Nuclear-Fuel-Cycle Risk Assessment: Descriptions of Representative Non-Reactor Facilities

Sections 1-14

DO NOT MICROFILM
COVER

Prepared by K. J. Schneider, Coordinator

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
**U.S. Nuclear Regulatory
Commission**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, or any of their employees, makes any warranty, expressed or implied, or assumes any legal liability of responsibility for any third party's use, or the results of such use, of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

Availability of Reference Materials Cited in NRC Publications

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

1. The NRC Public Document Room, 1717 H Street, N.W.
Washington, DC 20555
2. The NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission,
Washington, DC 20555
3. The National Technical Information Service, Springfield, VA 22161

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

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

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

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

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

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

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

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

Nuclear-Fuel-Cycle Risk Assessment: Descriptions of Representative Non-Reactor Facilities

Sections 1-14

Manuscript Completed: July 1982
Date Published: September 1982

Prepared by
K. J. Schneider, Coordinator

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
Division of Risk Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN B2402

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It
has been reproduced from the best available
copy to permit the broadest possible avail-

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

[Handwritten signature]

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

STUDY CONTRIBUTORS

STUDY LEADER

K. J. Schneider

VOLUME 1

Section 1 - Introduction

K. J. Schneider

Section 2 - Summary

K. J. Schneider

Section 3 - Technical Approach

K. J. Schneider

Section 4 - Definition of Representative Fuel Cycle Elements

K. J. Schneider

Section 5 - Representative Site for Mine or Mill

K. J. Schneider

Section 6 - Representative Site for Disposal of High-Level and Transuranic Wastes and Spent Fuel

C. A. Geffen

L. E. Duda^(a)

K. J. Schneider

Section 7 - Representative Site for Shallow Land Burial Grounds

K. J. Schneider

Section 8 - Representative Site for All Fuel Cycle Facilities Except Mines, Mills, and Waste Disposal Facilities

K. J. Schneider

Section 9 - Uranium Mining

C. A. Geffen

Section 10 - Uranium Milling

N. E. Miller^(b)

Section 11 - Uranium Purification and Conversion

N. E. Miller^(b)

Section 12 - Enrichment

K. R. Yates^(b)

Section 13 - Fuel Fabrication

R. R. Fullwood^(c)

Section 14 - Fuel Refabrication

R. R. Fullwood^(c)

VOLUME 2

Section 15 - Fuel Reprocessing

W. J. Zielenbach

Section 16 - Spent Fuel and High-Level and Transuranic Waste Storage

P. M. Daling

T. B. Powers

Section 17 - Spent Fuel and High-Level and Transuranic Waste Disposal

C. A. Geffen

R. E. Pepping^(a)

Section 18 - Low-Level and Intermediate-Level Waste Disposal

W. E. Bickford

Section 19 - Transportation of Radioactive Materials in the Nuclear Fuel Cycle

C. A. Geffen

P. M. Daling

Glossary

P. M. Daling

(a) Associated with Sandia National Laboratory

(b) Associated with Battelle-Columbus Laboratories

(c) Associated with Science Applications, Inc.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

FOREWARD
BY THE
NUCLEAR REGULATORY COMMISSION

Considerable attention has been focused on the use of risk assessment ^(a) in the regulation of nuclear power. The Advisory Committee on Reactor Safeguard (ACRS), the Commission (NRC) and the Lewis Committee (risk assessment review group to the NRC's Reactor Safety Study) have strongly recommended that risk assessment be used in the NRC regulatory and licensing processes. Therefore, the Division of Risk Analysis (DRA) of the Office of Nuclear Regulatory Research (RES) has placed major emphasis on the development of risk assessment methods and the application of these methods to provide useful information in regulating and licensing nuclear activities. The Reactor Safety Study, conducted in the early 1970's was a significant advance in the state-of-the-art for conducting risk assessment for light water reactors (LWR). Currently, research programs are underway or planned by the NRC and the utilities to further refine and develop LWR risk assessment methods, to perform plant specific risk assessment studies, and, to utilize the risk assessment results in fulfilling the NRC's mission to protect the health and safety of both the public and the workers in the nuclear industry. The development and application of LWR risk assessment methods has now reached a point where the potential use of risk assessment in the NRC decisionmaking processes is being given serious consideration.

The NRC has expended comparatively little effort in developing and applying risk assessment methods to other elements of the nuclear fuel cycle. Consequently, the state-of-the-art for risk assessment of fuel cycle facilities is not as advanced as for reactors. There have been some safety and risk assessment studies performed on the fuel cycle facilities but they differ significantly in the level of analysis, kinds of methods used and the degree of confidence that could be placed in the results. Therefore, RES, with the endorsement of the NRC's Office of Nuclear Material Safety and Safeguards (NMSS), has initiated this Nuclear Fuel Cycle Risk Assessment Program to (1) determine the types of risk that dominate the nuclear fuel cycle; (2) develop and apply risk assessment methods and associated computer codes; (3) provide insights for using risk assessment in licensing and regulatory decisionmaking; (4) determine the sources of major contributors to the risk; (5) develop in-house expertise in the application of risk assessment methods and computer codes for use in the regulatory process; and (6) respond to criticism that non-reactor fuel cycle risks have not been adequately considered in evaluating the potential risk to the public from nuclear power generation.

(^a) Synonymous with risk analysis

If the above goals are achieved, this program can provide (1) risk assessment methods for consistent and improved safety evaluation of fuel cycle facility designs and operations; (2) a rational basis for the development of standards and guides on design criteria, accident evaluation, siting, emergency planning, and safety classification of structures, systems and components; and (3) rationale for setting priorities on NRC research by identifying the major contributors to risk and associated uncertainties.

This multi-year program was initiated in late 1981. A research team from several sources has been assembled to provide technical strengths and expertise in the many areas involved in the program. The prime contractor is Battelle Pacific Northwest Laboratory ^(b) and the principal subcontractor is Battelle Columbus Laboratories. Contributions have also been made by staff at other research organizations.

The initial step in this program consisted on the establishment of the reference fuel cycles and the description of the fuel cycle elements as documented in this report. At the same time the various sources of available information on design, safety and risk have been located and reviewed. This information has been screened for use in subsequent program activities. Following this, the major program activities will be the ranking of the fuel cycle elements according to their risks (using available information and supplementing the work where necessary) and the assessment of the applicability of existing risk assessment methods to fuel cycle elements and their use in the regulatory process. Based on the result of the risk ranking and methods assessment activities, existing methods will be improved or new risk assessment methods developed as appropriate. The use of these methods and associated computer codes will then be demonstrated by performing risk assessment case studies. The last part of the program will consist of the transfer of these risk assessment methods and computer codes to the NRC staff for their application to the regulatory process.

For more information on the program of this report, please write to:

Director, Division of Risk Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

(b) Operated for the U.S. Department of Energy by the Pacific Northwest Laboratory of Battelle Memorial Institute.

ABSTRACT

The U.S. Nuclear Regulatory Commission has initiated the Fuel Cycle Risk Assessment Program to provide risk assessment methods for assistance in the regulatory process for nuclear fuel cycle facilities other than reactors. This report, the first from the program, defines and describes fuel cycle elements that are being considered in the program. One type of facility, (and in some cases two) is described that is representative of each element of the fuel cycle. The descriptions are based on real industrial-scale facilities that are current state-of-the-art, or on conceptual facilities where none now exist.

Each representative fuel cycle facility is assumed to be located on the appropriate one of four hypothetical but representative sites described in the report.

The fuel cycles considered in this report are for Light Water Reactors with once-through flow of spent fuel, and with plutonium and uranium recycle. Representative facilities for the following fuel cycle elements are described for uranium (or uranium plus plutonium where appropriate): mining, milling, conversion, enrichment, fuel fabrication, mixed-oxide fuel refabrication, fuel reprocessing, spent fuel storage, high-level waste storage, transuranic waste storage, spent fuel and high-level and transuranic waste disposal, low-level and intermediate-level waste disposal, and transportation. For each representative facility the description includes: mainline process, effluent processing and waste management, facility and hardware description, safety-related information and potential alternative concepts for that fuel cycle element.

The emphasis of the descriptive material is on safety-related information. This includes: operating and maintenance requirements, input/output of major materials, identification and inventories of hazardous materials (particularly radioactive materials), unit operations involved, potential accident driving forces, containment and shielding, and degree of hands-on operation.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

CONTENTS OUTLINE

VOLUME 1

1.0	INTRODUCTION.	1.1
2.0	SUMMARY	2.1
3.0	TECHNICAL APPROACH.	3.1
4.0	DEFINITION OF REPRESENTATIVE FUEL CYCLE ELEMENTS.	4.1
5.0	REPRESENTATIVE SITE FOR MINE OR MILL.	5.1
6.0	REPRESENTATIVE SITE FOR DISPOSAL OF HIGH-LEVEL AND TRANSURANIC WASTES AND SPENT FUEL	6.1
7.0	REPRESENTATIVE SITE FOR SHALLOW LAND WASTE BURIAL GROUNDS	7.1
8.0	REPRESENTATIVE SITE FOR ALL FUEL CYCLE FACILITIES EXCEPT MINES, MILLS AND WASTE DISPOSAL FACILITIES	8.1
9.0	URANIUM MINING.	9.1
10.0	URANIUM MILLING	10.1
11.0	URANIUM PURIFICATION AND CONVERSION	11.1
11.A	WET URANIUM CONVERSION WITH SOLVENT EXTRACTION PURIFICATION	11.2
11.B	DRY URANIUM CONVERSION WITH FRACTIONAL-DISTILLATION PURIFICATION	11.26
12.0	ENRICHMENT.	12.1
12.A	GASEOUS DIFFUSION ENRICHMENT	12.1
12.B	GAS CENTRIFUGE ENRICHMENT.	12.41
12.C	ALTERNATIVE ENRICHMENT PROCESS	12.66
13.0	FUEL FABRICATION.	13.1
14.0	FUEL REFABRICATION.	14.1
	GLOSSARY.	G.1

VOLUME 2

15.0	FUEL REPROCESSING	15.1
16.0	SPENT FUEL AND HIGH-LEVEL AND TRANSURANIC WASTE STORAGE	16.A.1
16.A	SPENT FUEL STORAGE FACILITY.	16.A.2
16.B	SOLIDIFIED HIGH-LEVEL WASTE STORAGE.	16.B.1
16.C	TRANSURANIC WASTE STORAGE FACILITY	16.C.1
17.0	SPENT FUEL AND HIGH-LEVEL AND TRANSURANIC WASTE DISPOSAL. . . .	17.1
18.0	LOW-LEVEL AND INTERMEDIATE-LEVEL WASTE DISPOSAL	18.1
19.0	TRANSPORTATION OF RADIOACTIVE MATERIALS IN THE NUCLEAR FUEL CYCLE	19.1
	GLOSSARY.	G.1

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

VOLUME 1 CONTENTS

1.0	INTRODUCTION	1.1
2.0	SUMMARY.	2.1
3.0	TECHNICAL APPROACH	3.1
4.0	DEFINITION OF REPRESENTATIVE FUEL CYCLE ELEMENTS	4.1
5.0	REPRESENTATIVE SITE FOR MINE OR MILL	5.1
5.1	LOCATION.	5.1
5.2	DEMOGRPAHY	5.1
5.3	LAND USE.	5.1
5.4	WATER USE	5.2
5.5	GEOLOGY	5.3
5.6	HYDROLOGY	5.3
5.7	METEOROLOGY.	5.4
5.8	ECOLOGY	5.6
REFERENCES		5.7
6.0	REPRESENTATIVE SITE FOR DISPOSAL OF HIGH-LEVEL AND TRANSURANIC WASTES AND SPENT FUEL	6.1
6.1	LOCATION.	6.1
6.2	DEMOGRAPHY	6.1
6.3	LAND USE.	6.1
6.4	WATER USE	6.1
6.5	GEOLOGY	6.2
6.6	HYDROLOGY	6.3
6.7	METEOROLOGY.	6.4
6.8	ECOLOGY	6.5
6.9	NEAR-SURFACE WATER PATHWAYS	6.5
REFERENCES		6.9

VOLUME 1 CONTENTS (Continued)

7.0	REPRESENTATIVE SITE FOR SHALLOW LAND WASTE BURIAL GROUNDS . . .	7.1
7.1	LOCATION.	7.1
7.2	DEMOGRAPHY	7.1
7.3	LAND USE.	7.1
7.4	WATER USE	7.2
7.5	GEOLOGY	7.3
7.6	HYDROLOGY	7.3
7.7	METEOROLOGY.	7.5
7.8	ECOLOGY	7.9
	REFERENCES	7.10
8.0	REPRESENTATIVE SITE FOR ALL FUEL CYCLE FACILITIES EXCEPT MINES, MILLS AND WASTE DISPOSAL FACILITIES	8.1
8.1	LOCATION.	8.1
8.2	DEMOGRAPHY	8.1
8.3	LAND USE.	8.1
8.4	WATER USE	8.2
8.5	GEOLOGY	8.3
8.6	HYDROLOGY	8.3
8.7	METEOROLOGY.	8.6
8.8	ECOLOGY	8.10
	REFERENCES	8.11
9.0	URANIUM MINING	9.1
9.1	SUMMARY	9.1
9.2	MAINLINE PROCESS DESCRIPTION	9.3

VOLUME 1 CONTENTS (Continued)

9.2.1	Site Preparation	9.3
9.2.2	Fragmentation of Rock	9.5
9.2.3	Loading and Haulage	9.5
9.2.4	Ore Preparation	9.6
9.2.5	Underground Services.	9.7
9.3	DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT SYSTEMS	9.8
9.3.1	Liquid Effluents	9.8
9.3.2	Liquid Effluent Processing and Control.	9.8
9.3.3	Airborne Effluents	9.9
9.3.4	Airborne Effluent Control	9.9
9.3.5	Solid Waste Management	9.10
9.4	PLANT LAYOUT.	9.10
9.4.1	Site Description	9.10
9.4.2	Facility Description.	9.11
9.5	SAFETY-RELATED INFORMATION	9.11
9.5.1	Operating and Maintenance Requirements.	9.11
9.5.2	Input/Output of Major Materials	9.12
9.5.3	Inventories of Major Hazardous Materials at Plant Locations Having Safety-Related Importance	9.17
9.5.4	Unit Operations Involved	9.17
9.5.5	Accident Driving Forces.	9.17
9.5.6	Containment and Shielding Systems	9.17
9.5.7	Relative Degree of Hands-On Operation	9.21
9.6	ALTERNATIVE PROCESS SCHEMES FOR URANIUM MINING	9.21
9.6.1	Open-Pit Mining	9.21
9.6.2	In-Situ Mining.	9.25
REFERENCES		9.31
10.0	URANIUM MILLING.	10.1
10.1	SUMMARY	10.1
10.2	MAINLINE PROCESS DESCRIPTION	10.2
10.2.1	Ore Handling and Preparation.	10.2

VOLUME 1 CONTENTS (Continued)

10.2.2	Mill Concentration.	10.4
10.2.3	Product Recovery	10.5
10.3	DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT . .	10.6
10.3.1	Effluent Processing	10.6
10.3.2	Waste Management	10.8
10.4	PLANT LAYOUT	10.10
10.4.1	Site Description	10.10
10.4.2	Facility Description	10.10
10.5	SAFETY-RELATED INFORMATION.	10.12
10.5.1	Operating and Maintenance Requirements	10.12
10.5.2	Input/Output of Major Materials	10.12
10.5.3	Inventories of Major Hazardous Materials at Plant Locations Having Safety-Related Importance	10.19
10.5.4	Unit Operations Involved.	10.20
10.5.5	Accident Driving Forces	10.20
10.5.6	Containment and Shielding	10.20
10.5.7	Degree of Hands-On Operation	10.20
10.6	OTHER PROCESS SCHEMES FOR URANIUM MILLING.	10.20
10.6.1	Alkaline Leach Process	10.22
10.6.2	Ion Exchange Recovery Process	10.22
10.6.3	Eluex Process	10.24
REFERENCES		10.24
11.0	URANIUM PURIFICATION AND CONVERSION	11.1
11.A	WET URANIUM CONVERSION WITH SOLVENT EXTRACTION PURIFICATION . .	11.2
11.A.1	SUMMARY	11.2
11.A.2	MAINLINE PROCESS DESCRIPTION	11.3
11.A.2.1	Feed Preparation.	11.3
11.A.2.2	Digestion	11.3
11.A.2.3	Solvent Extraction	11.3
11.A.2.4	Denitration and Reduction.	11.6
11.A.2.5	Hydrofluorination	11.6
11.A.2.6	Fluorination and Collection	11.6
11.A.2.7	Fluorine Production.	11.7

VOLUME 1 CONTENTS (Continued)

11.A.3	DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT SYSTEMS	11.7
11.A.3.1	Effluent Processing	11.7
11.A.3.2	Waste Management	11.10
11.A.4	PLANT LAYOUT	11.12
11.A.4.1	Site	11.12
11.A.4.2	Facility Descriptions.	11.12
11.A.5	SAFETY-RELATED INFORMATION	11.14
11.A.5.1	Operating and Maintenance Requirements	11.14
11.A.5.2	Input/Output of Major Materials	11.17
11.A.5.3	Inventory of Major Hazardous Materials Having Safety-Related Importance	11.17
11.A.5.4	Unit Operations Involved.	11.17
11.A.5.5	Accident Driving Forces	11.17
11.A.5.6	Containment and Shielding	11.24
11.A.5.7	Degree of Hands-On Operation	11.24
11.A.6	ALTERNATIVE PROCESS SCHEMES	11.24
REFERENCES		11.25
11.B	DRY URANIUM CONVERSION WITH FRACTIONAL-DISTILLATION PURIFICATION.	11.26
11.B.1	SUMMARY.	11.26
11.B.2	MAINLINE PROCESS DESCRIPTION.	11.27
11.B.2.1	Feed Preparation	11.27
11.B.2.2	Reduction.	11.27
11.B.2.3	Hydrofluorination	11.27
11.B.2.4	Fluorination and Distillation	11.27
11.B.2.5	Fluorine Production	11.31
11.B.3	DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT SYSTEMS.	11.31
11.B.3.1	Effluent Processing	11.31
11.B.3.2	Waste Management	11.32
11.B.4	PLANT LAYOUT	11.36
11.B.5	SAFETY-RELATED INFORMATION	11.36

VOLUME 1 CONTENTS (Continued)

11.B.5.1	Operating and Maintenance Requirements	11.36
11.B.5.2	Input/Output of Major Materials	11.36
11.B.5.3	Inventory of Major Hazardous Materials Having Safety-Related Importance	11.39
11.B.5.4	Unit Operations Involved.	11.39
11.B.5.5	Accident Driving Forces	11.39
11.B.5.6	Containment and Shielding Systems.	11.41
11.B.5.7	Degree of Hands-On Operation	11.41
11.B.6	ALTERNATIVE PROCESS SCHEMES	11.41
REFERENCES		11.41
12.0	ENRICHMENT	12.1
12.A	GASEOUS DIFFUSION ENRICHMENT	12.2
12.A.1	SUMMARY.	12.2
12.A.2	MAINLINE PROCESS DESCRIPTION OF GASEOUS DIFFUSION.	12.4
12.A.2.1	Description of Process Steps	12.4
12.A.2.2	Uranium Recovery	12.11
12.A.3	DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT SYSTEMS	12.11
12.A.3.1	Effluent Processing	12.11
12.A.3.2	Waste Management	12.21
12.A.4	PLANT LAYOUT	12.21
12.A.4.1	Site Description	12.24
12.A.4.2	Facility Description.	12.24
12.A.5	SAFETY-RELATED INFORMATION	12.29
12.A.5.1	Operating and Maintenance Requirements	12.29
12.A.5.2	Input/Output of Major Materials	12.29
12.A.5.3	Inventory of Major Hazardous Materials at Plant Locations Having Safety-Related Importance	12.30
12.A.5.4	Unit Operations Involved.	12.32
12.A.5.5	Accident Driving Forces	12.33
12.A.5.6	Containment Systems	12.33
12.A.5.7	Degree of Hands-On Operation	12.33
12.A.5.8	Systems Interactions	12.34
12.A.5.9	Criticality Safety.	12.35

VOLUME 1 CONTENTS (Continued)

12.B	GAS CENTRIFUGE ENRICHMENT.	12.36
12.B.1	SUMMARY	12.36
12.B.2	MAINLINE PROCESS DESCRIPTION OF GAS CENTRIFUGE ENRICHMENT	12.37
12.B.3	DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT SYSTEMS	12.40
12.B.3.1	Liquid Effluent Processing	12.40
12.B.3.2	Airborne Effluents	12.44
12.B.3.3	Waste Management.	12.46
12.B.4	PLANT LAYOUT	12.48
12.B.4.1	Site Description.	12.48
12.B.4.2	Facility Description	12.48
12.B.5	SAFETY-RELATED INFORMATION.	12.54
12.B.5.1	Operating and Maintenance Requirements	12.54
12.B.5.2	Input/Output of Major Materials.	12.56
12.B.5.3	Inventories of Major Hazardous Materials at Plant Locations Having Safety-Related Importance.	12.56
12.B.5.4	Unit Operations Involved	12.56
12.B.5.5	Accident Driving Forces	12.56
12.B.5.6	Containment Systems.	12.56
12.B.5.7	Relative Degree of Hands-On Operation.	12.56
12.C	ALTERNATIVE ENRICHMENT PROCESSES	12.57
REFERENCES.		12.57
13.0	FUEL FABRICATION.	13.1
13.1	SUMMARY.	13.1
13.2	MAINLINE PROCESS DESCRIPTION.	13.3
13.2.1	Material Receiving and Storage	13.4
13.2.2	Vaporizing and Hydrolyzing.	13.4
13.2.3	Comminution, Blending and Packaging.	13.7
13.2.4	Compaction, Granulation, Pelletizing, Boat Loading and Green Pellet Storage.	13.7
13.2.5	Sintering, Inspection and Pellet Storage	13.8

VOLUME 1 CONTENTS (Continued)

13.2.6	Pellet Grinding, Inspection and Storage Grinding	13.9
13.2.7	Fuel Rod Loading	13.10
13.2.8	Fuel Rod Testing, Inspection and Storage	13.11
13.2.9	Fuel Element Assembly and Shipping	13.11
12.2.10	Fuel Rod Repair and Dismantling	13.12
12.2.11	Clean Scrap Recovery System (CSRS)	13.13
12.2.12	Dirty Scrap Recovery System.	13.15
12.2.13	Decontamination and Hot Repair.	13.15
12.2.14	Analytical Services	13.17
13.3	DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT SYSTEMS	13.18
13.3.1	Liquid Effluents Processing.	13.18
13.3.2	Airborne Effluents Processing	13.20
13.3.3	Waste Management	13.24
13.4	PLANT LAYOUT	13.27
13.4.1	Site Description	13.27
13.4.2	Facility Description	13.27
13.5	SAFETY-RELATED INFORMATION.	13.31
13.5.1	Operating and Maintenance Requirements	13.31
13.5.2	Input/Output of Major Materials	13.38
13.5.3	Inventory of Major Hazardous Materials at Plant Locations Having Safety-Related Importance.	13.38
13.5.4	Unit Operations Involved.	13.38
13.5.5	Accident Driving Forces	13.30
13.5.6	Containment and Shielding Systems.	13.49
13.5.7	Degree of Hands-On Operation	13.52
13.5.8	Product Form and Behavior	13.52
13.6	ALTERNATIVE PROCESS SCHEMES.	13.55
13.6.1	Direct Conversion Fluidized Bed (DCFB)	13.55
13.6.2	Powder Front End	13.59
13.6.3	Dirty Scrap Recovery at Other Plants.	13.59
13.6.4	Pneumatic Transfer Air Recirculation.	13.60
13.6.5	Safeguards Considerations	13.60
REFERENCES		13.61
APPENDIX.		13.62

VOLUME 1 CONTENTS (Continued)

14.0	FUEL REFABRICATION	14.1
14.1	SUMMARY.	14.1
14.2	MAINLINE PROCESS DESCRIPTION.	14.3
14.2.1	Material Receiving and Storage	14.3
14.2.2	Fuel Material Unloading.	14.3
14.2.3	Powder Blending	14.6
14.2.4	Compaction, Granulation, Pelletizing, Boat Loading and Green Pellet Storage.	14.7
14.2.5	Sintering, Inspection and Pellet Storage	14.9
14.2.6	Pellet Grinding, Inspection and Storage	14.10
14.2.7	Fuel Rod Loading	14.10
14.2.8	Fuel Rod Testing, Inspection and Storage	14.11
14.2.9	Fuel Element Assembly and Shipping	14.12
14.2.10	Fuel Rod Dismantling and Repair	14.13
14.2.11	Clean Scrap Recovery System	14.14
14.2.12	Dirty Scrap Recovery System	14.16
14.2.13	Decontamination and Hot Repair	14.16
14.2.14	Analytical Services	14.19
14.3	DESCRIPTION OF EFFLUENT CONTROL PROCESSING AND WASTE MANAGEMENT SYSTEMS	14.19
14.3.1	Liquid Effluent Processing.	14.20
14.3.2	Airborne Effluent Processing	14.23
14.4	PLANT LAYOUT	14.31
14.4.1	Site Description	14.31
14.4.2	Facility Description.	14.32
14.5	SAFETY-RELATED INFORMATION	14.39
14.5.1	Operating and Maintenance Requirements.	14.39
14.5.2	Input/Output of Major Materials	14.39
14.5.3	Inventory of Major Hazardous Materials at Plant Locations Having Safety-Related Importance	14.47
14.5.4	Unit Operations Involved	14.47
14.5.5	Accident Driving Forces.	14.47
14.5.6	Containment and Shielding Systems	14.50
14.5.7	Degree of Hands-on Operation	14.50
14.5.8	Product Form and Behavior	14.50
14.6	ALTERNATIVES TO THE REPRESENTATIVE CONCEPT	14.54
14.6.1	Co-Precipitation	14.54
14.6.2	Other Considerations.	14.56

VOLUME 1 CONTENTS (Continued)

REFERENCES	14.60
APPENDIX 14	14.61
GLOSSARY	G.1

VOLUME 1 FIGURES

2.1	Fuel Cycle and Fuel Cycle Elements in This Study	2.3
6.1	Schematic Diagram of the Representative Site	6.3
6.2	Surface Zones Used in Representative Site Definition	6.6
6.3	Diagrammatic Representation of Zones Used in Representative Site	6.7
7.1	Geologic Profile - Representative Shallow Ground Waste Disposal Area	7.4
7.2	Mean Monthly Temperatures at the Representative Site for the Shallow Land Disposal Site	7.6
7.3	Precipitation Event Recurrence Intervals for the Representative Shallow Land Waste Disposal Site	7.7
7.4	Wind Rose Diagram - Representative Shallow Land Waste Disposal Site	7.8
8.1	Recorded Daily Average and Extreme River Flows at the Representative Fuel Cycle Facility Site	8.5
8.2	Daily Average and Extreme Water Temperatures at the Representative Fuel Cycle Facility Site	8.5
8.3	Liquid Effluents Dilution for the Representative River at the Representative Fuel Cycle Facility Site	8.6
8.4	Average ($\bar{X}/Q'$) Values Versus Distance in a Sector from the Representative River Site for Fuel Cycle Facilities	8.9
9.1	Mainline Process Flow Diagram for the Representative Underground Mining Facility	9.4
9.2	Schematic of Ore Loading and Haulage for Underground Mine .	9.6
9.3	Geographic Distribution of Commercial and Pilot In-Situ Uranium Mining Facilities	9.26
10.1	Overall Process Flow Diagram - Representative Acid-Leach Mill Process	10.3
10.2	Process Flow Diagram - Liquid and Airborne Effluent Treatment System for a Representative Acid-Leach Mill	10.7
10.3	Overall Waste Management Operations for a Representative Acid-Leach Mill	10.9

FIGURES (Continued)

10.4	Layout of the Representative Acid Leach Mill	10.11
10.5	Process Flow Diagram - Typical Alkaline-Leach Mill Process .	10.23
11.A.1	Representative Mainline Process for Wet Conversion	11.4
11.A.2	Mainline Process Flow Diagram for the Representative Uranium Wet Conversion Facility	11.5
11.A.3	Process Flow Diagram - Liquid Effluent Treatment System for a Uranium Wet Conversion Facility	11.8
11.A.4	Process Flow Diagram - Airborne Effluent Treatment System for a Uranium Wet Conversion Facility	11.9
11.A.5	Overall Waste Management Process for a Representative Uranium Wet Conversion Facility	11.11
11.A.6	Layout of a Solvent-Extraction Conversion Facility	11.13
11.B.1	Process Flow Diagram for Fluorination-Fractional Distillation Uranium Conversion Plant	11.28
11.B.2	Overall Mainline Process Flow Diagram for Representative Fluorination-Fractional Distillation Uranium Conversion Facility	11.29
11.B.3	Process Flow Diagram - Liquid Effluent Treatment for a Dry Conversion Facility	11.30
11.B.4	Process Flow Diagram - Dust Collection System for a Dry Conversion Facility	11.33
11.B.5	Process Flow Diagrams - Off-Gas Treatment Systems for a Dry Conversion Facility	11.34
11.B.6	Waste Management Process for a Fluorination-Fractional Distillation Uranium Conversion Facility	11.35
12.A.1	Overall Representative Mainline Process for Gaseous Diffusion Enrichment	12.5
12.A.2	Mainline Process Flow Diagram for the Gaseous Diffusion Plant	12.6
12.A.3	Schematic of Converter for Gaseous Diffusion Stage	12.8
12.A.4	Stage Arrangement - Gaseous Diffusion Facility	12.8

FIGURES (Continued)

12.A.5	Gaseous Diffusion Stage Heat Transfer System	12.9
12.A.6	Process Recirculation Cooling Water Flow Schematic	12.10
12.A.7	Uranium Recovery Flow Diagram	12.12
12.A.8	Process Flow Diagram - Liquid Effluent Treatment System for Gaseous Diffusion Facility	12.13
12.A.9	Process Flow Diagram - Airborne Effluent Treatment System for Gaseous Diffusion Facility	12.15
12.A.10	Overall Waste Management Processes for the Gaseous Diffusion Facility	12.22
12.A.11	Layout of 8.75 Million SWU/Yr Gaseous Diffusion Facility . .	12.25
12.B.1	Schematic of Gas Centrifuge	12.38
12.B.2	Gas Centrifuge Cascade Configuration	12.39
12.B.3	Concept of Centrifuge Building Blocks	12.41
12.B.4	Process Overview of a Gas Centrifuge Plant	12.42
12.B.5	Repair Activity at a Gas Centrifuge Plant	12.47
12.B.6	Site Layout for Reference 8.8 Million SWU/yr Stand-Alone Gas Centrifuge Plant	12.49
12.B.7	Flowchart for Gas Centrifuge Assembly and Repair Process in Recycle and Assembly Building	12.55
13.1	Schematic of the Fuel Fabrication Mainline Process	13.5
13.2	Dirty Scrap Recovery and Reconversion for the Fuel Fabrication Plant	13.16
13.3	Process Flow Diagram - Liquid Effluent Treatment System for the UO ₂ Fuel Fabrication Facility.	13.19
13.4	Process Flow Diagram - Airborne Effluent Treatment System for the UO ₂ Fuel Fabrication Facility	13.23
13.5	Overall Waste Management Operations for Representative UO ₂ Fuel Fabrication Plant	13.28

FIGURES (Continued)

13.6	Waste Management Operations with Baled Materials for the Representative UO_2 Fuel Fabrication Plant	13.29
13.7	Layout of the Representative UO_2 Fuel Fabrication Plant . .	13.30
13.8	Main Building Floor Plan for the Representative UO_2 Fuel Fabrication Facility	13.35
13.9	Roof Plan and Process Stack Locations for the Representative UO_2 Fuel Fabrication Facility	13.36
13.10	Building Floor Plan Showing Areas for Different Processes .	13.39
13.11	Material Balance of the Uranium Fuel Fabrication Plant . .	13.40
13.12	Pictorial of the Levels of Confinement Barriers	13.51
13.13	Variation in Uranium Dioxide Particle Size Distribution for a Range of Calcining Temperature between 800 and 1200°C . .	13.54
13.14	Flow Sheet of the Alternative Fluidized Bed (DCFB) Process	13.57
14.1	Fuel Refabrication Mainline Process Schematic	14.1
14.2	Dirty Scrap Recovery and Reconversion for Model 200 Mg Mixed-Oxide/Year Fuel Refabrication Plant	14.17
14.3	Process Flow Diagram - Liquid Effluent Treatment System for the Mixed-Oxide Fuel Fabrication Facility	14.21
14.4	Process Flow Diagram - Airborne Effluent Treatment System of the Mainline Process for the Representative Mixed-Oxide Fuel Refabrication Facility	14.24
14.5	Process Flow Diagram - Airborne Effluent Treatment for the Supporting Process for the Representative Mixed-Oxide Fuel Refabrication Facility	14.27
14.6	Overall Waste Management Operations for the Representative Fuel Refabrication Plant	14.28
14.7	Layout of the Representative Fuel Refabrication Facility .	14.33
14.8	Floor Plan for Basement of UO_2 - PuO_2 Manufacturing Building	14.34
14.9	Floor Plan for First Floor of UO_2 - PuO_2 Manufacturing Building	14.35

FIGURES (Continued)

14.10	Floor Plan for Second Floor of Mixed-Oxide Manufacturing Building	14.36
14.11	Physical Layout for Second-Floor Level of Representative Mixed-Oxide Fuel Fabrication Plant	14.37
14.12	Physical Layout for First-Floor Level of Representative Mixed-Oxide Fuel Fabrication Plant	14.38
14.13	Material Quantities and Flows in an 8-Hour Shift for 200 Mg/Year	14.46
14.14	Pictorial of the Levels of the Confinement Barriers	14.51
14.15	Variation in Plutonium Dioxide Particle Size Distribution for a Range of Calcining Temperature between 800 and 1200°C	14.53
14.A	Mass Concentration of Solid and Liquid Particles in Aerosols	14.63

