 11.B-8. (cont'd)

Material	Total Material ^(b)		Form		Fraction of ^(d) Plant Input
	Elemental kg/day	Ci/day	Chemical	Phase	
<u>Liquid Effluents</u>					
¹³² Te	1.2E-17	3.8E-9	NA	NA	(c)
¹³¹ I	2.0E-14	2.5E-6	NA	NA	(c)
¹³² I	1.3E-16	1.3E-6	NA	NA	(c)
¹³³ I	5.8E-15	6.5E-6	NA	NA	(c)
¹³⁴ I	2.0E-17	5.5E-7	NA	NA	(c)
¹³⁵ I	8.9E-16	3.1E-6	NA	NA	(c)
¹³⁴ Cs	2.2E-12	2.9E-6	NA	NA	(c)
¹³⁶ Cs	2.5E-14	1.8E-6	NA	NA	(c)
¹³⁷ Cs	7.9E-11	6.8E-6	NA	NA	(c)
¹³⁸ Cs	6.7E-17	2.8E-6	NA	NA	(c)
^{137m} Ba	1.1E-17	6.2E-6	NA	NA	(c)
¹³⁹ Ba	1.3E-17	2.1E-7	NA	NA	(c)
¹⁴⁰ Ba	2.8E-15	2.1E-7	NA	NA	(c)
¹⁴⁰ La	8.0E-17	4.5E-8	NA	NA	(c)
¹⁴¹ La	1.1E-17	6.5E-8	NA	NA	(c)
¹⁴² La	9.8E-18	1.4E-7	NA	NA	(c)
¹⁴¹ Ce	5.6E-16	1.6E-8	NA	NA	(c)
¹⁴³ Ce	1.8E-17	1.2E-8	NA	NA	(c)
¹⁴³ Pr	2.9E-16	2.0E-8	NA	NA	(c)
³ H	4.2E-9	4.1E-2	NA	NA	(c)
<u>Solid Wastes</u>					
⁵¹ Cr	2.4E-9	2.2E-1	NA	S	(c)
⁵⁸ Co	1.5E-7	4.8	NA	S	(c)
⁶⁰ Co	1.0E-6	1.2	NA	S	(c)
⁸⁹ Sr	6.5E-8	1.8	NA	S	(c)
⁹⁰ Sr	3.0E-6	4.2E-1	NA	S	(c)

TABLE 11.B-8. (cont'd)

Material	Total Material ^(b)		Form		Fraction of ^(d) Plant Input
	Elemental kg/day	Ci/day	Chemical	Phase	
Solid Wastes					
⁹⁹ Mo	1.3E-10	6.3E-2	NA	S	(c)
¹³¹ I	2.6E-9	3.2E-1	NA	S	(c)
¹³³ I	5.6E-11	6.4E-2	NA	S	(c)
¹³⁴ Cs	2.1E-7	2.7E-1	NA	S	(c)
¹³⁷ Cs	5.1E-6	4.4E-1	NA	S	(c)
¹⁴⁰ Ba	6.5E-9	4.8E-1	NA	S	(c)
²³⁹ Np	1.1E-9	2.5E-1	NA	S	(c)

Plutonium losses to solid wastes, airborne effluents, and liquid effluents, are estimated to be $<9 \times 10^{-6}$ kg/day (<0.14 Ci/day).^(e)

Uranium losses to solid wastes, airborne effluents and liquid effluents, are estimated to be $<2 \times 10^{-3}$ kg/day (<20.7 Ci/day).^(f)

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

(a) Uranium is enriched to 3.2% ²³⁵U.

(b) Values based upon one day operating at 100% capacity.

(c) This material does not enter the plant in this chemical form.

(d) Numbers in parentheses are not released to the environment.

(e) The total ¹³⁷Cs released in the airborne effluents, the liquid effluents, and the solid wastes from the reference BWR is calculated to be 5.1×10^{-6} kg ¹³⁷Cs/day or about 6.5×10^{-8} fraction of the average ¹³⁷Cs present in the reactor. Per Reference 11, the cumulative plutonium fraction leached after 616 days is approximately 0.2 that of ¹³⁷Cs. Thus the plutonium loss is estimated to be $6.5 \times 10^{-8} \times 0.2 = 1.3 \times 10^{-8}$ fraction of the average plutonium present in the reactor. This is equal to the release of 9.4×10^{-6} kg Pu/day.

(f) The total ¹³⁷Cs released is the same as in footnote (e) above. The cumulative uranium fraction leached after 616 days is assumed to be the same as the plutonium which is approximately 0.2 that of ¹³⁷Cs. Thus the uranium loss is then estimated to be $6.5 \times 10^{-8} \times 0.2 = 1.3 \times 10^{-8}$ fraction of the total uranium present in the reactor. This is equal to the release of 1.6×10^{-3} kg uranium/day.

TABLE 11.B-9. Overall Nonradioactive Materials Input to the Reference Boiling Water Reactor Facility

Material	Total Material (a)		Chemical	Form Phase	Density	Other	kg/day as 100%	Purpose
	kg/day	g/day						
Sulfuric Acid	7.5E2-1.5E3	NA	H ₂ SO ₄	L	NA	--	NA	Control of pH in cooling water and regeneration of make-up water demineralizer
Chlorine	1.1E2	3.4E4	Cl ₂	G	3.2 g/l	--	110	Prevention of biological growth
Sodium Hydroxide	6	2.8	NaOH	S	2.1 g/ml	--	6	Make-up water demineralizer regeneration
Alum	0.1	NA	NA	S	NA	--	0.1	Clarification of primary make-up water

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

(a) Values based on one day operating at 100% capacity.

TABLE 11.B-10. Overall Nonradioactive Airborne Effluents from Reference Boiling Water Reactor Facility

<u>Materials</u>	<u>Form</u>		<u>Output^(a)</u> <u>kg/day</u>
	<u>Chemical</u>	<u>Phase</u>	
Calcium	Ca ⁺²	NA	1.8E2
Magnesium	Mg ⁺²	NA	33
Sodium	Na ⁺¹	NA	19
Bicarbonate	HCO ₃ ⁻¹	NA	1.4E2
Chloride	Cl ⁻	NA	7.8
Sulfate	SO ₄ ⁻²	NA	3.7E2
Nitrate	NO ₃ ⁻¹	NA	1.9
Phosphate	PO ₄ ⁻³	NA	9.3E-2
Silica	SiO ₂	S	47
Sulfur Oxides	SO _x	G	2.5E4
Nitrogen Oxides	NO _x	G	2.7E4
Hydrocarbons	H _x C _y	NA	1.9E2
Nonradioactive Particulate	NA	S	6.1E2
Chlorine	Cl ₂	G	5.4

Key: S = Solid
L = Liquid
G = Gas
NA = Not available at this time

(a) Values based upon one day operating at 100% of capacity.

TABLE 11.B-11. Overall Nonradioactive Liquid Effluents from the Reference Boiling Water Reactor Facility

<u>Materials</u>	<u>Chemical</u>	<u>Form</u>		<u>Output^(a) kg/day</u>
		<u>Phase</u>	<u>Other</u>	
Calcium	Ca ⁺²	L,S	--	1.6E3
Magnesium	Mg ⁺²	L,S	--	3.0E2
Sodium	Na ⁺	L	--	1.7E2
Bicarbonate	HCO ₃ ⁻	L	--	1.3E3
Sulfate	SO ₄ ⁻²	L,S	--	3.3E3
Chloride	Cl ⁻	L	--	71
Nitrate	NO ₃ ⁻	L	--	17
Phosphate	PO ₄ ⁻	L	--	0.8
Chlorine	Cl ₂	G	--	0.7

Key: S = Solid

L = Liquid

G = Gas

NA = Not available at this time

(a) Values based upon one day operating at 100% capacity.

TABLE 11.B-12. Overall Solid Wastes from the Reference Boiling Water Reactor Facility

<u>Waste Material</u>	<u>Form</u>	<u>Package</u>	<u>Total^(a) L/day</u>
<u>Radioactive</u>			
Backwash Sludge	Wet Slurry	1416 L Shipping	9.6E2
Spent Resins			
Dry Waste	Rags, Paper, Small Equipment Parts, Solid Lab Wastes, Air Filters, etc.	208 L Drum	1.8E2
<u>Nonradioactive</u>			
Miscellaneous Waste	Rags, Grease, Oil Used Creating Lumber, Packing Boxes and Materials, Wornout Equipment Pieces, Damaged Stock Items, etc.	NA	NA

NA = Not available at this time

(a) Values based upon one day operating at 100% capacity.

11.B.6 FACTORS FOR OPERATING COST ESTIMATION

The basic plant operational requirements are given in this section to provide information for later estimation of direct operating costs.

11.B.6.1 Labor Requirements

The reference BWR plant is assumed to operate 24 hr/day, 7 days/wk for 292 days/yr (0.80 operating factor). Operating the reference plant is estimated to require approximately 170 full-time employees⁽¹⁰⁾ functioning in four main groups: operations, maintenance, technical support and health physics. About 35 employees are management, supervisory or professional personnel and about 135 are skilled or unskilled labor.

11.B.6.2 Material Requirements

The chemical material requirements for the reference BWR plant were identified in Table 11.B-9. The packaging material for offsite disposal of the solid waste is estimated at approximately 200 1400-l (50 ft³) containers per year for highly radioactive wastes and 250 208-l (55 gal) drums per year for low-radioactivity wastes. Small amounts of miscellaneous materials such as office materials, routine maintenance materials, etc., will also be required.

Following an initial operating period of about 1 to 1.5 years, approximately 20% of the reactor fuel will be replaced with new fuel each year.

11.B.6.3 Unusual Maintenance Requirements

Some equipment will require replacement and/or major repairs periodically. These special requirements are currently unknown.

11.B.6.4 Utility Requirements

Total estimated utility requirements for the BWR plant operating at full capacity are:

- Water: 8.4E7 kg/day
- Electricity: 5.0E4 kW-day/day

11.B.6.5 Transportation Requirements

All the plant materials, fuel assemblies, and output waste items must be transported to and/or from the site. Typical transport distances are not provided in this report.

11.B.6.6 Waste Disposal Requirements

The spent fuel is removed from the reactor and is assumed to be shipped to a fuel reprocessing plant in this study. The solid wastes are shipped offsite for ultimate disposition in approved repositories. The nonsalvagable nonradioactive wastes are assumed to be taken to a nearby landfill. Salvagable materials are shipped offsite for reuse.

11.B.6.7 Other Operating Cost Elements

Certain major operating cost elements are assumed to be performed by outside contractors. Laundering of noncontaminated and radioactive work clothing is assumed to be contracted. Also, transport of materials, disposal of radioactive wastes and disposal of nonradioactive wastes are assumed to be performed by outside contractors.

Other known special operating cost elements are the licensing and insurance costs associated with operating the reference reactor.

11.B.7 ENVIRONMENTAL IMPACT FACTORS

A summary of the overall direct environmental impact factors for the reference boiling water reactor facility is given in Table 11.B-13. These quantities are those used directly at the plant. Impacts of resources required for material input or output beyond the plant boundary are not included.

TABLE 11.B-13. Overall Environmental Impacts - Reference
Boiling Water Reactor Facility

	<u>Quantity</u>	<u>Remarks</u>
Total Land Committed	4.7 km ²	Fenced-in Area
Land Actually Used for Plant	0.12 km ²	High-Security Area
Water Used	8.4E7 kg/day	
Water Discharged as Liquid Effluent	1.4E7 kg/day	
Total Materials Added to Liquid Effluents	3.5E3 kg/day	
Air Used	2.2E5 kg/day	1.8E5 m ³ /day
Water Discharged as Airborne Effluent	7.0E7 kg/day	
Total Other Airborne Effluents	5.4E4 kg/day	
Electrical Energy Consumption	5.0E4 kW-day/day	Auxiliary Power for Plant Systems
Thermal Effluent Equivalent	2.2E6 kW-day/day	
Resource Use	See Table 11.B-9	

11.B.8 LIMITATIONS AND UNCERTAINTIES IN THE STUDY INFORMATION

Pertinent information concerning the overall effluent treatment system performance was not obtained in readily obtainable and usable format for this study. Final performance evaluations for the airborne and liquid effluent treatment systems were not made due to the lack of directly available input and output information. The information in this report is that readily available from documents for licensing of the reference reactor. Extrapolation and conversion of the available data for this format is necessary for completeness in this study. Other data sources are also likely to be available.

11.B.9 RESEARCH AND DEVELOPMENT NEEDS

Additional effort and information would be helpful for analyzing the performance of the airborne effluent processes other than the condenser off-gas treatment system. The airborne release data given in the licensing documents are based on measurements at similar operating plants. Additional system performance analysis data are required. These data relate primarily to the inventory of the airborne materials available for release from the various building release points.

Evaluation of alternative control processes for reducing the emission of the radioactive noble gases, iodine, tritium, and ¹⁴C may be beneficial.

SECTION 11: REFERENCES

1. Trojan Nuclear Plant, Environmental Report. U.S.A.E.C., Docket No. 50-344-23, November 1971.
2. Trojan Nuclear Plant, Final Safety Analysis Report. Portland General Electric Company, Docket No. 50-344, February 1977.
3. Trojan Nuclear Plant, Final Environmental Statement. U.S.A.E.C., Docket No. 50-344-66, August 1973.
4. Trojan Nuclear Plant, License Application, FSAR, Amendment 29. Portland General Electric Company, Docket No. 50-344-282, June 1976.
5. Trojan Nuclear Plant, Facility Operating License No. NPF-1. Appendix B, Environmental Technical Specifications, U.S.N.R.C., Docket No. 50-344, November 1975.
6. G. R. Bray, C. L. Miller, and J. W. Rieke, Assessment of ^{14}C Control Technology and Costs for the LWR Fuel Cycle. prepared for EPA by Science Applications, Inc., SAI 76-593-WA, October 4, 1976.
7. Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Pressured Water Reactors (PWR-GALE Code). U.S. Nuclear Regulatory Commission, NUREG-0017, April 1976.
8. WPPS Nuclear Project No. 2, Final Safety Analysis Report. U.S. NRC Docket No. 50-397, March 1977.
9. WPPS Nuclear Project No. 2, Environmental Report. Operating License Stage, U.S. NRC Docket No. 50-397, February 1977.
10. Energy Quarterly, October 14, 1977, p. 2.
11. Y. B. Katayama and J. E. Mendel, Leaching of Irradiated LWR Fuel Pellets in Deionized Water, Sea Brine, and Typical Ground Water. PNL-SA-6416, December 1977.

12.0 FUEL REPROCESSING

The purpose of a fuel reprocessing facility is to separate, purify, and prepare for recycle the uranium and plutonium present in the irradiated fuel elements discharged from nuclear reactors. The reference LWR fuel reprocessing facility selected for this study is representative of current technology and is modeled after an essentially completed commercial scale facility that is undergoing pre-startup testing.

The reference facility is based primarily on Allied-General Nuclear Services (AGNS) Barnwell Nuclear Fuels Plant (BNFP), located near Barnwell, South Carolina. The plutonium product facility in the reference facility is conceptual because the plutonium product facility is still in the planning stage at Barnwell, pending resolution of current uncertainties regarding the use of mixed plutonium and uranium oxide fuels.

The overall characteristics and bases for the reference LWR fuel reprocessing facility include the following:

- One facility, two feeds of spent fuel (enriched uranium dioxide and mixed oxide, both from LWRs) and two basic products (PuO_2 and UF_6).
- A single reference facility is assumed, that is capable of reprocessing spent LWR fuel at 1500 MTHM/year charged to the reactor. Plutonium and uranium are separated from the spent fuel, purified, and converted to PuO_2 and UF_6 , which are stored in product shipping containers.
- The facility is to receive spent LWR fuel from commercial BWRs and PWRs.
- The facility is assumed to operate at full capacity, 5 MTHM/day, for 300 days/yr and 24 hr/day for 40 yr.
- It is assumed that the reference facility can accommodate spent LWR fuel with an initial enrichment of up to 5% ^{235}U or Pu equivalent.

12.1 SUMMARY

The reference fuel reprocessing facility is designed to receive and store spent LWR uranium and mixed oxide fuels. The uranium and plutonium from five metric tons of fuel can be recovered each 24-hr operating day.

The fuel is mechanically declad, dissolved in nitric acid, and the fission product and transplutonic element contaminants are separated from the fuel materials by a liquid-liquid solvent extraction process. Plutonium and uranium are separated from each other and purified as nitrate solutions. The plutonium is then converted to the solid oxide form, utilizing an oxalate precipitation process followed by calcination. The plutonium is then shipped offsite, in this study, where it is available for fabrication into mixed oxide fuel elements. The uranium is converted successively to the oxide, to the fluoride, and then "burned" to the hexafluoride in a fluorine reactor. The UF_6 is then ready for recycle to a re-enrichment facility before reuse in a nuclear power system.

Liquids containing small amounts of radioactivity are vaporized for release as an airborne effluent. The airborne effluent has received extensive prior treatment to minimize the release of radioactive materials. The noble gases and the water containing most of the tritium in the spent fuel are released directly to the atmosphere with no treatment. Airborne effluents contain all of the krypton, xenon, and ^{14}C , about 70% of the tritium as the oxide, and less than 3% of the radioiodine within the original fuel. Less than 2E-8% (two trillionths) of the other fission products, less than 0.003% of the uranium, and less than 9E-8% (nine trillionthss) of the plutonium in the spent fuel to be processed are also released in the airborne effluents.

The predominant nonradioactive airborne effluents emanating from the processing are 2.4E6 kg/day of water and 2000 kg/day of mixed oxides of nitrogen. Totals of 2.0E5 kg/day of carbon dioxide and 390 kg/day of sulfur dioxide are among the contaminants released from the combustion of fossil fuels for onsite generation of heat. Among the compounds released in lesser amounts from the plant stacks are 67 kg/day of carbon monoxide, 22 kg/day of hydrogen sulfide, 7 kg/day of hydrogen fluoride, 1 kg/day of ammonia and 89 kg/day of hydrogen.

No radioactive materials of process origin are released in the liquid effluent. Nonradioactive contaminants discharged in the liquid effluent amount to about 1600 kg/day.

The liquid wastes, which contain essentially all of the fission products and the transplutonium elements as well as about 0.8% of the plutonium and 1% of the uranium from the spent fuel are stored in water-cooled tanks for an undefined period (no more than 5 years) before they are solidified for transfer to a federally designated repository. This waste solidification facility does not yet exist at the reference plant and is not part of the reference plant in this study. Solid wastes (containing about 0.2% of the uranium), which include the fuel cladding materials, general process trash, failed equipment, and radioiodine removal waste, are packaged and temporarily stored onsite pending decisions regarding their ultimate disposition.

The reference reprocessing plant occupies 0.3 km^2 of the total reference generic site B (4.7 km^2) described in Section 5. The plant uses 15,000,000 kg/day of water, 12,000 kW-days/day of electricity and dissipates 67,000 kW-days/day of heat to the environment.

While detailed operational information on this particular plant is not yet available, reprocessing technology is over 33 years old and is continually evolving in government-owned facilities in the United States and in foreign countries. Alternative processes that might be considered need the confidence obtained from demonstrations to provide a solid basis for extrapolation.

12.2 MAINLINE PROCESS DESCRIPTION OF THE REFERENCE LWR FUEL REPROCESSING FACILITY

The mainline process used can be divided into four main categories: 1) the process by which the uranium and plutonium are recovered in highly purified nitrate solutions, 2) the process by which the purified uranium is converted from nitrate solution to uranium hexafluoride, 3) the process by which the purified plutonium is converted from nitrate solution to plutonium dioxide, and 4) the waste management process. The first and last processes are performed in the main separations facility, the second process is performed in the UF_6 facility and the third process in the plutonium product facility.