VOLUME 1 TABLES

2.1	Summary of Site Characteristics for Representative Fuel Cycle Facilities	2.2
2.2	Summary Description of Representative Uranium Fuel Cycle Facilities.	2.6
2.3	Summary of Safety-Related Characteristics of Representative Uranium Fuel Cycle Facilities	2.8/9
4.1	Fuel Cycle Elements Included in the General Description of Facilities.	4.2
5.1	Population Distribution Around the Representative Mine-Mill Site.	5.2
5.2	Water Quality Data at the Representative Mine-Mill Site.	5.4
5.3	Average Wind Speed Classes at the Representative Mine-Mill Site.	5.4
5.4	Atmospheric Diffusion Characteristics for the Western U.S. Site for Uranium Mine-Mills	5.5
5.5	Atmospheric Dispersion ($\bar{X}/Q'$) for Each Segment from a 10-Meter Release Height (sec/m^3) at the Representative Site for Uranium Mine-Mills	5.6
6.1	Suggested Land and Water Use Parameters for Safety Analysis	6.2
6.2	Thicknesses and Composition of Hydrostratigraphic Units.	6.4
6.3	Hydraulic Properties of Stratigraphic Units of the Bedded Salt Representative Site	6.5
7.1	Population Distribution Around the Representative Shallow Land.	7.2
7.2	Water Balance Information for Representative Shallow Land Waste Disposal Site.	7.9
8.1	Population Distribution Around the Representative Fuel Cycle Facility Site.	8.2
8.2	Monthly Air Temperature Statistics ($^{\circ}\text{C}$) at the Representative Site for Fuel Cycle Facilities	8.7
8.3	Mean Monthly Relative Humidity (%) at the Representative Site for Fuel Cycle Facilities	8.7

TABLES (Continued)

9.1	Overall Material Input/Output for Representative Underground Mining Facility	9.13
9.2	Inventories of Hazardous Materials at Various Mine Locations .	9.18
9.3	Unit Operations Involved for Each Step in the Underground Uranium Mining Process Flow Scheme.	9.19
9.4	Accident Driving Forces Present at an Underground Uranium Mine Facility.	9.20
9.5	Relative Degrees of Hands-On Operations in Underground Uranium Mining	9.22
9.6	Uranium Open-Pit Mine Water Composition	9.24
9.7	Major Constituents in Liquid Streams for Different Lixiviant Systems, In-Situ Mining	9.28
9.8	Annual Nonradioactive Atmospheric Emissions From an In-Situ Leach Facility.	9.29
9.9	Annual Radioactive Atmospheric Emissions From an In-Situ Leach Facility.	9.29
10.1	Major Process and Auxiliary Areas Description for the Representative Acid Leach Mill	10.13
10.2	Major Process Equipment Descriptions for the Representative Acid Leach Mill	10.14
10.3	Overall Radioactive Materials Input/Output for the Representative Acid Leach Mill	10.15
10.4	Overall Nonradioactive Materials Input for the Representative Acid Leach Mill	10.16
10.5	Overall Nonradioactive Airborne Effluents Output From the Representative Acid Leach Mill	10.17
10.6	Overall Nonradioactive Liquid Effluents From the Representative Acid Leach Mill	10.18
10.7	Overall Solid and Liquid Wastes From Uranium Acid Leach Mill .	10.19
10.8	Reference List of Unit Operations in the Fuel Cycle	10.21

TABLES (Continued)

11.A.1	Major Process and Auxiliaries Areas Description - Representative Uranium "Wet" Conversion Facility	11.15
11.A.2	Major Process Equipment Descriptions - Representative Uranium Wet Conversion Facility.	11.16
11.A.3	Overall Radioactive Materials Input/Output for Representative Uranium Wet Conversion Facility	11.18
11.A.4	Overall Nonradioactive Materials Input to Representative Uranium Wet Conversion Facility	11.19
11.A.5	Overall Nonradioactive Airborne and Liquid Effluents From a Uranium Wet Conversion Facility	11.20
11.A.6	Overall Solid and Liquid Wastes From a Uranium Wet Conversion Facility	11.21
11.A.7	Unit Operations for a Uranium Wet Conversion Facility.	11.22
11.A.8	Reference List of Unit Operations in the Representative Fuel Cycles.	11.23
11.A.9	Accident Driving Forces for a Uranium Wet Conversion Facility.	11.24
11.B.1	Contents of Liquid Effluents From a Dry Conversion Facility.	11.37
11.B.2	Contents of Airborne Effluents From a Dry Conversion Facility.	11.38
11.B.3	Radionuclides in Leached Fluorinator Ash From a Dry Conversion Facility	11.39
11.B.4	Reference List of Unit Operations in the Representative Fuel Cycles.	11.40
11.B.5	Accident Driving Forces for a Dry Conversion Facility.	11.41
12.A.1	Overall Radioactive Materials Input/Output for Diffusion Facility	12.17
12.A.2	Overall Nonradioactive Materials Input for Gaseous Diffusion Uranium Enrichment Plant	12.18
12.A.3	Overall Nonradioactive Airborne Effluents From Gaseous Diffusion Uranium Enrichment Plant	12.19

TABLES (Continued)

12.A.4	Overall Nonradioactive Liquid Effluents From Gaseous Diffusion Uranium Enrichment Plant.	12.20
12.A.5	Overall Solid Wastes From the Gaseous Diffusion Uranium Enrichment Plant.	12.23
12.A.6	Major Process and Auxiliaries Areas Description--Gaseous Diffusion Facility	12.27
12.A.7	Major Process Equipment Descriptions--Gaseous Diffusion Facility	12.28
12.A.8	Inventory of Hazardous Materials--Gaseous Diffusion Plant	12.31
12.A.9	Unit Operations in Gaseous Diffusion Plants.	12.32
12.A.10	Accident Driving Forces	12.33
12.B.1	Maximum Radioactive Gaseous Releases for 8.8 Million SWU/Yr Gas Centrifuge Plant	12.45
12.B.2	Nonradioactive Gaseous Effluents for the 8.8 Million SWU/Yr Gas Centrifuge Plant	12.46
13.1	Average Yearly Water Chemical Effluents From the Representative UO_2 Fuel Fabrication Plant	13.21
13.2	Discharge Concentrations and Total Annual Release of Radioactivity in Liquid Effluent From the Representative UO_2 Fuel Fabrication Plant	13.22
13.3	Airborne Uranium Releases from the Representative UO_2 Fuel Fabrication Facility	13.25
13.4	Average and Maximum Ammonia and Fluoride Gaseous Effluent Concentrations for the Representative UO_2 Fuel Fabrication Plant (Westinghouse 1975).	13.26
13.5	Major Process Equipment Descriptions	13.32
13.6	Number of Workers by Task and Shift for the UO_2 Fuel Fabrication Plant	13.37
13.7	Overall Radioactive Materials Input/Output for Representative UO_2 Fuel Fabrication Facility	13.41
13.8	Overall Nonradioactive Materials Input to the Representative UO_2 Fuel Fabrication Facility	13.42

TABLES (Continued)

13.9	Overall Nonradioactive Airborne Effluents From the Representative UO ₂ Fuel Fabrication Facility	13.43
13.10	Overall Nonradioactive Liquid Effluents From the Representative UO ₂ Fuel Fabrication Facility	13.44
13.11	Overall Solid Waste From the Representative UO ₂ Fuel Fabrication Facility	13.45
13.12	Overall Environmental Impacts From Representative UO ₂ Fuel Fabrication Facility	13.46
13.13	Unit Operation in the Representative Fuel Fabrication Plant	13.47
13.14	Summary of Accidental Releases of UF ₆ (>5 kg Uranium) From Feed Cylinders to Gaseous Diffusion Plant	13.50
13.15	Classification of Process Steps by Directness of Exposure.	13.53
13.16	Isotopic Composition of Uranium Dioxide.	13.56
14.1	A Comparison of Ambient Chemical Concentrations in the Plant Discharge and Receiving Waters with Estimated Concentrations Due to MOX Plant Operation	14.22
14.2.a	Major Process Area Descriptions - Representative UO ₂ -PuO ₂ Fuel Refabrication Facility.	14.40
14.2.b	Major Process Area Descriptions - Representative UO ₂ -PuO ₂ Fuel Refabrication Facility.	14.41
14.3.a	Major Process Equipment Descriptions - Representative UO ₂ -PuO ₂ Fuel Refabrication.	14.42
14.3.b	Major Process Equipment Descriptions - Representative UO ₂ -PuO ₂ Fuel Refabrication.	14.43
14.3.c	Major Process Equipment Descriptions - Representative UO ₂ -PuO ₂ Fuel Refabrication.	14.44
14.4	Number of Workers by Task and Shift	14.45
14.5	Unit Operations in the Representative Mixed-Oxide Fuel Fabrication Plant	14.48
14.6	Classification of Process Steps by Directness of Exposure.	14.52
14.7	Isotopic Composition of Plutonium Dioxide	14.55

TABLES (Continued)

14.A	Fractional Penetration of Dry-Process Polydisperse Aerosol Through Various HEPA Filter Stages	14.61
14.B	Fractional Penetration of Dry-Process Polydisperse Aerosol Through Various HEPA Filter Stages	14.62
14.C	MOX Fabrication Plant Preliminary Hazard Analysis.	14.64

1.0 INTRODUCTION

The U. S. Nuclear Regulatory Commission has been placing increased emphasis on the development of probabilistic risk assessment (PRA) methods and the application of these methods to provide information for use in regulating and licensing nuclear activities. The emphasis to date has been to develop PRA methods for light water reactors (LWR). Comparatively little effort has been expended to develop methods applicable to fuel cycle facilities. The Division of Risk Analysis in NRC's Office of Nuclear Regulatory Research has initiated the Fuel Cycle Risk Assessment Program at the Pacific Northwest Laboratory to develop needed PRA methods for fuel cycle facilities. The objectives of this program are: 1) to identify the risks and develop a consistent comparison of the risks from different parts of the nuclear fuel cycle, 2) to develop comprehensive risk assessment methods that can be used to provide information for use in regulating and licensing the elements of the fuel cycle, 3) to demonstrate the use of these methods, and 4) to assist the NRC staff in developing expertise in the application of the methods and evaluation of risk assessments performed using these or similar methods.

Several activities are underway in the program to meet these objectives. These activities are: identifying and locating safety and risk assessment literature dealing with fuel cycle facilities, using available information to rank fuel cycle facilities on the basis of risk, and assessing the adequacy of existing methods to meet NRC's needs for information on the risks from fuel cycle facilities. Subsequent efforts in the program will accomplish objectives (3) and (4).

This report presents basic descriptive information on each of the fuel cycle elements being considered in the program. This information provides the basis for work currently underway in the program. More detailed descriptive information will be developed as it is needed in subsequent parts of the program. All the nonreactor fuel cycle elements in the once-through LWR fuel cycle and the LWR fuel cycle with reprocessing and plutonium and uranium recycle are described in the report. All processing, waste management and transportation activities associated with these fuel cycles are included. A broad scope of fuel cycle elements is considered to assure that all facilities that could potentially require NRC regulatory or licensing activity are treated in the program.

The report is intended to provide an overview description of each of the elements in the fuel cycles being considered in this program. Information on existing facilities was used where available. Conceptual design studies form the basis for information presented on facilities that have not yet been built. Several fuel cycle elements have major process or design alternatives that are also described.

Describing each fuel cycle element helps to identify the major fuel cycle systems, or alternatives, for which risk-related information is desired. This identification assists in locating information on various fuel cycle element alternatives in the literature review task in this program.

This report also provides the basic facility descriptive information for the risk ranking activity of the program. The representative facilities used in existing risk and safety studies may be different. Results of the existing risk and safety review will be adjusted to account for major inventory and process option differences using the information in this report as a primary basis. The site characteristics given in this report will be used to ensure that the radiological consequences are determined on the same basis. Similar uses of this report will be applied to the later phase of applying the methods developed in the program.

Information is provided for the program activities on review and evaluation of existing methods for risk assessment and the improvement of these methods. Information on fuel cycle element system description will assist these program activities in providing a good understanding of the operations and the various types of risk that could be associated with each fuel cycle element.

Emphasis in the descriptions is placed on information important to the safety of the facility. The process being employed in the facility is described, the facility and site layout are presented, operations and maintenance requirements are discussed, inventories of hazardous materials are presented and safety systems are described. A set of representative sites for the fuel cycle elements is also described.

The report is divided into 19 major sections. The summary is presented in Section 2.0. The study background and bases and the selection of the fuel cycle elements to be included are discussed in Sections 3 and 4. Site descriptions are given in Sections 5 through 8 and the fuel cycle elements are described in the remaining sections. A glossary of abbreviations is also given.

2.0 SUMMARY

This report provides descriptions of facilities that are representative of the Light Water Reactor (LWR) fuel cycle. The descriptions cover all major commercial-scale elements for the once-through fuel cycle and for plutonium recycle, from uranium mining to waste storage and disposal, and including transportation of radioactive materials. This information was developed for the U.S. Nuclear Regulatory Commission's Fuel Cycle Risk Assessment Program. The information in this report will provide much of the facility descriptive material for the ranking of fuel cycle elements by risk and for the assessment of risk methods that have been recently initiated in the program.

One type of facility (and in some cases, two) is described in detail for each element of the fuel cycle. These descriptions are based on facilities that are current state-of-the-art. All information is derived from available reports on real facilities where they exist or on conceptual facilities where none now exist. Some modifications to existing facilities are conceptualized to suit the purpose of this report.

Four hypothetical but representative sites are described briefly in this report. Each facility (except transportation hardware) is hypothetically placed on the site appropriate for that facility. This standardization of site characteristics will assist in later normalization of risk analysis information for each of the representative facilities. The characteristics of the four sites and the fuel cycle facilities for which each is used are summarized in Table 2.1. The two sites for mines, mills and geologic disposal facilities are representative of the western U.S., and the two sites for shallow land burial and all other facilities are representative of the eastern U.S. All are located in rural areas.

The fuel cycles considered in this report, and the relationships of the various fuel cycle elements, are shown schematically in Figure 2.1.

The description of each of the 15 facilities includes mainline processing, effluent processing and waste management, physical plant arrangement and major equipment. A summary of the descriptive information for each facility is given in Table 2.2. The facilities selected are existing, large-scale, and current state-of-the-art where available. Where such real facilities do not exist, available conceptual facility designs were used. In a few cases, some conceptualization was done in this study. Also for each fuel cycle element a brief description of major alternative process schemes is given, with some of the more important safety-related information presented qualitatively for the respective alternatives.

Significant emphasis is placed on providing safety-related information for the representative facilities. This includes descriptions of operating and maintenance requirements, input/output of major hazardous materials, inventories of major hazardous materials, unit operations involved, degree of remote and hands-on operation, accident driving forces, and containment

TABLE 2.1 Summary of Site Characteristics for Representative Fuel Cycle Facilities

	Site			
	A, for Mines Mills (Sect. 5)	B, for Geologic Disposal (Sect. 6)	C, for Shallow Land Burial (Sect. 7) ^(a)	D, for All Other Fuel Cycle Facilities (Sect. 8)
Typical part of the U.S.	West	West, with climate as in East	Southeast	Midwest or South Midwest
Total area, km ²	13	34.7	0.6	4.7
Population within 80 km	56,000	56,000	480,000	3,500,000
Regional land use				
• Farms, %	Low	Low	55	80
• Developed, %	Very low	Very low	20	NA
• Undeveloped, %	Most (cattle grazing)	70% (cattle grazing)	25	NA
Distance to nearest flowing stream, km	No streams nearby	<5 Intermittent ~40 Continuous	1	Onsite
Annual precipitation, mm	300	1022	1170	610
General climate	Semiarid	Temperate	Humid, subtropical	Continental
Lithology	Very thick, old sedimentary rocks	Thick, sedimentary rocks over bedded salt, 510 m deep	Various sedimentary rocks, >80 m deep	Moderate sedimentary over old bedrock
Depth to ground-water, m	32-46	<120	12-17	~5

(a) Also used in this study for the dry-well concept for storage of solidified high-level waste canisters.
NA = Not Available.

FIGURE 2.1. Fuel Cycles and Fuel Cycle Elements in This Study

and shielding systems. A summary of the safety-related characteristics of the fuel cycle facilities is given in Table 2.3. In general, the safety-related concerns increase as one progresses from the front end fuel cycle elements to a peak at the fuel reprocessing plant. Beyond there, these concerns are generally no greater than, or are less than, those in fuel reprocessing. As is known, most safety-related characteristics for the front-end fuel cycle elements are generally similar to those of conventional mineral processing. For enrichment and fuel fabrication, nuclear criticality becomes a potential concern and better containment and effluent control is used. For the remaining elements, containment and effluent control is exceedingly strict. Modest shielding is needed in mixed-oxide fuel refabrication and large quantities of plutonium are handled. Fuel reprocessing involves large amounts of fission products (which require heavy shielding), it involves numerous unit operations with radioactivity in many forms (many of which are highly dispersible), and it must deal with high rates of heat generation from radioactivity decay. Waste storage and disposal deals generally with the materials from fuel reprocessing (and from most other fuel cycle elements), but the material is handled in high-integrity, sealed packages. Transportation deals with all fuel cycle materials with safety concerns similar to those of the respective fuel cycle elements from which the materials arise. Transportation, however, is the only element wherein the radioactive materials exist in large quantities beyond the fence of a stationary production site.

This report is believed to contain more descriptive detail than any other known compilation for essentially all nonreactor elements of the uranium fuel cycle. The amount of information in this report was limited by the availability of appropriate information and by the time and resources available for developing this report. The information should provide a reasonable starting point for filling in more information for performing detailed safety/risk analysis of fuel cycle elements.

(This page has been left blank to accommodate Table 2.2.)

TABLE 2.2. Summary Description of Representative Uranium Fuel Cycle Facilities

Item	Fuel Cycle Element						
	Mining (Section 9)	Milling (Section 10)	Conversion		Enrichment		Fuel Fabrication (Section 13)
			Aqueous (Section 11.A)	Dry (Section 11.B)	Gaseous Diffusion (Section 12.A)	Gas Centrifuge (Section 12.B)	
Facility Based On	Ambrosia Lake	Highland	Sequoyah	Metropolis	Stand-alone, combination of 3 US plants	Conceptual stand-alone	Westinghouse/Columbia, SC
Major Process	Underground room-and-pillar, cutting, blasting	Acid-leach, solvent extn., precipitation	Solvent extraction, hydrofluorination, fluorination	Hydrofluorination, fluorination, fractional distillation	Gaseous diffusion, cold trapping, waste recovery	Gas centrifuge, cold trapping, waste recovery	ADU process, calcination, compaction, sintering, waste recovery
Capacity							
Feed/Mg/yr	Ore Vein/varies	Ore/6.6E5	Yellowcake/1.2E4	Yellowcake/7400	UF ₆ /1.3E4	UF ₆ /1.3E4	UF ₆ /2100
Product/Mg/yr ^(a)	Ore/1.3E6	Yellowcake/930	UF ₆ /9100	UF ₆ /6E00	UF ₆ /1400	UF ₆ /1400	Fuel assemblies/1460
GW _e Equivalent/yr ^(b)	3300	1600	15,400	11,500	15,500	15,500	16,000
Operating hr/d and d/yr	16/312	24/365	24/365	24/300	24/365	24/365	24/350
Total Staff	1100	92	155	NA	1400	2150	1850
Contact Operations	All; most is not direct contact	All; most is not direct contact	All; most is not direct contact	All; most is not direct contact	All maintenance	All maintenance	Receiving, rod and element assemblage, maintenance
Remote Operations	None	None	None	None	Most operations	Most operations	Chemical processing, scrap recovery (not shielding)
Alternative Concepts	Open-pit, in-situ (Solution)	Alkaline leach ion exchange	None	None	U Laser, UF ₆ Laser, U plasma ion	U Laser, UF ₆ Laser, U plasma ion	Fluidized bed, powder front-end

TABLE 2.2. (Cont.)

Item	Fuel Cycle Element							
	MOX Fuel Refabrication (Section 14)	Fuel Reprocessing (Section 15)	Spent Fuel (Section 16.A)	Waste Storage High-Level Waste (Section 16.B)	TRU Waste (Section 16.C)	Geologic Waste Disposal (Section 17)	Shallow Land Waste Disposal (Section 18)	Transportation (Section 19)
Facility	Conceptual Westinghouse Recycle Fuels Plant	Barnwell with conceptual additions	Conceptual, stand-alone, water basin	Conceptual, stand-alone, dry-well	Conceptual, stand-alone, vault and outside pad	Conceptual NMTS disposal repository in salt formation	Conceptual stand-alone	State-of-the-art; specific to each material
Major Process	Powder blending, compaction, sintering, waste recovery	PUREX, UF ₆ and Pu conversion, HLW vitrification	Wet unloading and storage, ion exchange, heat exchange	Wet unloading, encapsulation, dry-well storage	Solids handling (shielded and unshielded), above grade storage	Solids handling, underground blasting, machine excavation	Burial in below-grade trenches	Truck and rail transport cross-country
Capacity								
Feed/Mg/yr	UO ₂ ; PuO ₂ /436; 18	Spent fuel/1500	Spent fuel/500 HM	Solidified HLW/320	TRU-waste/50,000	Spent fuel, HLW TRU waste/3900 HM equiv.	LLW, ILW/50,000 m ³	Individual shipping capacity/container for each material
Product/Mg/yr ^(a)	MOX assemblies/400 HM	U/1410; Pu/15	NAp	NAp	NAp	NAp	NAp	
GWD _e Equivalent/yr ^(b)	4400	15,500	5500	15,500	27,600	43,000	29,000	--
Operating hr/d and d/yr	24/350	24/300	24/365	24/365	20/300	24/365	8/250	Varies
Total Staff	260	500	~50	~100	28	259	70	1-2/shipment
Contact Operations	~All; most is not direct contact	Receiving, some maintenance	Receiving, maintenance	Receiving, maintenance	All CH-TRU ~1/2 RH-TRU	Receiving, ~All CH-TRU ~1/2 RH-TRU	~All; most is not direct contact	Direct contact with containers
Remote Operations	Pellet preparation, scrap recovery	Most operations	Fuel unloading and handling, waste-treatment	Most operations	~1/2 RH-TRU	~1/2 RH-TRU ~All spent fuel, HLW	None	Remote unloading for most materials
Alternative Concepts	Co-precipitation, remote maintenance	Many variations of PUREX, Others	Dry well, cask, tunnel rack, vault consolidation	Dry well, cask, tunnel rack, vault	Below-grade, mine storage, berms	Basalt, granite, tuff; self-shielded packages	Onsite processing, various burial variations	Variations of hardware for most containers

NA = not available

NAp = not applicable

(a) As U and/or Pu except from mining.

(b) Based on product rate to fuel fabrication and 11,000 MWD_e/MgHM.

TABLE 2.3. Summary of Safety-Related Characteristics of Representative Uranium Fuel Cycle Facilities

	Mining (Section 9)	Milling (Section 10)	Conversion		Enrichment		Fuel Fabrication (Section 13)
			Aqueous (Section 11.A)	Dry (Section 11.B)	Gaseous Diffusion (Section 12.A)	Gas Centrifuge (Section 12.B)	
Containment	Open equipment, ventilation control for staff.	Some open equip., some closed equip. and process vents.	Closed process equip., treated process vents.	Closed process equip., treated process vents.	Closed process equip., treated process vents.	Closed process equip., treated process vents inside treated bldg. air.	Sealed process equip., treated process vents.
Inventory of Radionuclides	Thousands of Mg of ore	~1E4 Mg of ore	~2E5 Mg of yellowcake, plus similar amount of UF_6	~2E5 Mg of yellowcake, plus similar amount of UF_6	~400 Mg UF_6	~100 Mg UF_6	~100 Mg UF_6 + UO_2
U+LA	NA	~20 Mg of yellowcake					
TRU	0	0	0	0	0	0	0
FPs + AP	0	0	0	0	0	0	0
Effluents							
Airborne	Ore with U+daughters 1900 kg/yr	Ore with U+daughters 2000 kg/yr	Yellowcake + UF_6 ~30 kg/yr	~0.1 Ci/yr nat. U+daughters	~10 kg U/yr	~40 kg U/yr	~2 kg U/yr
Liquid	Ore with U+daughters 2000 kg/yr	Ore with U+daughters NA	Yellowcake + UF_6 ~10,000 kg/yr	~0.5 Ci/yr nat. U+daughters	~140 kg U/yr	~6 kg U/yr	~0.2 kg U/yr
Other	Dust, CO, ore mts.	Dust, NO_x , HC	HC, NO_x , SO_x , CO, HF	NH_3 , SO_x , HF	~250 Mg/yr chemicals	~3 Mg/yr chemicals, HF, NO_x , SO_x	~1 Mg/yr NH_3 , HF in air ~1000 Mg/yr other
Nonradioactive Hazardous Materials	Explosives Flammable Materials	H_2 , SO_2 , oxidants, NH_3 , Kerosene	HF, HNO_3 , NH_3 , HC	HF, NH_3	HNO_3 , H_2SO_4 , O_2 , BHC	HNO_3 , AF, SO_x	NH_3 , H_2 , HC, HNO_3 , HCT
Major Unit Operations	Solids handling, blasting, solids size reduction	Solids handling, solids reduction, solvent extraction, precipitation, drying, packaging	Solids handling evaporation, solvent extraction, denitration, cold trapping, solid-gas chemical reaction	Solids handling, calcining, solid-gas chemical reactions, high-temperature distillation, cold trapping	Solids handling, solid-gas conversion, solvent extraction, vapor pumping	Solids handling, centrifuging, vapor pumping	Solids handling, solids heating, solids pressing, solids grinding, solvent extraction, evaporation
Major Accident Driving Forces	Explosives, fires, falling objects	High temperature processing, chemical reactivity, flammability	High temperature processing, exothermic chemical reactions, flammability	High temperature processing, exothermic chemical reactions	Much electrical energy, high chemical reactivity, nuclear criticality	Rotating mechanical energy, high chemical reactivity, nuclear criticality	Mechanical impact, air filter failure, chemical reactivity flammability, nuclear criticality

NA = not available
 HC = hydrocarbons
 HHC = halogenated hydrocarbons
 U = uranium
 LA = lower actinides
 TRU = transuranic elements
 FP = fission products
 AP = activation products

TABLE 2.3. (Cont.)

	MOX Fuel Refabrication (Section 14)	Fuel Reprocessing (Section 15)	Spent Fuel (Section 16.A)	Waste Storage High-Level Waste (Section 16.B)	TRU Waste (Section 16.C)	Geologic Waste Disposal (Section 17)	Shallow Land Waste Disposal (Section 18)	Transportation (Section 19)
Containment	Sealed process equip. inside sealed hoods inside tight work rooms. Highly treated process and bldg. vents.	Sealed and high-integrity process equip. inside tight cells inside tight bldg. Highly treated process and bldg. vents. Thick shielding walls.	Sealed containers under water in tight building. Treated process and bldg. vents.	Sealed containers in outer sealed con- tainers in sealed caissons.	Sealed containers in tight bldg. or in earthen berms.	Sealed containers in tight caissons in geologic formation.	Tight containers buried under ground.	For large quantities: sealed canister in- side sealed trans- porter; others are in tight containers.
Inventory of Radionuclides	<div> <div>U+LA</div> <div>4 Mg UO₂</div> </div> <div> <div>TRU</div> <div>0.1 Mg PuO₂</div> </div> <div> <div>FPS + AP</div> <div>0</div> </div>	<div> <div>Total up to equivalent of several hundred Mg of spent fuel.</div> </div>	<div> <div>Total up to 3000 Mg of spent fuel.</div> </div>	<div> <div>Modular; total up to equivalent of 2500 Mg HM equivalent per module.</div> </div>	<div> <div>Total up to 868 Ci of radionuclides, mostly transuranics.</div> </div>	<div> <div>Total up to equivalent of 86,000 Mg of spent fuel.</div> </div>	<div> <div>Total up to ~2E7 Ci mixed radionuclides.</div> </div>	<div> <div>Total up to 32 kg PuO₂, or up to 3.5 Mg spent fuel, or up to 22 Mg spent fuel equivalent as HLW.</div> </div>
Effluents								
Airborne	Trace Pu, U	-0.1 g FP/yr, 1 g U/yr; -0.01 g Pu/yr, all ⁸⁵ Kr + 14C + 3H in fuel	300 Ci/yr gaseous FPS; trace others	~1 Ci ³ H/yr; trace others	Trace radionuclides	Trace radionuclides	Negligible	Combustion products
Liquid	NA	0	Trace	Negligible	Trace radionuclides	Trace radionuclides	Negligible	Negligible
Other	NA	NO _x , HF, HCl	NO _x	Combustion products	~2 Mg/yr combustion products	Combustion products	Fugitive dust	Fugitive dust
Nonradioactive Hazardous Materials	NH ₃ , H ₂ , HCl, HNO ₃ , HCl	HNO ₃ , HCl, NH ₃ , HF, H ₂ SO ₄ , KOH	NaOH, HNO ₃ , HCl	NaOH, HNO ₃ , HCl	HCl, plastic film, wood	HCl	HCl	HCl
Major Unit Operations	Solids handling, solids heating, solids press- ing, solids grinding, solvent extraction, evaporation.	Solids handling, boiling liquids, solids-gas sepa- ration, solids dissolv- ing, solvent extraction, solids-gas chemical reaction, absorption, adsorption.	Solids hardware handling, heat exchange evaporation, filtration, sorption.	Solid hardware han- dling, heat exchange, evaporation, filtra- tion, sorption.	Solids hardware han- dling and conveying operations	Solids hardware handling, mining operations	Solids hardware han- dling and conveying, earth moving evapo- ration, compaction	Solids hardware han- dling and conveying
Major Accident Driving Forces	Mechanical impact, air filter failure, chemical reactivity, flammability, nuclear criticality.	Boiling liquids, pres- surized process piping, corrosion, flammability, exothermic, chemical re- actions, high temperature solids processing, heat from radioactive decay, nuclear criticality.	Heat from radioactive decay, nuclear criticality, potential (dropping) energy.	Heat from radioac- tive decay, poten- tial (dropping) energy, flammability.	Potential (dropping) energy, flammability.	Heat from radioac- tive decay, flamma- bility, nuclear criticality, cor- rosion structural failure, potential (dropping) energy.	Moderate chemical reactivity, poten- tial (dropping) energy, mechanical impact.	Transport accident forces, heat of radioactive decay, flammability.

NA = not available
 HC = hydrocarbons
 HHC = halogenated hydrocarbons
 U = uranium
 LA = lower actinides
 TRU = transuranic elements
 FP = fission products
 AP = activation products

3.0 TECHNICAL APPROACH

The overall approach in the study was: 1) select the representative light water reactor (LWR) fuel cycles of current and near-future licensing interest to the U.S. Nuclear Regulatory Commission; 2) select representative facilities for each element in the fuel cycle, as discussed in Section 4.0; and 3) describe each representative fuel cycle facility with emphasis on description that is pertinent to safety. This is done in Sections 9 through 19.

The fuel cycles selected are for the LWR with plutonium and uranium recycle and the LWR once-through fuel cycle. Processes and technology that have not advanced at least through pilot plant scale were not considered. Actual facilities using state-of-the-art technology were selected wherever possible; in some cases, these real facilities were conceptually modified to represent near-future considerations. Where existing or planned facilities do not exist, conceptual facilities were used. In some cases, more than one facility was studied.

The characterization of the representative facilities in this report includes:

- description of mainline process
- description of effluent processing and waste management systems
- description of plant and site layout
- description of safety-related features
- brief descriptions of alternative schemes to the representative one.

The emphasis in this report is to provide descriptive information that is pertinent to the safety aspects of operating and decommissioning each facility. Safety-related information includes the following basic information:

- operating staff
- input and output (products, wastes, effluents) of major hazardous materials
- inventory of major hazardous materials at plant locations having safety-related importance
- unit operations involved in each major operating step
- relative extent of hands-on versus remote operation
- accident driving forces available (e.g. pressures, temperatures, chemical reactivity, mechanical or potential energy, thermal energy, nuclear reactivity)
- containment (barriers) and shielding systems.

The brief descriptions of the alternative schemes to those in the representative facilities include qualitative identification of the major differences in safety-related features where available. In some cases, alternative schemes that are currently considered to have low likelihood of near-term implementation are also identified.

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 at each facility in this study includes treatment, handling, packaging, and interim onsite storage of the wastes.

Four generic sites were defined in this study to allow for later comparisons of safety impacts of the various fuel cycle elements. One generic site (Site A), representative of dry western U.S. areas is used for mines and mills; the second generic site (Site B), a composite of western U.S. geology and demography and temperate climate, is used for the deep geologic repository; the third generic site (Site C), representative of the southeastern U.S., is used for the shallow land waste burial ground; and the fourth generic site (Site D), representative of midwestern or south mid-eastern U.S., is used for all other fuel cycle facilities.

The information in this study is a compilation of readily available information with modification and supplementation in some places to meet the needs of this program. The report was developed from publicly available documents and investigators' judgment where information was conflicting or lacking. In some cases, 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. However, its identification is considered a part of the completeness of this study and may form the basis of further inquiry if needed.

4.0 DEFINITION OF REPRESENTATIVE FUEL CYCLE ELEMENTS

The bases for the selection of the representative fuel cycles were discussed in the program kick-off meeting held at the U.S. Nuclear Regulatory Commission (NRC) on October 22-23, 1981 and at the meeting of the NRC Research Review Group for the program on October 26, 1981 (Eng 1982). The major considerations and conclusions from those discussions are summarized here. Primary considerations in selecting the fuel cycle elements to be given major emphasis in the initial phases of the study were identified and agreed upon. These considerations are:

1. Does the fuel cycle element present important safety/risk concerns that exist in the fuel cycle?
2. Does the fuel cycle element have near- to medium-term (i.e., 10-20 years) application in the fuel cycle in the U.S.A.?
3. Is the fuel cycle element expected to play a major role in the overall fuel cycle scheme in the U.S.A.?

While these points are not believed to be absolute criteria, a fuel cycle element for which the answers are all "no" would likely not be given major effort in the subsequent activities of the program. Consideration 1 is really a controlling criterion; however, because the project team does not want to prejudge the outcome of risk ranking for the various elements of the fuel cycle, all of the basic fuel cycle elements identified here are to be considered during the literature review and early risk ranking program activities to assure that the high-risk elements are identified on a credible technical basis. Thus, the latter two questions become the primary points of concern. Representative fuel cycle elements selected for study at any phase of the program do not necessarily have to comprise a complete or real fuel cycle as long as they satisfy the main intent of the major considerations above. In addition, the elements and options to be studied in the initial phase of the program should be kept to a reasonable number to allow for the overall program objectives to be met.

After taking the above considerations into account, the following general fuel cycles and their elements were identified as candidates for study:

1. Light water reactor (LWR), once-through with spent fuel disposal
2. LWR with reprocessing
 - a. no recycle, U and Pu storage
 - b. U only recycle, Pu storage
 - c. U and Pu recycle
3. LWR + liquid metal fast breeder reactor (LMFBR) with reprocessing and U and Pu recycle
4. LWR + high-temperature gas reactor (HTGR) with reprocessing and U and Pu recycle.

It was decided that fuel cycles 1 and 2c were the most compatible with the considerations discussed above, based on the current status of the U.S. nuclear industry and on current federal policy. Fuel cycles 3 and 4 may merit attention at a later date.

From the two selected representative fuel cycles (shown schematically in Figure 2.1), the following elements (or types of facilities) of the fuel cycles were identified for characterization and consideration in the program as shown in Table 4.1.

TABLE 4.1. Fuel Cycle Elements Included in the General Description of Facilities

ELEMENT	DEFINITION
1. U Mining	One underground mine
2. U Milling	One mill process (acid leach followed by solvent extraction)
3. U Purification and Conversion	One aqueous conversion process and one pyrochemical conversion process
4. U Enrichment	One simplified gaseous diffusion plant and one simplified centrifuge plant
5. U Fuel Fabrication	One conventional plant
6. U-Pu Fuel Refabrication	One mechanical-blending plant that produces completed fuel assemblies with UO_2 - PuO_2
7. Fuel Reprocessing	One conventional plant using Purex solvent-extraction process
8. Spent Fuel Storage	One independent wet storage facility
High-Level Waste Storage	One independent dry-well storage facility
Transuranic Waste Storage	One independent earthen-covered pad facility
9. High-Level Waste, Transuranic Waste and Spent Fuel Disposal	One deep geological disposal facility (in bedded salt) with separate management of transuranic wastes
10. Low-Level and Intermediate-Level Waste Storage-Disposal	One independent shallow land burial facility
11. Transportation and Handling of Fuel Cycle Materials	One representative system for shipping each material; materials are: U ore, U yellowcake, natural UF_6 , enriched UF_6 , PuO_2 powder, PuO_2 - UO_2 fuel assemblies, UO_2 fuel assemblies, spent fuel, high-level wastes, contact-handled transuranic wastes, remotely handled transuranic wastes, and low- and intermediate-level non-transuranic wastes.

These facilities are each defined with their individual industrial-scale capacities. Comparisons of safety from various elements of the fuel cycle can then be normalized using these capacity values.

In this report, the transportation step generally begins/ends at the outer perimeter of the facility site (whether or not a fence exists there), or at the point where the primary mover for hauling on public property is connected or disconnected, whichever is closer into the facility. Operations carried out by fixed facility staff are part of the fixed facility operations. Activities between connecting and disconnecting with fixed facility prime movers are part of that facility's operations.

REFERENCES

Eng, C. C. 1982. Minutes of Kick-off Meeting, October 22-23, 1981 and Research Review Group Meeting, October 26, 1981. U.S. NRC Memo for Fuel Cycle Research Program File (FIN B2402).

5.0 REPRESENTATIVE SITE FOR MINE OR MILL

Four representative sites are used to illustrate potential generic safety effects of nuclear fuel cycle activities. Site A is a typical mine or mill location and is discussed in this section; Site B is representative for deep geological disposal of high-level wastes, transuranic wastes and spent fuel (described in Section 6); Site C is representative for shallow land disposal of low-level and intermediate-level wastes (described in Section 7); and Site D provides a baseline for identifying environmental impacts of all other steps in the LWR fuel cycle.

Each site description provides a generic basis for estimating typical safety impacts. No intent exists to endorse these particular environments for any nuclear fuel facility. The representative sites are considered to be useful for comparative analyses.

Individual features of the representative 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 safety impacts. Site-specific descriptions would be required for assessment of specific individual facilities.

The representative Site A for mines and mills is based primarily on the site of a contemporary surface mine and mill complex near Douglas, Wyoming (AEC 1973). It is believed to be representative of sites for the majority of mines and mills in the U.S.

5.1 LOCATION

Representative Site A, for a typical mine or mill, is located in the western or southwestern United States in a semiarid, sparsely populated area. The site for 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.

5.2 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 5.1.

5.3 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 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 (AEC 1973, Sears 1975).

TABLE 5.1. Population Distribution Around the Representative Mine-Mill Site

Distance from Facility		Population		
Miles	Kilometers	Density (Persons/mi ²)	Total in Ring(a)	Cumulative
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.

5.4 WATER USE

Seepage water is pumped from the mines at an average rate of 20,000 liters/minute (EPA 1975, pp. 22,23). 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 (EPA 1975). 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 (AEC 1973).

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 (AEC 1973, Sears 1975).

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.

5.5 GEOLOGY

The mine-mill site is located on an intermountain plateau. The area is characterized by rolling foothill topography 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 representative site, are relatively old sedimentary formations. Immediately beneath the surface soils, which vary from 1 to 3 meters (3 to 10 feet), 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 (AEC 1974) i.e., one for which "minimum damage" is expected from earthquakes.

5.6 HYDROLOGY

The site lies in a hilly, arid region with no permanent surface water within a radius of 25 kilometers (16 miles). Intermittent streams flow in the valleys after periods of heavy rain and during periods of melting snow. Because of low precipitation, the stream system does not flow continuously at any time of the year (AEC 1973). 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) and its depth is 32 to 46 meters (120 to 150 feet). The groundwater is potable. The quality of the water is given in Table 5.2

TABLE 5.2. Water Quality Data at the Representative Mine-Mill Site^(a)

<u>Contaminant</u>	<u>Concentration</u>
Uranium	1-100 parts per billion
Arsenic	0.5 parts per million
Selenium	0.2 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

(a) Based on US AEC March 1973, US AEC 1974.

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. The water supply outside the plant boundary is unaffected.

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 site during the operating life of the plant.

5.7 METEOROLOGY

The site has a semiarid climate with an average precipitation rate of 30 cm (12 in.) per year. Snowfall ranges between 89 and 170 cm (35 to 65 in.). 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 5.3, Table 5.4 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 5.5.

TABLE 5.3. Average Wind Speed Classes at the Representative Mine-Mill Site

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

TABLE 5.4. Atmospheric Diffusion Characteristics for the 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 5.5. Atmospheric Dispersion ($\bar{X}/Q'$) for Each Segment from a 10-Meter Release Height (sec/m³) at the Representative Site for Uranium Mine-Mills

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 approximately 21°C (70°F). Extreme seasonal temperatures reach 38°C (104°F) and -40°C (-40°F).

5.8 ECOLOGY

The area around the site is uncultivated and used only for limited grazing. The dominant vegetation is shrubs and grasses. 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 representative mine-mill site.

The most important wildlife in the area of the representative site is Pronghorn Antelope and Sage Grouse. Other wildlife present are Mule Deer, Cottontail Rabbits, Hungarian Partridge, Mourning Doves, Coyotes, Bobcats, Red Fox, Badger, Prairie Dogs, Song Birds, and Migrating Waterfowl.

The soil in the area of the site is 30 to 90 cm (1 to 3 ft) 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 hillsides. Embankments, 3 to 6 m (10 to 20 ft) high and composed of fine sand silt, are adjacent to both of the creeks in the area.

REFERENCES

Atomic Energy Commission (AEC). 1973. Final Environmental Statement Related to the Operation of the Highland Uranium Mill by the Exxon Company. USAEC Docket No. 40-8102.

Atomic Energy Commission (AEC). 1974. Environmental Survey of the Uranium Fuel Cycle. WASH-1248.

Environmental Protection Agency (EPA). 1975. Water Quality Impacts of Uranium Mining and Milling Activities in the Grants Mineral Belt, New Mexico. EPA 906-9-75-002.

Sears, M.B., et al. 1975. Correlation of Radioactive 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.

6.0 REPRESENTATIVE SITE FOR DISPOSAL OF HIGH-LEVEL AND TRANSURANIC WASTES AND SPENT FUEL

Several geologic media are being considered for the disposal of high-level spent fuel and transuranic waste. Because most of the risk studies and conceptual design for the deep geological facility have been done for bedded salt sites, this medium is considered to contain the representative repository site for this study.

The representative Site B is hypothetical, and as a result, most of the topics in this chapter cannot be factually addressed. To circumvent the lack of data on certain subjects, the site was attributed characteristics of several bedded salt sites. By approaching the site definition in this way, no particular site is endorsed, but reasonable data are used for the hypothetical site. The site occupies 34.7 km² (13.41mi² or 8585 acres) in a rectangular shape of 4.62 km (2.87 mi) by 7.52 km (4.67 mi).

6.1 LOCATION

The hypothetical site is located in a rural area that is a composite of several areas in the contiguous 48 states. The rainfall, use, and ecology are for a temperate climate, as expected in the Michigan Basin or western New York. Demography and land use are similar to those of the Paradox Basin, located in south western Colorado. Meteorology is similar to that of the Pala Duro Basin, in northern Texas.

6.2 DEMOGRAPHY

Most of the population in the region is located in small towns. 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 about 56,000. The distribution of the surrounding population is assumed to be the same as that for the representative mine/mill site as portrayed in Table 5.1.

6.3 LAND USE

Because of the low population density of the region, only about one percent of the land is devoted to residential use. Almost 70% of the land surrounding the representative repository site is predominantly used for the grazing of cattle or limited farming. Recreational and natural areas are mostly in the higher elevations and along the major rivers. These areas contain thirty percent of the total area.

Based on the land use patterns discussed above, some of the agricultural parameters for the representative site are given in Table 6.1.

6.4 WATER USE

Despite the relatively high rainfall in the region, the presence of a sandy soil and uneven distribution of precipitation throughout the year results in many of the larger streams being intermittent. As a result, water from the rivers and the upper sandstone aquifer is used for irrigation.

TABLE 6.1. Suggested Land and Water Use
Parameters for Safety Analysis

<u>VALUE</u>	<u>Parameters</u>
0.25 ^(a)	Fraction of radionuclides in water used for irrigation retained on plants (unitless).
0.17 ^(b)	Length of time for irrigation (yr)
5.2 ^(c)	Plant density (kg/m ²)
.038 ^(a)	Weathering half-life for radionuclides deposited on plants by sprinkler irrigation.
50 ^(d)	Consumption of water by cattle (l/day)
50 ^(d)	Consumption of plant material by cattle (kg/day)

(a) Boone et al. (1981)

(b) This value corresponds to an irrigation time of 2 months.

(c) This value is derived from data in Lieth and Whittaker (1975) and corresponds to a relatively high rate of plant production. A somewhat lower value is given in NUREG 1.109 (1976, p. 1.109-55).

(d) NUREG 1.109 (1976, Table A-10)

Heavy industry does not exist in the region, and mining activities are few and small-scale. Population centers are small and scattered, using an insignificant amount of water from the hydrologic system.

Groundwater in the lower sandstone aquifer has a high salinity. For this reason, and the presence of shallower, high-quality groundwater, this aquifer does not contribute to water used in this region.

6.5 GEOLOGY

The representative bedded-salt site is located within a symmetrical basin having low to moderate topographic relief (see Figure 6.1). A ridgeline that defines the perimeter of the valley has an elevation of approximately 1,830 meters and is a divide for both the surface drainage and groundwater flow. Surface drainage is through a series of intermittent streams (such as River U) to River L, which transports the water from the valley. The elevation of River L and A' (Figure 6.1) is 762 meters.

FIGURE 6.1. Schematic Diagram of the Representative Site
(Cranwell et al. 1982)

At the representative site, the stratigraphic sequence of units consists of a series of sedimentary rocks unconformably overlying a basement of granitic rocks. Both the age sequence and thicknesses of the units are indicated in Table 6.2. With the exception of the upper sand and gravel, the sedimentary rocks are of marine origin. The salt was formed by precipitation from sea-water in a basin. Part of the upper sandstone and all of the upper shale represent part of another deposition. At some time after the deposition of the upper shale, the area underwent regional uplift. Subsequent erosion of the units above the upper shale was followed by deposition of the upper sand and gravel by processes accompanying continental glaciation.

Either the regional uplift or later deformation of the region produced a series of broad, low-amplitude folds. The symmetrical valley that contains the representative site is a syncline formed in this way. The formations dip at a slight angle toward the axis of the fold, which is from the ridge toward River L of the site.

6.6 HYDROLOGY

The representative site is assumed to be in a temperate climate that receives 102 cm of rain per year. Of this rainfall, 41 cm return to the atmosphere by evapotranspiration and the remaining 61 cm enter the groundwater system. Because of the dip of the beds perpendicular to River L and the location of the repository in the valley, the groundwater flows from the recharge areas down the dip of the beds for eventual discharge at River L. This flow is parallel to line A-A' in Figure 6.1.

TABLE 6.2. Thicknesses and Composition of
Hydrostratigraphic Units
(From Cranwell et. al. 1982)

<u>Rock Type</u>	<u>Thickness (m)</u>
Upper Sand & Gravel	120
Upper Shale	30
Middle Sandstone	300
Shale Above Salt	60
Salt	210
Shale Below Salt	60
Lower Sandstone	90
Basement	90

Each of the sandstones and the upper sand and gravel is an aquifer, whereas the shales and the salt are aquitards. The basement is assumed to be an impermeable boundary. Table 6.3 lists the hydraulic properties of these units.

Hydraulic heads throughout most of the area have a downward flow gradient. The breach in the upper shale aquitard at River L and the pinchout of the middle and lower shales beneath River L relieve the confining pressure on the aquifers, thereby allowing an upward flow gradient beneath the river. As a result, both the lower and middle sandstone aquifers discharge into River L.

6.7 METEOROLOGY

This region is in a temperate climate with an average equivalent rainfall of 102 cm per year. The rate of precipitation is greater in the winter than at other times of the year. Subfreezing conditions in winter and snow melting in the spring result in significant variations in runoff. Flooding along the major rivers in the region is common.

The dominant wind directions are from the south and southwest with the southerly winds dominant in the months of May through September. Wind speeds range from a low mean of 9.7 to 14.5 km/h in the winter to a high mean of 14.5 to 17.7 km/h in the spring. Mean annual wind speed is 14.5 km/h with the dominant direction being from the southwest. Because more meteorological data are not readily available for this site, the atmospheric diffusion parameters in Section 5.7 are assumed to apply to this site.

TABLE 6.3. Hydraulic Properties of Stratigraphic Units of the Bedded Salt Representative Site (Cranwell et. al. 1982)

Unit	Hydraulic-Conductivity (m/s)		Porosity %
	Horizontal	Vertical	
Upper Sand and Gravel	9.5×10^{-4}	9.5×10^{-5}	30
Upper Shale	3.5×10^{-8}	3.5×10^{-11}	30
Middle Sandstone	1.8×10^{-4}	4.9×10^{-6}	30
Middle Shale	3.5×10^{-8}	3.5×10^{-12}	30
Salt	3.5×10^{-11}	3.5×10^{-12}	3.0
Lower Shale	3.5×10^{-8}	3.5×10^{-9}	30
Lower Sandstone	1.4×10^{-4}	2.5×10^{-5}	30
Basement	Impermeable		

6.8 ECOLOGY

The land ranges from cleared for grazing and farming to deciduous woods at the lower elevations to conifer-dominated woods along the ridges. Of the mammals present in the region, those with which man may have contact are game animals and fur-bearers. These include deer, bear, rabbit, squirrel, muskrat, raccoon, badger, weasel, skunk, fox, bobcat and coyote. Local populations of beaver, mink, and martin also may exist.

Game birds most likely to be encountered are pheasant, dove, quail, grouse, turkey, and migrating waterfowl. An assortment of game fish inhabit the rivers.

Nonfur-bearing animals and non-game mammals, birds, and fish, as well as reptiles, amphibians, and invertebrates are expected to have chance encounters with man. Other than crops, plants may reach man by way of the food chain.

6.9 NEAR-SURFACE WATER PATHWAYS

The surface environment was defined in detail for use in studies with the bedded-salt site (Cranwell et. al. 1982).

The surface environment for the representative site was defined for use with a model^(a) for the surface movement of radionuclides (Helton and Kaestner 1981) in the vicinity of the repository. The definition may have to be modified to determine exposures for individuals farther removed from the repository or to determine population exposures.

Two zones were used to represent the surface environment; the nature of these zones is indicated in Figure 6.2. The first zone consists of a 10-kilometer stretch of the River L and the stationary sediments beneath this stretch of river. Further, the soil and groundwater subzones associated with this zone are taken to constitute a strip of land 4 kilometers wide and extending back towards the repository for a distance of 40 kilometers and the portion of the upper sand and gravel aquifer which lies beneath this strip of land. The second zone consists of the 40-kilometer stretch of the River L immediately below the first zone along with the stationary sediments beneath this stretch of river. The soil and groundwater subzones consist of a 2-kilometer wide strip of flood plain on either side of the river and the portions of the upper sand and gravel aquifer which lie beneath the preceding strips of flood plain.

(a) Some of the terminology (i.e., zone and subzone) used in the following discussion derives from the nature of this model, which henceforth is referred to as the Pathways model.

FIGURE 6.2. Surface Zones Used in Representative Site Definition

A diagrammatic representation of the zones and subzones used in the site description is given in Figure 6.3. The arrows in this figure represent potential directions of movement for water and solid material. Data for pathways modeling are presented in Cranwell et. al. (1982).

For each zone, the groundwater subzone is taken to be the portion of the upper sand and gravel aquifer beneath the soil subzone. The layer comprising the groundwater subzones is assumed to have an average thickness of 30 meters, a porosity of 30 percent, a saturation of 100 percent and a mean particle density of 2.8 g/cm³. Water is assumed to move directly from the groundwater subzones to the surface-water subzones; that is, there is no discharge from the groundwater subzones to soil or sediment subzones. This discharge is assumed to be 5.4E7 μ /yr/m and to involve only dissolved materials; specifically, there is no movement of solid material out of the groundwater subzones.

Note: Arrows represent potential directions of movement for water and solid material.

FIGURE 6.3. Diagrammatic Representation of Zones Used in Representative Site

The soil subzones are assumed to have a depth of 0.5 meters, a porosity of 50 percent, a saturation of 50 percent, and a mean particle density of 2.8 g/cm^3 . Water flow through the soil to the groundwater below is 0.60 m/yr . The following assumptions are made with respect to water and solid movement from the soil subzones to the corresponding surface water subzones: 1) Annual water flow from a soil subzone to the corresponding surface-water subzone is the water volume required to fill the pore space of the soil subzone, and 2) Annual solid flow from a soil subzone to the corresponding surface-water subzone is $1\text{E-}3$ of the mass of solids contained in the soil subzone.

As indicated earlier, Zones 1 and 2 contain 10-kilometer and 40-kilometer long stretches of the River L. The amount of sediment carried in the river is derived from assumptions about erosion in the river's watershed. In particular, it is assumed that 1) the watershed is eroding at the rate of $5.0 \text{ cm/1000 years}$, 2) the material being eroded has a bulk density of 2.8 g/cm^3 and 3) 33 percent of the eroded material is carried in solution. The discharge of the river at the head of Zone 1 is taken to be $1.4\text{E}13 \text{ l/yr}$, and this discharge increases downstream at the constant rate of $1.0\text{E}8 \text{ l/yr/m}$; this increase is due to a discharge of $5.4\text{E}7 \text{ l/yr/m}$ from the upper sand and gravel aquifer and a discharge of $5.1\text{E}7 \text{ l/yr/m}$ from the middle sandstone aquifer. Thus, the discharge from Zone 1 is $1.5\text{E}13 \text{ l/yr}$, and the discharge from Zone 2 is $1.9\text{E}13 \text{ l/yr}$. The preceding assumptions lead to the surface water subzones having volumes of $5.5\text{E}9$ liters and $2.2\text{E}10$ liters, respectively, and a suspended sediment concentration of $1.6\text{E-}4 \text{ kg/l}$. These values are derived with the assumption that the river flow rate is 1 m/sec . For Zone 1, there is assumed to be no movement from the surface water subzone to the soil subzone. For Zone 2, the movement from the surface water subzone to the soil subzone is taken to equal the movement from the soil subzone to the surface water subzone.

The sediment subzones are assumed to have a depth of 2.0 meters, a porosity of 50 percent and a mean particle density of 2.6 g/cm^3 . Further, it is assumed that 10 percent of the sediment is resuspended each year. To maintain equilibrium, it is also assumed that 10 percent of the sediment is resuspended each year. To maintain equilibrium, it is also assumed that the movement of water and solid material from the surface water subzones to the sediment subzones is equal to the movement of water and solid material from the sediment subzones to the surface water subzones.

Exposure calculations are performed assuming that sprinkler irrigation is used in the production of land-based food (i.e., plants, milk, meat).

REFERENCES

- Boone, F. W., Y. C. Ng and J. M. Palms. 1981. "Terrestrial Pathways of Radionuclide Particulates." Health Physics 41: 735-747.
- Cranwell, R. M., J. E. Campbell, J. C. Helton, R. L. Iman, D. E. Longsine, G. E. Runkle and M. J. Shortencarier. 1982. Risk Methodology for Geologic Disposal of Radioactive Waste: Final Report, SAND81-2573, Sandia National Laboratories, Albuquerque, New Mexico.
- Helton, J. C., and R. L. Iman. 1980. Risk Methodology for Geologic Disposal of Radioactive Waste: Sensitivity Analysis of the Environmental Transport Model. NUREG/CR-1636, SAND79-1393, Vol. 2, Sandia National Laboratories, Albuquerque, New Mexico.
- Helton, J. C., and P. C. Kaestner. 1981. Risk Methodology for Geologic Disposal of Radioactive Waste: Model Description and User Manual for Pathways Model. NUREG/CR-1636, SAND78-1711, Vol. 1, Sandia National Laboratories, Albuquerque, New Mexico.
- Lieth, H., and R. H. Whittaker, eds. 1975. Primary Productivity of the Biosphere. Springer-Verlag, New York, New York.
- Runkle, G. E., R. M. Cranwell and J. D. Johnson. 1981. Risk Methodology for Geologic Disposal of Radioactive Waste: Dosimetry and Health Effects. SAND80-1372, Sandia National Laboratories, Albuquerque, New Mexico.
- U. S. Nuclear Regulatory Commission. 1976. Calculation of Annual Doses to Man From Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10CFR Part 50 Appendix I. Regulatory Guide 1.109 U. S. Regulatory Commission, Washington, D.C.

7.0 REPRESENTATIVE SITE FOR SHALLOW LAND WASTE BURIAL GROUNDS

Representative Site C is based primarily on the hypothetical reference site described in Report NUREG 0782 (NRC 1981). It is believed to be representative of potential sites in the U.S.A. with mild, continental-type climates that are relatively humid with moderate amounts of precipitation.

7.1 LOCATION

Representative Site C, shallow land waste burial ground, is located in an area similar to the southeastern United States. This site does not represent any particular location, nor advocacy of any particular site or location. The fenced-in site occupies 0.60 km² (148 acres) in a rectangular area approximately 0.6 km by 1.0 km.

7.2 DEMOGRAPHY

The site is located in a rural area that has low population density, with the highest population density occurring at a distance of 50 to 65 km (31 to 40 mi). The population distribution is given in Table 7.1. Approximately 50 km to the northeast of the site is a city with a population of 175,000; a cluster of smaller suburban communities surround the city. There are five small rural communities (each with a community population of no more than 2,000) within 20 km (12.5 mi) of the site.

The total labor force within 48 km (30 mi) of the site is estimated to be 75,000 full time workers. Of that total, 50% of the work force is devoted to manufacturing (predominantly electronics, textile, and light equipment), 35% to farming (cotton, soybeans), 5% in retail sales labor, 5% in construction, and 5% employed by public utilities.

7.3 LAND USE

The site is located in a rural area that is characterized by agricultural land, forests, some small industrial development, and some small residential communities.

Within an 80-km (50-mi) radius of the site, there are three principal categories of land use: 1) woodland, 2) farmland, and 3) developed land. Approximately 25% of the land area is woodland (both private and government preserves), 55% is farmland (with an approximate 50:50 mixture of row crops and pasture), and 20% is developed land (light industry and residential dwellings). The area occupied by the site had been used for farming in the past. However, for the last several years the land has been lying uncultivated and a thick secondary growth has grown up.

The predominant mineral resources within 50 km of the site are dimension stone, crushed stone, sand and gravel, and clay. Development of extensive mining efforts for metals has not been made in the area of the site. There are no known precious metals or fossil fuel mineral deposits within 8 km of

the site. About 680 Mg/yr of sand is mined at a nearby borrow pit. A kaolin (clay) borrow pit is operated approximately 16 km (10 mi) to the southwest of the site. There is little potential at the site for cost effective withdrawal of kaolin for construction-grade clay, although limited quantities are available for onsite use. The small thickness and poor quality of the limestone formation beneath the site makes it generally unattractive to major dimension stone producers.

Within 2 km (1.25 mi) of the site are approximately 45 residences, two churches, one schoolhouse and two windmills. The nearest dwelling is a farmhouse located 0.5 km from the site. A milk cow is kept at this farm and maintained on fresh pasture, which borders the site, 7 months of the year. A family garden is kept for vegetables with a growing season of 5 months. Well water is used to irrigate this garden (Schneider and Kabele 1979).

TABLE 7.1. Population Distribution Around the Representative Shallow Land Waste Disposal Facility(a)

<u>Distance From Facilities</u>		<u>Population Density</u>	<u>Total Population</u>	<u>Cumulative</u>
<u>(miles)</u>	<u>(kilometers)</u>	<u>(persons/mi²)</u>	<u>in Annulus(b)</u>	<u>Population</u>
0-1	0-1.6	26(c)	14	14
1-2	1.6-3.2	26(c)	248	262
2-3	3.2-4.8	26(c)	413	675
3-4	4.8-6.4	26(c)	580	1,255
4-5	6.4-8.0	26(c)	745	2,000
5-10	8.0-16	34	8,100	10,100
10-20	16-32	38	36,000	46,100
20-30	32-48	80	125,000	171,100
30-40	48-64	92	203,500	374,600
40-50	64-80	37	104,900	479,500

a. NUREG 0782, Volume 3, Table E.3, population projected to the year 2010.

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

c. Values for each 1 mile circle up to 5 miles are taken from the value from NUREG 0782 for 0-5 miles and are assumed to have equal population density.

7.4 WATER USE

The local consumptive use of well water from the shallowest aquifer for potable purposes is low and consists of 6 domestic wells within 5 km (3.2 mi) and 60 wells used for farming and livestock. The closest down-gradient well is located 2.25 km from the site. The closest major withdrawal location is 36 km (22.5 mi) to the northeast where water is pumped from the lower confined aquifer for a municipal drinking water supply.

7.5 GEOLOGY

The site is located within the Liptone Upland segment of the Coastal Plain physiographic province at elevations ranging from 120 to 122 m (394 to 400 ft) above mean sea level. The site vicinity is characterized by gently rolling hills with broad summits and by relatively flat-lying fields bordered by somewhat broad drainage depressions. In general natural surface drainage at the site is good. As a result of the low topographic relief at the site, the probability of significant erosional events is low. The local surface drainage system has a typical perennial stream spacing of 1,000 to 2,000 m or more (3,280 to 6,560 ft).

The geologic profile of the site is provided in Figure 7.1. The site is underlain by 22 to 24 m of colluvium. Underlying the colluvium is a cherty limestone formation about 4 m thick. The limestone has an average permeability of approximately 0.01 cm/s and forms the lower boundary of an unconfined aquifer. Solution features in the limestone are minor and are not of the type that would result in sinkhole development. Underlying the cherty limestone is a 2 m layer of arenaceous limestone which in turn is underlain by another 2 m layer of argillaceous limestone. These are underlain by a 5 m layer of calcareous, marine clay. Below the clay is a 12 to 15 m layer of a well-bedded, fine- to coarse-grained, calcareous sand with clay occurring as thin beds or lenses. Below that is another 12 to 14 m layer of clay which serves as an aquiclude to deeper aquifers.

The soils covering the site are predominantly sandy loam and loamy sand. In engineering terms, these soils may be described as medium-dense silty sands and clayey sands. The surficial soils generally consist of 0 to 8 cm of topsoil mixed with silty sand. This surficial soil layer is underlain by 10 to 12 m of sandy clay. This sandy-clay layer has an average permeability of about 5×10^{-6} cm/s. Underlying this layer of sandy clay are unconsolidated and semiconsolidated sediments about 50 million years old. This sedimentary layer generally consists of fine-to-coarse sands that are locally partially cemented with occasional thin lenses of silt present. This sandy layer is approximately 12 to 14 m thick. The average permeability of this horizon is 1×10^{-4} cm/s.

The site is located within an area having a peak estimated horizontal ground acceleration from seismic events of 0.11 times the acceleration of gravity, with a recurrence interval of more than 500 years. Capable faults have not been identified in the general vicinity of the site. The probability of significant ground displacement at the site is quite low.

7.6 HYDROLOGY

The nearest perennial stream is located approximately 1000 m southeast of the site, and flows from the site in a southerly direction. This is the nearest point of groundwater discharge, at an approximate elevation of 90 m (295 ft) mean sea level. The creek discharges into the river about 30 km downstream from the site which subsequently drains into a second river. The second river ultimately empties into the Atlantic Ocean by way of a bay. The other major stream in close proximity to the site is a creek that

FIGURE 7.1. Geologic Profile - Representative Shallow Ground Waste Disposal Area

is located approximately 2000 m (6600 ft) north of the site and flows from the site in a westerly direction. This creek has an average discharge of 0.028 m³/s, and drains into a second creek which joins a river about 60 km downstream from the site. This river eventually drains into a larger river and ultimately into the Atlantic Ocean.

The depth to groundwater from the original ground surface at the site ranges from 12 to 17 m. The aquifer is unconfined and is generally a subdued replica of the local topography. Recharge to the local groundwater system results primarily from infiltration of precipitation. Well yields in the unconfined aquifer are typically in the range of 4 to 40 L/min. Larger capacity uses are satisfied by deeper wells into the confined aquifer more than 80 m below the surface. The groundwater quality meets the National Primary Drinking Water Standards.

7.7 METEOROLOGY

The representative Site C is located within a humid subtropical climate. Four distinct seasons are observed at the site. The winters are somewhat short and mild with an average temperature of 9°C (48°F). The summers are characterized by warm weather with temperatures generally averaging between 24° and 27°C (75° and 81°F). January is the coldest month and July is the warmest month. The temperature characteristics of the site are given in Figure 7.2.

The annual average precipitation at the site over the past twenty years has been 1168 mm (46 in.), with an annual range of 838 to 1473 mm (33 to 58 in.). The maximum 24-hour rainfall recorded at the site over the last twenty years is 152 mm (6 in.). Snowfall at the site is generally light and rarely exceeds 8 cm (3 in.) for one snowfall. The average snowfall is 12 mm (0.5 in.). Snowfall is generally observed during the months of January and February. Precipitation event intervals for the representative disposal site are shown in Figure 7.3.

Water balance information for the site is presented in Table 7.2. As shown in the table, approximately 180 mm (7 in.) out of an annual 1168 mm of precipitation percolates into the site soils.

The prevailing winds at the site are south-southwesterly with an average wind speed of 13 km/h (8.8 mph). The wind rose for the site is presented in Figure 7.4. The average humidity at the site is 78%, with an average low of 68% usually occurring in January and an average high of 88% occurring in August.

The relatively mild temperature variation observed at the site suggests that large-scale desiccation and frost-heaving of trench caps are not likely to occur. The highest intensity storms result from the remnants of inland travel of hurricanes and tropical storms.

FIGURE 7.2. Mean Monthly Temperatures at the Representative Site for the Shallow Land Disposal Site

Tornado activity within the immediate area of the site proper is moderate with an estimated occurrence of one tornado every 500 years; however, the occurrence of tornadoes within 50 km (31 mi) of the site is approximately once every fifty years.

The air quality at the site is quite good with concentrations of all major pollutants below US EPA standards. The good air quality is largely due to lack of point sources of pollution near the site. The only major point source of airborne pollutants is a coal-fired electrical generating station located 43 km (27 mi) to the northwest of the site. Farming activity on land adjacent to the site is also a source of air pollutants.

FIGURE 7.3. Precipitation Event Recurrence Intervals for the Representative Shallow Land Waste Disposal Site

NOTE:
BASED ON RECORDS FOR THE
1965-1974 PERIOD OF RECORD.

FIGURE 7.4. Wind Rose Diagram - Representative Shallow Land Waste Disposal Site

TABLE 7.2. Water Balance Information for Representative Shallow Land Waste Disposal Site

Item ^(a)	Average mm of Moisture for Month Shown												Annual
	J	F	M	A	M	J	J	A	S	O	N	D	
P	80	100	96	84	82	102	149	147	103	64	77	81	1168
R ^(b)	11	14	13	12	11	12	18	18	12	8	11	11	151
I	69	86	83	72	71	90	131	129	91	56	66	70	1014
S	100	100	100	100	64	32	21	16	12	11	48	100	
AET	13	15	37	65	113	147	162	151	107	63	29	13	915
PERC	56	71	46	7	0	0	0	0	0	0	0	0	180

Note (a)

P = Precipitation

R = Surface runoff

I = Infiltration

S = Soil moisture storage

AET = Actual evapotranspiration

PERC = Percolation into groundwater system

(b) The surface runoff coefficient (dimensionless) is 0.14 for the fall-winter-spring months of November through May; it is 0.12 for the remaining months.

7.8 ECOLOGY

Much of the general area of the representative disposal site is composed of undeveloped woodland, which is dominated by pine and oak trees. The biomass of the forests and fields is generally high. Mild climate and sufficient rainfall promotes rich, stratified vegetative growth, which provides suitable habitat and abundant food source for many herbivores and omnivores. Primary and upper level carnivores, in turn, rely on the abundance of these species.

The most common mammals found in the pine communities are the pine mouse, fox squirrel, and raccoon. Other mammals associated with the hardwood communities include the opossum, woodrat, flying squirrel, gray squirrel, and swamp rabbit. Bobcat and gray fox have also been observed. Common mammals found in the old field communities, and also in the cultivated fields are several species of mice, cottontail rabbit, least shrew, striped skunk, raccoon and opossum. Burrowing animals that have been observed are the gopher, mole and tortoise. Gopher tunnels are generally over 30 m in length and dug at a depth of 15 to 20 cm. Most tunnels leading to the resting chambers of the eastern mole are only 3 to 5 cm deep, and may extend for over 800 m.

Common bird species include the junco, nuthatch, pine warbler, bluejay, common crow, golden-crowned knight, flicker, woodpecker, meadowlark, sparrow, mockingbird, robin, and common grackle. Predatory birds such as hawks and owls are also found in moderate numbers in the woodlands.

The more common reptiles of the area are several types of snake, salamander, frog, and turtle. Many species of fish are known to occur in the surface water system. The most abundant fish are shiners, minnows, sunfish, and darter. Common recreational species include largemouth bass, pickerel, channel catfish, black crappie, and sunfish.