The reference facility receives fuel elements; these are processed by shearing them into short sections to expose the fuel, dissolving the fuel in nitric acid, and recovering the uranium and plutonium in highly purified

nitrate solutions by solvent extraction operations. The uranium nitrate is converted to uranium hexafluoride by calcining to UO_3 , reducing to UO_2 , hydrofluorinating to UF_4 , and fluorinating to UF_6 . The plutonium nitrate is converted to plutonium dioxide by precipitating plutonium (IV)-oxalate which is then calcined to PuO_2 . A simplified flow diagram of these processes is shown in Figure 12-1.

12.2.1 Description of Mainline Process Steps

The reference reprocessing facility uses the Purex recovery process, which has been in large-scale use for over 20 yr and is currently used, with minor variations, by most reprocessing plants now operating throughout the world. A detailed overall process flow sheet is presented in Figure 12-2, which can be referred to for the remaining descriptions of this section.

- Fuel Assembly Receiving

The irradiated fuel assemblies arrive at the facility in shielded casks. The cask and carrier are monitored for outside radioactive contamination to determine if any leakage has occurred, and are washed to remove outside road dirt. The cask is removed from the carrier and vented, and the fuel-containing cavity is flushed to remove radioactive contaminants dislodged during transit that would unnecessarily contaminate the fuel storage pool.

- Fuel Assembly Storage

The cooled cask is moved by the cask handling crane to the cask unloading pool (CUP). The head bolts are loosened before lowering to the pool bottom. The top of the cask is opened and the contained fuel is removed under water and placed in storage canisters. These canisters are moved to the fuel storage pool (FSP) for retention until the fuel is scheduled for reprocessing.

- Fuel Assembly Shearing and Dissolution

The fuel assemblies are remotely transferred from the storage pool to the feed mechanism of the mechanical bundle type shear after a full processing lot has been accumulated. Here a fuel assembly is chopped

FIGURE 12-1. Overall Mainline Processes for the Fuel Reprocessing Plant

FIGURE 12-2. Mainline Process Flow Diagram for the Reference Fuel Reprocessing Facility

into segments 5 to 12 cm long to expose the fuel to the dissolvent. The fuel segments fall into the dissolver containing hot 3 to 8M nitric acid (and a small concentration of gadolinium nitrate, which serves as a neutron poison). The acid dissolves virtually all the uranium, plutonium, and fission products.

The undissolved cladding materials and accompanying hardware of stainless steel or Zircaloy remain in the dissolver basket. The dissolver solution is centrifuged to remove fine solids, which are sent to the high-level waste storage system after washing and slurrying from the centrifuge. The clarified dissolver solution is transferred to tanks to be sampled for accountability; the acid concentration is adjusted to 2 to 3M nitric acid before the solution is fed to the solvent extraction process. The cladding hulls are rinsed with dilute nitric acid, monitored for residual fissile material, packaged in the remote maintenance and scrap cell, and transferred to the interim underground waste storage area.

- Solvent Extraction, Partitioning, and Stripping of Plutonium and Uranium

After acid adjustment, the feed solution is sent to the first solvent extraction cycle where it is contacted countercurrently in a 10-stage centrifugal contactor with a solution of tributyl phosphate (30% TBP) in normal paraffin hydrocarbon diluent (dodecane). The lighter organic solution preferentially extracts the tetravalent plutonium and hexavalent uranium, leaving about 98% of the fission products in the aqueous solution.

The organic solution from the centrifugal contactor passes through a pulsed scrub column where a 3M aqueous nitric acid solution removes about 98% of the remaining fission products and is recycled back to the centrifugal contactor. The final aqueous solution leaving the centrifugal contactor contains about 99.9% (or more) of the fission products, essentially all of the transplutonium elements and about 0.5% of the uranium and plutonium; it is then sent to a high-level waste concentrator.

The organic solution from the pulsed scrub column is then joined by organic raffinates (used organic streams) from the plutonium purification sections and passes through a partitioning column where tetravalent plutonium is electrochemically reduced to the less extractable trivalent state. This extractability change enables the plutonium to be stripped into an aqueous nitric acid solution containing hydrazine as a holding chemical reductant, all within the same electrochemical device. The organic uranium-containing solution passes through the final first cycle pulsed column where the uranium is stripped into acidified water (about 0.01M HNO_3).

- Second Uranium Solvent Extraction and Concentration

The aqueous strip solution containing the uranium is concentrated from 0.3M to 1.5M uranium and adjusted to about 2M nitric acid. It is then sent to the second uranium solvent extraction cycle where it is preferentially extracted by another 30% TBP organic solution in a pulsed column. Before leaving the column, the organic solution is scrubbed with nitric acid solution, which removes additional fission products. Hydroxylamine nitrate and hydrazine are also added to the scrub solution to remove residual plutonium by chemical reduction to the less extractable trivalent state.

Uranium is stripped from the organic solution in the subsequent pulsed column, using acidified water (0.01M nitric acid). This solution is concentrated in an evaporator from 0.4M uranium to 1.5M uranium. Finally, the concentrated uranium solution from the second cycle is passed through silica gel beds, if necessary, to remove residual traces of the fission products zirconium-niobium. Uranyl nitrate product solution is analyzed on a batch basis and piped to the separate onsite facility for conversion to UF_6 .

- Second Plutonium Solvent Extraction

Plutonium in the aqueous stream leaving the partitioning column in the first cycle is reoxidized to the extractable tetravalent state with nitrogen dioxide or sodium nitrite and sent to the second plutonium solvent extraction cycle. Here it is preferentially extracted into

30% TBP organic solution in another pulsed extraction column. In the top portion of the same column, the organic stream is scrubbed with 1.0M nitric solution to remove most of the residual extracted fission products. The organic product stream then passes through a strip column where tetravalent plutonium is transferred to an aqueous stream of dilute (0.3M) nitric acid.

- Third Plutonium Solvent Extraction and Concentration

The extraction-scrubbing sequence is repeated in a third plutonium cycle for further removal of fission products. To effect a higher plutonium product concentration, the plutonium is chemically reduced in the third strip column by hydroxylamine nitrate to the trivalent state to allow it to be more readily stripped into the aqueous phase. A TBP-organic scrub solution is added to remove residual uranium from the plutonium aqueous stream as it leaves this third strip column. The plutonium nitrate solution is washed with organic diluent to remove traces of TBP.

Final plutonium nitrate solution concentration from 60 g/l to 200 g/l is accomplished in a concentrator made of titanium. The plutonium product solution is analyzed and stored in thin slab-shaped tanks (to prevent nuclear criticality reaction) until it is transferred to the plutonium product facility (PPF) for conversion to PuO_2 .

- Solvent Cleanup and Recovery

The organic solvent stream from the first (partition) cycle is washed successively with dilute aqueous solutions of sodium carbonate, nitric acid, and sodium carbonate to remove organic degradation products by extraction or precipitation. Precipitated solids are removed by filtration. Fresh TBP or diluent is added (as required) to maintain the 30% TBP concentration and the total solvent inventory. The solvent is then reused in the first cycle and in the plutonium cycles. The organic solvent stream from the second uranium cycle is treated similarly, except the second alkaline wash is omitted. This solvent is kept in a separate system.

- Secondary Product Recovery by Solvent Extraction

The aqueous waste (raffinate) streams from the plutonium and uranium cycles are treated with nitrogen dioxide or sodium nitrate for valence adjustment to Pu (IV) and U (VI) and passed through a secondary recovery solvent extraction cycle. Here they are processed in a pulse column where most of the residual uranium and plutonium are recovered by extraction into a TBP organic solution. The uranium and plutonium are recycled back to the first (co-decontamination) cycle. The aqueous raffinate stream is concentrated in a low-level process waste concentrator, the bottoms from which are transferred to the high-level waste concentrator.

An overall analysis of the uranium and plutonium recovery process shows that the uranium and plutonium product streams contain about one part in ten million of the fission products originally present in the spent fuel. This purity translates to a radioactivity level in recovered uranium of about twice that of natural uranium. Other separation factors are given in Table 12-1. The radioactivity levels in the various processing areas range from very high levels that require artificial cooling to remove the heat from the radioactive decay to levels low enough to permit direct personal contact.

- Conversion of Uranium Nitrate to the Hexafluoride

The reference fuel reprocessing UF_6 facility converts uranium nitrate solutions to uranium hexafluoride. A simplified flow scheme for this conversion is depicted in Figure 12-3. A more detailed UF_6 facility process flow chart is shown in Figure 12-4 where the sources of effluents from the various processes steps are also presented.

- 1) Uranium Nitrate Receiving and Storage

The UF_6 facility receives nitrate solution recovered from spent fuel in the adjacent main separations facility. The solution is received in an accountability tank where it is measured, sampled, and then transferred to the storage tanks.

TABLE 12-1. Typical Separation Factors of Fission Products (FP) and Transuranics (TRU) from U and Pu in the Reference Fuel Reprocessing Plant

<u>Separation Step</u>	<u>Approximate Separation Factor (a)</u>
<u>Fuel Dissolution</u>	
Noble gases from Pu and U	>10,000
Radioactive carbon from Pu and U	~100
Iodine from Pu and U	30
All other FPs, TRUs from Pu and U	1
<u>1st Cycle Solvent Extraction</u>	
FPs, TRUs from U and Pu	10,000
U from Pu and Pu from U	10,000
<u>2nd Cycle Solvent Extraction</u>	
FPs, TRUs from U	100
FPs, TRUs from Pu	100
U from Pu and Pu from U	100
<u>3rd Cycle Solvent Extraction</u>	
FPs, TRUs from U	10
FPs, TRUs from Pu	10
<u>Cumulative</u>	
FPs, TRUs from Pu and U	10,000,000
<u>Waste</u>	
Pu from waste	125
U from waste	100

(a) Separation factor here is the quantity of FPs and/or TRUs associated with the U and Pu in the original irradiated fuel after the separation step compared to that before the separation step.