REFERENCES

Nuclear Regulatory Commission. 1981. Draft Environmental Impact Statement on CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste". Report NUREG-0782, Volume 3, pp E-16-E-30.

Schneider, K. J., and T. J. Kabele. 1979. Description of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles. PNL-2286, Pacific Northwest Laboratory, Richland, Washington.

8.0 REPRESENTATIVE SITE FOR ALL FUEL CYCLE FACILITIES EXCEPT MINES, MILLS AND WASTE DISPOSAL FACILITIES

Representative Site D is based primarily on typical LWR sites defined in the ALAP study for 10 CFR 50 Appendix I (AEC 1973) for the river site for the year 2000. It is believed to be representative of potential sites for fuel cycle facilities other than mines, mills or waste disposal facilities in the U.S. The ecological information was derived from the environment of an operating nuclear reactor (AEC 1972).

8.1 LOCATION

The representative site is located in a rural area similar to the mid-western or south mideastern United States. The site occupies 4.7 km^2 (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.

8.2 DEMOGRAPHY

The representative site is located in a rural area that has moderately low population density, with the highest population densities occurring at distances of 16 to 64 km (10 to 40 mi), and gradually reducing population densities out to 177 km (110 mi). The population distribution is given in Table 8.1. The total population within 80 km (50 mi) of the site is 3.52 million.

8.3 LAND USE

The use of any part of the total site area of 4.7 km^2 (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 km^2 , or 30 acres) of the site. There is a minimum distance of 1 km (0.6 mi) between the point of plant airborne releases and the outer site boundary (fences and marked).

Most of the surrounding area, approximately 80%, is land. The main crops in this area [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 14 to 19 km (9 to 12 mi) from the site. A state forest and campground are located about 14 km (9 mi) from the site, situated near the wildlife refuge. A state park is located about 10 km (6 mi) in the opposite direction.

TABLE 8.1. Population Distribution Around the Representative Fuel Cycle Facility Site

<u>Distance from Facilities</u>		<u>Population Density</u>	<u>Total Population</u>	<u>Cumulative</u>
<u>(miles)</u>	<u>(kilometers)</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.

The nearest dwelling is a farmhouse located 1.3 km (0.8 mi) from the site. A milk cow is kept at this farm and 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 to irrigate this farm. There are also large truck gardens in the area.

8.4 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, marinas and docks, and the public has complete access to the river (except to onsite shorelines). In the vicinity of the plant, limited numbers of individuals do some swimming, boating, and fishing on the shoreline. Essentially no fresh water molluscs or crutacea are taken from the river. The region has no large commercial fishing operations. Most of the fish catch is caught by local recreational anglers for home consumption.

Drinking water is taken from the river by larger towns and cities, with the closest being 60 km (37 mi) downstream. Individuals living immediately downstream near the river derive their potable water from wells and not directly from 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 mi) downstream.

8.5 GEOLOGY

The representative Site D 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 representative 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 of 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 times the acceleration of gravity.

8.6 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 a 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 river flow rate of 1420 m³/s (50,000 cfs). Flow and river water temperature data pertinent to the site are shown in Figures 8.1 and 8.2, respectively.

The river is assumed to be reasonably free of pollution with total solids varying from 140 to 220 mg/l. It is moderately turbulent during the spring. Little or no stratification of water occurs and there is no tidal influence. The average river velocity at the site varies between 0.46 and 0.76 m/s (1.5 to 2.5 ft/s) for flows below 2000 m³/s (72,000 cfs). The river drops about 3 m (10 ft) from 2.4 km (1.51 mi) upstream to 2.4 km (1.5 mi) downstream of the site; rapids frequently occur in this stretch of the river.

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

The "maximum probable flood" was estimated to reach a peak stage elevation of 286 m (939 ft) mean sea level at the representative 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 groundwater table under normal conditions is higher than the river surface; thus, groundwater and runoff drain to the river.

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.

FIGURE 8.1. Recorded Daily Average and Extreme River Flows at the Representative Fuel Cycle Facility Site

FIGURE 8.2. Daily Average and Extreme Water Temperatures at the Representative Fuel Cycle Facility Site

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 8.3 are assumed for evaluations of the representative 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 8.3. Liquid Effluents Dilution for the Representative 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 (AEC 1973).

8.7 METEOROLOGY

Representative Site D 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 8.2 shows monthly temperature statistics.

TABLE 8.2. Monthly Air Temperature Statistics (°C)
at the Representative 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>
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) or 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 are 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 8.3.

TABLE 8.3. Mean Monthly Relative Humidity (%) at the
Representative 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.), or 70% of the 610-mm (24-in.) annual rainfall. The maximum 24-h 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/h (7 mph) and for the other seasons is about 16 km/h (10 mph). The maximum reported wind speed of 148 km/h (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 $5E-4$ per year. For design purposes a wind velocity of 480 km/h (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 h/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 h.

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. An average dispersion factor was obtained for each selected downwind distance for all sixteen sectors (AEC 1973).

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 on the Beaufort wind scale.

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 (Slade, 1968).

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. 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 used to determine the ratio of the minimum effective dilution (maximum dispersion factor) to the mean sector value, and are applied to the present data.

The value obtained for the ratio of dispersion factor in the sector with the minimum dispersion factor to average sector dispersion factor was 2.5, and this value was used for all release heights in these data. The dispersion factors for the average sector as a function of height of release and downwind distance are shown in Figure 8.4.

FIGURE 8.4. Average ($\bar{X}/Q'$) Values Versus Distance in a Sector from the Representative River Site for Fuel Cycle Facilities

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 8-4.

Where large volumes of heated air are being ejected, the plume rise constant for momentum is estimated to be about $50 \text{ m}^2/\text{s}$ ($540 \text{ ft}^2/\text{s}$). Assuming an annual average wind speed of 2 to 3 m/s, (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 8.4 are larger than they would be if credit is taken for buoyance and momentum.

8.8 ECOLOGY

Less than 20% of the land within 40 km (25 mi) of the plant site is covered with pristine vegetation. Remnants of the native climax hardwood forest are found on the larger islands, with some lesser stands in isolated pockets along the river bank. Tree and shrub cover remains stable from year to year except for disturbances from cattle grazing or browsing, clearing, and cutting. Most of the areas adjacent to the border are largely agricultural crop and grazing land.

The river area and the numerous nearby ponds, lakes and swampy areas are heavily utilized by waterfowl and shorebirds, whose presence is mostly seasonal. Other birds are the blackbird, wren, blue heron, and a variety of upland game birds. Several species of fish are known to be present and some sport fishing is done. The wildlife considered to be rare, endangered, or threatened within the area are the bald eagle, the peregrine, the falcon, and the prairie chicken.

Some important mammals in the area are: badger, bat, beaver, bobcat, chipmunk, rabbit, coyote, squirrel, deer, mouse, mink, mole, muskrat, opossum, gopher, raccoon, fox, shrew, skunk, vole, and weasel.

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.

REFERENCES

- Atomic Energy Commission. 1973. 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.
- Atomic Energy Commission. 1972. Final Environmental Statement Related to Operation of Monticello Nuclear Generating Plant. Docket No. 50-263, pp. II-15 - II-26.
- Slade, D. H., ed. 1968. Meteorology and Atomic Energy 1968. TID 24190, p. 73.

9.0 URANIUM MINING

An underground mining facility representative of current technology for commercial scale uranium mining is described in this section. Although other mining techniques, such as open-pit mining, are currently being used to recover uranium, the present trend is toward underground mining. Underground mines usually contain a higher grade ore and thus contribute more, on a per ton basis, to the national production of uranium concentrates. Also, as the more shallow deposits are mined out, the remaining reserves of uranium are located at depths where underground mining is necessary (U.S. NRC 1979).

The mine described in this section is primarily based on a group of seven mines near Ambrosia Lake, New Mexico, owned and operated by Kerr-McGee Corporation. Underground mining at the Ambrosia Lake complex of mines is performed by a modified room-and-pillar mining method. The Ambrosia Lake complex in 1977 produced about 4234 Mg of ore/16-hr day ($1.32\text{E}6$ Mg 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 representative mine facility include the following:

- 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 representative facility supplies about 6.4 Mg U/day (1981 Mg U/yr, or 7.5 Mg U_3O_8 equivalent (2337 Mg U_3O_8 /yr).
- The facility is assumed to operate 312 days/yr and 16 hrs/day, with one 8-hr maintenance shift each operating day, for 20 years.

9.1 SUMMARY

The representative underground mining facility is based on a complex of seven mines (currently only five of the mines are operating) near Ambrosia Lake, New Mexico, operated by the Kerr-McGee Corporation. These are conventional underground room-and-pillar mines with a production capacity of 4230 Mg of ore per day ($1.32\text{E}6$ Mg of ore/year, for 85.5% operating efficiency). The facility operates 16 hours a day, 312 days a year.

The major operations at the mining facility consist of constructing mine access shafts and tunnels; fragmenting the ore body; collecting the ore and transporting it to the mine surface; and preparing the ore for transportation to a milling facility for further processing.

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

Effluents from the mining process include liquid and airborne materials. The primary liquid effluent is produced by water that enters the mine from groundwater seepage and must be pumped out of mine excavation areas to retention ponds at the surface. The amount of water produced by the mine is about $9E8$ liters per year, containing an average of 50 pCi/l , or a total of $4.5E-2 \text{ Ci/yr}$. One fourth of this water is utilized directly by a uranium milling facility; the remainder is transported to a treatment plant for processing before being released to the environment. Airborne effluents include dust and particulates released during the activities of fragmenting rock, loading the crushed rock and blending the ore for final delivery to the mill. Of primary concern among these effluents are the radioactive decay products of uranium, especially radon 222. The amount of rock dust produced at the representative mine is about 65 Mg per year. Airborne emissions of radon 222 at the site consist of about $0.04 \text{ grams radon per year}$, or about $6740 \text{ Ci radon 222 per year}$.

The principal solid wastes generated by the mining process are the overburden or barren rock; low grade material waste rock; and scrap material and equipment that may be contaminated at some low level. The volume of this waste will vary with the grade of ore being mined. The low grade waste rock has a specific activity of about $3.5E-10 \text{ Ci/gram}$. The wastes at the mine site are eventually disposed of in surface landfills or within abandoned sections of the underground mine.

The mine facility described in this report utilizes 1100 employees (10% of which are managerial or professional staff) with two production shifts and one maintenance shift per day. Major material inputs required at the site include excavation equipment, energy sources, such as diesel fuel and electricity, and fresh air for ventilation. Outputs from the facility primarily include the produced uranium ore and waste products. Of these input/output materials, radioactive product and effluents, power sources and water treatment chemicals present the greatest hazard potential.

At an underground mining facility, workers are faced with potentially hazardous materials at all stages of the operation. The primary accident driving forces at these locations include mechanical energy such as power tools or power equipment or from falling objects, and chemically reactive materials, such as flammables or explosives.

Personnel at the underground uranium mine facility work in direct contact with much of the radioactive rock material underground. These workers are subjected both to internal and external radiological exposures. Personnel are also exposed to the many hazards of underground construction work. These hazards may include flooding, collapse of mine walls, loss of ventilation, fire, or explosion. Containment and shielding of radioactive materials and other hazardous substances at the mine site is primarily achieved with barriers of distance and ventilation. Flammable materials and explosives are protected in special storage tanks and locations. Primary alternatives to underground uranium mining include open-pit mines and in-situ leaching.

9.2 MAINLINE PROCESS DESCRIPTION

Underground mining operations in the Ambrosia Lake complex consist of the room-and-pillar method, which involves constructing a number of parallel tunnels in the ore body. Another series of tunnels is constructed at right angles to the first set, leaving a grid of ore pillars to support the overlying rock. Mining advances along several headings simultaneously by cutting, drilling, blasting, cleaning out the rock, and using roof bolts to support the overburden. These operations are performed sequentially in each heading. Ore is moved by cleaning out each heading with a loading machine which loads ore into a shuttle car. The shuttle cars take the ore to the primary mine haulage system, which transports the ore to the mine surface.

The overall general mainline process flow is portrayed in the diagram in Figure 9.1. It shows the unit operations of underground uranium mining in some detail. The first step in mining involves preparation of the site. Once the mine site and entryways have been prepared and constructed, the cyclical operations of the mining activity begin. The rock is fragmented by cutting, drilling and blasting. The broken rock is then collected, crushed as necessary and transported to the surface of the mine. At the mine surface, the rock is loaded into dump trucks and scanned for uranium ore content. The ore is then blended and prepared for transport to the representative uranium milling facility. The actual transportation of the ore to the mill is discussed in Section 19 of this report.

During underground mining, other unit operations are also required. These include support of mine walls and roof, removing seepage water from the mine (dewatering), and the supporting services for mining activities, such as ventilation, utilities, and communication systems. The following paragraphs discuss the primary unit operations of underground uranium mining in more detail.

9.2.1 Site Preparation

The initial phase of mine development requires construction of access roads to the site, as well as maintenance and personnel facilities. The necessary utilities must also be brought to the site, including water and electricity. The equipment used for surface site preparation primarily consists of bulldozers, scrapers and loaders.

Before mining activities can begin, access to the underground ore body must be provided by constructing a vertical or sloped shaft and initial tunnel entryways. The access shaft is typically circular, compartmented and concrete-lined. Shafts are drilled and/or blasted from the surface to the ore horizon and range in size from 3 to 6 meters in diameter. Once the desired depth is reached, tunnels are constructed to provide access to the ore seam itself. Entryways are constructed by blasting with explosives. Some tunneling may be performed utilizing special tunneling machines. Depending on ground stability and/or the permanence of the tunnel, steel plates, timber or concrete is used to support tunnels extending from the shaft. The waste rock (muck) created by

FIGURE 9.1. Mainline Process Flow Diagram for the Representative Underground Mining Facility

excavation activities is transported by buckets (attached with wire rope to mine hoists) to the surface from where it is transferred by front-end loader or dump truck to a muck disposal area.

9.2.2 Fragmentation of Rock

The purpose of rock fragmentation is to separate the ore-containing material from its place in the earth and provide this material in pieces of a size convenient for subsequent handling and haulage. Yet at the same time, the unfragmented rock must be left in as stable a form as possible to facilitate ground control and support (National Academy of Sciences 1979).

Three separate operations are included in rock fragmentation. These are cutting, drilling and blasting. First, a cutting machine, which operates somewhat like a large chain saw, cuts a slice under the ore seam. This is necessary to provide room for expansion when blasting the rock. A mobile drilling rig is then used to drill several holes in the seam to permit insertion of explosives. The drill machine is a rubber-tired drill mounted on a boom. This configuration allows improved access to the working face. During drilling operations, water is injected beside the drill bit to reduce the amount of dust released while drilling. The drill holes are then loaded with explosives. At each hole, a primer cap is inserted with the first explosive; additional explosives are placed and tamped in the hole and the hole is then plugged with rock dust. After all the drill holes are loaded, the final connections are made to the blasting cable and battery. After the warning to the workers is sounded and the area has been cleared of personnel, the explosives are detonated.

At the Ambrosia Lake complex, blasting is accomplished at 8 am, 12 noon, 4 pm and 12 midnight. A working face is advanced approximately 3 m with each blast. There are about 30 working faces per mine (Schneider 1979).

Support for the mine walls and roof must also be provided as the working face is advanced. The system used most frequently for roof support involves drilling holes in the roof and inserting bolts that are equipped with expansion heads or some other fastening system. These roof bolts generate compressive stresses to strengthen the roof. Until the roof bolts are installed as permanent support, safety jacks or posts must be used at regular intervals to support the roof properly.

9.2.3 Loading and Haulage

The broken rock is moved away from the working face using a slusher. The slusher is a mechanical scraper device used to pull or push materials horizontally. The slusher equipment basically consists of a slusher bucket or scraper that is suspended by means of cables. The cables are wound around a double drum hoist which is normally operated by a clutch and an electric motor mechanism. One cable is attached to the front of the 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. The hoist drum and motor assembly used

for the slusher is anchored to the slusher operator platform. The broken rock is thus scraped away from the working face by the slusher and directly to an ore pass or raise, which is a vertical opening leading from one working level in the mine to another. A schematic of the ore loading and haulage process is shown in Figure 9.2.

FIGURE 9.2. Schematic of Ore Loading and Haulage for Underground Mine

The rock flows by gravity down the ore pass into shuttle cars which are located on the haulage level below. The loaded ore cars are transported by diesel locomotive to the shaft station, where the ore is unloaded from the cars into a loading trench. The ore-containing rock is scraped from the loading trench into skips using another slusher. The skips or buckets are used to haul the rock to the mine surface through the vertical mine access shaft (Schneider 1979). At the mine surface, the ore is dumped from the skips into a back dump truck.

9.2.4 Ore Preparation

Before the uranium ore can be taken to the mill for further processing, it must be separated according to the grade of ore contained in the rock. The dump truck loaded with rock passes under a gamma energy scanner to determine

the approximate ore grade of the material. The ore is then dumped onto a stockpile which contains the same grade of ore. Rock with less than about 0.02% U_3O_8 (0.017% U) is distributed near the mine shaft opening for ultimate disposal.

To facilitate ore handling and transportation to the mill, the stockpiled ore is blended at the mine to form two product streams. For this study, one stream is assumed to have 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 grades with a front-end loader. The two product streams are shipped by truck to a milling facility about once a week.

9.2.5 Underground Services

There are several activities required in underground mining which, although not directly involved with the mining unit operations, are necessary for the safety of the crew and efficient mine production. These include mine dewatering, ventilation and communications.

In the Ambrosia Lake complex, large quantities of groundwater seep into the mines, and must be pumped from the mine to prevent flooding. Ore bodies are dewatered by drilling holes from the access tunnels and shafts into the ore horizon, permitting water to flow from these long holes into the access entryways and then pumping it to the surface for discharge. The water usually flows by gravity to sumps near the mine shaft, and then is pumped to the surface. The water is then passed through settling basins to an ion exchange plant for removal of contained uranium, is used as mill process water, or is discharged to surface water courses (EPA 1975).

Ventilation is required in most underground mines to prevent the buildup of noxious gases in the working environment and to maintain an adequate oxygen level for the crew. In uranium mines, ventilation is especially important to prevent the buildup of radon 222 gas (a uranium daughter product) and its prodigy to concentrations that might be hazardous to the miners' health. Ventilation systems usually contain both primary and auxiliary systems. The primary system moves air through the mine via ventilation shafts, which are drilled from the surface to connect with the underground workings. These shafts are typically 0.9 to 1.8 m in diameter. Large fans installed at the surface of each ventilation shaft exhaust the mine air which enters the shaft (U.S. NRC 1979). Auxiliary systems distribute the air from the main air courses to locations underground by means of small fans and flexible ducts. These systems are continually being extended, modified or replaced to conform with the changing mine layout as the excavation proceeds.

Of special consideration in ventilating uranium mines are the short half-lives of the radon daughters that present a hazard to workers underground. For a given radon concentration, the hazard increases rapidly with time (as the daughter concentrations increase). Thus, the more rapidly contaminated air is removed from work locations, the lower will be the concentration of radon daughters in any given situation. An increase in ventilation rate thus has the

dual effect of diluting the concentration of radon and reducing the time available for growth of radon daughters (IAEA 1976).

Communications systems in mines usually consist of a 25-volt battery system used with telephone wire that is strung throughout the mine, connecting the surface, the working faces, and all important intermediate points (such as loading stations). Voice communication is also used by crew members at adjacent stations. The communication system used in the mine allows two-way signaling (Stefanko 1978).

9.3 DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT SYSTEMS

Effluents generated by the underground mining process include liquid and airborne matter. The materials of greatest concern in effluent control are uranium, radium, radon and radon daughters. Specific effluents from the Ambrosia Lake complex and control measures used at the mining facility are discussed below.

9.3.1 Liquid Effluents

The primary liquid effluent of concern in underground uranium mining is the mine water resulting from groundwater seepage into the mine workings. This water is pumped from underground mine excavation points to a holding pond at the surface of the mining facility. At one of the mines at the reference facility, thirty compact electric submersible pumps are used to continuously remove an estimated 75 ℓ /s of mine water. Water volumes at other mines in the Ambrosia Lake complex range from 25 to 50 ℓ /s (Sisselman 1978).

Mine drainage water can contain significant levels of radioactivity from dissolved and suspended uranium and its daughters. Discharge from one of the representative mines contains an average of 50 pCi/ ℓ of dissolved radium 226 (EPA 1975). Mine water may also contain dissolved uranium, radon, other metals, ammonium nitrate and oils. Specific components of mine waste water are detailed in Section 9.5.2.

9.3.2 Liquid Effluent Processing and Control

The mine water is pumped to the surface and is collected in holding ponds. However, before it can be released to the environment, it must be treated to remove some of the contaminants. Some of the water from the holding pond (about 25%) is discharged to the adjacent mill and is used directly for mill process water. The remainder of the water in the holding pond is passed through an ion exchange circuit to remove uranium (Schneider 1979).

Ion exchange recovery is accomplished by using specific resins which are extremely selective in the removal of dissolved uranium. The mine water is passed through the resin column until the resin reaches its capacity for uranium. Water flow is then diverted to another barren resin column. Uranium is removed from the resin columns using a sodium chloride brine, which is then treated at the uranium mill to precipitate yellowcake. The treated effluent from an ion exchange plant can contain less than 1 mg/ ℓ uranium in solution (EPA 1975).

Mine water out of the ion exchange plant is further treated with barium chloride to remove radium from the water. This treatment is performed in a second holding pond, as portrayed in Figure 9.1. Although other treatment methods are available to achieve additional purification of the water, the mine effluent water at Ambrosia Lake is discharged to the environment at this point by seepage into the ground and/or by evaporation from the holding pond (Schneider 1979).

9.3.3 Airborne Effluents

The airborne effluents at the representative underground mining facility primarily consist of dust, combustion gases, radon gas and radon daughters. These airborne contaminants are generated in greatest amounts during the blasting, loading and ore blending activities of the mining operation. Dust is also released to the atmosphere at the facility surface by winds that entrain dust from dried-out ore stockpiles (Schneider 1979). Unlike ore dust and other airborne effluents which are produced only during mining operations, radon gas emanation is continuous (IAEA 1976). Radon gas is estimated to emanate from New Mexico sandstone formations such as those encountered at Ambrosia Lake at a rate of more than 5×10^{-14} mCi/cm²/sec (Schneider 1979). It is estimated that, on the average, underground uranium mines experience airborne emissions of 5.1 mCi radon 222 and 50 g dust per metric ton of ore mined (U.S. DOE 1979).

The primary chemical gaseous effluents from uranium mining are released from the burning of fossil fuel for power requirements and the use of diesel fuel for driving mining equipment (U.S. NRC 1976). Additional information on specific effluents from the representative mine is provided in Section 9.5.2.

9.3.4 Airborne Effluent Control

The mine ventilation system is the primary mechanism for controlling the concentration of airborne radionuclides and other contaminants in the air. The ventilation system moves dilution air into, through and out of the mine using ventilation fans and mine openings that provide air passages. Sufficient fresh air is provided through ventilation shafts at a rate that reduces the concentration of airborne effluents to acceptable levels. The ventilation system 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 (Schneider 1979).

Filtration is another method used at the mine to remove contaminants from the mine air. This method is effective mostly for dust and radon daughter removal. 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 sometimes used in place of filter units in some of the underground mines because the precipitators provide lower pressure drops in the mine ventilation system than filters.

Another control method used in some mines is isolation of unused openings or areas in the mine. This is done by using barricades or "stoppings" in the mine passageways that are made as nearly air-tight as possible. These areas are then kept under negative pressure by exhaust ventilation into the return airway. The negative pressure helps prevent diffusion of radon through stoppings to the working areas of the mine.

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 wetted 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 (Schneider 1979).

9.3.5 Solid Waste Management

The only radioactive solid waste from the representative 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/Mg of waste rock). 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 (Schneider 1979).

9.4 PLANT LAYOUT

This section contains descriptions of the underground uranium mine facility.

9.4.1 Site Description

The representative underground uranium mining facility is assumed to be located on the 13-km² generic site (Site A) for mines and mills described in

Section 5 of this report. Each of the seven individual mine sites occupies about 0.03 to 0.04 km². Therefore, the total mining facility area is about 0.30 km² (Schneider 1979).

The surface site is characterized by service buildings, a headframe with a truck loading facility, a mine waste pile and settling ponds for mine water. The area occupied by the hoisting and loading facilities, workshops, warehouse, changehouse and office is only a few acres; the majority of the land utilized is represented by the tunnels and mine workings underground (U.S. NRC 1976). The entrance to the 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 directed around the mine openings by dikes and/or ditches (Schneider 1979).

9.4.2 Facility Description

The representative underground mining facility is primarily based upon the existing group of seven 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. The underground workings consist of 1.2 m x 1.8 m stopes^(a) in the ore horizons and 2.7 m x 2.7 m haulageways in the rock below the ore zone. Raises connect the stopes with the ore haulageway 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 (Schneider 1979).

9.5 SAFETY-RELATED INFORMATION

This section presents a discussion of relevant safety-related information that can be used to help identify the risks associated with underground uranium mining activities at the representative site. Included in this information are operating and maintenance requirements of the facility, material inventories, and potential accident driving forces present at the site.

9.5.1 Operating and Maintenance Requirements

The representative underground mining facility is assumed to operate 24 hours/day and 6 days/week (312 days/year). Eleven hundred (1100) employees are used with two production shifts and one maintenance shift per day. Ten percent of these employees (about 100) are management and professional staff; the remaining 90% are composed of skilled and unskilled labor (Schneider 1979).

Although crew sizes may vary somewhat among the individual mines, the basic mining work unit crew consists of a foreman and nine equipment operators. The production unit requires the following personnel (Théodore Barry and Associates 1974):

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

Foreman	1
Shuttle car operator	3
Slusher operator	1
Roof bolting machine operator	1
Cutting machine operator	1
Face drill operator	1
Shooting buggy operator	1
Utility man/helper	1
	<u>10</u>

Additional personnel required at the mine surface include a shift boss, one or more hoistmen, a top lander and a mechanic.

The severe working environment underground usually results in equipment repair and/or replacement on a relatively frequent basis. Minor repairs to equipment are usually performed as required by the mechanic on duty. Major repairs are performed during the maintenance shift each day. Some replacement parts and spare equipment are available to allow production to continue at a relatively even pace. Small maintenance/parts shops are located underground to facilitate work on minor repairs.

9.5.2 Input/Output of Major Materials

The major materials required as inputs and produced as outputs at the underground mining facility are outlined in Table 9.1. These materials include excavation equipment, energy sources and utilities. Outputs from the facility primarily include the produced ore, effluents and wastes.

Facility Inputs and Products

Required inputs to the underground mining facility include excavation equipment, power sources, such as explosives and diesel fuel, services and utilities, including fresh air, water and electricity, and materials required for effluent treatment and/or control. These inputs are listed in Table 9.1. Miscellaneous materials such as office materials, office furniture, routine maintenance supplies, etc. are also required. The facility product primarily consists of uranium ore, produced at a rate of about 4230 Mg per full working day.

Effluents and Wastes

Both radioactive and nonradioactive effluents are generated by the underground mining facility. Radioactive effluents are released as airborne matter or liquid. Of principal concern are the uranium compounds in the ore itself and radon gas. These effluents were discussed in more detail in Section 9.3 of this report. Nonradioactive effluents generated by the facility include rock dust and particulates, blasting fumes, emissions from diesel-operated vehicles, and heavy metals present in mine waste water. Wastes primarily include scrap material and refuse, and overburden. The solid refuse from the mine is assumed to be buried in a landfill onsite. Some of the waste rock is used as backfill in excavated parts of the mine; the remaining portion is distributed at the mine surface for disposal.

TABLE 9.1 Overall Material Input/Output for Representative Underground Mining Facility

INPUT MATERIAL TO FACILITY

<u>Material</u>	<u>Total Material^(a)</u>		<u>Form</u>	
	<u>kg/day</u>	<u>g/day</u>	<u>Chemical</u>	<u>Phase</u>
Explosives	NA	NA	NA	S
Diesel Fuel	NA	2.65E4 ^(b)	NA	L
Fresh Air	6.2E7	6.3E10 ^(b)	N ₂ -O ₂	G
Electricity	NA	NA	---	---
Fresh Water	NA	NA	H ₂ O	L
Roof Bolts	NA	NA	NA	S
Barium Chloride	NA	NA	BaCl ₂	S
Filters	NA	NA	NA	S
Ion Exchange Resin	NA	NA	NA	S

Capital Equipment Requirements

Slusher Hoists
 Front-end Loaders
 Dump Trucks
 Ore Skips
 Locomotives/shuttle cars
 Drills/cutting machines
 Gamma Scanners

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.

TABLE 9.1. (contd)

OUTPUT FROM FACILITY

Radioactive Material	Total Material (a)		Form		Specific Activity
	kg/day	kgU/day	Chemical	Phase	Ci/g
Uranium Ore	4.2E6 ^(b)	6.4E3	[U(SiO ₄) _{1-x} (OH) _{4x}] ⁺	S	1.2x10 ⁻⁹
			UO ₂ +	S	
			[Ca(UO ₂) ₂ (VO ₄) ₂ ·	S	
			5-8 H ₂ O] +		
			[K ₂ (UO ₂) ₂ (VO ₄) ₂ ·	S	
			1-3 H ₂ O]		
Airborne Effluents:					
Gas - 222Rn	2.5E-6	---	222Rn	G	1.5x10 ⁵
Solids - 226Ra	2.3E-6	---	NA	S	9.9x10 ⁻¹
Radon Daughter Products					
218Po	1.4E-9	---	NA	S	2.8x10 ⁸
214Pb	1.4E-8	---	NA	S	3.3x10 ⁷
214Bi	9.0E-9	---	NA	S	4.4x10 ⁷
214Po	1.3E-15	---	NA	S	3.2x10 ¹⁴
210Pb	NA	---	NA	S	7.7x10 ¹
210Po	NA	---	NA	S	4.5x10 ³
Uranium Compounds	NA	5.7	NA	S	NA
230Th	NA	---	NA	S	2.0x10 ⁻²
Liquid Effluents:					
226Ra	1.80E-7	---	NA	L,S	9.9x10 ⁻¹
Uranium Compounds	NA	6.56	NA	L,S	NA
230Th	6.33x10 ⁻⁶	---	NA	L,S	2.0x10 ⁻²
Solids:					
Waste Rock	NA	NA	NA	S	3.5x10 ⁻¹⁰

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.

TABLE 9.1. (contd)

OUTPUT FROM FACILITY continued

Nonradioactive Material	Total Material ^(a) kg/day	Form	
		Chemical	Phase
Airborne Effluents:			
Rock Dust	2.1E2	NA	S
Nonradioactive Particulates ^(b)	41	NA	S
Benzopyrene	4.3E-4	C ₂₀ H ₁₂	NA
Beryllium	6.3E-3	NA	NA
Cadium	1.3E-2	NA	NA
Sulfur (blasting)	3.1	NA	NA
Zinc	1.3E-1	NA	NA
Lead	1.3E-1	NA	NA
Gas (from diesel air compressors) ^(b)			
Carbon Monoxide	7.2E2	CO	G
Nitrogen Oxides	1.2E3	NO _x	G
Hydrogen Sulfide	NA	H ₂ S	G
Sulfur Oxides	86	SO ₂	G
Aldehydes	10	NA	G
Hydrocarbons	1.2E2	H _x C _y	G
Liquid Effluents:			
Vanadium	15.32	NA	NA
Selenium	0.64	NA	NA
Molybdenum	18.08	NA	NA
Arsenic	0.43	NA	NA
Suspended Fines	8.72E2	NA	S
Chlorides	3.40E4	CL ⁻	L
Nitrates	2.02E2	NO ₃ ⁻	L
Sulfates	6.57E3	SO ₄ ⁻	L
Copper	2.13	NA	S,L
Silica	3.02E2	NA	S
Fluoride	27.23	NA	L
Iron	3.4	NA	S,L
Magnesium	3.66E2	NA	S,L

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.

TABLE 9.1. (contd)

OUTPUT FROM FACILITY continued

<u>Nonradioactive Material</u>	<u>Total Material^(a)</u> <u>kg/day</u>	<u>Form</u>	
		<u>Chemical</u>	<u>Phase</u>
Calcium	8.04E2	NA	S,L
Zinc	0.64	NA	S,L
Phosphate	4.25	NA	S,L
Sodium	2.84E4	NA	L
Ammonia	19.36	NA	L
Kjeldahl Nitrogen	17.44	NA	---
Aluminum	9.57	NA	S,L
Beryllium	0.21	NA	S,L
Titanium	20.21	NA	S,L
Solids:			
Scrap Equipment	NA	---	---
Refuse	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.

9.5.3 Inventories of Major Hazardous Materials at Plant Locations Having Safety-Related Importance

The major inventory of radioactive materials at the representative underground uranium mine is the uranium ore product and the effluents released during mining by the excavation techniques used. Other hazardous materials are located at various stations at the mine site. These include the explosives used for rock fragmentation, diesel fuel to power underground equipment, and chemicals required for mine water treatment. Table 9.2 summarizes these inventories of hazardous materials.

9.5.4 Unit Operations Involved

This section identifies the unit operations involved for each step in the process flow scheme for the representative underground uranium mine. These operations were also shown in Figure 9.1. The unit operations involved in underground uranium mining are listed in Table 9.3.

9.5.5 Accident Driving Forces

Mine safety and accident prevention are critical in underground uranium mining. Besides the safety problems involved with the use of heavy equipment and explosives, the problems of ventilation, fire and explosion control, and working in cramped environments present additional concerns for underground mining operations. The driving forces that could potentially cause accidents at an underground uranium mining facility and their locations are listed in Table 9.4.

9.5.6 Containment and Shielding Systems

Containment and shielding of radioactive materials and other hazardous substances at the mine site is primarily achieved with barriers of distance and ventilation. Flammable materials and explosives are protected in special storage tanks and locations.

Radioactive materials are encountered during every process operation in underground uranium mining. Mine personnel are subjected both to internal and external radiological exposures. Internal exposures in underground mining occur primarily through inhalation of radon and radon daughters with subsequent potential exposure to the lung tissue. These are the hazards of most concern in underground mines and are thus strictly controlled by ventilation. The ventilation system in an underground mine is essentially the only containment/shielding system employed in working areas of the mine. Partitions between areas of the mine are also employed in an attempt to reduce the concentrations of radon in the underground atmosphere.

External gamma radiation intensities in underground uranium mines seldom exceed 2.5 mR per hour, and average intensities are only a fraction of this. However, in mining occasional high grade ore pockets (5% or greater U_3O_8) external radiation shielding to personnel may be required. This is usually achieved simply by reducing personnel working hours, and thus reducing personnel exposure (U.S. NRC 1976).

TABLE 9.2. Inventories of Hazardous Materials at Various Mine Locations

Location	Material	Form		Quantity	Potential Hazard	Radioactivity Level
		Chemical	Phase			
Surface Stock-pile	Uranium Ore	See Table 9.1	S	4.2E6 kg/day	Radiological	1.2E-9 Ci/g
Surface Waste Storage	Waste Rock	NA	S	NA	Radiological	3.5E-10 Ci/g
Surface Settling Ponds	Waste Water	NA	L+S	2.9E6 ℓ /day	Radiological/ Chemical	50 pCi/ ℓ
Water Treatment Plant	Waste Water	NA	L+S	2.2E6 ℓ /day	Radiological/ Chemical	50 pCi/ ℓ
	Barium Chloride	BaCl ₂	S	NA	Chemical	---
Storage Areas (surface and at underground stations)	Diesel Fuel	NA	L	2.6E4 ℓ /day	Flammable	---
	Explosives	NA	S	NA	Flammable/ Explosive	---
Underground Working Area	Diesel Fuel	NA	L	NA	Flammable	---
	Explosives	NA	S	NA	Flammable/ Explosive	---
	Uranium-Bearing Rock	NA	S	NA	Radiological	5E-14 Ci/cm ² /sec

TABLE 9.3. Unit Operations Involved for Each Step in the Underground Uranium Mining Process Flow Scheme

<u>Process Step</u>	<u>Unit Operations</u>
Site Preparation	Solids Handling (lifting/assembly) Solids Drilling/Blasting/Cutting Solids Melting (Welding) Liquids Pumping
Uranium Ore Extraction	
- Rock Fragmentation	Solids Drilling/Blasting Liquid Pumping (Water spray/removal)
- Loading/Haulage	Solids Handling (lifting, moving) Solids Size Reduction (crushing)
- Ore Preparation	Solids Handling/Size Reduction
Waste and Effluent Management	
- Liquids	Liquids Pumping Natural Evaporation Solid-liquid separation (settling) Solid-liquid sorption (ion exchange) Precipitation (barium chloride)
- Airborne	Gas pumping (ventilation)
- Solid Waste	Solids Handling Solids Burial

TABLE 9.4. Accident Driving Forces Present at an Underground Uranium Mine Facility

<u>Accident Driving Force</u>	<u>Location</u>	<u>Characteristics</u>
Temperatures	Working Face	50°C - 150°C
Pressure	Underground roof structure	>10 atm
	Ventilation Air	0 - 1 atm
Chemical Reactivity	Explosives (working face)	Explosive
	Diesel Fuel Storage	Flammable
	Water Impurities	Corrosive
	Ion Exchange Column	Moderate reactivity
Mechanical Energy	Mine Shafts/Raises	Skip/bucket/drop
	Working face	Equipment collisions, failures
		Flooding
		Injury from power tools or equipment
		Roof falls.
Nuclear Reactivity	All locations underground	Natural

At the mine surface, containment of radioactive materials is accomplished by providing for specific storage/disposal areas for ore product and solid waste materials. Nonradioactive materials (both on surface and underground) are contained in storage tanks or other type of containment.

9.5.7 Relative Degree of Hands-On Operation

This section identifies the relative degree of hands-on operation required for each step in the mainline process scheme. The approximate frequency and types of required handling and the amount of direct contact required for each unit operation is shown in Table 9.5 for normal operations as well as for maintenance activities.

9.6 ALTERNATIVE PROCESS SCHEMES FOR URANIUM MINING

Other schemes are used for mining uranium ore. This section discusses briefly the major alternatives in use for mining of ore.

9.6.1 Open-Pit Mining

Open-pit mining is an alternative mining method for uranium recovery which is currently employed at 35 to 40% of the uranium mines in the U.S. Open-pit mining is often more cost-effective than underground mining for recovery of ore deposits lying less than about 90 m below the earth's surface, especially when the overlying rock can be removed with little blasting. However, as the industry grows and shallow deposits are mined out, remaining uranium reserves will need to be obtained using underground mining. Thus, although open-pit mining is currently used at almost half of the nation's mines, this relative fraction is expected to decline in the near future.

Mainline Process Description

Open-pit mining is characterized by a large open excavation, large piles of earth and rock overburden placed nearby, a network of operating roads and yards, and a flow of mine water pumped into the local surface drainage. Shops, warehouse, office and changehouse structures are also located at the site.

Uranium ore recovery in open-pit mining is achieved by stripping the overburden from the ore deposit, and then simply removing the ore and waste from the ore zone. The unit operations in open-pit mining are similar to those employed in underground mining. After site preparation, the overburden and ore zones must be fragmented to facilitate removal. In some cases, rock fragmentation will require the use of explosives. However, drilling and blasting operations are often not required, especially in shallower mines. In these cases, equipment used for stripping overburden may include tractors with rippers, rubber-tired scrapers and tractor-pushers, diesel power shovels and large trucks. Conventional heavy equipment is also used to remove rock where blasting has been required.

TABLE 9.5. Relative Degree of Hands-On Operations
in Underground Uranium Mining

<u>Process Step</u>	<u>Operations Required</u>	<u>Type of Contact</u> ^(a)	<u>Relative Frequency During This Operation</u>
Site Preparation	Solids Moving/Lifting	Semi-remote	Continuous
	Welding/Assembly	Direct	Continuous
Ore Extraction	Fragmentation	Semi-remote	
		Direct	
	Loading	Semi-remote	Continuous
	Haulage	Semi-remote/remote	Continuous
	Preparation	Semi remote	Continuous
Waste and Effluent Management	Ventilation	Remote	Continuous
	Settling Ponds (water treatment)	Remote	Continuous
	Ion. Exchange	Semi-remote	Continuous
Maintenance	Welding	Direct	Continuous
	Parts Replacement	Direct	Continuous
	Inspections	Direct	Continuous

(a) Types of contact are defined as follows:

- Direct = Immediate hands-on contact with the material by personnel.
- Semi-Remote = Use of major piece of equipment for operation; personnel required to directly operate equipment, but do not directly contact material.
- Remote = Process automatic or personnel are far removed from process step; operation of required equipment takes place from a remote control station.

Once the ore zone is exposed, tractors with rippers are used to loosen the material and the uranium is scanned with gamma scanners for radioactivity. Markers are then set up to provide control points for varying ore grades in the zone. Ore is then removed using bulldozers, front-end loaders, diesel shovels, draglines or backhoes. Ore is usually piled on the mine floor until there is a sufficient amount to fill the large trucks used for transport to the mill.

Mining operations are carried out successively in relatively small sections of the total area. In each section, overburden is removed, the ore is mined, and the pit is refilled with mine waste material.

Open-pit mines do not require some of the support services of underground mines, such as ventilation. However, dewatering is required in many open-pit mines. Mine water is pumped from the mine using the same basic equipment used in underground dewatering. This water is pumped to a settling pond for solids removal, then is treated for removal of radium before being released to the environment. Open-pit mine facilities also require drainage systems to control runoff into the open pits and from the waste dump. These systems usually consist of dikes and drainage ditches. Surface runoff from the waste dump is channeled to the settling pond used for mine discharge water (U.S. NRC 1977).

Process Effluents and Wastes

Open-pit operations produce liquid and gaseous effluents and solid wastes. Liquid effluents from the facility primarily consist of mine and runoff water. The primary sources of gaseous pollutants are the engines of heavy duty equipment and dust. Soil disturbance from mining operations will also result in the release of some radon gas.

The largest liquid effluent stream from open-pit mining operations is mine drainage water. The water tends to be slightly acidic to slightly alkaline with a high ratio of suspended solids. Mine drainage water also contains some dissolved and suspended uranium and daughter products. Constituents of mine waters from three open-pit mines are shown in Table 9.6 as representative of open-pit mine water compositions.

The chemical gaseous effluents produced in open-pit mining are the combustion products of petroleum used to fuel the heavy earth moving equipment. These are mostly CO, CO₂, SO₂, and unburned vapors of diesel fuel residues. Fugitive dust produced by mining of uranium and by disposal of solid wastes is largely chemically inert, but may contain considerable amounts of calcium and magnesium, as well as traces of uranium, vanadium, copper and phosphorous. This dust is typically controlled using water sprays (National Academy of Sciences 1979). Airborne radioactive effluents such as uranium-bearing dusts and radon and its daughters are also released to the atmosphere when an ore body is exposed and broken up during mining operations.

The primary solid waste material produced by mining is the barren rock and earth overburden, which contains a small quantity of uranium and its daughter products. The quantity of overburden that becomes airborne is minimized by utilizing water sprays for control of dust. This waste rock is ultimately

TABLE 9.6. Uranium Open-Pit Mine Water Composition

	Composition at Open-Pit Mines ^(a)		
	Mine A	Mine B	Mine C
Flow Rate, thousands ℓ /d	1740	5450	10900
pH	7.9	7.5	6.7-8.2
Alkalinity (as CaCO_3)	180	164	144-150
Total Dissolved Solids	411	627	750-825
Total Suspended Solids	163	49	40-420
Total Volatile Solids	38	164	40-92
Ammonia (as N)	0.22	1.33	1.42-1.60
Kjeldahl Nitrogen	0.22	1.33	1.42
Nitrate (as N)	<0.01	0.002	0-1.06
Phosphorus Total as P	0.05	0.07	2.30
Alpha-Total ^(b)	360	104	--
Beta Total ^(b)	168	77	--
Gamma Total ^(b)	N.D.	N.D.	--
U_3O_8 ^(b)		--	140-1100

(a) Composition data given in mg/ ℓ unless otherwise specified.

(b) $\mu\text{Ci}/\text{m}\ell \times 10^{-9}$

Source: U.S. NRC 1977

disposed of as backfill material for the mine. Used solid expendable stores, supplies and trash are of relatively small volume and are burned or buried in earth fills on the site (U.S. AEC 1974).

9.6.2 In-Situ Mining

In-situ (also called solution) mining has recently emerged as a new technology for the recovery of uranium from deeply buried sandstone ore bodies or from ore bodies that are not economically recoverable by conventional mining methods. It is estimated that in 1980, in-situ uranium mining methods produced approximately 10% of the U.S. uranium supply (Cowan et al. 1980). A brief description of the mainline process is provided below, as well as major environmental and safety-related differences from other uranium mining technologies.

Mainline Process Description

The in-situ mining process consists of injecting suitable leaching solutions into the underground ore body to solubilize the uranium minerals and then recovering the enriched solution by pumping it to the surface for further processing. Uranium ore bodies must satisfy several geologic/hydrologic/chemical criteria to be suitable for recovery by in-situ mining. These criteria are:

- a relatively horizontal orientation underlain and overlain by impermeable strata
- complete saturation with groundwater
- permeability adequate to sustain economically acceptable flow rates of the leaching chemicals
- a uranium form that is amenable to leaching
- porosity and hydrology that are favorable to application of the technology
- sufficient size of deposit and grade of ore to justify the operation.

Deposits satisfying these requirements are primarily located in Wyoming and Texas, as shown in Figure 9.3. Figure 9.3 also shows the locations of current/recent in-situ mining operations.

In-situ mining is accomplished by drilling injection and production wells into the ore body. These wells are usually patterned based on the direction of groundwater flow. Salt solutions of ions, such as sulfate, bicarbonate, carbonate and ammonium, known to form stable aqueous complexes with hexavalent uranium, are pumped to the ore body via the injection well. A solution of oxidant (NaClO_3) may be added to increase leaching efficiency. The inflow of solution is continued until the leach zone is depleted, as indicated by a decrease in uranium concentration in the produced leach solution. The uranium

FIGURE 9.3. Geographic Distribution of Commercial and Pilot In-Situ Uranium Mining Facilities (Cowan et.al. 1980)

is recovered at the surface from this solution by conventional milling operations, which are discussed in the next section of this report.

Process Effluents and Wastes

The in-situ mining process is designed to facilitate recycling of process chemicals. However, some liquid, solid and atmospheric emissions do result from the recovery activities.

The amounts and constituents in liquid effluent streams depend on the chemical processes used, constituents in the groundwater at the site and characteristics of daily operations. Table 9.7 shows the primary components of the liquid slurry streams for several types of in-situ mining processes. These wastes are disposed of either in a lined evaporation pond or by deep well injection (primarily used in Texas) (Cowan et al. 1980).

The solid wastes generated by in-situ mining are also dependent on the chemical processes used and the constituents of the groundwater, as well as other factors. Primary sources of solid waste from in-situ mining include the following:

- calcium carbonate - from the leaching process
- ammonia and alkaline earth salts - formed during evaporative concentrations of impounded liquid wastes
- sulfates and others - from containment control systems
- sand, chemical sludges - trapped in filters and surge tanks
- solids - from well acidification and other sources
- radioactive resins, filters and other materials.

Atmospheric releases from the mining or leaching process itself primarily include routine releases of ammonia and radon 222 emissions from wells and surge tanks. These emissions are outlined in more detail in Tables 9.8 and 9.9.

Differences from other Mining Methods

In in-situ mining, no conventional ore mining, transporting, or grinding operations are needed prior to chemical processing to recover the uranium. Although some solid wastes (primarily calcium salts comobilized with the uranium complex) are generated, large quantities of mine or mill tailings are not produced. Wastes produced in conventional uranium mining contain essentially all of the associated radium 226 (and its daughter products); on the other hand, less than 5% of the radium (along with the mobilized calcium) from a given ore body is commonly brought to the surface by solution mining techniques (Cowan et al. 1980). Also, the labor requirements for solution mining are estimated to be about half that of conventional mining operations,

**TABLE 9.7. Major Constituents in Liquid Streams for
Different Lixiviant Systems, In-Situ Mining**

Constituent	Concentration (mg/l)		
	Ammonium carbonate- bicarbonate	Sodium carbonate- bicarbonate	Sulfuric acid
Ca	78 - 2,040	2,220 - 3,900	0.3
Mg	18 - 400		0.03
Na	100 - 3,400	1,000 - 1,800	7,600
HCO ₃	300 - 3,600	440 - 1,300	230
SO ₄	400 - 4,700	9 - 19	18,200
Cl	350 - 44,000	1,000 - 1,400	61
NH ₄	50 - 23,000		
Mo	0 - 100		
V	0 - 25		0.7
As	0 - 75		
K	25 - 600		
SiO ₂			1.0
Al			0.06
Free Acid			330
U ₃ O ₈	1 - 30	1 - 2	0.1
pH	4.0 - 9.5		
Gross α	1,000 - 15,700	1,120	0 - 140
Gross β	4,550 - 6,060	757.3	0 - 330
Radium 226	600 - 2,500	100 - 500	3 - 15

Source: Cowan et al. 1980

TABLE 9.8. Annual Nonradioactive Atmospheric Emissions
From an In-Situ Leach Facility

Source	Annual Emission Rates, 10^3 kg/yr			
	NH_3	CO_2	NH_4Cl	H_2O
Recovery processes	2.7-4	680-1360	13.6-24.5	---
Calcium control unit	1-1.8	2.7-4	0.03-0.04	177-213
Calcite storage pond	1.1-1.6	4-4.5	4.3-4.8	~3600
Liquid waste ponds	4-5	3.2-3.6	12.2-14	~4200

Source: Cowan et al. 1980

TABLE 9.9. Annual Radioactive Atmospheric Emissions From an
In-Situ Leach Facility

Source	Annual Emission Rates Ci/yr	
	^{238}U	^{222}Rn
Recovery process	0.151	---
Calcium control unit	---	0.04
Calcite storage pond	---	1.36
Surge tanks	---	76

Source: Cowan et al. 1980

as well as drawing from a different pool of worker skills. Most in-situ operations currently existing employ about fifty people (Cowan et al. 1980).

A potential disadvantage of this method of uranium extraction is possible deterioration of the groundwater quality. The potential for groundwater contamination can occur in a variety of ways, including increased groundwater concentrations of uranium and trace minerals, accidental spills, intrusion of injection materials beyond the mining zone, well casing failure and leaks from waste ponds (Cowan et al. 1980). However, groundwater contamination can be limited by process controls. Techniques for mitigation of localized pollution are available if needed.

Direct measurement of the uranium content of the ore body is much more difficult in in-situ mining than in conventional mining. For this reason, the efficiency of recovery is more difficult to estimate, but is expected to be less than in conventional mining (U.S. NRC 1979).

REFERENCES

- Cohen, S.C., and Dance, K.D. 1975. Scoping Assessment of the Environmental Health Risk Associated with Accidents in the LWR Supporting Fuel Cycle. Prepared for the Washington Environmental Research Center by Teknekron, Inc., Washington, D.C.
- Costle, D.M., et al. 1978. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Ore Mining and Dressing Point Source Category. U.S. Environmental Protection Agency, Washington, D.C.
- Cowan, C.E., et al. 1980. Some Implications of In Situ Uranium Mining Technology Development. PNL-3439, Prepared for the U.S. Department of Energy by Pacific Northwest Laboratory, Richland, Washington.
- Environmental Protection Agency. 1975. Water Quality Impacts of Uranium Mining and Milling Activities in the Grants Mineral Belt, New Mexico. PB-251470, Dallas, Texas.
- International Atomic Energy Agency. 1976. Management of Wastes from the Mining and Milling of Uranium and Thorium Ores. Safety Series No. 44, Vienna.
- National Academy of Sciences. 1979. Surface Mining of Non-Coal Minerals. Washington, D.C.
- Schneider, K. J., and Kabele, T. J. 1979. Descriptions of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles. PNL-2286, Prepared for the U.S. Department of Energy by Pacific Northwest Laboratory, Richland, Washington.
- The Science and Public Policy Program. 1975. Energy Alternatives: A Comparative Analysis. University of Oklahoma, Norman, Oklahoma.
- Theodore Barry and Associates. 1974. Analysis of Ore Handling Systems in Underground Metal Mines for Improved Safety and Efficiency. PB-237861, Prepared for the Bureau of Mines, Washington, D.C.
- U.S. Atomic Energy Commission. 1974. Environmental Survey of the Uranium Fuel Cycle. WASH-1248, Washington, D.C.
- U.S. Department of Energy. 1979. Environmental Development Plan. Uranium Mining, Milling and Conversion. DOE/EDP-0058, Washington, D.C.
- U.S. Nuclear Regulatory Commission. 1977. Draft Environmental Statement Related to Operation of Sweetwater Uranium Project. NUREG-0403, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1976. Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors. NUREG-0002, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1979. Generic Environmental Impact Statement on Uranium Milling. NUREG-0511, Washington, D.C.

10.0 URANIUM MILLING

The uranium mill receives crude ore from the mine to recover and concentrate the uranium into a semi-refined product called yellowcake for shipment to the uranium conversion facility. Twenty-one mills were operating in this country in 1979 with a capacity of 43,900 Mg ore/day (U.S. NRC, 1980). Seven additional mills were expected to start up by 1982 with an additional capacity of 12,200 Mg/day. These sites are located in western states, most in the Wyoming Basins, the Colorado Plateau (which covers parts of Colorado, Utah, New Mexico, and Arizona), and the Texas Gulf Coast.

The milling process involves three basic steps: ore handling and preparation, mill concentration, and product recovery. The processes and operations in these three steps vary from mill to mill depending on the physical nature and constituents of the ore and the values in addition to uranium which are to be recovered. Ore handling and preparation include ore blending, crushing, fine ore storage, grinding, and possibly drying or roasting. Some newer mills use a wet semi-autogenous grinding which eliminates the dry crushing process. Mill concentration consists of extraction or leaching of uranium from the ore by dilute sulfuric acid or alkaline carbonate solutions. The product is recovered from the acid solution by solvent extraction or ion exchange, precipitation, and filtration, followed by drying, and packaging for shipment.

To a large extent, the process solutions are recovered and recycled in the milling process. Unrecycled solutions are discharged as waste and are used to carry the sand and slimes from the leached ore to the tailings pond.

The acid-leach process dominates most milling operations and a representative acid-leach mill is described below including some variations in the process. For comparison, the alkaline leach process is also described.

10.1 SUMMARY

The representative uranium mill, using the acid-leach process, operates 24 hours per day, 365 days per year with an average processing rate of 1,800 Mg/day of ore containing an average of 0.15 percent uranium. The plant is capable of producing 3.3 Mg/day of yellowcake (2.5 Mg/day of uranium). At 11,000 MWDe/MT (3.2 percent ^{235}U), the daily production of yellowcake is equivalent to an electric production rate of 4,200 Mwe. The mill employs 92 people, 18 percent of which are management/professional. The representative mill is primarily based on the Highland Uranium Mill near Douglas, Wyoming.

The milling process involves three basic steps: ore handling and preparation, mill concentration, and product recovery. The first step includes blending, crushing, storage, and grinding. Mill concentration consists of leaching of uranium from the ore by dilute sulfuric acid. The leached product is recovered by solvent extraction, precipitation, and filtration, followed by drying and packaging of the yellowcake.

Solid, liquid, and gaseous (or airborne) wastes and effluents are generated during the normal operations of the mill. Approximately 97 percent of

the ore appears after processing as solid waste in the mill tailings at a rate of 6.5×10^5 Mg/yr. About 6.5 percent of the uranium and all of the uranium decay products from the original ore are contained in the tailings.

The liquid portion of the wastes is about equal in weight to the solids weight and is used to slurry the solid tailings to the tailings pond. The liquid waste stream may contain about 1 percent dissolved solids with metallic, chloride, sulfate, ammonium, and phosphate ions, and minor amounts of flocculants and organic solvents.

Gaseous radon-222 is released from the ore, the tailings, and the product during and after mill operations. Crushing, grinding, and drying of ore and product produce dusts which contain the radionuclides from uranium decay. During and long after milling operation, a dry exposed tailings pile can be a source of wind-blown dust carrying uranium decay products.

Exposure of the mill operators to airborne radionuclides and noxious vapors is controlled by exhaust hoods. Dust is collected from exhaust air before the air is discharged through roof vents.

The tailings pond is constructed to minimize liquid seepage that could enter surface streams. Active tailings pond areas that are continually wetted tend to minimize dust release from this source. Inactive tailings piles are stabilized by appropriate cover to control dusting and leaching which could release radioactive contamination.

With natural uranium, criticality accidents are not a concern at the mill. Process temperatures and pressures are modest (except for drying yellowcake at 400 C) and present little driving force for accidents.

10.2 MAINLINE PROCESS DESCRIPTION

The overall process description for the acid leach mill is shown in Figure 10.1. The major operations in the mill are described in this section according to the steps shown in Figure 10.1. Information is generally taken from Clark and Kerr, 1974; Sears, 1975; Schneider and Kahle, 1979; and USNRC, 1980.

The major operations in the mill are described in this section according to the steps shown in Figure 10.1. The overall process description is shown in Figure 10.1.

10.2.1 Ore Handling and Preparation

Ore handling and preparation refers to all the steps from receipt of the ore until the ore is ready for acid leaching.

Blending

The ore is blended to achieve a feed with uniform physical and chemical characteristics to promote more efficient operation of the mill. Blending is done by careful mixing of selected ore from trucks directly from the mine and

FIGURE 10.1. Overall Process Flow Diagram--Representative Acid-Leach Mill Process

from stockpiles at the mill. Separate stockpiles are usually based on the uranium concentration and/or characteristics of the ore. Blending also reduces extremes in ore hardness which limits grinding capacity, in slimy ores which interfere with ion exchange, and in sandy ores which cause problems by settling in pipes and tanks. Blending can reduce high molybdenum content or organic matter which adversely affect ion exchange.

Crushing

The ore is moved by bulldozers, loaders, or trucks from the stockpiles to receiving bins at the crushing plant. Mine-run ores are reduced by impact-type crushers to a size between minus 1.9 cm and 3.8 cm. A bar screen is used to separate undersized materials which are sent to the fine ore storage bins. If required, kiln drying of moist ore is done to improve handling during crushing or storing.

Fine Ore Storage

Crushed ore is stored in covered metal bins which have a capacity equal to or greater than the daily rated capacity of the mill. Multiple bins provide flexibility in ore blending. Storage bins can have heated walls to prevent freezing of moist ore in the winter months.

Grinding

The ore is transferred from the crushing plant by conveyor belt at a controlled feed rate to the grinders. The ore is wet ground in rod mills to reduce the ore to minus 1 mm for acid leaching. Classifiers size the ore and return coarse particles to the grinder. Clarifier effluent or mill solutions can be recycled to reduce water consumption for the grinding operation.

10.2.2 Mill Concentration

The chemical and physical characteristics of the ore determines the leaching process which is most effective for removal of the uranium from the ore. Important characteristics are the type of uranium mineralization, ease of liberation, other minerals present, but most important, is the lime content. Ores with a low lime content are leached with acid. Acid leaching is usually done with sulfuric acid because of its lower cost and less corrosive nature than other acids. Approximately 80 percent of uranium ore is processed by acid leaching.

Acid Leaching

A representative acid-leach mill process was illustrated by the flow diagram in Figure 10.1. The ore slurry from the grinding process is heated to 35°C and fed to a series of eight wooden tanks equipped with mechanical agitators. Sulfuric acid is continuously added to the tanks to maintain a pH of 2 to 0.5 or from 1 to 90 grams of free acid per liter. An oxidant, sodium chlorate, is also continuously added with the acid to oxidize the uranium from a tetravalent to the hexavalent state. Iron, from the ore and from grinder wear particles, is present in the solution for this oxidation reaction to

occur. The ore leaching proceeds for nominally seven hours while most of the uranium and some of the other metals (including uranium decay products) are removed from the ore. For ores treated solely for uranium recovery, the sulfuric acid consumption ranges from 20 to 60 kg per Mg of ore.

The leach liquor, containing the dissolved uranium, is separated from the sands and slimes by countercurrent decantation washing in thickening tanks (five stages) by repeated thickening, decantation of clarified solution, and redilution of thickened solids. Flocculants are added to promote settling of the suspended solids. The separated solids, the underflow from the last thickener, are washed free of dissolved uranium and pumped as a slurry to the tailings pond. The tailings solution typically weighs 1.5 to 2 times the processed ore and the solids are composed of 70 to 80 percent sands and 20 to 30 percent slimes (smaller particles).

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.

10.2.3 Product Recovery

Following the extraction of uranium from the ore by the acid leach process, the leach solution is purified and concentrated by solvent extraction.

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 dewatered precipitated uranium slurry is dried in a multiple-hearth dryer at 370 to 430°C. The dried product, yellowcake, is crushed and packaged in 210-l drums for shipment.

10.3 DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT

Effluents are materials that are deliberately discharged to the environment; wastes are controlled or disposed of with the intent of isolating them from man's environment. This section describes the systems that treat effluents and wastes at the representative mill.

10.3.1 Effluent Processing (Clark and Kerr, 1974; Schneider and Kabele, 1979)

As milling operations expanded in the 1950s, little attention was given to management of the wastes, and mill tailings were often released to unrestricted areas. Most of the mills were located near streams, and the contamination of surface waters with chemical and radiological contaminants became evident. Since about 1960, improved methods of tailing impoundment have been developed. A process flow diagram for liquid and airborne effluent control for the representative mill is shown in Figure 10.2.

Most mills retain tailings in ponds which may cover 100 or more hectares (250 or more acres). The tailing solids are slurried with liquid waste and pumped into ponds formed behind earthen dams. The liquid phase is removed by natural evaporation, seepage, and by recycling to the mill. Seepage into nearby streams is controlled by using low-permeability clays for dam filler and by lining the ponds with clay or synthetic materials. Seepage is also collected in sumps and returned to the ponds. Settling of suspended solids is promoted by neutralization of acid tailings with crushed limestone or quicklime. Dissolved radium may be reduced further by precipitation with barium chloride.

Tailings pile stabilization will control the dispersal of contaminated dust from the pile. Dried tailings piles are stabilized by covering with materials appropriate for the region. Open-pit mines can be backfilled with tailings and when covered provide stabilization and reclamation. Tailings piles are covered with soil and further stabilized against erosion by vegetation, rock cover, or by spraying with a binding agent. A soil cover several feet thick will allow for decay of much of the radon before it can diffuse to the surface.

The handling and crushing of dry ore produces air-borne dust. For dust control, air exhaust hoods are located over crushers, screens, and points of ore discharge. Dust is removed from the exhaust air by wet dust collectors before the air is discharged to the atmosphere through roof vents.

Radon-222, the gaseous decay product of ^{226}Ra , is released from ore and tailings during and after mill operations. It presents a radiological hazard because it is mobile, it is an alpha emitter with a short half-life (3.8 days), and it is the parent of a chain of three alpha emitters and four beta emitters, all with short half lives. Radon emanation is primarily a problem if allowed to accumulate in poorly ventilated enclosures.

During the mill operations, the dry crushing of ore, and the crushing and packaging of yellowcake produce dusts which contain the radionuclides present in the ore and the uranium products. During and long after milling operation, a dry exposed tailings pile can be a source of wind blown dust carrying uranium decay products. These sources of dust must be controlled to protect the mill workers and the public.

The mill is also a source of nonradiologic effluents such as carbon dioxide and nitrogen oxides from the heating boilers and chemical vapors such as organic solvents (kerosene), sulfuric acid, and ammonia.

10.3.2 Waste Management

Solid and liquid wastes are generated during the normal operations of a uranium mill. The degree and time at which any of these wastes enter the environment (i.e., in unrestricted areas) depend upon the process controls and waste management practices employed. The majority of the wastes appear in the mill tailings which include the residual solids from the ore and an aqueous phase containing dissolved ore constituents and process chemicals. The waste management operations for the representative acid-leach mill is illustrated in Figure 10.3.

Solid Wastes

Approximately 97 percent of the ore appears after processing as solid waste in the mill tailings. The solids are composed of 70 to 80 percent sands (largely silica particles with equivalent diameters of 75 to 500 μm) and 20 to 30 percent slimes (<75 μm particles). The slimes consist of silica with minor amounts of complex metallic silicate complexes.

Uranium and its decay products are the major radionuclides in the ore. If none of the decay products has been removed from the ore by natural leaching or other mechanisms, the decay products are in equilibrium with the ^{238}U in the ore. Ore that assays at 0.16 weight percent U_3O_8 has 450 pCi/g of ^{238}U and of each of its 13 decay products, (^{234}Th , ^{234}Pa , ^{234}U , ^{230}Th , ^{226}Ra , ^{222}Ra , ^{218}Po , ^{214}Pb , ^{214}Bi , ^{214}Po , ^{210}Pb , ^{210}Bi , and ^{210}Po). The final product is stable ^{206}Pb . The total activity is 6300 pCi/g.^(a) About 6.5 percent of the uranium and essentially all of the uranium decay

(a) This ignores the small contribution from ^{235}U and ^{232}Th and their decay products.

FIGURE 10.3. Overall Waste Management Operations for a Representative Acid-Leach Mill

- Airborne Effluents
- Liquid Effluents

products from the original ore are contained in the tailings. Approximately 5 percent of the thorium is removed by the mill process also. The tailings, then, contain most of the original activity, or about 5800 pCi/g. This specific activity varies in proportion to variations in uranium assay and is affected by variations in mill processes.

Radium-226 is considered an important pollutant in the ^{238}U decay chain. Studies of the acid-leach process have shown that of the original radium in the ore, 0.05 to 0.1 percent is precipitated with the uranium product, 0.15 to 0.3 percent is discharged in the liquid phase of the tailings, and the remaining 99.6 to 99.8 percent is retained in the tailing solids. The slimes contain about four times as much radium as do the sands.

Nonradioactive solid waste consisting of chemical containers, cardboard boxes, and general refuse is buried onsite by conventional landfill methods.

The liquid portion of the wastes from the acid leach milling operation is generally about equal in weight to the solids weight in the tailings and contains about 1 percent dissolved solids. The solutions contain a number of ions of metals, chloride, sulphate, ammonium, and phosphate. There are also minor amounts of flocculants and organic solvents. The pH is usually 1.2 to 2.0. The liquid wastes are used to slurry the solid tailings to the tailings pond. Up to 70 percent of the water is recycled to the mill process. Much of the remaining liquid in the tailings pond becomes an effluent by natural evaporation.

10.4 PLANT LAYOUT

The description of the site and facility is given for the representative acid-leach mill. Much of the information was obtained from Sears (1975) and Schneider and Kabele (1979).

10.4.1 Site Description

The representative plant requires an area of approximately 0.12 km² within the larger 13 km² plant site described in Section 5. The tailings area requires another 1.0 km² during the life of the facility. 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.

10.4.2 Facility Description

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 10.4 shows the layout of the representative mill area.

FIGURE 10.4. Layout of the Representative Acid Leach Mill

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 and covers a large area to provide a sufficient natural evaporation rate. Temporary water flows from periods of high precipitation are diverted around the tailings pond by small dikes and ditches.

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 km² (250 acres). The waste discharge pipe to the pond is moveable, 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.

Table 10.1 lists the major process areas and buildings, and Table 10.2 describes major process equipment.

The mill is assumed to have an operating life of 20 years. The life is limited primarily by the quantity of ore available in the mines that supply the ore.

10.5 SAFETY-RELATED INFORMATION

This section identifies the safety-related information that can be used to help identify the risks associated with operating the representative mill.

10.5.1 Operating and Maintenance Requirements

The representative 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%)
	<u>92</u>

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

10.5.2 Input/Output of Major Materials

The routine material input requirements consist of those materials given as inputs in Tables 10.3 and 10.4 and drums for packaging the yellowcake

TABLE 10.1. Major Process and Auxiliary Areas Description
for the Representative Acid Leach Mill

<u>Process Area</u>	<u>Overall Dimensions L x W x H, m</u>	<u>Primary 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 10.2. Major Process Equipment Descriptions for
the Representative 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	NA	5.7E4 liters

NA = Not available at this time

TABLE 10.3. Overall Radioactive Materials Input/Output for the Representative Acid Leach Mill

Material	Total Material (a)		U(a,b) kg/day	From		Fraction of Plant Input(c)
	kg/day	g/day		Chemical	Phase	
<u>Input to Mill</u>						
Uranium Ore	1.8E6 ^(d)	NA ^(d)	2.7E3	See Table 9-1	S	(1)
<u>Output from Mill</u>						
Product:						
Yellowcake	3.3E3 ^(d)	NA ^(d)	2.5E3	(NH ₄) ₂ U ₂ O ₇	S	(0.935)
Airborne Effluents:						
Uranium	5.4E2 ^(d)	NA ^(c)	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	---
Waste:						
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 10.4. Overall Nonradioactive Materials Input for the Representative Acid Leach Mill

Material	Total Material ^(a)		Form	
	kg/day	l/day	Chemical	Phase
Water	2.7E6	2.7E6	H ₂ O	L
Kerosene	8.1E2	NA	H _x C _y	L
Ammonia	2.0E3	NA	NH ₃	G
Sulfuric Acid	8.1E4	NA	H ₂ SO ₄	L
Sodium Chlorate	2.5E3	NA	NaClO ₃	S
Ammonium Sulfate	NA	NA	(NH ₄) ₂ SO ₄	S
Major Constituents in Ore	1.8E6	NA	NA	S
Tertiary Amine	2.7E1	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 10.5. Overall Nonradioactive Airborne Effluents Output from the Representative 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.