FIGURE 12-3. Simplified Flow Diagram of the UF_6 Conversion Process - Reference Fuel Reprocessing Facility

FIGURE 12-4. UF_6 Facility Flow Chart - Reference Fuel Reprocessing Facility

2) Uranyl Nitrate Concentration

From storage, the 40 wt% (350 g U/l) uranyl nitrate solution is pumped to a steam-heated thermosyphon reboiler where water is removed to form uranyl nitrate hexahydrate (UNH) containing 78.5 wt% uranyl nitrate. The water removed is condensed and returned to the main separations facility for recycle.

3) Uranyl Nitrate Hexahydrate Calcination

Next, the UNH is continuously calcined to uranium trioxide (UO_3) in a bed of UO_3 fluidized by superheated steam at 315°C . A controlled discharge of UO_3 is withdrawn from the bed and fed to the next process step. By denitrating in steam, the nitrate values in the calciner vapors are condensed as 45 wt% nitric acid (HNO_3), which is returned to the main separations facility for recycle.

4) Uranium Trioxide Reduction

The UO_3 is then put through a feed preparation step where it is milled and screened to a uniform particle size, chemically activated by small amounts of H_2SO_4 (to aid in the following process steps) and is continuously converted to uranium dioxide (UO_2) by reduction with hydrogen in a fluidized bed. The hydrogen is obtained by dissociation of ammonia.

5) Uranium Dioxide Fluorination

The UO_2 is reacted with hydrogen fluoride (HF) continuously in a bed fluidized by HF to form uranium tetrafluoride (UF_4). After milling and blending, the UF_4 solids from hydrofluorination are fed to the fluorinator, which contains a bed of inert granular material (alumina) fluidized with gaseous fluorine. Fluorine is produced onsite by electrolysis of anhydrous HF in an electrolyte of molten potassium bifluoride. After milling and screening, solid UF_4 is converted to gaseous UF_6 which, along with excess F_2 and by-product HF, is filtered and passed to cold traps for UF_6 collection.

6) Uranium Hexafluoride Collection, Loading, and Storage

The bulk of the UF_6 is condensed to a solid in a primary cold trap. Secondary and tertiary traps operate at lower temperatures and remove additional UF_6 . Product UF_6 is removed from the cold traps intermittently by melting and is transferred as a liquid through surge tanks into approved 14-ton UF_6 storage and shipping cylinders. It is sampled, cooled and solidified before moving to the storage pad.

- Conversion of Plutonium Nitrate to the Dioxide

The plutonium product facility (PPF) converts plutonium nitrate solutions to plutonium oxide powder. The conversion process consists of continuous precipitation of plutonium oxalate followed by filtration and calcination to plutonium dioxide (PuO_2). This process has been used for over 20 years in various nuclear installations. Two parallel conversion lines (i.e., precipitation through product packaging) are provided, each furnishing half the total capacity. A simplified block flow diagram of the process is shown in Figure 12-5. The process functions and chemical reactions are summarized in Table 12-2.

1) Plutonium Nitrate Precipitation

Plutonium nitrate solution is transferred in batches from plutonium nitrate storage to feed preparation tanks. In these tanks, the nitric acid concentration is adjusted to 3M by adding concentrated nitric acid, the plutonium valence is controlled to +4 by adding hydroxylamine nitrate, and the plutonium concentration is approximately 150 g/l. The adjusted product feed and oxalic acid (1M) streams flow continuously to a precipitator vessel where they are mixed and precipitation commences. From the precipitator vessel the slurry overflows to successive digestion vessels to allow crystal growth.

FIGURE 12-5. Simplified Flow Diagram of the Plutonium Product Facility - Reference Fuel Reprocessing Facility

TABLE 12-2. Summary of Plutonium Conversion Functions and Chemical Reactions

Feed Preparation

Receipt and preparation of solution for precipitation

Valence adjustment:

Excess hydroxylamine nitrate destruction:

Precipitation and Digestion

Separation of plutonium compound from solution:

Filtration and Drying

Separation of plutonium compound from solution, decontamination from trace impurities, and removing moisture.

Calcining

Conversion to product compound:

Mechanical Handling, Storage, and Shipping

Disposition of plutonium oxide product

Filtrate Concentration

Disposition of filtrate and reduction of volume of solution containing plutonium:

2) Plutonium Oxalate Filtration and Calcination

The slurry is filtered continuously on a rotary vacuum drum filter. The precipitate is then dried and calcined in a rotary screw calciner at temperatures up to 750°C.

3) Plutonium Dioxide Screening and Blending and Packaging

The plutonium oxide powder is screened, oversize particles are ground, and the total product is blended to achieve product uniformity. The oxide is then sampled and packaged in canisters, which are decontaminated, weighed, and stored in special shipping containers that hold 32 kg of PuO₂.

4) Secondary Product Precipitation and Filtration

The filtrate is held in a surge vessel to allow time for any post-precipitation and then refiltered in a polishing or secondary filter after adding more oxalic acid. These solids from the polishing filter are returned to the vacuum filter by backwashing with nitric acid.

5) Filtrate Treatment

The filtrate (about 2.4M HNO₃, 0.1M H₂C₂O₄) is concentrated in a distillation column. Excess oxalic acid is destroyed in the boiling 12M HNO₃ bottoms. If necessary, potassium permanganate is added to assist in destroying excess oxalate in the concentrate in the sample tank. Then the concentrate is sampled for accountability and transferred to the third solvent extraction step in the main process building for recovery of plutonium. The distillate is combined with condensate from the plutonium calcination off-gas system, sampled for accountability, and transferred to the main separations facility for concentration in the low-activity waste concentrator.

12.2.2 Waste Management

The waste materials generated in the reference fuel reprocessing facility are radioactive solid and liquid wastes and nonradioactive solid wastes.

The other "waste" materials are released to the environment as radioactive and nonradioactive airborne effluents and nonradioactive liquid effluents.

- Radioactive Solid Wastes

All radioactive solid wastes^(1,2) from the main separations facility, the UF_6 facility, and the plutonium product facility are retrievably stored in the onsite solid waste storage area (SWA) for future transfer to a licensed repository. Wastes emitting highly penetrating radiation (surface dose rates greater than 50 R/hr at the container surface) are placed in stainless steel containers in caissons in the hulls container storage area (HCS) of the solid waste storage area. Wastes that could cause a container surface dose rate of 50 R/hr or less at the surface are placed in 208 L (55 gal) and 303 L (80 gal) steel drums. Wastes reading from 50 mR/hr to 50 R/hr are stored in the high-level storage area (HLS), while those wastes reading 50 mR/hr or less at the surface are stored in the low-level storage area (LLS).

The main separations facility and the plutonium product facility produce low-level and high-level general process wastes that are stored in the low-level storage area and the high-level storage area, respectively. The general process waste consists of discarded equipment, tools, gloves and clothing, decontamination wipes, filters, etc. The main separations facility also produces contaminated failed equipment, which is packaged and then stored in the failed equipment vault located in the hulls container storage area. High-level general process trash, failed process equipment, fuel hulls packed in sand in hull containers, and iodine scrubber waste absorbed on vermiculite inside hull containers are stored in the hulls container storage area.

The UF_6 facility also produces low-level general process trash that is stored in the low-level storage area. In addition, the UF_6 facility produces scrap that is stored in a separate storage area (USS).

- Radioactive Liquid Wastes

Two types of radioactive liquid wastes are produced in the main separations facility. One is classified as high-level liquid waste and

the other is classified as intermediate-level liquid waste. These wastes originate from the mainline process and support functions. The high-level liquid waste consists of the aqueous waste stream from the primary extraction centrifugal contactor, the bottoms from the low activity waste concentrator, and the solids from the initial spent fuel solution centrifugation step. The first two components are concentrated in the high activity waste concentrator and then joined by the centrifuge solids. This combined stream is then stored in water-cooled stainless steel tanks.

The intermediate-level liquid waste comes from the service concentrator and the general purpose concentrator. The service concentrator concentrates low-to-intermediate-level liquid wastes associated with or generated by process support functions. The general purpose concentrator concentrates low-level liquid wastes associated with or generated by the main process. The liquid wastes from the concentrators are stored in the intermediate-level liquid waste storage tanks.

Any potential liquid wastes produced in the UF_6 facility or plutonium product facility are transferred to the main separations facility for appropriate treatment and/or storage, depending upon the composition of the wastes.

- Nonradioactive Solid Wastes

Most of the nonradioactive solid wastes are generated by support activities. They originate in offices, lunchroom, shop areas, and utility areas, and are general to the chemical and nonnuclear industries. They typically contain nothing peculiar to the nuclear industry. These solid nonradioactive wastes are disposed of to a nearby sanitary landfill operation.

The UF_6 facility also generates some spent potassium bifluoride electrolyte waste, waste calciner solid waste, and spent fluorinator bed materials. The electrolyte contains little or no uranium, and the solid wastes are drummed and buried in the sanitary landfill area. The waste management processes for the reference fuel reprocessing facility are summarized in Figure 12-6.

[illegible]

12-25

12.3 EFFLUENT CONTROL PROCESS DESCRIPTIONS

The control of radioiodine, nitrogen oxides, and radioactive particulates in the effluent air is a major concern for processes in the main separation facility. In the plutonium product facility, minimizing release of plutonium particulates is the primary concern, and in the UF_6 facility, minimizing release of uranium particulates and gaseous fluoride is a major concern.