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

TABLE 10.6. Overall Nonradioactive Liquid Effluents from the Representative 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	F ⁻	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	CN ⁻	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	NO ₃ ⁻	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

product. Sulfuric acid and sodium chlorate are two major routine chemicals. Miscellaneous materials such as office materials, and routine maintenance supplies, etc., are also required.

The input/output information in Table 10.3 indicates the overall input/output for radioactive material from the reference facility. It is assumed that 6.5 percent of the uranium supplied to the milling facility ends up in either the airborne and liquid effluents or the liquid and solid wastes. Table 10.4 gives the overall input of nonradioactive materials, and Table 10.5 gives the output of nonradioactive airborne effluents. Table 10.6 gives output of nonradioactive liquid effluents, and Table 10.7 gives the output of radioactive and nonradioactive solid and liquid wastes.

TABLE 10.7. Overall Solid and Liquid Wastes from Uranium Acid Leach Mill

<u>Waste Material</u>	<u>Total^(a)</u>		<u>U Content^(a)</u>		<u>Radioactivity of Uranium and Decay Products, Ci/yr</u>
	<u>lb/day</u>	<u>kg/day</u>	<u>kg/day</u>	<u>Form</u>	
Uranium-Contaminated					
Spent Ore	NA	1.8E6 ^(b)	1.7E2	S	NA
Liquid Tailings Waste	NA	2.3E6 ^(b)	4.3	L	3.5E3 ^(c)

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

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

(c) Values based on assumptions defined in 10.3.1.

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

The liquid and solid wastes listed in Table 10.7 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 or in with the tailings.

10.5.3 Inventories of Major Hazardous Materials at Plant Locations Having Safety-Related Importance

The major inventory of radioactive material at the mill site is the tailings pile which accumulates solids at a rate of 6.5×10^5 Mg/yr which contain most of the radioactivity from the original ore. At the end of the expected 20-year life, the pile would contain 1.3×10^7 Mg of the tailings. The unprocessed ore is stored in the receiving storage area; one week's supply is assumed here and is 1.25×10^4 Mg of ore. The yellowcake product is stored onsite until shipped to the conversion plant and would accumulate at the rate of 23 Mg/week. One week's production is the inventory assumed here.

The major inventories of nonradioactive materials are believed to be sulfuric acid, sodium chlorate, ammonia, and kerosene. The quantities of these materials are not available but may be estimated from the daily input data in Table 10.4. It is believed that two to eight week's supply of these materials are reasonable inventories.

10.5.4 Unit Operations Involved

The unit operations are indicated in the process flow diagram, Figure 10.1, by the numbers in each box. The relationship between the numbers and the unit operations is given in Table 10.8.

10.5.5 Accident Driving Forces

Most process temperatures and pressures are near ambient (<50C) in the acid leach mill. The yellowcake drying operation at 370 to 430°C is the exception. Fluid pressures in piping is sufficient to affect material transfer.

All uranium is natural and nuclear criticality is not a concern. Large quantities of chemically reactive materials, particularly sulfuric acid, gaseous ammonia, sodium chlorate, and kerosene are available and are identified in Table 10.4.

10.5.6 Containment and Shielding

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.

10.5.7 Degree of Hands-On Operation

The radiation levels from the ore, process vessels, and yellowcake are low and require no shielding or remote operations for normal and maintenance activities. However, in some confined locations, working time for the staff may be restricted.

10.6 OTHER PROCESS SCHEMES FOR URANIUM MILLING

The representative milling scheme presented is the most commonly used in the U.S.A. and is well demonstrated. However, other processes have been used successfully and are discussed briefly in this section.

TABLE 10.8. Reference List of Unit Operations in the Fuel Cycle

Solids

1. Solids materials handling (packaging, conveyance, screening, mixing, pressing)
2. Solids materials cutting (metallic materials)
3. Solids materials size reduction (crushing, grinding)
4. Solids drilling/blasting
5. Solids materials melting (welding, glass making)
6. Solids materials burial

Liquids

7. Liquid materials handling (pumping, mixing)
8. Distillation (concentration, evaporation, fractionization)
9. Natural evaporation
10. Solvent extraction (organic/aqueous)
11. Electrolysis

Gases

12. Physical gaseous separation (diffusion, centrifugation)
13. Gas/vapor compression

Solid-Liquid

14. Solids dissolution (leaching, dissolving)
15. Solid-liquid separation (filtration, settling)
16. Solid-liquid sorption (adsorption, ion exchange)
17. Precipitation
18. Solidification at nonhigh temperatures (cementing, bitumenization)
19. High-temperature processing (drying, roasting, calcining, melting)

Solid-Gas

20. Solids separation (filtration)
21. Sorption

Other Phase Combinations

22. Sorption (scrubbing [l-g])
23. Incineration
24. Vapor/gas cooling (cooling, condensing, sublimation)
25. Chemical reactions (g-g, g-l, g-s, l-l, l-s)
26. Storage (s, l, g)

10.6.1 Alkaline Leach Process

Ores with a high lime content (>12 percent) would consume a large amount of acid leachant, and for these ores, an alkaline leach process is more economical. A flow diagram illustrating an alkaline-leach mill is shown in Figure 10.5. In this process, a slurry of finely ground ore ($\sim 74 \mu\text{m}$) somewhat finer than for acid leaching ($< 75 \mu\text{m}$) from the grinding process, containing about 55 percent solids, is pumped to a series of leach tanks. The leach solution contains 40 to 50 grams per liter of sodium carbonate and 10 to 20 grams per liter of sodium bicarbonate. (The bicarbonate prevents reprecipitation of the uranium through reaction with the hydroxyl ion.) The leach rate may be accelerated by elevated temperature and pressure. Steam-heated leach tanks about 6 m diameter and 18 m deep are commonly used so that the hydrostatic pressure and heated solution (85 C) will increase the leach rate. Air is continuously bubbled through the tank to oxidize the uranium to the hexavalent state. The batch leaching process varies from 24 to 72 hours depending on the ore characteristics and the process conditions. In some mills the first stage of carbonate leaching in an autoclave at 4.5×10^5 Pascals (65 psig) and 93 C is used to increase the leach rate.

The uranium bearing leach solution is separated from the solids in a series of countercurrent filtrations in which the solids are washed free of dissolved uranium. The filter cake is slurried and pumped to the tailings pond.

The uranium in the filtrate from an alkaline leach solution is precipitated as sodium diuranate by the addition of sodium hydroxide without the intermediate extraction and stripping operations used in acid leaching. Precipitation takes place in agitated tanks as the pH is increased to above 12. The barren solution containing sodium carbonate and sodium hydroxide can be regenerated by contacting with carbon dioxide from flue gas and recycled to the leaching circuit.

There is insufficient information to make a quantitative comparison of the safety of the alkaline leach process to the acid leach. The alkaline leaching is conducted at an elevated temperature (85 to 93°C) and, in some cases, a greater pressure (4.5×10^5 Pascals). On the other hand, alkaline leach does not use organic solvents. Also, the alkaline leachant is somewhat more hazardous than the acid leachant.

10.6.2 Ion Exchange Recovery Process

Uranium can be extracted from acidic or alkaline leach solutions with high-solids content (pulp) as well as from clarified solutions by ion exchange. Strong and intermediate base anionic-type resins preferentially adsorb uranium anion complexes from solution and exclude metallic cations to concentrate purified uranium on the resin. After washing, the loaded resin is stripped of uranium by a weak solution of chloride, nitrate, bicarbonate, or an ammonium sulphate-sulfuric acid.

FIGURE 10.5. Process Flow Diagram--Typical Alkaline-Leach Mill Process

Ion exchange is applied by four different types of contactors in uranium mills. A fixed-bed type circuit employs stationary columns packed with resin. The leach solution is fed through the columns to adsorb the uranium, the resin is washed and the uranium is stripped by the eluting solution. The fixed bed columns are subject to plugging by solids. In the moving-bed type circuit resin is moved to different stationary columns for absorption, washing, and eluting operations. In the resin-in-pulp process, resin and slurries flow counter-currently through tanks and are separated by screens and agitated by bubbling air. In this continuous process, the resin is successively loaded, washed, and eluted. In the basket resin-in-pulp process, the resin is held in cubical baskets which are moved up and down in the process solution in a tank. The feed, wash, and eluting solutions are pumped in turn through the tank. The latter two methods can be used with feed solutions with high solids content.

10.6.3 Eluex Process

In the Eluex process, the uranium is absorbed from the leach solution by ion-exchange resins, the resins are eluted with a sulfuric acid solution which is then fed to a Dapex or Amex solvent extraction process. The Eluex process eliminates the use of nitrate or chloride reagents and results in a purer product. In an improved Eluex process which may be employed in new plants, the number of stages, the retention time, and the resin volume are greatly reduced by coupling a stage of solvent extraction with each stage of resin elution. The Eluex process is a new development which is employed at newer plants.

10.7 REFERENCES

- Clark, D. A., and Kerr, R. S. 1974. State-Of-The-Art: Uranium Mining, Milling, and Refining Industry. EPA-660/2-74-038, National Environmental Research Center, U.S. Environmental Protection Agency, Corvallis, Oregon.
- Schneider, K. J., and Kabele, T.J. 1979. Description of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles. PNL-2286, Battelle's Pacific Northwest Laboratory, Richland, Washington.
- Sears, M. B., et al. 1975. Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle--Milling of Uranium Ores. ORNC-TM-4903, Vol. 1, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- U.S. Nuclear Regulatory Commission. 1980. Final Generic Impact Statement on Uranium Milling. NUREG-0706, Washington, D.C.

11.0 URANIUM PURIFICATION AND CONVERSION

A uranium purification and conversion plant receives a semirefined ore concentrate, called yellowcake, from the milling operation and purifies and converts the uranium to UF_6 for shipment to an enrichment plant.

Two processes are used for uranium conversion in the U.S. which employ similar methods for fluorination but differ in the method of uranium purification and thereby in the wastes they produce. In one process, the yellowcake is converted to a nitrate solution from which a purified uranyl nitrate is extracted by solvent extraction. The uranyl nitrate is subsequently converted to UF_6 . Much of the waste from this process appears in liquid streams. In the other process, the yellowcake is converted to a UF_6 product which is then purified by fractional distillation. The major waste streams in this process are solids, some in the form of particulates.

Most of the conversion facilities in the western world employ the solvent extraction method of purification. However, in the United States, each method is employed to produce about half of the country's supply of UF_6 . As a result, both processes are described in this report. The conversion industry is very competitive, employing proprietary methods, thus all details of the facilities and their operations are not available.

11.A WET URANIUM CONVERSION WITH SOLVENT EXTRACTION PURIFICATION

This section describes a representative solvent-extraction uranium purification and conversion plant based on the Kerr-McGee Sequoyah Uranium Hexafluoride Plant (Schneider and Kabele 1979, Elder 1981).

11.A.1 SUMMARY

The wet uranium conversion plant receives ammonium diuranate ore concentrate from a number of uranium mills and converts the uranium to a purified UF_6 product for shipment to an enrichment plant. The reference solvent-extraction conversion plant described in this section is based on the Kerr-McGee Sequoyah Uranium Hexafluoride Plant, at Sequoyah County, Oklahoma. For this study the plant is assumed to be on the generic site described in Section 8.0 of this report.

The plant purifies the ammonium diuranate (yellowcake) by a solvent-extraction process for subsequent conversion to UF_6 . The facility processes 33 Mg/d of yellowcake to produce 37 Mg/d of solid UF_6 (25 Mg/d of natural uranium). Assuming 11,000 MWDe/MT (3.2 percent ^{235}U), the daily production of UF_6 is equivalent to the production of 43,400 MWe.

The yellowcake, received in 210-l drums, is weighed, sampled, and fed to digester tanks for dissolution in a 40 weight percent nitric acid solution. Uranyl nitrate is extracted from the acid solution by an organic solvent in pumper-decanters, then stripped from the solvent with water. The aqueous solution of uranyl nitrate is concentrated by evaporation, and denitrated and oxidized to uranium trioxide by heating in air before being reduced to uranium dioxide. By a two-stage hydrofluorination with hydrogen fluoride, followed by a two-stage fluorination with fluorine, the uranium dioxide is converted to uranium hexafluoride which is solidified in product cylinders.

The plant is operated 24 h/d, 365 d/yr by a workforce of 155 (10 percent management-professional). No remote or shielded operations are required for radiation protection, but protective clothing is worn for all work in the processing facility. Maintenance is performed on process equipment by direct contact by onsite staff wearing protective clothing for contamination control. Maintenance of process equipment is assumed to be equivalent to replacement every 20 years. Unusual maintenance is required on the fluorine electrolytic cells of which 8 of 68 are rebuilt each month and the fluorine off-gas lines which are replaced once every 2 years.

Assuming a one-week accumulation of major input/output materials, 230 Mg of yellowcake and 260 Mg of solid uranium hexafluoride are stored on the site. The major chemical usage is 22.3 Mg/d of nitric acid, 14.6 Mg/d of anhydrous hydrogen fluoride, and 6 Mg/d of anhydrous ammonia.

The denitration, reduction, hydrofluorination, and fluorination processes are conducted at $> 150^\circ C$ temperature with materials of high chemical reactivity (HNO_3 , H_2/N_2 , HF , and F_2). Process pressures are not

high, but are greater than atmospheric. Electrically powered motors for driving pumps, conveyors, crushers, and blowers present accident driving forces from mechanical and electrical energy. The natural uranium does not present a criticality concern.

The representative plant is the only commercial wet uranium conversion plant in operation in the U.S. and alternate processes are not presented.

11.A.2 MAINLINE PROCESS DESCRIPTION

A flow diagram for the solvent-extraction process, commonly known as the wet process, is shown in Figure 11.A.1 and in greater detail in Figure 11.A.2. Discussion of the major process steps is given in the following subsections.

11.A.2.1 Feed Preparation

The yellowcake is assumed to be a composite product from various domestic uranium mills and is primarily ammonium diuranate with some sodium diuranate and uranium trioxide. Some yellowcake may contain small amounts of U_3O_8 and magnesium diuranate. The feed is received in 210- drums which have been in storage for several months. During this time, the ^{234}Th and ^{234}Pa will have come into secular equilibrium with the ^{238}U . The ^{234}U extracted from the ore with ^{238}U , remains in secular equilibrium with the ^{238}U . The ^{230}Th and ^{226}Ra are assumed to be 5.0 and 0.2 percent, respectively, of the uranium activity as carryover from the mill extraction process. No recycle uranium is assumed to be included in the feed.

The incoming drums of yellowcake are each weighed and sampled after which the feed may be redrummed for interim storage or is conveyed to the digester hopper.

11.A.2.2 Digestion

The yellowcake is fed on a batch basis to one of several digester tanks for up to 8 hours of digestion in hot 40 weight percent nitric acid solution. An additional digester tank receives recycle material from various points in the plant for recovery of uranium in an ammonium nitrate solution. The uranyl nitrate solutions from the digester tanks are adjusted in pH and fed to the solvent extraction step.

11.A.2.3 Solvent Extraction

The uranyl nitrate is extracted from the aqueous solution by an organic solvent (30 percent tributyl phosphate in hexane diluent) in pumper-decanters. The organic solvent containing the uranyl nitrate is washed with an acid solution to remove impurities and then the uranyl nitrate is stripped from the organic solution with water. The organic solvent is purified for recycle to the extraction stage. The aqueous uranyl nitrate solution is washed with hexane to remove residual tributyl phosphate, and is concentrated and partially denitrated to about 1200 g of U/l in two stages of evaporation.

KEY:

▽A = AIRBORNE EFFLUENTS

C = CONTINUOUS

B = BATCH

Numbers above blocks indicate
unit operation involved as
identified in Table 11.A.8.

FIGURE 11.A.1. Representative Mainline Process for Wet Conversion

FIGURE 11.A.2. Mainline Process Flow Diagram for the Representative Uranium Wet Conversion Facility

11.A.2.4 Denitration and Reduction

The concentrated uranyl nitrate solution is denitrated and oxidized to uranium trioxide by calcining (heating) in air to about 275°C. The uranyl nitrate solution is fed to each of several electrically heated, mechanically-stirred calciners. The dried uranium trioxide is pulverized in a hammer mill and fed to the reduction system.

The uranium trioxide is reduced to uranium dioxide in a fluidized bed reactor at about 540°C. The fluidizing gas, a mixture of hydrogen and nitrogen formed by the dissociation of ammonia, is also the reducing agent. The uranium dioxide product is carried from the reactor by the exhaust gas to a collection hopper where it is retained by filters.

11.A.2.5 Hydrofluorination

The uranium dioxide is converted to uranium tetrafluoride by reaction with anhydrous hydrogen fluoride at approximately 345°C. The uranium dioxide is fed by a screw feeder into the first of two reactors in series. The partially reacted output of the first reactor is collected in the feed hopper for the second reactor. The outlet gases are filtered and vented. The hydrofluorinated product (uranium tetrafluoride) from the second reactor (containing small amounts of incompletely reacted uranium) is carried by the outlet gases to the product hopper where the gases, after filtering, are recycled to the inlet of the first reactor. Both reactors have electrical heaters and external forced-air cooling for temperature control.

11.A.2.6 Fluorination and Collection

The uranium tetrafluoride product is reacted with elemental fluorine in a primary reactor (flame tower) to produce uranium hexafluoride. The exothermic reaction occurs nearly instantaneously as the uranium tetrafluoride is charged to the flame tower with an excess quantity of fluorine. Most of the uranium tetrafluoride is converted to gaseous uranium hexafluoride. The heat from the reaction is transferred to a steam coolant circulated through external cooling coils. Incompletely reacted uranium and some impurities are collected in an ash receiver below the flame tower for recycle for uranium recovery.

The gas leaving the primary reactor passes through two cold traps in series which condense the uranium hexafluoride. The outlet gases from the cold traps are routed to a cleanup reactor or are recycled after filtering to the inlet of the primary reactor. In the cleanup reactor the gases react with an excess quantity of uranium tetrafluoride as heat is supplied to maintain a temperature of 455°C to consume the fluorine. The exhaust gas is cooled to condense uranium hexafluoride, filtered to remove other solid fluorides, and vented to the gas cleanup system.

The first cold trap (heat exchanger) after the primary reactor is cooled to about 4°C by a circulating water-glycol coolant. The second cold trap is cooled to about 50°C with a Freon coolant. Periodically, the coolants in the cold traps are heated to above the melting point of the uranium hexafluoride and the product is drained into cylinders for storage or shipping.

11.A.2.7 Fluorine Production

Elemental fluorine is produced at the plant by the electrolysis of fused potassium bifluoride (KHF_2). Electrolytic cells containing the fused salt are compartmented to separate the hydrogen and fluorine evolved by electrolysis. The composition of the bath is maintained by a continuous flow of anhydrous hydrogen fluoride into the bath.

The fluorine from the cell is filtered to remove entrained electrolyte, compressed by a centrifugal compressor, cooled to condense hydrogen fluoride, and fed to the fluorine supply system. Hydrogen, treated by a similar method to remove electrolyte and hydrogen fluoride, is fed to a gas burner.

11.A.3 DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT SYSTEMS

The processing of effluents and management of wastes from the wet conversion plant are discussed in this section.

11.A.3.1 Effluent Processing

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.

Liquid Effluents

Figure 11.A.3 illustrates the liquid effluent treatment system. The fluoride-containing liquid stream 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, 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 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. The 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.

Airborne Effluents

The treatment of airborne effluents from the facility is shown schematically in Figure 11.A.4. Treatment consists mainly of filtration and scrubbing by various systems.

FIGURE 11.A.3. Process Flow Diagram--Liquid Effluent Treatment System for a Uranium Wet Conversion Facility

FIGURE 11.A.4. Process Flow Diagram--Airborne Effluent Treatment System for a Uranium Wet Conversion Facility

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

The reduction reactor off-gas is filtered through sintered metal filters and bag filtered 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, 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, 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 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 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.

11.A.3.2 Waste Management

The waste materials generated in a solvent-extraction uranium purification and conversion facility are radioactive liquid wastes and radioactive and nonradioactive solid wastes. Figure 11.A.5 shows waste management methods; the methods of waste management are discussed in the following subsections.

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. This raffinate stream is neutralized with ammonia, which precipitates most of the

FIGURE 11.A.5. Overall Waste Management Process for a Representative Uranium Wet Conversion Facility

radioactive elements and other heavy metal impurities. The resulting slurry is confined in storage ponds having sealed bottoms. The evaporating liquid becomes an airborne effluent.

Another liquid stream produced in the facility, the fluoride stream, is assumed to be an effluent because part of this stream discharges to the environment.

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 processed to recover the residual uranium, and the solid wastes in the fluoride storage ponds may be buried onsite according to 10CFR20.304, 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 10CFR20.304.

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.

11.A.4 PLANT LAYOUT

This section summarizes the descriptions of the site and facility and its hardware.

11.A.4.1 Site

The solvent-extraction uranium purification and conversion facility is assumed to lie on the generic 4.7-km² site described in Section 8.0. The facility itself (within the restricted area fence) requires an area of 0.30 km² 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, 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 the site. The airborne effluents are assumed to be discharged 1 km away from three sides of the rectangular generic site.

11.A.4.2 Facility Descriptions

The facility, shown in Figure 11.A.6, consists primarily of three buildings (main process building, solvent-extraction building, and warehouse

FIGURE 11.A.6. Layout of a Solvent-Extraction Conversion Facility

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 59.9-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.

The solvent-extraction building occupies 372 m² (4,000 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 are descriptions is given in Table 11.A.1 and that for major process equipment in Table 11.A.2.

11.A.5 SAFETY-RELATED INFORMATION

This sections provides available safety-related information for the wet conversion facility.

11.A.5.1 Operating and Maintenance Requirements

The representative facility is assumed to operate 24 h/d and 365 d/yr. The work force for the facility is assumed to include the following:

Management and professional	15
Nonmanagement and nonprofessional	<u>140</u>
	155

Most of the equipment within the representative facility is assumed to last 20 years. A total of 8 of the 68 fluorine cells are rebuilt per month. Unusual maintenance on the fluorine cell off-gas lines is required because of buildup of solidified electrolytes deposited during hydrogen-fluorine recombination reactions. This maintenance is assumed to be equivalent to replacing these off-gas lines about once every 2 years. The maintenance of other process-contacting equipment is assumed to be equivalent to replacement every 20 years. Maintenance is assumed to be done by on-site staff on a continual basis. Maintenance is performed by direct contact of the staff with the equipment while wearing protective clothing.

TABLE 11.A.1. Major Process and Auxiliaries Areas Description -
Representative 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 & Capacity

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

NA = Not available at this time

**TABLE 11.A.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 $\pm$	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 $\pm$	NA
Concentration:				
Single Effect Evaporator	1	NA	12,301 $\pm$ /hr(in) 2,574 $\pm$ /hr(out)	NA NA
Boildown Tanks	3	3.0 diameter 3.0 high	22,710 $\pm$	NA
Denitration:				
Denitrator	3	NA	NA	Trough-type 274°C Op. Temp.
UO ₃ Bin	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.

11.A.5.2 Input/Output of Major Materials

The routine material requirements for the facility consist of those radioactive and nonradioactive materials given as inputs in Tables 11.A.3 and 11.A.4 and packaging materials for solid waste disposal. Miscellaneous materials such as office materials, office furniture, routine maintenance supplies, etc., are also required.

The overall effluent control performance for radioactive material is indicated by the input/output information in Table 11.A.3. Approximately 0.15 percent of the uranium supplied to the representative facility ends up in either the airborne and liquid effluents or the liquid and solid wastes. Table 11.A.4 gives the overall input of nonradioactive materials, and Table 11.A.5 gives the output of nonradioactive airborne and liquid effluents. The output of radioactive and nonradioactive solid and liquid wastes is given in Table 11.A.6.

The solid wastes listed in Tables 11.A.3 and 11.A.6 are managed in either of two ways. The solid wastes in the raffinate ponds and the solid wastes in the fluorine ponds are retained indefinitely. The other solid wastes are buried onsite. The solid wastes listed in Table 11.A.6 are either burned in an open-pit incinerator or in an enclosed incinerator. The ashes from the incinerators are buried onsite without containers.

11.A.5.3 Inventory of Major Hazardous Materials Having Safety-Related Importance

Information to quantify the inventory of hazardous materials is not available from the conversion facility site. However, order-of-magnitude estimates can be made from the daily input/output data in Tables 11.A.3 and 11.A.4 by assuming a one week accumulation.

The major radioactive materials are the ammonium diuranate feed material (received and stored in 210 $\pm$ drums) and the uranium hexafluoride product (stored in product/shipping cylinders on an outside storage pad).

The major nonradioactive hazardous materials are nitric acid (in the solvent-extraction building and storage tanks), anhydrous hydrogen fluoride and anhydrous ammonia (stored in tanks at the tank farms).

11.A.5.4 Unit Operations Involved

The unit operations are indicated in the process flow diagram, Figure 11.A.1, by the numerals over each box and in Table 11.A.7. The decoding of the numerals and the reference set of unit operations used in this study is given in Table 11.A.8.

11.A.5.5 Accident Driving Forces

The conversion of yellowcake to uranium hexafluoride occurs as a result of successive chemical reactions, most of which are exothermic and occur at elevated temperature with chemically reactive materials as indicated in Table 11.A.9. Information on the pressures within the reaction vessels is not

TABLE 11.A.3. Overall Radioactive Materials Input/Output for Reference Uranium Wet Conversion Facility^(a)

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

(a) Taken from Schneider and Kabele, 1979.

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

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

KEY: S = Solid

L = Liquid

G = Gas

NA = Not available at this time

TABLE 11.A.4. Overall Nonradioactive Materials Input to Representative Uranium Wet Conversion Facility

Material	Total Material(a) kg/day	Form		
		Chemical	Phase	Other
Nitric Acid	22,332	HNO ₃	L	60%
Anhydrous Ammonia	6,096	NH ₃	L	Compressed
Lime	12,427	CaO	S	NA
Anhydrous Hydrogen Fluoride	14,615	HF	G	NA
Nitrogen	NA	N ₂	L	Compressed & Cooled
Hexane	>460	C ₆ H ₁₄	L	NA
Tributyl Phosphate	273	[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	KF-HF	S	NA
Lithium Fluoride		LiF	S	NA
Ammonium Sulfate	1,076	(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	NA	H ₃ PO ₄	L	NA
Iron Solution	NA	NA	L	NA

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

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

TABLE 11.A.5. Overall Nonradioactive Airborne and Liquid Effluents
From a Uranium Wet Conversion Facility

Material	Form		Output (a) kg/day
	Chemical	Phase	
Airborne Effluents			
Carbon Monoxide	CO	G	17
Fluorine	F ₂	G	0.36
Hexane	C ₆ H ₁₄	G	4.6E2
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 one day operating at 100% capacity.

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

TABLE 11.A.6. Overall Solid and Liquid Wastes from a Uranium Wet Conversion Facility

Waste Material	Form	Package	Total ^(a) kg/day	U Content ^(a) kg/day	Fraction of U Plant Input	Ci/Yr
Uranium-Contaminated						
Raffinate Liquid Wastes	Nitric Acid-nitrate liquid	Confined in ponds	~82,800	NA	NA	
Raffinate Solid Wastes	Precipitate	Confined in ponds	NA	~3.3	1.3×10^{-4}	~0.8
Fluoride Solid Wastes	Mainly CaF_2	Settled out	~1,900	~7.6	3.1×10^{-4}	~1.9
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) Assuming 677 $\mu\text{Ci/kg}$ of U_{nat} .

TABLE 11.A.7. Unit Operations for a Uranium Wet Conversion Facility

<u>Process Step</u>	<u>Unit Operation</u>
Feed Preparation	Solids materials handling, b
Digestion	Liquid materials handling, b Solids dissolution, b
Solvent Extraction	Solvent Extraction (organic/aqueous), c
Denitration	High-temperature processing, c
Reduction	High-temperature processing, c
Hydrofluorination	Chemical reaction (g-s), c
Fluorination	Chemical reaction (g-s), c
Product Collection	Vapor/gas cooling, b

b = (batch)

c = (continuous)

TABLE 11.A.8. Reference List of Unit Operations
in the Representative Fuel Cycles

Solids

1. Solids materials handling (packaging, conveyance, screening, mixing, pressing)
2. Solids materials cutting (metallic materials)
3. Solids materials size reduction (crushing, grinding)
4. Solids drilling/blasting
5. Solids materials melting (welding, glass making)
6. Solids materials burial

Liquids

7. Liquid materials handling (pumping, mixing)
8. Distillation (concentration, evaporation, fractionization)
9. Natural evaporation
10. Solvent extraction (organic/aqueous)
11. Electrolysis

Gases

12. Physical gaseous separation (diffusion, centrifugation)
13. Gas/vapor compression

Solid-Liquid

14. Solids dissolution
15. Solid-liquid separation (filtration, settling)
16. Solid-liquid sorption (adsorption, ion exchange)
17. Precipitation
18. Solidification at nonhigh temperatures (cementing, bitumenization)
19. High-temperature processing (drying, roasting, calcining, melting)

Solid-Gas

20. Solids separation (filtration)
21. Sorption

Other Phase Combinations

22. Sorption (scrubbing [l-gl])
23. Incineration
24. Vapor/gas cooling (cooling, condensing, sublimation)
25. Chemical reactions (g-g, g-l, g-s, l-l, l-s)
26. Storage (s, l, g)

available. However, most pressures are believed to be moderate, sufficient to provide gas flow rates for fluidizing particulates and filtration.

TABLE 11.A.9. Accident Driving Forces for a Uranium Wet Conversion Facility

<u>Process</u>	<u>Temperature</u>	<u>Pressure</u>	<u>Chemical Reactivity</u>
Purification	<50°C	NA	High (HNO ₃)
Denitration	175°C	NA	Low
Reduction	540°C	NA	High (H ₂ /N ₂)
Hydrofluorination	350°C	NA	High (HF)
Fluorination	455°C	NA	High (F ₂)
Electrolysis	50°C	NA	High (F ₂ /H ₂)

Only natural uranium is processed at the representative plant and nuclear criticality is not a problem.

11.A.5.6 Containment and Shielding

Systems radiation levels from the natural uranium and its decay products are sufficiently low that shielding is not needed to protect the work force from exposure to direct radiation. However, the work force and the public must be protected from airborne gases and particulates in order to control the uptake of radioactive and toxic materials. The off-gases from building ventilation and process systems are filtered and scrubbed, if necessary, to control the release of particulates and noxious gases (HF and F₂).

Liquified anhydrous HF and ammonia are stored in tanks onsite in significantly large quantities to present a hazard onsite and offsite if accidentally released to the atmosphere. A smaller quantity of gaseous fluorine is stored in piping systems, much of which is contained in buildings. Containment for potentially hazardous materials is provided by process vessels, piping, and building off-gas and ventilation systems.

11.A.5.7 Degree of Hands-On Operation

The radiation levels in the facility are low and require no shielding or remote operations for normal and maintenance activities. Protective clothing is used for all work in the process facility for contamination control.

11.A.6 ALTERNATIVE PROCESS SCHEMES

The representative plant is the only solvent-extraction uranium conversion facility in commercial operation in the U.S. and alternative processes are not presented.

REFERENCES

Elder, H. K. 1981. Technology, Safety and Costs of Decommissioning a Reference Uranium Hexafluoride Conversion Plant, NUREG/CR-1757, U.S. Nuclear Regulatory Commission, Washington, D.C.

Schneider, K. J. and T. J. Kabele. 1979. Description of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles, PNL-2286, Pacific Northwest Laboratory, Richland, Washington.

11.B DRY URANIUM CONVERSION WITH FRACTIONAL-DISTILLATION PURIFICATION

This section describes a representative uranium conversion facility with a fraction-distillation purification process based on the Allied-Chemical UF₆ Plant (Sears 1977).

11.B.1 SUMMARY

The dry uranium conversion plant receives ammonium diuranate ore concentrate from a number of uranium mills and converts the uranium to a purified UF₆ product for shipment to an enrichment plant. The representative fractional-distillation purification plant is based on the Allied Chemical UF₆ Plant at Metropolis, Illinois.

The plant converts the ammonium diuranate feed (yellowcake) to an impure uranium fluoride by a two-step hydrofluorination/fluorination process followed by a fractional distillation process to produce a high purity uranium hexafluoride product. The facility processes 44 Mg/d of yellowcake (33.3 Mg/d of natural uranium), operating 24 h/d, 300 d/yr to produce 50 Mg/d of UF₆. Assuming 11,000 MWDe/MT (3.2 percent ²³⁵U), the daily production of the plant is equivalent to the production of 57,900 MWe.

The yellowcake, received in 210-l drums, is weighed, sampled and converted to a uniformly-sized uranium trioxide feed for the process. After being reduced to uranium dioxide in a fluidized bed with dissociated ammonia, the impure uranium dioxide is converted to uranium tetrafluoride in two fluidizing beds in series by reaction with anhydrous hydrogen fluoride at 350 to 590°C. In the final fluoridization step, the uranium tetrafluoride is reacted with fluorine in a fluidized bed reactor at 425 to 535 C. The resulting uranium hexafluoride is purified by fractional distillation and condensed as solid in collection cold-traps prior to being drained into product cylinders for shipment or storage.

The size of the work force and a description of operating and maintenance requirements is not available. It is assumed maintenance is performed by direct contact by onsite staff wearing protective clothing. Fluorine cells are assumed to require frequent maintenance.

Information was unavailable to quantify plant inventories. Essentially all of the 10,000 Mg/y of natural uranium which enters the plant as yellowcake is converted to solid uranium hexafluoride. Large quantities of anhydrous hydrogen fluoride and anhydrous ammonia are consumed with supplies stored in onsite storage tanks.

The major accident driving forces which were identified result from high temperature chemical processes (<600°C) with highly reactive chemicals (H₂/N₂, HF, and F₂).

The representative plant is the only plant of this type in commercial operation in the western world and alternative processes are not described.

11.B.2 MAINLINE PROCESS DESCRIPTION

A flow diagram for the fractional-distillation process, known as the hydrofluor or dry process, is shown in Figure 11.B.1. A more detailed flow diagram for the representative plant is shown in Figure 11.B.2. The information in this section was obtained from Sears (1977).

11.B.2.1 Feed Preparation

The yellowcake feed from the uranium mills is assumed to be the same as that described for the solvent-extraction process in Section 11A.2.1. After sampling and prior to blending, yellowcake with sodium diuranate is treated with a hot 10 percent ammonium sulfate solution to remove the sodium by precipitation of the uranium as ammonium diuranate. Sodium is undesirable because it causes caking in the fluorinator. The blended sodium-free feed is pelletized, calcined at 370°C to 480°C, crushed, and classified to a 75 to 420 μm (-40 to +200 mesh) uranium trioxide feed for the reduction process.

11.B.2.2 Reduction

The uranium trioxide is reduced to uranium dioxide in a fluidized bed reactor using an excess of hydrogen from cracked (disassociated) ammonia as the reducing and fluidizing gas. The reaction is exothermic, but the feed may require heating or the reactor may require cooling to maintain the bed in the optimum temperature range of 540 to 620°C. Excessive temperature will cause sintering of the particles which will interfere with further reduction and the subsequent hydrofluorination process. The product of the reduction process is a reactive uranium dioxide feed for fluorination.

11.B.2.3 Hydrofluorination

The uranium dioxide is hydrofluorinated to uranium tetrafluoride by reaction with anhydrous hydrogen fluoride in a fluidized bed reactor at a temperature of 350 to 590°C. Two fluidizing beds in series are used with up to 70 percent of the reaction occurring in the primary reactor. Good temperature control is necessary, as low temperatures cause powder caking from water condensation and high temperatures cause sintering of the product. External cooling is usually required for the primary reactor but heating or cooling may be needed in the second reactor. Essentially all of the uranium is converted to uranium tetrafluoride to feed to the fluorination process.

11.B.2.4 Fluorination and Distillation

Uranium tetrafluoride is converted to uranium hexafluoride by reaction with elemental fluorine in a fluidized bed reactor. The reaction is highly exothermic and the heat generation rate can exceed the rate of heat transfer across the bed. Calcium fluoride is used as a bed material to dilute the uranium tetrafluoride to control the reaction rate and, with an air jacket cooler, to limit the temperature to the 425 to 535°C range.

The gases leaving the reactor contain uranium hexafluoride, unreacted fluorine, hydrogen fluoride (an impurity in fluorine), and the fluorides of

FIGURE 11.B.1. Process Flow Diagram for Fluorination-Fractional Distillation Uranium Conversion Plant

FIGURE 11.B.2. Overall Mainline Process Flow Diagram for Representative Fluorination-Fractional Distillation Uranium Conversion Facility

FIGURE 11.B.3. Process Flow Diagram--Liquid Effluent Treatment for A Dry Conversion Facility

metallic impurities that were present in the original ore (primarily vanadium and molybdenum). These gases pass through a sintered-metal filter to two cold traps in series where the uranium hexafluoride and other condensibles are collected. Noncondensable gases, mainly fluorine and hydrogen fluoride, pass on through the traps and, by means of an air ejector, enter the off-gas treatment system.

The crude uranium hexafluoride is melted and drained from the cold traps to the distillation feed tanks where it is kept in the liquid state. The uranium hexafluoride is vaporized into a multi-tray (typically 100 trays), low-boiler, bubble-cap column which separates the uranium hexafluoride from more volatile impurities. Off-gases from the low-boiler column pass through a cold trap and are routed to the off-gas treatment system. Uranium hexafluoride, containing high boiling impurities, passes on to another multi-tray (typically 45 trays) bubble-cap column where the high purity uranium hexafluoride is volatilized and collected in cold traps. The low-boiler column operates at about 93°C and 580 KPa and the high-boiler column operates at 115°C and 650 KPa. Still bottoms and tops are stored since present values do not justify uranium recovery. The collection cold traps are periodically heated and the pure uranium hexafluoride is drained into product cylinders.

A portion of the bed material is periodically removed from the fluorination reactor to prevent the buildup of nonvolatile impurities in the reactor. This material, referred to as ash, contains essentially all of the radioactive impurities from the yellowcake feed. The ash is stored in drums for several months to allow decay of the ^{234}Th and ^{234}Pa prior to leaching with sodium carbonate to recover the uranium.

11.B.2.5 Fluorine Production

Fluorine is produced at the plant by the electrolysis of a fused fluoride salt in a similar manner to that described in Section 11.A.2.7.

11.B.3 DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT SYSTEMS

The processing of effluents and management of wastes from the dry uranium purification and conversion plant are discussed in this section.

11.B.3.1 Effluent Processing

Emissions from process systems and building ventilation must be controlled to limit the quantities of radioactive and noxious chemical releases to acceptable levels. Effluent controls are described in this section.

Liquid Effluents

The liquid effluents from a dry conversion facility arise from the treatment of aqueous solutions from the ash leaching process, the sodium removal process, the scrub solutions from the off-gas treatment systems, and support facility drains. The treatment of these streams are illustrated in Figure 11.B.3. Generally, these liquid streams are treated to remove chemical and radioactive contaminants by precipitation in sealed-bottomed settling basins.

The clarified liquids are adjusted in pH by addition of sulfuric acid and the neutralized liquid is released to the onsite river.

Airborne Effluents

Large quantities of airborne dusts from handling dry materials are the source of most of the release of radionuclides from the fluorination-fractionation conversion plant. Effective dust collection systems are necessary to control the loss of uranium and to minimize human exposure. Dust collection and return to the process is also necessary for economic operation of the process. Yellowcake dusts are collected from sampling and feed preparation. Uranium tetrafluoride dusts are collected from the conversion plant. Ash dusts are collected before and after leaching. Bag filters are used in dust control for process systems and scrubbers are used for process cooling and building ventilation systems. These are illustrated in Figure 11.B.4.

The off-gas from the chemical process systems is treated by scrubbing to remove fluorine, fluorides, and uranium as illustrated in Figure 11.B.5. Solids are precipitated from scrub liquids in settling basins and the clarified liquids are adjusted in pH, diluted, and released.

11.B.3.2 Waste Management

The fluorinator ash is the largest volume of solid waste generated in the facility. Other solid wastes arise in the feed handling and process off-gas treatment systems and the liquid waste treatment systems. Liquid wastes are produced by the ash leaching and sodium removal processes, and the off-gas treatment systems. The liquid wastes are treated for solids removal and their release is described as effluents. A waste management flow diagram is shown in Figure 11.B.6.

Radioactive Liquid Wastes

Uranium is recovered from the fluorinator ash by leaching with a sodium carbonate/sodium bicarbonate solution. This process is similar to the alkaline leach process employed at some uranium mills, except that a more concentrated carbonate solution is used. The leached uranium is precipitated with sodium hydroxide leaving a liquid with high concentrations of carbonate, bicarbonate, hydroxyl, sodium, and fluoride ions contaminated with radioactive decay products of uranium. The volume of this radioactive and chemical waste stream is reduced by a factor of ten or more by regeneration of the carbonate solution by recarbonation and recycle to the leaching circuit. The hydroxyl and fluoride content of this liquid is reduced by recarbonating the solution with carbon dioxide (from boiler flue gas). A portion of the stream must be discarded and replaced with fresh carbonate solution to prevent the buildup of bicarbonate.

The removal of sodium from yellowcake feed results in a liquid waste stream with high concentrations of sulfate, ammonium, and sodium ions contaminated with uranium decay products. There is no simple treatment for regeneration of this solution for recycle and the waste stream is released to a settling basin. Although not assumed in the representative facility, an

Sampling

Process

Vacuum Cleaner

Cleaner Bag

Feed Preparation

Drum Dumping

Drum Cleaning

Calciner

Heater

Air Classifier

Vacuum Cleaner

Cleaner Bag

Conversion

UF₄ Handling

Ash Handling

Vacuum Cleaners

Cleaner Bag

Carbonate Leach

Drum Dumping

Waste Calciner

Heater

Waste Packaging

Vacuum Cleaners

Cleaner Bag

Process Cooling

Building Ventilation

Baffle (Orifice)
Water Scrubber

KEY:

= AIRBORNE EFFLUENTS

FIGURE 11.B.4. Process Flow Diagram--Dust Collection System for a Dry Conversion Facility

FIGURE 11.B.5. Process Flow Diagrams--Off-Gas Treatment Systems for a Dry Conversion Facility

Radioactive Wastes

Figure 11.B.6. Waste Management Process for a
Fluorination-Fractional Distillation
Uranium Conversion Facility

effective way to reduce the amount of this waste stream is to remove the sodium at the mill, where this addition to the tailings pond is manageable.

Solid Wastes

The fluorination ash and the still bottoms are two large solid waste streams which are an unavoidable part of the fluorination-fractionation process. The ash is mainly calcium fluoride with essentially all of the radioactive impurities originally in the yellowcake feed. The ash, after leaching and drying, is a chemically stable, highly insoluble, nonvolatile (except for radon) solid which is packaged in drums and sent to approved low-level waste burial grounds. The still bottoms are principally vanadium, molybdenum, and uranium fluorides and oxyfluorides. This waste is packaged and stored onsite and will require further (currently undefined) treatment before disposal in the future.

11.B.4 PLANT LAYOUT

Not available.

11.B.5 SAFETY-RELATED INFORMATION

This section provides the available safety-related information for the dry conversion facility,

11.B.5.1 Operating and Maintenance Requirements

The plant is assumed to operate 24 h/day, 300 days/yr. Information on operation, work force, and maintenance is not available. It is assumed that the fluorine cells require frequent maintenance as described in Section 11.A.5.1. Maintenance is assumed to be done by onsite staff on a continual basis. Maintenance is performed by direct contact of the staff with equipment while wearing protective clothing.

11.B.5.2 Input/Output of Major Materials

Little information is available on the plant input other than it is assumed that it processes 10,000 Mg of uranium per year and that essentially all of the input uranium is converted to UF_6 .

The facility treats about 223,000 kg/d (59,000 gal/d) of liquid wastes using about 3400 kg/d (7500 lb/d) of calcium oxide (lime). The treatment results in a recycle of 60,600 kg/d (16,000 gal/d), a liquid effluent of 163,000 kg/d (43,000 gal/d), and 5000 kg/d (11,000 lb/d) of solid wastes in the settling basin and effluent. The chemical and radionuclide content of the liquid effluents is given in Table 11.B.1.

The airflow through the facility is approximately 255,000 kg/s (540,000 cfm). The chemical and radionuclide content of the airborne effluent is given in Table 11.B.2.

The major solid radioactive waste stream requiring disposal results from the fluorinator ash treatment. Approximately 1100 Mg/yr of leached ash is

TABLE 11.B.1. Contents of Liquid Effluents from a Dry Conversion Facility(a)

<u>Ion</u>	<u>kg/d</u>	<u>kg/yr</u>
CO_3^-	5.2E1	1.6E4
F^-	9.5E0	2.9E3
SO_4^{--}	8.8E3	2.6E6
NH_4^+	2.8E3	8.3E5
Na^+	6.3E2	1.9E5
K^+	7.8E2	2.3E4
<u>Radionuclide</u>	<u>$\mu\text{Ci}/\text{m}\ell$</u> ^(b)	<u>Ci/yr</u>
nat_U	3.00E-6	2.55E-1
^{234}Th	1.08E-6	9.17E-2
$^{234\text{m}}\text{Pa}$	1.08E-7	9.17E-2
^{230}Th	1.22E-8	1.03E-3
^{226}Ra	2.12E-7	1.80E-2

(a) This table is based on data from Sears (1977) assuming Case 3 methods for effluent controls, except using the Case 2 method of sodium removal.

(b) The liquid flow is $1.79\text{E}5$ ℓ/d ($4.7\text{E}4$ gal/d)

TABLE 11.B.2. Contents of Airborne Effluents^(a)
from a Dry Conversion Facility

<u>Chemical</u>	<u>kg/d</u>	<u>kg/yr</u>
NH ₃	9.6E1	2.9E4
SO ₂	5.9E2	1.8E5
HF	5.7E-1	1.7E2
		<u>Ci/yr^(b)</u>
nat _U		2.5/E-2
²³⁴ Th		2.57E-2
^{234m} Pa		2.57E-2
²³⁰ Th		1.47E-3
²²⁶ Ra		1.62E-4
²²² Ra		7.18E+1

(a) This table is based on data from Sears (1977) assuming Case 3 methods for effluent controls, except using Case 2 method of sodium removal.

(b) Flow rate is assumed to be 6.6×10^9 l/yr.

drummed for shallow-land burial. Other solid wastes from liquid waste treatment are held in settling basins. Solid still overheads and bottoms are stored onsite at a rate of 40 Mg/yr. Both stored waste streams will require treatment for future disposal. The volume and radionuclide content of the predominantly CaF_2 ash is given in Table 11.B.3.

TABLE 11.B.3. Radionuclides in Leached Fluorinator Ash(a)
from a Dry Conversion Facility(b)

<u>Radionuclide</u>	<u>Ci/Yr</u>
natU	9.47E-2
^{234}Th	9.47E-2
^{23}mPa	9.47E-2
^{230}Th	1.42E+2
^{226}Ra	1.57E+1

(a) Ash is generated at a rate of 1100 Mg/yr.

(b) Table is based on data from Sears (1977) method of sodium removed.

11.B.5.3 Inventory of Major Hazardous Materials Having Safety-Related Importance

Information was unavailable to quantify plant inventories. However, order-of-magnitude estimates can be made from the daily input/output data by assuming a one-week accumulation.

The major radioactive materials are the ammonium diurnate feed material (received in 210-l drums) and the uranium hexafluoride product (stored in product/shipping cylinders on an outside storage pad).

The major nonradioactive hazardous materials are anhydrous hydrogen fluoride and anhydrous ammonia (stored in tanks at the tank farms).

11.B.5.4 Unit Operations Involved

The unit operations are indicated on the process flow diagram, Figure 11.B.2, by the numerals under each box. The decoding of the numbers and the reference set of unit operations used in this study is given in Table 11.B.4.

11.B.5.5 Accident Driving Forces

The conversion of yellowcake to uranium hexafluoride occurs as a result of successive chemical reactions, most of which are exothermic and occur at elevated temperatures with chemically reactive materials as indicated in Table 11.B.5. Information on the pressures within the reaction vessels is not available. However, most pressures are believed to be moderate, sufficient to provide gas flow rates for fluidizing particulates and filtration.

Only natural uranium is processed at the representative plant and nuclear criticality is not a problem.

TABLE 11.B.4. Reference List of Unit Operations in the
Representative Fuel Cycles

Solids

1. Solids materials handling (packaging, conveyance, screening, mixing, pressing)
2. Solids materials cutting (metallic materials)
3. Solids materials size reduction (crushing, grinding)
4. Solids drilling/blasting
5. Solids materials melting (welding, glass making)
6. Solids materials burial

Liquids

7. Liquid materials handling (pumping, mixing)
8. Distillation (concentration, evaporation, fractionization)
9. Natural evaporation
10. Solvent extraction (organic/aqueous)
11. Electrolysis

Gases

12. Physical gaseous separation (diffusion, centrifugation)
13. Gas/vapor compression

Solid-Liquid

14. Solids dissolution (leaching, dissolving)
15. Solid-liquid separation (filtration, settling)
16. Solid-liquid sorption (adsorption, ion exchange)
17. Precipitation
18. Solidification at nonhigh temperatures (cementing, bitumenization)
19. High-temperature processing (drying, roasting, calcining, melting)

Solid-Gas

20. Solids separation (filtration)
21. Sorption

Other Phase Combinations

22. Sorption (scrubbing [l-g])
23. Incineration
24. Vapor/gas cooling (cooling, condensing, sublimation)
25. Chemical reactions (g-g, g-l, g-s, l-l, l-s)
26. Storage (s, l, g)

TABLE 11.B.5. Accident Driving Forces for a Dry Conversion Facility

<u>Process</u>	<u>Temperature</u>	<u>Pressure</u>	<u>Chemical Reactivity</u>
Calcination	480°C	NA	Low
Reduction	620°C	NA	High (H ₂ /N ₂)
Hydrofluorination	590°C	NA	High (HF)
Fluorination	NA	NA	High (F ₂)
Distillation	115°C	95 psi	Low

11.B.5.6 Containment and Shielding Systems

Radiation levels from the natural uranium and its decay products are sufficiently low that shielding is not needed to protect the work force from exposure to direct radiation. However, the work force and the public must be protected from airborne gases and particulates in order to control the uptake of radioactive and toxic materials. The off-gases from building ventilation and process systems are filtered and scrubbed, if necessary, to control the release of particulates and noxious gases (HF and F₂).

11.B.5.7 Degree of Hands-on Operation

The radiation levels in the facility are low and require no shielding or remote operations for normal and maintenance activities. Protective clothing is worn by the work force in the process facility for contamination control.

11.B.6 ALTERNATIVE PROCESS SCHEMES

The representative plant is the only fluorination-fractional distillation uranium conversion plant in commercial operation in the western world. Alternative processes are not presented.

REFERENCES

Sears, M. B., et al. 1977. Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle-Fluorination-Fractionation Process, ORNL/NUREG/TM-7, U.S. Nuclear Regulatory Commission, Washington, D.C.

12.0 ENRICHMENT

Current generation LWRs in the U.S. require fuel having approximately 2.0 to 4.0 weight percent ^{235}U . Since natural uranium has 0.71 weight percent ^{235}U , an enrichment process must be undertaken to increase the ^{235}U concentration to make it suitable for LWR use. A variety of enrichment processes are possible. Gaseous diffusion enrichment has been used by the U.S. for many years and gas centrifuge enrichment capacity is being constructed. Descriptions of each of these enrichment processes follows.

12.A. GASEOUS DIFFUSION ENRICHMENT

A gaseous diffusion uranium enrichment facility representative of current technology for industrial scale plants is defined in this section. This facility is partly conceptual. It is a full-scale, "stand-alone" plant designed to furnish complete uranium enrichment services for commercial LWRs without assistance from any other gaseous diffusion plant. It receives natural enrichment uranium hexafluoride (UF_6), enriches this UF_6 up to any level required for a commercial PWR or BWR, and is based primarily on the Portsmouth gaseous diffusion uranium enrichment plant expansion (ERDA 1976a).

The facility is capable of 8.75 million separative work units (SWU) per year, using 2,700 MW of electrical power (ERDA 1977a). 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	1,820	5.4
FY 1977 Totals	4,954	15.1

These plants were initially built to supply enriched uranium for nuclear weapons and now operate primarily to supply enriched uranium for commercial power reactors, both foreign and domestic (AEC 1974). Programs recently completed have resulted in an updated plant capacity of 27.7 million SWU/yr in 1981 (ERDA 1977b).

Although the plant described here 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 among the present enrichment plants (AEC 1972). The Portsmouth conceptual "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.

12.A.1 SUMMARY

The "stand-alone" gaseous diffusion uranium enrichment facility is assumed to have a nominal plant capacity of 8.75 million kg SWU/yr. It is designed to receive 13,410 Mg of 0.711 percent ^{235}U feed material annually, produce 2,083 Mg of 3.2 percent ^{235}U product with 11,250 Mg of 0.25 percent ^{235}U tails material also withdrawn from the cascades of the plant. In each case, uranium is assumed to be in the form of UF_6 . The facility is assumed to operate 365 days and 24 hr/day for 40 years.

The enriched product is 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 percent ^{235}U tails material is assumed to be stored onsite. As in the case of 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 plant is assumed to receive uranium in the form of UF_6 in transport cylinders ready for direct feed to the diffusion cascade. However, the plant is designed such that it can be modified later to receive U_3O_8 , UNH , or UO_3 , and convert them to UF_6 for feed.

During routine operations nearly all radioactive materials in the effluents result from maintenance of the main process equipment, and from the decontamination solutions 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. Any UF_6 escaping from the process condenses quickly in air as UO_2F_2 which settles out on equipment surfaces and may be transported by the building ventilation systems. The uranium is recovered by several process steps in a decontamination and recovery building.

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 solvent with a hydrocarbon diluent is used (shown later in Figure 12.A.7) for solvent extraction. The uranyl nitrate hexahydrate is calcined to produce U_3O_8 . A flame tower reactor then converts the UO_2 to UF_6 . (Alternatively, the UO_2 may be hydrofluorinated to uranium tetrafluoride (UF_4) and then fluorinated to UF_6). UF_6 is collected in a cold trap, then heated, condensed to a liquid, and drained into cylinders prior to being recycled back into the cascade.

A total of about 28.1 million ℓ /day of aqueous liquid effluents is discharged from the plant to a 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 airborne effluents contain about 3,800 kg/day of chemical contaminants (mostly ammonia, nitrogen oxides, and some fluorides), and $5.5\text{E}-2$ kg uranium/day.

Uranium contaminated waste primarily consists of about 390 ℓ /day of CaF_2 sludge, which is held in lagoons (ERDA 1976b). 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 usually 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 approximately 1.62 km^2 of the 4.7 km^2 site described in Section 8.

Safety related items of interest include: (1) the potential release of large quantities of UF_6 during cylinder handling accidents or as a result of external events, leading to inhalation of UO_2F_2 particulate and exposure to HF vapors by plant staff and possibly the public; (2) the potential exposure of plant staff to ClF_3 and F_2 vapors, (3) the potential for a nuclear excursion and the exposure of plant staff and the public to radiation from such an event; (4) the potential for a large cascade equipment fire; and (5) the routine exposure of the public and plant staff to chemical and radioactive effluents.

12.A.2 MAINLINE PROCESS DESCRIPTION OF GASEOUS DIFFUSION

The gaseous diffusion facility performs a variety of physical and chemical operations in the enrichment of uranium. The facility receives natural uranium as solid UF_6 in cylinders, as shown in the general process flow diagram in Figure 12.A.1. The UF_6 cylinders are weighed, and the contents are sampled and assayed for purity. Following storage of the cylinders, the UF_6 is heated, vaporized, and fed to the diffusion cascade. Following the enrichment of UF_6 in the diffusion cascade, the enriched UF_6 is condensed to a liquid and withdrawn from the cascade into cylinders. The UF_6 subsequently cools to a solid. The solidified enriched UF_6 is shipped in cylinders to fuel fabrication facilities. Uranium is recovered from miscellaneous wastes and effluents by chemical processing for recycle. The uranium tails are condensed to a liquid and withdrawn into cylinders. Again, the UF_6 subsequently cools to a solid. Tails cylinders are assumed to be stored onsite.

12.A.2.1 Description of Process Steps

Figure 12.A.2 gives a more detailed process flow diagram. The following sections discuss the major process steps.

UF_6 Cylinder Receiving, Storage, and UF_6 Evaporation. The cylinders of UF_6 are weighed and samples of UF_6 are taken from the cylinders to be assayed for purity. After the UF_6 cylinders have been sampled and assayed, they are stored in a cylinder yard until the diffusion plant is ready to feed them.

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. Gaseous UF_6 is then fed into the diffusion cascade.

FIGURE 12.A.1. Overall Representative Mainline Process for Gaseous Diffusion Enrichment

FIGURE 12.A.2. Mainline Process Flow Diagram for the Gaseous Diffusion Plant

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 12.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 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 12.A.4. The UF_6 feed material is pumped by an electric motor-driven axial flow compressor through a large cylindrical vessel, the converter, which contains both a gas cooler and the diffusion barrier. Refer to Figure 12.A.5 for a process diagram of the gaseous diffusion stage heat transfer system and to Figure 12.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 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 depleted 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. The isotopic separation achievable in a single stage is very small. Producing 3.2 weight percent ^{235}U enriched uranium for commercial LWRs from natural uranium feed material with 0.25 percent tails requires approximately 1,350 diffusion stages in series.

Light gas 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 gas contaminants in the process gas.

Product Withdrawal. The product UF_6 is condensed to a liquid and withdrawn from the diffusion cascade into cylinders. Upon cooling, the UF_6 becomes a solid. 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 condensed to a liquid and withdrawn from the bottom stages of the production cascade into cylinders. Upon cooling, the UF_6 becomes a solid. The cylinders are then taken to storage.

FIGURE 12.A.3. Schematic of Converter for Gaseous Diffusion Stage

FIGURE 12.A.4. Stage Arrangement--Gaseous Diffusion Facility

FIGURE 12.A.5. Gaseous Diffusion Stage Heat Transfer System

[illegible]

12.A.2.2 Uranium Recovery

The uranium recovery system reclaims uranium from decontamination operations, laboratory wastes, alumina traps, and other process operations for recycle. Figure 12.A.7 shows the sources and their flow paths through the uranium recovery system. This flow diagram shows that 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 percent tributyl phosphate and about 80 percent 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 adsorb volatile impurities, and then cold-trapped. Heat is applied to the cold trap and the resultant liquid UF_6 drained into product cylinders. Cylinders are then taken to the cylinder storage yard for storage and eventual transfer to the feed station.

12.A.3 DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT SYSTEMS

Some materials, called effluents, are deliberately discharged to the environment from the facility. Other materials, or wastes, are controlled or disposed of with the intent of isolating them from man's environment. This section discusses those systems.

12.A.3.1 Effluent Processing

Effluent treatment systems are included in the 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 (ERDA, 1976a) 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 (Schneider and Kabele, 1979).

Liquid Effluents. About 28 million L/day of liquid effluents are discharged from the plant. These effluents contain about 120 kg/day of chemical contaminants (mostly salts of calcium, ammonia, and fluoride ions) and about 0.37 kg/day of uranium (about 0.0074 percent of plant product output). Figure 12.A.8 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

FIGURE 12.A.7. Uranium Recovery Flow Diagram

FIGURE 12.A.8 Process Flow Diagram--Liquid Effluent Treatment System for Gaseous Diffusion Facility

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.

Laundry effluents with extremely low contamination levels 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 steam plant fly ash are discharged to the steam plant 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.

Airborne Effluents. The airborne effluents contain about 3,800 kg/day of chemical contaminants (mostly ammonia, nitrogen oxides, and some fluorides), and $5.5\text{E-}2$ kg U/day. Figure 12.A.9 summarizes the treatment of airborne effluents from the 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 exhauster. The trap materials are periodically replaced with fresh filter materials. The exhausted trap materials are rinsed with appropriate inorganic 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 shipment to an offsite low-level waste 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.

FIGURE 12.A.9. Process Flow Diagram--Airborne Effluent Treatment System for Gaseous Diffusion Facility

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 UF₆ 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 percent 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.

Effluent Control Performance. Overall radioactive materials input and output from the reference facility are given in Table 12.A.1. The only radioactive material routinely available for effluent release is uranium. However, if recycle uranium is fed to the plant, trace quantities of fission products such as ⁹⁹Tc will tend to accumulate in cascade equipment and eventually contribute to radioactive effluents. (Generally an insignificant amount of radioactive decay products of uranium are present.) About 0.00018 percent of the uranium fed to the plant is present in the airborne effluents, and about 0.0013 percent of the uranium is in the liquid effluents.

Overall input of nonradioactive materials is given in Table 12.A.2, while the nonradioactive materials in the airborne effluents and the liquid effluents are shown in Tables 12.A.3 and 12.A.4, respectively.

TABLE 12.A.1. Overall Radioactive Materials Input/Output for Diffusion Facility

Material	Total Material ^(a)		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 12.A.2. Overall Nonradioactive Materials Input for Gaseous Diffusion Uranium Enrichment Plant (GAT, 1973)

Material	Total Material		Chemical	Form		kg/day as 100%
	kg/day	l/day		Phase	Other	
Sodium Fluoride	NA	NA	NaF	S	NA	NA
Alumina	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

TABLE 12.A.3. Overall Nonradioactive Airborne Effluents from Gaseous Diffusion Uranium Enrichment Plant (ERDA, 1976a)

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 12.A.4. Overall Nonradioactive Liquid Effluents from Gaseous Diffusion Uranium Enrichment Plant (ERDA, 1976a)

Materials	Form		Output ^(a)		Fraction of Plant Input
	Chemical	Phase	kg/day	ℓ/day	
Water	H ₂ O	L	2.8E7	2.8E7	~0.3
Aluminum ^(b)	Al ⁺³		0.68	NA	NA
Calcium ^(b)	Ca ⁺²	L,S	5.1E2	NA	NA
Sodium ^(b)	Na ⁺	L	7.7E2	NA	NA
Ammonium ^(b)	NH ₄ ⁺	L	17	NA	NA
Fluoride	F ⁻	L	1.2	NA	NA
Sulfate ^(b)	SO ₄ ⁻²	L,S	5.1E2	NA	NA
Sulfite ^(b)	SO ₃ ⁻²	L,S	0.86	NA	NA
Nitrate ^(b)	NO ₃ ⁻	L	91	NA	NA
Chloride ^(b)	Cl ⁻	L	7.7E2	NA	NA
Residual Chlorine	Cl ₂	G	4.9	NA	NA
Phosphate ^(b)	PO ₄ ⁻³	L	12.0	NA	NA
Chromium ^(b)	Cr ⁺³	L,S	0.80		
Iron ^(b)	Fe ⁺³	L,S	34	NA	NA
Boron ^(b)	BO ₃ ⁻³	L	0.86	NA	NA
Nickel ^(b)	Ni ⁺²	L,S	3.4	NA	NA
Magnesium ^(b)	Mg ⁺²	L,S	0.86	NA	NA
Molybdenum ^(b)	Mo ⁺⁶	L,S	0.86	NA	NA
Silver ^(b)	Ag ⁺	L,S	0.86	NA	NA
Varzol	NA	L	0.51	NA	NA
Manganese ^(b)	Mn ⁺²	L,S	0.86	NA	NA
Tributyl Phosphate	PU(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 ^(c) Mostly	H ₂ O	L,S	3.0E6	3.0E6	~0.32
Zinc ^(b)	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) Value based upon one day operating at 100% capacity.

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

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

12.A.3.2 Waste Management

Gaseous diffusion enrichment facilities generate radioactive and nonradioactive solid wastes. 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 12.A.10 summarizes waste management activities at the plant.

If recycled UF_6 is used as feed, trace quantities of fission products and transuranics will be incorporated with waste streams and effluents. Additionally, fission products, such as ^{99}Tc will tend to accumulate in cascade equipment. The gradual buildup of such fission products will make cascade equipment removal and subsequent recovery operations more hazardous than these same operations when using virgin uranium feed.

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, and segments of process piping. 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. Sludge is periodically removed, sampled, and sent to a conventional landfill or an authorized contaminated burial site, as necessary. Overall output of solid wastes is shown in Table 12.A.5.

12.A.4 PLANT LAYOUT

This section contains descriptions of the gaseous diffusion facility and its site.

FIGURE 12.A.10. Overall Waste Management Processes for the Gaseous Diffusion Facility

TABLE 12.A.5. Overall Solid Wastes from the 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

12.A.4.1 Site Description

The gaseous diffusion enrichment facility is assumed to lie on the generic 4.7 km² (1160 acres) site described in Section 8. The plant itself requires a fenced area of 1.82 km² (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 larger 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 a river flowing near 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.

12.A.4.2 Facility Description

The facility is largely based on a conceptual design of a 8.75 million SWU/yr stand-alone gaseous diffusion plant (ERDA, 1977a). Figure 12.A.11 shows the overall layout of the gaseous diffusion plant within the 1.8 km² area of the immediate plant.

The major facilities of the gaseous diffusion plant are:

- UF₆ 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
- 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).

FIGURE 12.A.11. Layout of 8.75 Million SWU/Yr Gaseous Diffusion Facility

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.

The UF₆ receiving building is designed to minimize accidental releases of UF₆ 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 (compression, liquefaction, etc.).

The purge and product withdrawal building contains the purge equipment and the five stations for product withdrawal.

The process buildings are two-level structures, the upper level of which contains 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 converter, one cooler, one compressor, and a motor that drives the compressor.) Coolant drain tanks and related equipment are placed outside the process building.

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

The air plant can produce 142 scm/min of compressed air that is filtered and dried in alumina driers.

The nitrogen plant can supply a normal flow of 1.0 scm/min. 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 facility is expected to operate for 40 years. Table 12.A.6 summarizes the various process area descriptions and Table 12.A.7 summarizes the major process equipment descriptions.

Many of the plant facilities and operations, such as those listed below, cannot be described in detail at this time due to lack of information:

- furnace to melt scrap aluminum
- fluorine manufacturing plant
- radio and telephone communications
- hospital and first aid stations.

Of these operations, the fluorine plant is a potential contributor to plant risk.

TABLE 12.A.6. Major Process and Auxiliaries Areas Description--
Gaseous Diffusion Facility

Process Area	Overall Dimensions 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

NA = Not available

TABLE 12.A.7. Major Process Equipment Descriptions--Gaseous Diffusion Facility

Equipment	Location	No.	Other Features
Steam Autoclave	URB	3	Pressure and electrical conductivity controls
Steam Autoclave	FTWB	8	Pressure and electrical conductivity controls
Diffusion Stages	One of the four PB	~1350	Stage made up of one cooler, one convertor, one compressor, and one motor
Liquid Withdrawal Station	PPWB	5	
Liquid Withdrawal Station	FTWB	NA	NA
Incinerator	DURB	1	NA
Continuous Dissolver Calciner	DURB	NA	NA
Flocculating Columns	DURB	NA	NA
Storage Columns	DURB	NA	NA
Measuring Columns	DLRD	NA	NA
Extraction Loops	DLRD	NA	NA
Calciners	DLRD	NA	NA
Flame Tower	DURB	1	NA
Cold Traps	DURB	NA	NA
Steam Boilers	SPB	4	Coal-fired
Air Compressors	AP	NA	NA
Liquid Nitrogen Tank	NP	1	NA

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

12.A.5 SAFETY-RELATED INFORMATION

This section contains a description of safety-related systems and information relevant to gaseous diffusion plant operation.

12.A.5.1 Operating and Maintenance Requirements

The plant is assumed to operate 24 hr/day, 7 days/wk, including holidays. The plant is estimated to employ 1,400 people at the steady-state level (ERDA, 1976a).

A complex of three buildings covering approximately 0.03 km² (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 converters, 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 converters present a special requirement, as they are assembled and maintained in the converter assembly and maintenance buildings. Approximately 15 to 25 converters need overhauling each year due to plugged barriers, leaking heat exchanger tubes, or a combination of both. About 10 to 20 axial-flow compressors also need to be overhauled each year to maintain compressor efficiency.

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

12.A.5.2 Input/Output of Major Materials

At design level of operations 13,410 Mg/year of uranium containing 0.711 percent ²³⁵U in feed is needed for a total weight of 19,800 Mg of UF₆ feed material. This is usually received in about 1,600 feed cylinders, each containing up to 12,500 kg (either 10 or 14 Mg each) of UF₆. Occasionally some feed is received in smaller cylinders. Typical operation produces 2096 Mg of 3.2 percent ²³⁵U product (3100 Mg UF₆) and 11,314 Mg of 0.25 percent ²³⁵U tails (16,733 Mg UF₆) per year.