12.3.1 Liquid Effluents

Since all of the liquid streams leaving either the plutonium product facility or the UF_6 facility are piped back to the main separations facility for liquid treatment, no liquid effluents come from these facilities without additional treatment. The main separations facility does not routinely release radioactive liquid effluents. It releases liquids such as blowdown from the cooling towers and boilers, demineralizer regeneration wastes, and single-pass cooling water discharges. These are all nonradioactive discharges under normal operations and are discharged to a retention pond. The liquids are retained in the pond up to 17 days before their discharge to the nearby river. Comprehensive sampling and analysis is done to assure that no radioactive liquid effluents are released to the environment via these discharges. A liquid effluent flow diagram is shown in Figure 12-7.

12.3.2 Airborne Effluents

Each of the three processing areas (main separations facility, UF_6 facility, and plutonium product facility) has its own separate airborne effluent treatment system, each discussed below.

- Main Separations Facility

The airborne effluent treatment system for the main separations facility is shown in Figure 12-8. The main process off-gas system starts with the dissolver off gases, which pass through a condenser and a knockout (de-entrainment) pot. The gases are joined by various other process off gases and then pass through a scrubber to remove radioiodine using $HNO_3 - Hg(NO_3)_2$ scrub, and a water absorber to recover NO_x as nitric acid for reuse.

FIGURE 12-7. Process Flow Diagram - Liquid Effluent Treatment System for the Reference Fuel Reprocessing Facility

The remaining process gases are added to this stream of gases. These gases pass through another condenser, another knockout pot, another HNO_3 - $\text{Hg}(\text{NO}_3)_2$ iodine scrubber, a heater, and seven parallel banks of filter units. Each unit has a prefilter, a silver zeolite iodine adsorber, and two final stages of HEPA filters in series.

The treated gases are discharged to the main (100m) stack. The building ventilation system provides two stages of roughing-plus-HEPA bank filtration for exhausted air. The off gases from the concentrated plutonium process areas are first filtered by a roughing filter and two stages of HEPA filters before joining the building ventilation air where they are again filtered by a roughing-plus-HEPA filter bank.

- UF₆ Facility

The airborne effluent treatment system for the UF₆ facility is shown in Figure 12-9. Generally, where uranium particles could be released, the effluent treatment consists of some form of filtration (assumed here to be cloth bag and HEPA filters) and possibly other particle collection systems. For cases where HF, F₂, or UF₆ gases are in potential effluents, chemical scrubbing is used for effluent treatment. In most cases, the chemical used in off-gas scrubbing is potassium hydroxide solution. Combustion gases that are produced at various steps for process heating are released to the atmosphere without treatment.

- Plutonium Product Facility

The airborne effluent treatment system for the plutonium is shown in Figure 12-10. All off gases from the process vessels pass through a condenser, a knockout (de-entrainment) pot, a heater, a roughing filter and two stages of HEPA filters in series. They are then routed to the final building ventilation system for one more stage of roughing-plus-HEPA filtration and exit through the main stack of the main separations facility.

FIGURE 12.9.

Process Flow Diagram - Airborne Effluent Treatment for Reference Fuel Reprocessing Facility

PLUTONIUM PRODUCT FACILITY

FIGURE 12-10. Process Flow Diagram - Airborne Effluent Treatment System for Plutonium Product Facility for Reference Fuel Reprocessing Facility

Exhaust air from the vacuum cleanup system used to clean up major spills in the dry process cells discharges through its sintered metal and HEPA filters to the recirculation dry air system. From there it is routed to the building ventilation exhaust duct where it passes through one more stage of HEPA filters before being discharged to the main separations facility main stack.

The off gas from the cold chemical system for plutonium processing passes through two stages of HEPA filters in series before being discharged to the main separations facility main stack.

12.4 FACILITY AND SITE DESCRIPTION

This section summarizes the description of the site and the facility and its hardware. This information will be used as the primary basis for capital cost estimates and as background for plant performance.

12.4.1 Site

The reference LWR fuel reprocessing facility is assumed to lie on the 4.7 km² generic site B described in Section 5. The facility itself (within the inner security fence) requires an area of 0.32 km²⁽¹⁾ within the larger plant site. The facility layout assumes a well-labeled perimeter fence exists around the total site to exclude the public. Another fence surrounds the smaller rectangular facility area and includes security entrances. The plant is located so that the main stack is 1 km away from 3 sides of the generic rectangular site. The liquid effluents are to be discharged onsite into the river that flows through one corner of the site.

12.4.2 Facility Description

The reference facility is based primarily on the Barnwell Nuclear Fuel Plant (BNFP) owned by Allied General Nuclear Services. The plant is located near Barnwell, SC, and is nearly completed.

Three main process buildings are included in the reference reprocessing facility; these are the main separations facility, the UF₆ facility, and the plutonium product facility (PPF). An overall layout of these facilities is given in Figure 12-11. The reference facility is assumed to operate for 40 years.

FIGURE 12-11. Overall Layout of the Reference Fuel Reprocessing Facility

- Main Separations Facility

The main separations facility consists primarily of the main process building, the fuel receiving and storage station, and the high- and intermediate-level liquid waste storage area. It is designed and constructed to minimize release of radioactive materials to man's environment during routine operation and under accident conditions. At least two physical barriers (and frequently more than two) are used to contain the radioactive materials within the facility during operation. These barriers are typically the process equipment (vessels, pipes, etc.) and the building around the process equipment. In most cases, the building itself provides two barriers; the hot cell or room where the process equipment is located, and the outer building shell. Process equipment is fabricated from materials resistant to failure from corrosion. Where failure of process equipment (under conditions assumed to be credible) can result in major releases of radionuclides, the equipment design basis is designated "Q".^(a)

Structural barriers are designed to contain process materials if primary equipment barriers are breached. The principal barriers are constructed of heavily reinforced concrete with partial lining of stainless steel added to areas containing large quantities of radiologically hazardous materials in corrosive acid solutions.

The process structural barriers are generally termed radioactive process cells and are typically surrounded by maintenance or operating areas. The two process cells containing the highest radiation levels are designed for remote maintenance (i.e., maintenance from outside the cell through the use of in-cell cranes or shielding windows and manipulators). Other process cells are designed for direct personnel entry using

^(a) "Q" classification is for systems whose failure could cause an immediate potential hazard to the public. Immediate potential hazard is defined as whenever insufficient time or access is available for corrective action to be taken to prevent an unacceptable release of materials to offsite. "Q" systems must maintain process containment integrity during a design basis earthquake or a design basis storm such as a tornado.

protective clothing and contact maintenance, but only after appropriate remote decontamination has been completed to allow safe entry.

Isometric projections of the main process building and the attached fuel receiving and storage station are presented in Figures 12 to 15. These facilities are constructed of heavily reinforced concrete with walls up to 2 m thick in some areas. These areas are designed to withstand natural phenomena such as earthquakes and tornadoes. Other noncritical areas are generally constructed of concrete slabs or insulated steel siding.

The liquid waste storage area is found below and near the waste tank equipment gallery (WTEG), a concrete building approximately 30 m². This high- and intermediate-level waste tank equipment building is separate from, but near, the main process building as shown in Figure 12-11. It houses the heat exchangers, a sample cell, condensers, knock-out pots, ventilation filters and a control room for the high- and intermediate-level liquid waste storage tanks located below the building. Two high-level (one a spare) and one intermediate-level waste storage tanks are connected through a small underground waste diverter cell and an underground piping vault to the main process building.

The following auxiliary areas are also considered as part of the main separations facility: analytical laboratories, emergency utility area, administration buildings, maintenance shop, stores warehouse, plutonium product storage area, cask wash station, cooling tower, retention pond and pump house (buried), meteorological tower, utility area, main stack, solid waste storage area, and sanitary waste system.

- UF₆ Facility

The UF₆ facility consists of the main process building, the fluorine manufacturing building, UF₆ cylinder storage area, and the chemical tank farm. The process building is a reinforced steel structure enclosed with corrugated aluminum siding and is made according to standard chemical plant construction guidelines.

FIGURE 12-12.

NOTES: 1 FT = 0.3m

ALL ELEVATIONS ARE RELATIVE

FIGURE 12-13. Main Separations Facility
Lower Middle Elevation -
Reference Fuel Reprocessing
Facility

FIGURE 12-14. Main Separations Facility
Upper Middle Elevation -
Reference Fuel Reprocessing
Facility

FIGURE 12-15. Main Separations Facility Upper Elevation -
Reference Fuel Reprocessing Facility

- Plutonium Product Facility

The plutonium product facility consists of one process building, contiguous to the main separations facility. Its overall dimensions are about 49 m by 50 m and 16 m high. The overall layout is shown in Figure 12-16. The building arrangement of the facility is shown in Figures 12-17 through 12-22.

Tables 12-3, 12-4, and 12-5 summarize the various process area descriptions for the reference reprocessing facility, major process equipment for the main process building, the plutonium product facility, and the UF_6 facility, respectively.

12.5 EFFLUENT CONTROL PERFORMANCE

Tables 12-6, 12-7, 12-8, and 12-9 show the overall effluent control performance for radioactive material from the reference facility, the overall input of nonradioactive materials, the output of nonradioactive airborne and liquid effluents, and the overall output of solid waste, respectively.

The residual fission products in the recovered uranium and plutonium are only 1E-5% of those that entered the plant in the spent fuel. The effluent treatment system can be expected to limit the release of particulate fission products to the effluent air to less than 1E-6%. Gaseous fission products not retained within the facility constitute less than 0.1% of the input radioactive content of the spent fuel.

Fluoride emissions are effectively limited to less than 0.3% of plant input by the use of KOH scrubbers and packed absorber columns. The 1200 kg/day of nitrogen oxides in the airborne effluents represent typical recovery that can be expected from water absorbers of the more efficient design available.

INDEX

CA	CHANGE AREA
CLRA	CHANGE AND LUNCH ROOM AREA
HCLA	HOT AND COLD LABORATORY AREA
CWA	COOLING WATER AREA
FRSS	FUEL RECEIVING AND STORAGE STATION
LD	LOADING DOCK
PNSL	PLUTONIUM NITRATE STORAGE AND LOADOUT
PPF	PLUTONIUM PRODUCT FACILITY
PSS	PLUTONIUM STORAGE STATION
SRA	SHIPPING AND RECEIVING AREA

FIGURE 12-16. Location of Plutonium Product Facility within the Reference Fuel Reprocessing Plant

FIGURE 12-17. Plutonium Product Facility Building Plan - 1st Level

FIGURE 12-18. Plutonium Product Facility Building
Plan - 2nd Level

FIGURE 12-19. Plutonium Product Facility Building
Plan - 3rd Level

FIGURE 12-20. Plutonium Product Facility Building
Plan - 4th Level

FIGURE 12-21. Plutonium Product Facility Building -
Elevation Section A-A

FIGURE 12-22. Plutonium Product Facility Building -
Elevation Section B-B

TABLE 12-3. Major Process Area Descriptions - Reference Fuel Reprocessing Facility

Process Area	Overall Dimensions L x W x H, m	Perimeter Construction Material	Other Features
<u>Main Separations Facility</u>	105 x 87 x 30	Reinforced Concrete	
Remote Process Cell (RPC)	15.8 x 7 x 21.3	Reinforced Concrete and SS Floor Plan	35-T, 5-T cranes power manipulator, periscope, four windows and pairs of master manipulators
Remote Maintenance and Scrap Cell (RMSC)	7.3 x 7 x 21.3	Reinforced Concrete SS Floor Plan	5-T, 10-T cranes periscope, power and master manipulators, four windows hull transfer cart
High-Level Cell (HLC)	15.8 x 7.9 x 8.5	Reinforced Concrete SS Floor Plan	Centrifuge can be remotely removed, contact maintenance
High-Intermediate-Level Cell (HILC)	15.8 x 8.2 x 12.2	Reinforced Concrete SS Floor Plan	Electro pulse column is remotely replaceable contact maintenance
Intermediate-Level Cell (ILC)	15.8 x 8.2 x 11.6	Reinforced Concrete SS Floor Plan	Contact maintenance
Uranium Product Cell (UPC)	15.8 x 8.2 x 9.4	Reinforced Concrete SS Floor Plan	Contact maintenance
Plutonium Product Cell (PPC)	15.8 x 8.2 x 6.1	Reinforced Concrete SS Floor Plan	Contact maintenance
Control Room Area/Plutonium Nitrate Storage and Loadout (CRA/PNSL)	20 x 25 x 18.5	Reinforced Concrete SS Floor Plan	48 titanium slab tanks only
Fuel Receiving and Storage (FRS)	45.7 x 45.7 x 27.7	Reinforced Concrete SS Lined Basins	125-T, 10-T, 2-15T cranes; 2 unloading bays; 2 unloading pools

TABLE 12-3. (cont'd)

Process Area	Overall Dimensions L x W x H, m	Perimeter Construction Material	Other Features
Waste Tank Equipment Gallery (WTEG)	31 x 33.5 x 12	Reinforced Concrete	3 SS tanks
Emergency Equip- ment and Ventila- tion	35 x 40 x 18	Reinforced Concrete	NA
<u>UF₆ Facility</u>	61 x 30.5 x 35.1	Steel Structure Aluminum Siding	NA
<u>F₂ Manufacturing</u>	30.5 x 16.8 x 9.1	Concrete Mat and Footing	NA
Process Building	61 x 31.5 x 35.1	Same as above	NA
Cylinder Storage Area	30.5 x 23	Reinforced Concrete	NA
Chemical Tank Farm	52 x 15 x 4.3	Concrete	NA
<u>Plutonium Product Facility</u>	22 x 49 x 16 19 x 28 x 16	Reinforced Concrete	NA
Conversion Feed Cell	12 x 1.5 x 4.7	Reinforced Concrete	NA
Conversion Contact Cell	12 x 5.5 x 12	Stainless steel interior, car- bon steel exterior	NA
Precipitation Cells	4.6 x 1.7 x 3.7	Reinforced Concrete	NA
Conversion Dry Cells	9.1 x 1.7 x 7.3	Reinforced Concrete	NA
Plutonium Storage Stations	14.3 x 9.1 x 3.7	Reinforced Concrete	NA

NA = Not available at this time

SS = Stainless steel

TABLE 12-4. Major Process Equipment Descriptions for the Main Separations Facility -
Reference Fuel Reprocessing Facility

Equipment	No.	Size (L x W x H), m	Construction Material	Process Duty Capacity, Each	Location	Other Features
Fuel Transfer Conveyor	1	Cart: 7.2 L Track: 30.5	304L SS	1 Fuel Assembly	Remote Process Cell per Transfer	(RPC)
Fuel Bundle Shear	1	Shear Head: 3.0 x 1.5 x 1.7 Shear Feed Magazine: 9.3 x 0.9 x 1.8	304L SS	1 Fuel Assembly	RPC per Loading	
Chopped-Fuel Diverter	1	2.4 Dia Cone 3.8 H	304L SS		RPC	
Dissolver	3	1.0 Dia (Top Section) 0.8 Dia (Bottom Section) 4.8 H	304L SS	6 MTU/day	RPC	
Dissolver Baskets	NA	NA	304L SS		RPC	
High Activity Waste Concentrator	1	1.6 Dia x 5.6 L	Titanium			RPC
Dissolver Transfer Tank	4	0.1 Dia x 4.3 L	304L SS	378 ℓ	High Level Cell (HLC)	
Feed Adjustment Tank	2	1.8 Dia x 3.7 H	304L SS	8,516 ℓ	HLC	
Dissolver Flush Accumulation Tank	1	1.8 Dia x 5.1 H	304L SS		HLC	
Feed Surge Tank	1	2.3 Dia x 3.5 L	304L SS	11,639 ℓ	HLC	
Accountability Tank	1	1.8 Dia x 3.4 H	304L SS	8,138 ℓ	HLC	
General Purpose Concentration Feed Tank	1	2.4 Dia x 3.7 H	304L SS	16,465 ℓ	HLC	
Centrifuge	1	0.122 Bowl	304L SS	6 MTU/day	HLC	
First Cycle Solvent Extraction Columns	4		304L SS		High-Intermediate Level Cell (HILC)	
Centrifugal Contractor	1		304L SS	3,942 ℓ/hr	HILC	
High Activity Waste Condenser	1		304L SS		HILC	
Secondary Product Recovery Column	1		304L SS	3,810 ℓ/hr	HILC	
No. 1 Solvent Treatment Columns	3		304L SS		HILC	
General Purpose Concentrator	1		304L SS	1,363 ℓ/hr	HILC	
NO ₂ Absorber (Dissolver Off Gas)	1	1.5 Dia x 8.2 H	304L SS	20,400 ℓ/min	Intermediate Level Cell (ILC)	

TABLE 12-4. Major Process Equipment Descriptions for the Main Separations Facility - Reference Fuel Reprocessing Facility (cont'd)

Equipment	No.	Size (L x W x H), m	Construction Material	Process Duty Capacity, Each	Location	Other Features
Acid Fractionator	1	Top: 1.7 Dia 5.2 H Bottom: 0.9 Dia 5.2 H			ILC	
Vessel Off-Gas Knock-Out Pot	1	1.8 Dia x 2.4 H	304L SS	124,325 l	ILC	
Low Activity Waste Concentrator	1	1.2 Dia x 2.1 H		240 l/hr	ILC	
Waste Solvent Burner	1		Inconel	9 kg/hr	ILC	
No. 1 Iodine Scrubber	1	0.9 Dia x 7.0 H	304L SS		ILC	
No. 2 Iodine Scrubber	1	1.7 Dia x 8.5 H	304L SS		ILC	
Second U Solvent Extraction Columns	2		304L SS		Uranium Product Cell (UPC)	
Silica Gel Beds	2		304L SS	587 l/hr	UPC	
No. 2 Solvent Treatment Columns	2		304L SS		UPC	
ICU Concentrator	1		304L SS		UPC	
Second Pu Solvent Extraction Columns	2		304L SS		Plutonium Product Cell (PPC)	
Third Pu Solvent Extraction Columns	2		304L SS		PPC	
Pu Product Concentrator	1	0.2 m Inside Dia 4.1 m H	Titanium	61 l		
<u>UF₆ Facility</u>						
Uranyl Nitrate Concentrator	1				Process Building	Steam Heated Thermo-Syphon Reboiler
Uranyl Nitrate Hexahydrate Calciner	1				Process Building	Fluidized Bed
Reduction Reactor	1				Process Building	H ₂ Atmosphere
Hydrofluorinator	2				Process Building	
Fluorinator	1				Process Building	Fluidized Bed
Cold Traps	3				Process Building	

TABLE 12-4. Major Process Equipment Descriptions for the Main Separations Facility - Reference Fuel Reprocessing Facility (cont'd)

<u>Equipment</u>	<u>No.</u>	<u>Size (L x W x H), m</u>	<u>Construction Material</u>	<u>Process Duty Capacity, Each</u>	<u>Location</u>	<u>Other Features</u>
<u>Plutonium Product Facility</u>						
Precipitator Feed Preparation Tank	2				Conversion Feed Cell	
Filtrate Concentrator Feed Tank	1				Conversion Contact Cell (CCC)	
Process Vessel Off-Gas Knock-Out Pot	1				CCC	
Filtrate Concentrators	2				CCC	
Precipitator	2				One in Each Precipitation Cell	
1st, 2nd, 3rd Stage Digesters	6				One of Each Stage in Each Precipitation Cell	
Vacuum Filter	2				One in Each Precipitation Cell	

TABLE 12-5. Major Process Equipment Descriptions for the Plutonium Product and UF₆ Facilities - Reference Fuel Reprocessing Facility

Equipment	No.	Size (L x W x H), m	Construction		Process Duty or Capacity, each	Location	Other Features
			Material	Other			
<u>Plutonium Product Facility</u>							
Precipitator Feed Preparation Tank	1	3.4 x 2.1 x 0.057	304L SS	Cooling Coils and Air Sparger	410 ℓ 102 kg Pu	Conversion Feed Cell	NA
Filtrate Concentrator Feed Tank	1	2.0 x 1.8 x 0.057	304L SS	NA	209 ℓ Pu (2200 g/ℓ)	Conversion Contact Cell (CCC)	NA
Process Vessel Off-Gas Knock-Out Pot	1	1.8 x 1.5 x 0.05	304L SS	212 acfm	CCC		NA
Filtrate Concentrators	2	5.3 x 0.86 x 0.05	304L SS	Steam Coils	82 ℓ/hr	CCC	NA
Precipitator	2	0.1 dia x 1.2 H	304L SS	NA	8.7 ℓ + 7% FB	One in Each Precipitation Cell	NA
Filtrate Surge Tank	2	0.92 x 2.7 x 0.05	304L SS	60° Conical Bottom	25.4 ℓ + 218% FB	CCC	NA
1st, 2nd, 3rd Stage Digesters	6	0.1 dia x 1.2 H	304L SS	NA	8.7 ℓ + 7% FB	One of Each Stage in Each Precipitation Cell	NA
Vacuum Filter	2	0.46 dia x 0.18 H	304L SS	NA	5 kg Pu oxalate /hr	CCC	NA
Drier - Calciner	2	0.4 dia x 3.1 H	304L SS	NA	2.4 kg PuO ₂ /hr	Blender Cell	NA
<u>UF₆ Facility</u>							
Uranyl Nitrate Concentrator	1	NA		NA	NA	UF ₆ Process Building	Steam-heated Thermo Syphon Reboiler
Uranyl Nitrate Hexahydrate Calciner	1	NA	304L SS		6 MTU/day	UF ₆ Process Building	Fluidized Bed
Reduction Reactor	1	NA	304L SS	NA	NA	UF ₆ Process Building	H ₂ Atmosphere
Hydrofluorinator	2	NA	Nickel	NA	NA	UF ₆ Process Building	NA
Fluorinator	1	NA	Nickel	NA	NA	UF ₆ Process Building	Fluidized Bed
Cold Traps	3	NA	Copper		NA	UF ₆ Process Building	NA

KEY: NA = Not Available

FB = Free Board

SS = Stainless Steel

**TABLE 12-6. Overall Radioactive Materials Input/Output for
Reference LWR Fuel Reprocessing Facility**

Material	Total Material (a)(b)		Form		Fraction of (c) Plant Input
	Elemental kg/day	Ci/day	Chemical	Phase(c)	
<u>Input to Facility</u>					
Spent Fuel	46	5.2E5	PuO ₂	S	(1)
	4776	19.6	UO ₂	S	(1)
	175	1.9E7	Fission Products	S,G	(1)
<u>Output from Facility</u>					
Airborne Effluents:					
¹⁴ C	8E-4	2	CO ₂	G	1
Noble Gases	30	5E4	Ne, Ar, Kr, Xe	G	1
⁸⁵ Kr	0.10	4E4	Kr	G	1
Tritium	1.6E-4	1.6E3	HTO	G,L	0.6
Iodine	0.04	0.14	I ₂ ,CH ₃ I	G	0.03
Ruthenium	1E-9	2.5E-4	RuO ₄	G,S	1E-8
All Other Fission Products	2E-8	2.2E-3	Oxides, Nitrates Fluorides	S,L	2E-9
Uranium	0.10	4E-4	UO ₂ F ₂ , UO ₂ , UO ₃ , UF ₄	S,L	3E-5
Plutonium	4E-8	6E-4	PuO ₂ , Pu(NO ₃) ₄	S,L	5E-9
All Other Transuranics	1E-9	3E-5	Oxides, Nitrates	S,L	2E-9
<u>Accumulation</u>					
Liquid Wastes:					
High-Level	150 ^(d)	1.91E7 ^(d)	Acidic, Nitrates	L,S	NA
Intermediate-Level	<1E4 ^(d)	10 ^(d)	Acidic, Nitrates	L,S	NA
Solid Wastes:					
Fuel Cladding Hardware	4 ^(d)	5E5 ^(d)	Zirconium, SS Inconel	S	NA
Other	<3E-5 ^(d)	8 ^(d)		S	NA
<u>Products</u>					
Uranium	4728	19.4	UF ₆	S	(0.99)
Plutonium	45	5.17E5	PuO ₂	S	(0.992)

Key: G = Gaseous
L = Liquid
S = Solid
NA = Not available at this time

- (a) Values based upon one day operating at 100% of capacity.
(b) Numbers used do not always express accuracy, but are used for material balance purposes.
(c) Numbers in parenthesis are not released to the environment.
(d) Values indicate total of radioactive and nonradioactive sources.

TABLE 12-7. Overall Nonradioactive Materials Input to the Reference Fuel Reprocessing Facility

Material	Total Material		Form			Other	kg/day ^(a)	Quantity Stored
	kg/day	l/day	Chemical	Phase	Density			
Acrolein	10	12	CH ₂ =CHCHO	L	0.84	Compressed Gas	10	680 l
Alumina	200	51	Al ₂ O ₃	S	3.99		200	
Ammonia	500	612	NH ₃	L	.817		500	35,000 l
Calcium Oxide (lime)	815	245	CaO	S	3.32		815	
Calcium Phosphates	1	NA	Ca ₃ (PO ₄) ₂	S	3.14			
Carbon Dioxide	Nil	NA	CO ₂	L	1.1	Compressed Gas	NA	
Chlorine	2	NA	Cl ₂	L	1.56		2	544 l
Decontaminating Agents	NA	NA	Assorted	S & L	NA		NA	
Dioctyl Phthalate	1	NA	C ₈ H ₄ - 1, 2[C(COO(CH ₂) ₇ CH ₃) ₂	L	NA		NA	
Dodecane, n	180	240	CH ₃ (CH ₂) ₁₀ CH ₃	L	0.75		180	
Gadolinium Oxide	50	6.8	Gd ₂ O ₃	S	7.4		NA	
Halon 1301	Fire Extinguisher		CF ₃ Br	L	NA	Compressed Gas	NA	
Hydrazine	NA	165	N ₂ H ₄	L	NA		105	6,400 l
Hydrogen Fluoride	2,500	2,500	HF	L	1		2,500	72,000 l
Hydrogen Oxide (water)	1.5E7	1.5E7	H ₂ O	L	1		1.5E7	
Hydrogen Peroxide	3	2.1	H ₂ O ₂	L	1.43		NA	
Hydroxylamine nitrate	NA	52	NH ₂ OH-HNO ₃	L	1.35		70	
Lithium Fluoride	NA	NA	LiF	S	2.3		NA	
Magnesium Phosphates	1	NA	Mg ₃ (PO ₄) ₂	S	1.6		1	
Mercuric Nitrate	4	NA	Hg(NO ₃) ₂	S	4.3		4	
Natural Gas	8.4E4	NA	CH ₄	G			NA	
Nitric Acid	5,000	3,570	HNO ₃	L	1.4	68%	3,400	15,300 l
Nitrogen	NA	NA	N ₂	G	NA		NA	
		NA	N ₂	L	0.8		NA	53,000 l
Nitrogen Tetraoxide	100	NA	N ₂ O ₄	L	1.45		100	1,000 kg
Oil, Light Fuel	7.3E3	NA	NA	L	0.8		NA	
Oxalic Acid	50	30	H ₂ C ₂ O ₄	S	1.65		50	
Potassium Fluoride	15	6	KF	S	2.48		15	
Potassium Hydroxide	300	150	KOH	S	2.0		300	
Potassium Nitrate	NA	NA	KNO ₃	S	2.1		NA	
Potassium Permanganate	4	1.5	KMnO ₄	S	2.7		4	
Propane	NA	NA	C ₃ H ₈	L	0.59	Pressurized	NA	68,000 l
Silver Zeolite	0.1	NA	AgNO ₃ -Zeolite	S	1		NA	
Sodium Carbonate	50	20	Na ₂ CO ₃	S	2.53		50	
Sodium Nitrate	160	75	NaNO ₂	S	2.2		160	
Sodium Sulfate	2.5	1	Na ₂ SO ₄	S	2.7		2.5	
Sodium Sulfite	0.5	0.2	Na ₂ SO ₃	S	2.6		0.5	
Sucrose	30	19	C ₁₂ H ₂₂ O ₁₁	S	1.59		30	
Sulfuric Acid	65	35	H ₂ SO ₄	L	1.84	93%	60	
Tributyl Phosphate	90	92	[CH ₃ (CH ₂) ₃ O] ₃ PO ₄	L	0.98		90	
Trisodium Phosphate	0.4	0.16	Na ₃ PO ₄	S	2.54		0.4	

^(a) Values based upon one day operating at 100% capacity

Key: G - gaseous

L - liquid

S - Solid

NA - Not available at this time

TABLE 12-8. Overall Nonradioactive Airborne and Liquid Effluents from the Reference Fuel Reprocessing Facility

Material	Chemical	Form		Output (a) kg/day
		Phase	Other	
<u>Airborne:</u>				
Ammonia	NH ₃	G	--	1
Fluorine	F ₂	G	--	5.5E-4
Combustion Gases:				
Carbon Dioxide	CO ₂	G	--	2E5
Carbon Monoxide	CO	G	--	67
Hydrogen Sulfide	H ₂ S	G	--	22
Nitrogen Oxides	NO _x	G	--	8.0E2
Sulfur Oxides	SO _x	G	--	3.9E2
Hydrocarbons	H _x C _x	G	--	12
Fluorocarbons	NA	G	--	1.1E2
Hydrogen	H ₂	G	--	89
Hydrogen Fluoride	HF	G	--	7
Nitrogen	N ₂	G	--	NA
Nitrogen Oxides	NO _x	G	--	1.2E3
Nonradioactive Particulates	NA	S	--	79
Water Vapor	H ₂ O	G	Tower Drift	2.4E6
<u>Liquid:</u>				
Cooling Water	H ₂ O	L	--	1.3E7
	Na ₃ PO ₄	S,L	--	9
	NA ₂ SO ₃	S,L		
	NA ₂ SO ₄	S,L		
Calcium	Ca ⁺²	S,L	--	13
Iron	Fe ⁺³	S,L	--	6.4
Magnesium	Mg ⁺²	S,L	--	6.4
Phosphorus Ortho	PO ₄ ⁻³	S,L	--	0.51
Nitrate	NO ₃ ⁻	L	--	9.0
Potassium	K ⁺	L	--	1.9E2
Sulfate	SO ₄ ⁻²	S,L	--	38
Sulfite	SO ₃ ⁻²	S,L	--	0.64
Carbon Dioxide	CO ₂	G	NA	5.1E2
Sodium	Na ⁺	L	NA	7.5E-1
Chloride	Cl ⁻	L	NA	3.5E-2

Key: G = Gaseous
L = Liquid
S = Solid
NA = Not available at this time

(a) Values based upon one day operating at 100% of capacity.

(b) This material does not enter the plant in this chemical form.

TABLE 12-9. Overall Solid Wastes from the Reference Fuel Reprocessing Facility

Waste Material	Form	Package	Total ^(a)			Fraction of Plant Input
			g/day	kg/day	Ci/day	
Noncombustible Trash	Glass, Metals	Drums	5.0E3	5.0E3	Trace	(b)
Combustible Trash	Gloves, Clothing	Drums	7.0E3	7.0E3	Trace	(b)
Failed Equipment	Disassembled Metal Apparatus	Hulls Container	5.0E2	NA	Trace	NA
Waste Calciner Discharge - UF ₆ Facility	Solid	Drums	1.0E3	NA	Trace	(b)
Potassium Diuranate Mud	Solid	Drums	2.5E2	4.0E2 6(c)	Trace 0.026	(b) 1E-3
Spent Beds - UF ₆ Facility	Solid	Drums	50	30 0.03(c)	0.5 1E-4	1 6E-6
Fluorinator Finges	Solid	Drums	3.7E2	2.5E2 7(c)	3 0.03	(b) 1E-3
Spent Electrolyte	Solid	Drums	NA	13	Trace	1
Resins, Silica Gel, Vermiculite	Solid	Drums	2.5E2	1.3E2	4	1
Silver Zeolite	Solid	Drums	0.1	0.1	<1	5E-5
Filters	Metal, Glass Fibers, Asbestos	Drums	8.5E2	850	Trace	1
Nonradioactive Trash	Solid	Dumpsters	2.0E3	NA	Trace	(b)

Key: NA = Not available at this time

Trace - detectable, but below waste discharge limits

(a) Value based upon one day operating at 100%.

(b) This material does not enter the plant in this chemical form.

(c) Amount of uranium in the material

12.6 FACTORS FOR OPERATING COST INFORMATION

The available basic plant operational requirements are presented to enable later estimation of direct operating costs.

12.6.1 Labor Requirements

The reference facility is assumed to operate 24 hr/day, 7 days/wk, 300 full rate days/yr and to be manned by operating and security forces at all times.

BNFP had 337 people at mid-year 1975; 118 were for operating and maintaining the UF_6 Facility. An additional 80 people are thought to be necessary for operation and maintenance of the main separations facility when processing spent fuel. Approximately 50 additional people are estimated to be needed for the plutonium product facility when it is built. Thus the total is estimated at about 470.

Approximately 100 of the work force are estimated to be professional management, supervisory or staff; about 370 employees are skilled or unskilled labor. Many of these latter staff people include trained operators certified by the Nuclear Regulatory Commission.

12.6.2 Material Requirements

The routine material requirements for the reference facility consist of those materials given as inputs in Table 12-7 and packaging materials for storage or disposal of solid wastes. Miscellaneous materials such as office materials, office furniture, routine maintenance supplies, etc., will also be required.

12.6.3 Unusual Maintenance Requirements

Some equipment will require replacement and/or major repairs frequently where the service is relatively severe. The remotely replaceable equipment (e.g., centrifugal contactor and electro-chemical pulse column) present special problems in removal because of their intensely radioactive contamination and large size. Maintenance of most process equipment is assumed to be comparable to replacing it every 20 years. Extensive remote decontamination

is required before maintenance activities which necessitate direct access to the process cells occur. All HEPA filters and roughing filters are also assumed to be replaced annually.

12.6.4 Utility Requirements

Total estimated utility requirements for the reference facility for each day of operation at 100% capacity are:

- Water 1.5×10^7 kg/day
- Electricity 12,000 kW-day/day
- Natural gas $8.4E4$ kg/day
- Light fuel oil 7.3×10^3 kg/day

The electrical power used by the BNFP main separations facility and plutonium product facility is about 8000 kW. The UF_6 facility is estimated to use about 4000 kW.

The main process building boilers (20 MW gross heat) use natural gas when available (assumed to be used 50% of the time). A low-sulfur light fuel oil (less than 1% sulfur) will be used as an alternative fuel in these boilers, in the administration building steam boiler (0.3 MW gross heat), and in the two warm air furnaces of the stores building (0.44 MW total heat).

12.6.5 Transportation Requirements

All the plant input materials listed in Table 12-8 must be transported to the facility. The PuO_2 and UF_6 will need to be transported to their destination. High-level and intermediate-level liquid wastes will eventually be solidified. These and the solid radioactive wastes will have to be transported to approved repositories (currently unknown). Typical transport distances are not within the scope of this report.

12.6.6 Waste Disposal Requirements

All the radioactive solid wastes are to be retrievably stored in the solid waste storage area onsite. They will require eventual offsite disposal in a manner to be determined. The nonradioactive solid wastes are assumed to be buried in a nearby sanitary landfill.

12.6.7 Other Operating Cost Elements

Other major operating cost elements are those performed by outside contractors. The laundry services for the reference facility and the transportation of materials to and from the reference facility are assumed to be contracted.

Other known special operating costs are for licensing and insuring such a nuclear materials processing facility.

It is assumed that security services will be contracted and would require about 15 people.

12.7 ENVIRONMENTAL IMPACT FACTORS

Table 12-10 summarizes the overall direct environmental impact factors for the reference facility. These quantities are those used directly at the plant. Impacts of resources required for material input or output beyond the plant boundary are not included.

TABLE 12-10. Overall Environmental Impacts - Reference Fuel Reprocessing Facility

	<u>Quantity</u>	<u>Remarks</u>
Total Land Committed	4.7 km ²	Fenced-in Area
Land Actually Used for Facility	0.32 km ²	Most of this is in High Security Area
Water Used	1.5E7 kg/day	
Water Discharged as Liquid Effluent	1.3E7 kg/day	
Total Materials Added to Liquid Effluents	~1600 kg/day	
Air Used	4.7E4	m ³ /min
Water Discharged as Airborne Effluent	2E6 kg/day	2% of this is from Process
Total Other Airborne Effluents	2E5 kg/day	
Electrical Energy Consumption	12 MW	
Thermal Effluent Equivalent	67 MW	~20% from Stacks, ~80% from Cooling Tower and Pond, and Special Maintenance Requirements
Resources Used	See Table 12.7	

12.8 LIMITATIONS AND UNCERTAINTIES IN THE STUDY INFORMATION

Many of the input and output values are judgmental estimates. Thus, some numbers could be in error by as much as one or two orders of magnitude. Even the better known input/output numbers are probably accurate only to within a factor of two. All values quoted require verification. Similar uncertainties prevail in the areas of materials added to the facility and of solid wastes from the plant.

The facility descriptions for both the plutonium product facility and the UF_6 facility have many unknowns. The design of the PPF has not been completed and while the UF_6 facility has been built, its details are proprietary. Onsite waste storage areas have also been designed, but are not yet built.

An assessment of possible additional operational and maintenance forces for minimizing individual exposures to radiation is unavailable for this plant. The relatively few pieces of remotely replaceable equipment could possibly increase manpower and material needs.

The detailed disassembly and handling capability for failed major equipment was not defined in available references.

12.9 RESEARCH AND DEVELOPMENT NEEDS

Additional information is desired on the reference fuel reprocessing plant in two major areas: 1) facility and hardware and 2) process flow sheets. Plant and facility information, particularly on the UF_6 facility and parts of the plutonium product facility is desirable. More detailed process flow sheets are needed to provide design or experience factors for some mainline plant and effluent control systems and to provide better estimates of the characteristics of the materials in the effluents.

Alternative processes aimed at reducing the amounts of radioactive krypton, tritium, carbon and iodine released with the effluents may warrant investigation. Studies of separations process alternatives that do not separate plutonium from uranium, or do not require thorough removal of

fission products from the processed fissile materials, may also be warranted. The solidification of liquid wastes, and the need and techniques for separating solids from the dissolved fuel before solvent extraction, may also warrant study for their effluent control effects.

SECTION 12: REFERENCES

1. Draft Supplement to the Final Environment Statement Related to Construction and Operations of Barnwell Nuclear Fuel Plant, NUREG-0082, by Office of Nuclear Materials Safety and Safeguards - US Nuclear Regulatory Commission, Allied-General Nuclear Services Docket No. 50-332, June 1976.
2. Environmental Report October 1975 Update for Barnwell Nuclear Fuel Plant - Separations Facility, Docket No. 50-332 by Allied-General Nuclear Services, October 1975.
3. Environmental Report, Docket No. 70-1327 UF₆ Facility, Barnwell Nuclear Fuel Plant, Allied-Gulf Nuclear Services, June 30, 1972.
4. Preliminary Safety Analysis Report, Barnwell Nuclear Fuel Plant, Addendum No. 7, Plutonium Product Facility, Docket No. 50-332 by Allied-General Nuclear Services, July 1974.
5. Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle, ERDA-76-43, May 1976.

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