Peak steam load is estimated at 136,000 kg/hr (ERDA, 1976a). Forty-one thousand Mg 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 UF₆ vaporization, steam traces where needed to maintain process UF₆ as a gas, and general space heating for the facility buildings.

The routine material input requirements are those identified previously in Table 12.A.2. Packaging materials for disposal of solid wastes (listed in Table 12.A.5) and small amounts of miscellaneous materials such as office materials are also required.

Major liquid and airborne effluents and plant wastes have been previously described in Section 12.A.3.

12.A.5.3 Inventory of Major Hazardous Materials at Plant Locations Having Safety-Related Importance

Although the exact inventory of a variety of materials associated with gaseous diffusion plant operation is either classified or not generally available, order of magnitude estimates are provided. The estimated inventories are given in Table 12.A.8 and are discussed below.

UF₆. Uranium hexafluoride is obviously present in large quantities during the operation of a gaseous diffusion plant. This material is very corrosive and forms $\text{UO}_2\text{F}_2 + \text{HF}$ upon release to moist air. It is assumed that a three month supply (400 cylinders each containing 12,500 kg UF_6) of UF_6 feed is maintained at all times. Furthermore, it is assumed that approximately 1340 tails cylinders, each containing 12,500 kg of depleted UF_6 , accumulate during each year of plant operation. Therefore, 40 years of operation will result in 53,600 tails cylinders.

A smaller, but still significant, inventory of UF_6 exists in the diffusion cascade itself. A rough estimate of the diffusion cascade volume is about 30,000 m^3 . Assuming a UF_6 density of ~10 g/l, approximately 300,000 kg of UF_6 inventory is always present in the total cascade, or about 220 kg UF_6 /enrichment stage. The interstage piping is arranged such that groups of typically eight stages are arranged in an insulating enclosure called a cell housing. Each cell may be quickly isolated from any other cell. Therefore, damage to one cell, which may potentially result in a UF_6 release, can be effectively isolated and any UF_6 release limited. A series of surge drums also exist which may be used for temporary storage of UF_6 -freon or UF_6 -light gas mixtures which result from a cooler leak or wet air leak. Surge drum contents are subsequently passed through a cold trap to recover UF_6 .

Conditions which may result in a UF_6 release include: feed, product, and tails cylinder handling; explosion or fire in cascade; rupture of feed cylinder in autoclave; or compressor seal failure.

ClF_3 . ClF_3 is present in surge drum operations. It is used as a drying agent (mixed with fluorine) in the cascade after a cell has been offstream. This material is highly irritating if inhaled. It also reacts violently with organic materials. Inventory typically consists of a few pressurized gas cylinders. Conditions leading to ClF_3 release may involve improper cylinder handling. Explosion may result from improper surge drum operation.

HF. HF is used to generate fluorine in an enrichment plant. A typical inventory of HF consists of the contents of one railroad tank car. A release

TABLE 12.A.8. Inventory of Hazardous Materials--Gaseous Diffusion Plant

<u>Material</u>	<u>Quantity</u>	<u>Location</u>
UF ₆ (feed)	5,000 MT	Outdoor Concrete Pads
(cascade gas in process)	300 MT	Process Equipment
(tails)	16,733 Mg (1 year accumulation)	Outdoor Concrete Pads
	669,320 Mg (40 year accumulation)	
ClF ₃	< 10 Compressed Gas Cylinders	Process Building
F ₂	< 300 m ³ (gas)	F ₂ cells & Associated Piping
HF	1 Railroad Tank Car	Railroad Spur at F ₂ Cell

of HF may be caused by improper transfer of HF from tank to storage tank or from storage tank to fluorine generation cells. HF is a fuming corrosive liquid or gas, dangerous to humans via skin contact or inhalation.

F₂. Fluorine is used to condition cascade equipment before installation in the cascade. This treatment essentially passivates cascade equipment interior surfaces to the corrosive effects of UF₆. Fluorine is also mixed with ClF₃ for use as a drying agent in the cascade after a cell has been offstream. It is highly irritating to skin and dangerous to mucous membranes and the respiratory tract. Fluorine is also highly reactive with many materials. Fluorine present in the fluorine generation cells, plant fluorine lines, etc. may amount to a few hundred m³.

Others. As with many other industrial plants, many other hazardous materials are available in small quantities. These materials include: acids, bases, TBP, kerosene, and miscellaneous lab chemicals.

12.A.5.4 Unit Operations Involved

A variety of unit operations occur in a gaseous diffusion plant. Each major process step and its corresponding unit operation is presented in Table 12.A.9. Unit operations are also designated as "batch" or "continuous".

TABLE 12.A.9. Unit Operations in Gaseous Diffusion Plants

<u>Process Step</u>	<u>Unit Operation</u>
Receiving, Weighing, Sampling and Storage of UF ₆ Feed	Solids Materials Handling--Batch
Vaporization of UF ₆ in Autoclaves	Solid-Gas Conversion (Sublimation)--Batch
Uranium Enrichment	Physical Gaseous Separation (Diffusion)--Continuous
Product Withdrawal/Tails Withdrawal	Gas-Liquid Conversion (Compression/Condensation) --Condensation (Continuous) --Withdrawal (Batch)
UF ₆ Sampling/Storage	Solids Materials Handling--Batch
Uranium Recovery	Solvent Extraction--Batch
Conversion of UNH → UF ₆	Chemical Reactors--Batch
UF ₆ Cold Trap	Vapor-Gas Cooling, or Conversion (Desublimation)--Batch
Uranium Recovery Liquid Withdrawal	Liquid Material Handling--Batch

12.A.5.5 Accident Driving Forces

Table 12.A.10 presents the potential accident driving forces associated with diffusion plant operation.

TABLE 12.A.10. Accident Driving Forces

<u>Cascade</u>	<u>Accident Driving Forces</u>
Electrical Energy	2700 MW (large electrical switchgear, high voltage power lines, etc.)
Cascade Pressure	Top and bottom of cascade < 1 atm; middle of cascade > 1 atm
Cascade Temperature	65°-82°C
Mechanical Energy	Rotating apparatus such as large (several thousand horsepower) motor, and large axial compressors
Nuclear Reactivity	Enrichments to ~4.0% ^{235}U in large quantities
Chemical Reactivity	HF, UF_6 , ClF_3 --high reactivity

12.A.5.6 Containment Systems

Containment of UF_6 is provided in several ways in the cascade. The entire cascade (i.e., compressors, coolers, piping, converters) is a welded enclosed system. In addition, the top and bottom of the cascade are below atmospheric pressure. At high operating power levels the middle portion of the cascade may be slightly above atmospheric, however, and a leak would emit UF_6 to the cascade building. The cascade buildings are quite large and act to prevent dispersion of UF_6 to the environs. UF_6 reacts quickly in moist air to form $\text{UO}_2\text{F}_2 + \text{HF}$. Therefore, even though the ventilation system moves air through the cascade buildings, UO_2F_2 will tend to settle out. Only small quantities will escape the process buildings.

Containment in recovery operations is generally provided by filtration and adsorption. See Sections 12.A.2 and 12.A.3.

12.A.5.7 Degree of Hands-On Operation

A gaseous diffusion plant, when functioning properly, requires little hands-on operation. As long as motors, compressors, coolers, and converters run properly, the cascade operating personnel essentially monitor operation. Of course, feed and withdrawal operation require hands-on contact.

Several factors may occur which bring operating personnel into direct contact with the cascade. These include: changes in required operating conditions--primarily operating pressures; valving orders to bypass or isolate a cell, split the flows in a cascade, route cell contents to a surge drum, etc.; maintenance activities on cascade equipment or interstage piping; maintenance activities on support systems such as lubricating oil, freon, recirculating water, or electrical systems. The vast number of valves associated with the cascade require care and experience to avoid misvalving. Surge drum operations also require a great deal of hands-on operation.

Uranium recovery is also reliant to a large extent on the knowledge of operating personnel and involves direct, hands-on operation. Operators control equipment disassembly, cylinder cleaning, solution makeup, solution transfer, oxide conversion, and cold trap operations.

12.A.5.8 Systems Interactions

The major systems associated with the operation of the gaseous diffusion cascade include: freon coolant system, recirculating water system, electrical system, lubricating oil system, fire protection system, and building ventilation system. Failures in one system may potentially effect the cascade or other auxiliary systems.

A freon leak into the cascade introduces light gases to the cascade. Depending on the magnitude of the leak, the stage motors will experience surging and compressor deblading.

A loss of recirculating water will cause the cascade to overheat causing the cessation of operations. Typically, a 24-hour water supply is maintained. A leak of water to the freon system is unlikely because freon is at a higher pressure than the water.

Loss of electric power will cause the cessation of cascade operations. UF₆ inventory in the cascade will deposit throughout the equipment but should not lead to a criticality. However, equipment startup may be complicated by these deposits. Depending on the exact piece of electrical equipment which fails, a variety of cascade disturbances may ensue.

Lubricating oil is supplied to the stage motors. This oil is flammable. As a result of a motor-compressor failure at the Paducah plant over 20 years ago, a large fire occurred.

The cascade buildings are assumed to be equipped with automatic sprinklers and operated as "improved risk" facilities. Care must be exercised, therefore, in preventing water from entering the cascade and leading to a nuclear criticality. Generally, this is not a problem.

Ambient air is supplied to the cascade cell floor to maintain a suitable environment for operation and maintenance activities. Loss of a supply fan motor would have minor consequences.

12.A.5.9 Criticality Safety

Because uranium will be enriched to power reactor-grade enrichments (2 to 4 percent ^{235}U), criticality safety is important. In general, moderating materials are not present in the cascade. As a result of air inleakage to the cascade, however, deposits of UO_2F_2 of 100 kilograms, or more, may occur in cascade equipment. Since moderating materials are not generally available, criticality incidents are not likely and have never occurred in existing facilities due to such deposits.

Uranium recovery operations deal with uranium solutions. These recovery operations are assumed to take place in geometrically safe equipment wherever possible. For example, solvent extraction and flame tower operations take place in geometrically safe equipment.

Nuclear criticality safety must also be considered for: cylinder storage, incinerator operation and ash handling, cylinder cleaning, equipment decontamination, UF_6 or uranium solution releases, and laboratory operations.

12.B GAS CENTRIFUGE ENRICHMENT

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

The 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 levels required for commercial PWRs or BWRs and is based primarily on the proposed Portsmouth gas centrifuge uranium enrichment plant expansion (ERDA, 1977a). A facility capable of 8.8 million kg SWU/yr is contemplated.

12.B.1 SUMMARY

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

Uranium hexafluoride (UF_6) containing natural uranium (0.711 percent of the U is ^{235}U) is received as feed material at the rate of 13,410 Mg per year. Tails, containing 0.25 percent ^{235}U , are either stored onsite or shipped offsite, and are withdrawn at the rate of 11,314 Mg per year. All the foregoing figures are for uranium in the form of uranium hexafluoride (UF_6).

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 MW 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. It should be noted that the power requirement for this centrifuge plant is approximately one-twentieth of the power required for a similar capacity diffusion plant.

Since commercial facilities have been used in the past to convert U_3O_8 , UO_3 , and UNH to UF_6 , we assume the centrifuge plant will receive its uranium in the form of UF_6 in transport cylinders ready for direct feed to the cascade. 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 12.B.3.1, so that very little radioactivity intrudes into the environment from this plant.

A centrifuge plant requires more personnel but less power than a gaseous diffusion plant of equal capacity. The plant employs 2450 persons and plant facilities occupy about 1.5 km² of the generic site (4.7 km²). The

expected operating life of the gas centrifuge plant is 40 years, and the plant is assumed to operate 24 hr/day, 365 days/yr.

As in the case of the gaseous diffusion plant, safety-related concerns for a gas centrifuge plant include: (1) potential releases of large quantities of UF_6 ; (2) potential release of ClF_3 or F_2 vapors; (3) potential for a nuclear excursion; and (4) routine emissions of chemical and radioactive effluents.

12.B.2 MAINLINE PROCESS DESCRIPTION OF GAS CENTRIFUGE ENRICHMENT

A volatile compound of uranium must be used in either the gaseous diffusion process or the gas centrifuge process; the hexafluoride (UF_6) is the only known suitable compound. Since UF_6 is solid at room temperature, the process must be operated at temperatures and pressures necessary to maintain the UF_6 in gaseous form. Although it is a stable compound, UF_6 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 selection of process materials that come into contact with UF_6 , such as nickel and aluminum, which resist the corrosiveness of UF_6 . 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 $^{235}\text{UF}_6$ molecules from the $^{238}\text{UF}_6$ molecules by their difference in weight. Descriptions of process steps appear in the following sections.

A gas centrifuge plant is made up of a large number of centrifuges rotating at a high rate of speed. The UF_6 molecules containing ^{238}U tend to migrate to the outside wall of the centrifuge, whereas the molecules containing ^{235}U tend to migrate toward the center axis because they are slightly lighter. The feed UF_6 steadily enters the rotor near its middle, 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 12.B-1).

This separative effect is small, although greater than for gaseous diffusion, and must be repeated in hundreds of centrifuges in series. To achieve the desired quantity, hundreds of centrifuges must also be operated in parallel.

The dotted lines in the upper diagram of Figure 12.B.2 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.

FIGURE 12.B.1. Schematic of Gas Centrifuge

FIGURE 12.B.2. Gas Centrifuge Cascade Configuration

The concept of "Centrifuge Building Blocks" is shown in Figure 12.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 12.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.

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. Rotor failure may possibly lead to a UF_6 release of small magnitude.

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 flow overview of a gas centrifuge plant is shown in Figure 12.B.4.

Facilities for receiving and handling UF_6 , the vaporization of UF_6 at the feed stations, and the withdrawal equipment are described in Section 12.B.4.2.

12.B.3 DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT SYSTEMS

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 airborne effluents.

12.B.3.1 Liquid Effluent Processing

At a gas centrifuge plant using only virgin natural uranium feed, the radioactive liquid effluents contain only uranium, its daughters, and its compounds. In general, liquid effluents are similar in nature to those from the gaseous diffusion plant. 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 a building having the same functions. Low-level radioactive liquid effluents are released from the uranium recovery systems and from a number of other systems.

The eight process buildings are designed so that most of the contamination is contained in the service modules for most types of centrifuge failures.

FIGURE 12.B.3. Concept of Centrifuge Building Blocks

FIGURE 12.B.4. Process Overview of a Gas Centrifuge Plant

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 Section 12.8.5.1. Leachates from crushed rotors and other heavily contaminated parts contain 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) (ERDA, 1977a) of decontamination water is pumped from the recycle and assembly building activities to the uranium recovery facility.

The uranium recovery facility is contained within the recycle and assembly building. 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. Remaining recovery activities are essentially the same as for the gaseous diffusion plant.

Spills from drinking fountains, water from shift change showers, flushing of toilets and water from the plant laundry are all routed to a 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. The effluent from the laundry equipment passes through a filter trap for removal of solids before being discharged to the plant's sanitary sewage treatment facility.

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 discharged to the primary holding pond. The portion of water run through each unit depends on the alkalinity of the feed water, the alkalinity of the mixed effluent, and the free mineral acidity of the hydrogen zeolite effluent. After softening, a degasifier removes CO_2 and the water is treated for corrosion control. This reduces the quantity of boiler blowdown needed.

The steam plant for an isolated "stand-alone" plant would have to provide 9,070 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 (ERDA, 1976a). Year-round operations result in the burning of 52,000 Mg/yr of coal.

There are two holding ponds (also referred to as "lagoons"), each 40,000 m² in area. They are provided to: (1) prevent accidental discharge of harmful chemicals to the environment, and (2) 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 liquid is possible, but treatment of the individual source streams is done and generally minimizes or obviates 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 be discharged to the environment, but have been in the process area and could possibly be contaminated with uranium. 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 is 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. About 141 m³ (5,000 ft³) of radioactive wet sludge settle out in the holding ponds each year (ERDA 1977a). Periodically, this is removed and dried out.

As a result of the effluent control processes, less than two (2) curies/yr of radioactive substances are carried by liquids to the environment.

12.B.3.2 Airborne Effluents

Airborne radioactive effluents in a gas centrifuge plant originate from the following sources:

- purge cascade
- equipment breakdown within the process cells
- feed receiving and assaying
- feed gasification

- product withdrawal and solidification
- tails withdrawal and solidification
- recycle and assembly building (service module and centrifuge repair or replacement)
- uranium recovery facility
- laboratory
- incineration of burnable contaminated solid wastes
- burning of coal at steam plant.

Locations indicated above have water scrubbers and/or HEPA (high efficiency particulate air) filtration of the off-gas streams which are highly effective (ERDA, 1976a). 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.

Some airborne effluents are the result of maintenance operations using liquids which eventually become a gas. Converters, compressors, and other equipment exposed to the UF₆ 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 that 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 uranium recovery from most of the alumina is accomplished by leaching of the alumina with nitric acid in the decontamination and recovery facility.

The radioactive gas releases from locations listed above are included in Table 12.B.1.

TABLE 12.B-1. Maximum Radioactive Gaseous Releases for 8.8 Million SWU Gas Centrifuge Plant (ERDA, 1977a)

<u>Radionuclide</u>	<u>Grams/Year</u>	<u>Ci/Year</u>
234U	5.02	3.6E-2
235U	654	1.4E-3
238U	19,000	6.4E-3
U-Total	19,700	4.38E-2

The burning of coal to provide steam for process and space heating also results in the release of small quantities of radioactive gaseous effluents.

The coal-fired steam plant, which provides process steam and space heat, is a major contributor to the airborne nonradioactive effluents. The primary airborne emissions from 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 percent of the particulates from the stack effluents; the fly ash and bottom ash are collected and routed to the steam ash pond.

The principal nonradioactive gaseous effluents are listed in Table 12.B.2.

TABLE 12.B.2. Nonradioactive Gaseous Effluents for the 8.8 Million SWU/Yr Gas Centrifuge Plant (ERDA, 1977a)

Constituent	Process and Support Facilities (10 ⁵ g/year)	Steam Plant Share (10 ⁵ g/year)	Total for Plant (10 ⁵ g/year)	Source
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

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.

12.B.3.3 Waste Management

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, and segments of process piping. Centrifuge repair activity is shown in Figure 12.B-5. 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 low-level waste site. Combustible items such as the paper, cloth, and plastic articles used in equipment decontamination are reduced to ash in a specially designed 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 a low-level waste disposal site.

FIGURE 12.B.5. Repair Activity at a Gas Centrifuge Plant

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. About 141 m^3 ($5,000 \text{ ft}^3$) of mildly radioactive wet sludge is dried out and removed each year. Contaminated waste is sent to a low-level waste disposal facility offsite.

12.B.4 PLANT LAYOUT

This section summarizes the description of the site, the facility and its hardware. Operating life of the plant is planned to be 40 years.

12.B.4.1 Site Description

The gas centrifuge enrichment facility is assumed to be located on the representative site described in Section 8.0 of this report. The plant itself requires a fenced area of 1.5 km^2 (450 acres) within the larger plant site. The layout of the plant, shown in Figure 12.B.6, is such that maximum practicable distance is provided from airborne effluents sources to the four sides of the 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 a river.

A nearby river is amply capable of providing the year-round requirement for about $12 \times 10^6 \text{ l/day}$ of make-up water for the plant. 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.

12.B.4.2 Facility Description

The general layout of the gas centrifuge facility is shown in Figure 12.B.6. 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
- nitrogen and air plant

FIGURE 12.B.6. Site Layout for Reference 8.8 Million SWU/yr Stand-Alone Gas Centrifuge 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")
- garage, motor pool, vehicle, and mobile equipment maintenance and warehouse building.

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 UF_6 to 3.2 percent ^{235}U assay. The feed for the process buildings is 0.711 percent ^{235}U assay, and the tails are assumed to be 0.25 percent ^{235}U assay.

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 centrifuge 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.

The central control building is centrally located with regard to the eight process buildings. 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 UF₆ 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 vaporizing the UF₆ and to permit vaporizing the UF₆ and assaying incoming and outgoing shipping cylinders, and a crane system designed to handle 12.7 Mg (14 ton) shipping cylinders for incoming "natural" UF₆. 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 m² 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 UF₆ feed; a tails withdrawal compression-liquefaction system consisting of two compressor trains of four compressors in series; and similar product withdrawal station. Each feed and product and tails withdrawal building contains approximately 2280 m² (24,700 ft²) of floor space, of which about 1,970 m² (21,200 ft²) are process area and 325 m² (3,500 ft²) 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 m² (340,000 ft²) of enclosed floor area, plus about 10,200 m² (110,000 ft²) of open area for receiving and storage.

The uranium recovery facility shares a common wall with the 210 m x 150 m, 31,500 m² recycle assembly building. The uranium recovery facility provides an additional 15,000 m² of area 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 x 30 m wide.

The nitrogen and air plant is about 40 m x 30 m x 8 m high, of noncombustible construction. About 600 m² of floor area 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 UF₆. Large quantities of nitrogen are used for purging of the cascades. About 600 m² of floor area is used to prepare dry air which is also used in the cascades.

Excess heat from the cascade 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. The cooling tower consists of eight cells, with a total installed capacity of 303,000 l/min (80,000 gal/min) or 436E6 l/day (115E6 gal/day). This provides a spare cell, so that seven cells can normally be available while one cell is out of service for maintenance. The cooling tower is 46 m x 7 m x 10 m high. The adjacent RCW water treatment and pump house is 8 m x 5 m x 5 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 UF₆ pipes, valves and fittings at a temperature that will maintain the UF₆ in its gaseous state. This would require three coal-fired boilers each producing 50,000 kg of steam per hour and another 50,000 kg/hr boiler as a spare. Steam is furnished at 7 kg/cm² (7.8 atm). The steam plant building is noncombustible, steel frame, transite siding, built-up roof, 50 m x 40 m x 12 m high.

The incinerator plant is located adjacent to the steam plant and designed to produce steam at 7 kg/cm² (7.8 atm) 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. Its exhaust is treated by a scrubber system to remove most of the radioactive particulates from the gaseous effluents. 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 the 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 2,450 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 UF₆ 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 kw diesel-electric generators are provided. These are housed in separate concrete cubicles so that a fire on one diesel would 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 2,450 plant workers must pass through change houses to remove their street clothes and to 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 constructed of materials that are noncombustible and are 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 liters 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 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 dirty 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 in 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 removes surface oil and floating materials. The effluent is visually monitored for oil, silt, etc., and automatically monitored for conductivity, pH, dissolved oxygen, fluorides, and chromates.

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.

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.

12.B.5 SAFETY-RELATED INFORMATION

This section contains a brief description of safety-related systems relevant to gas centrifuge operation.

12.B.5.1 Operating and Maintenance Requirements

The plant is assumed to operate 24 hr/day, 7 days/wk, including holidays. The plant is estimated to employ 2450 persons, of which about 250 are expected to be supervisory or professional staff. The expected high rate of gas centrifuge machine failures makes 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. A flowchart of the assembly process is presented in Figure 12.B.7.

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 UF₆ inventory in the centrifuges is removed in the cascade before their disconnection, except for those machines having a complete rotor failure.

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

FIGURE 12.B.7. Flowchart for Gas Centrifuge Assembly and Repair Process in Recycle and Assembly Building

centrifuge parts are buried at approved low-level waste burial sites after recovery of as much uranium as practicable.

The wash water (sanitary water) used during decontamination of the sub-assemblies and component parts is collected in tanks that are critically safe by geometry. From there the water is pumped to the uranium recovery section of the recycle and 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 and also serves as a repair station for centrifuges and other process equipment which can be repaired.

12.B.5.2 Input/Output of Major Materials

These are essentially the same as for the gaseous diffusion plant (see Section 12.A.5.2).

12.B.5.3 Inventories of Major Hazardous Materials at Plant Locations Having Safety-Related Importance

In general, the types and quantities of hazardous materials associated with the gas centrifuge facility are similar to those associated with the gaseous diffusion facility described earlier in this section. See Section 12.A.5.3 and Table 12.A.8.

12.B.5.4 Unit Operations Involved

Unit operations for the centrifuge facility, with the exception of the withdrawal method (gas-solid, desublime), are basically the same as in the gaseous diffusion plant. See Section 12.A.5.4.

12.B.5.5 Accident Driving Forces

Accident driving forces for a centrifuge plant are similar to those in a diffusion plant except that the total electrical energy is less by a factor of approximately 20 and mechanical energy is stored in centrifuges rather than motor-compressors (see Section 12.A.5.5).

12.B.5.6 Containment Systems

Containment systems are similar to those for gaseous diffusion (see Section 12.A.5.6).

12.B.5.7 Relative Degree of Hands-On Operation

Relatively little hands-on operation is required for gas centrifuge plant operation. The majority of hands-on operation is related to maintenance activities.

12.C ALTERNATIVE ENRICHMENT PROCESSES

Numerous uranium enrichment processes are possible. However, none of these alternatives will contribute to the U.S. enrichment capacity for some time. Therefore, the three front running enrichment process candidates for the future are merely identified. LLNL is developing uranium atomic vapor laser enrichment; LANL is developing UF₆ vapor laser enrichment, and TRW is developing uranium plasma ion cyclotron resonance enrichment. A decision is expected soon within DOE to select the leading candidate among these processes (Nuclear News, 1982).

REFERENCES

Nuclear News, April 1982. "AIS Decision Looms; Los Alamos Tells Progress," Volume 25, No. 5.

Schneider, K. J., and T. J. Kabele, 1979. Descriptions of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles. PNL-2286, Pacific Northwest Laboratory, Richland, Washington.

U.S. AEC, 1972. AEC Diffusion Plant Operation. ORO-684, U.S. Atomic Energy Commission.

U.S. AEC, 1974. The Nuclear Industry. WASH-1174-74, U.S. Atomic Energy Commission.

U.S. ERDA, 1976a. U.S. ERDA, 1977a. Final Environmental Statement - Expansion of the U.S. Uranium Enrichment Capacity. ERDA-1543.

U.S. ERDA, 1976b. Draft Environmental Impact Statement - Portsmouth Gaseous Diffusion Plant. Volumes 1 and 2, ERDA-1549.

U.S. ERDA, 1977a. Final Environmental Statement - Portsmouth Gaseous Diffusion Plant Expansion, Piketon, OH. ERDA-1549.

U.S. ERDA, 1977b. Draft Environmental Impact Statement - Portsmouth Gaseous Diffusion Plant. Volume 1, ERDA-1555-D.

13.0 FUEL FABRICATION

The fabrication of uranium fuel in the fuel cycle takes the purified and slightly enriched uranium as a solidified gas and converts it into an encapsulated ceramic fuel for light water reactors (LWR).

13.1 SUMMARY

The example plant chosen for this study is principally based on the Westinghouse Nuclear Fuel Plant (WNFCS) located at Columbia, South Carolina, but draws heavily on the representative plant discussed by Schneider and Kabele (1979), GESMO (USNRC, 1976), and the Uranium Fuel Cycle Survey (USAEC, 1974). It also draws upon the Westinghouse plant at Anderson (Westinghouse 1973), which is a mixed-oxide design; after the blending stage, the manufacturing process for this representative plant is the same as the Westinghouse plant. The WNFCS is the largest fuel fabrication plant for LWRs in the United States. The daily throughput is about 5 MgU with an 80% capacity factor equaling an annual production capacity of 1460 MgU/year.

The plant receives UF_6 having <5% enrichment, which is shipped as a 21.8 kg (4800 lb.) solid in OR-30A or OR-30B pressurized cylinders (depending upon customer requirements), in units of 21.8 kg (4800 lb.). The UF_6 is vaporized, hydrolized, and reacted with ammonium hydroxide. The ammonium diuranate (ADU) precipitate is separated and calcined to form UO_2 powder. The UO_2 is compressed and fired to form small ceramic pellets. These pellets are loaded into zirconium tubes to form fuel rods, and the rods are assembled to become fuel elements which are shipped to the power plants purchasing the fuel.

The plant is designed to protect the workers (1850 persons) and public from radiation and actinide ingestion through the use of shielding, controlled air-flow, and filtration of air before exhaust. No radioactively contaminated liquid effluent is discharged from the plant. Ancillary activities within the plant concern physical security, material accountability, scrap recovery, waste preparation and packaging, and test and maintenance.

The plant is suitable for the future fuel cycle, including recycle, in that the heavy elements that build up in spent fuel may not be routed to the fuel fabrication plant. Therefore, the plant design and results from a risk analysis for this plant should be applicable for some time in the future. However, the plant is suitable only for unrecycled fuel, i.e., material that has never been used in a reactor. If recovered uranium were used, this plant and process may not be suitable for protecting the workers from the radiation. Converting UF_6 to UO_2 at the enrichment plant and converting the UF_6 to UO_2 by the dry-process direct conversion fluidized bed are alternatives to the processing in this plant.

The enriched uranium used in unexposed nuclear fuel has a very low specific activity ($3E-4$ Ci/g), and, as such, presents a relatively low hazard. Because of the low enrichment level, a nuclear criticality accident requires

not only a considerable amount of uranium but also a highly favorable geometry. Such a situation could potentially occur at the head-end in the wet ADU process, or as a result of a break in the water-cooled furnaces or in the dirty scrap recovery in association with the Purex process. The particular concern about a criticality accident is the direct and inhaled radiation exposure to the plant worker and the exposure of the public from the reaction products - noble gases and semi-volatiles - that can penetrate the plant filtration. Furthermore, the fission products have high specific activities in contrast with the rather benign isotopes of uranium. The dirty scrap recovery process also presents accident potential in the form of solvent fires. The sintering furnaces and the reduction-oxidation-reduction process used for clean scrap recovery have the potential for hydrogen explosions.

The UF_6 solid received at the plant head-end flashes to a gas if released. This gas not only will penetrate the plant filtration but is particularly noxious chemically by forming hydrofluoric acid in the lungs.

Other types of hazards to which the plant is subject are airplane crashes that could disrupt the multiple plant barriers normally protecting the public, earthquakes in excess of the design basis, tornado-driven missiles that penetrate the protection barriers, and floods that can remove radiological material by water transport out of the plant. Fires and explosions in the plant have been mentioned but are mitigated by careful control over process solvents, electrical wiring, and by plant siting away from forests. Failure of the HEPA ventilation filters can result in an accidental release of the contained material. Failed glove-box gloves, spills and blow-back on the instrumentation sampling lines are examples of potential accidents that would affect the plant worker. Since this plant is suitable only for unrecycled fuel, i.e., material that has never been used in a reactor, if recovered uranium were used, this plant and process would not be suitable for protecting the workers from the radiation.

The plant inventory is 6540 kg (14,400 lb.) of UF_6 , 5100 kg of UO_2 in calcination and storage, and 6300 kg in powder storage. Once the material is pelletized, it is constrained in the ceramic fuel matrix and is dispensible with considerable difficulty.

The unit operations are: UF_6 receiving; uranium conversion including vaporizing, hydrolyzing, precipitation and calcination; powder preparation including comminution and blending; pellet preparation including composition; granulation pelleting; boat loading; sintering; inspection; fuel rod loading including hardware preparation; pellet loading; welding; pressurization and testing; fuel element assembly including rod assembly and inspection and shipping. In addition to these main-line processes there are extensive waste treatment activities including collection, clean scrap recovery, dirty scrap recovery, liquid waste treatment, composition, concretizing, and shipping. The last process to call attention to is analytical service including non-destructive assay, chemical assay, and radiographic analysis.

The accident driving forces contained within these processes and external forces to which the plant is subjected are: earthquakes, tornadoes, flood, aircrash, fire (external), pressurized release (UF_6), criticality, solvent or hydraulic fluid fire, H_2 explosion, spills, and glove box glove failure.

13.2 MAINLINE PROCESS DESCRIPTION

The Westinghouse (W) plant at Columbia, South Carolina (1969) was chosen as the representative facility because of its process scheme, its size and its completeness. It should continue to be typical of future plants. The overall characteristics of the representative UO_2 fuel fabrication facility include:

- A facility accepting uranium feed with multiple enrichment mixtures, and two basic uranium fuel products (UO_2 fuel assemblies for PWRs and BWRs).
- This facility is capable of producing and shipping PWR and BWR fuel assemblies to large, modern reactors at the rate of 5 MgU/day (1460 MgU/year).
- The facility is assumed to operate with 80% availability for 40 years.
- The facility receives UF_6 in solid form and fuel rod and element hardware and fabricates UO_2 fuel rods, ships UO_2 powder, and produces and ships UO_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 facility is set up to accommodate fuels with the highest expected ^{235}U (5%) enrichments. No process changes are necessary if lower enrichment fuels are used.
- With respect to space and equipment needs, the 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.

The representative UO_2 fuel fabrication facility produces and ships fuel assemblies for large, modern PWRs and BWRs. A PWR assembly contains 0.46 MgHM in the Zircaloy-clad UO_2 fuel rods and a BWR assembly contains 0.19 MgHM in the UO_2 fuel rods.

The 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 in 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 a Purex process before being recycled to the product stream.

The ADU conversion process is responsible for most of the chemical effluents from the plant. A total of about 720,000 liters/day (1.9E5 gallons/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 49,000 liters/day (13,000 gallons/day) of CaF_2 sludge held in lagoons. Other contaminated wastes shipped offsite amount to slightly over 1000 liters/day (264 gallons/day). Total contaminated wastes contain about 0.2% of the uranium fed to the plant. Some of the nonuranium-contaminated wastes are 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.

Figure 13.1 provides a schematic of the mainline plant processes. Each box in the schematic contains a number that keys it to the subsection where the process step is discussed (e.g., box 1 is discussed in Section 13.2.1).

13.2.1 Material Receiving and Storage

The material directly needed for fuel fabrication is the uranium-bearing feedstock (UF_6) and the fuel rod and element hardware.

The enriched UF_6 is shipped from the enrichment plant to the Fuel Fabrication Plant (FFP) in 2180 kg quantities in OR-30A or OR-30B pressurized containers (see Sect. 19). The UF_6 is solid at this temperature and pressure, and must be vaporized in a steam autoclave. The shipping containers arrive by truck, are removed by fork-lift trucks, and are stored within the plant, awaiting usage. The fuel rod and fuel element hardware is shipped by truck in hermetically sealed packages, unloaded at the dock by fork-lift truck and transferred to the rod assembly area where it is stored in its shipping containers until required.

13.2.2 Vaporizing and Hydrolyzing

As required, a UF_6 cylinder is removed from storage by fork-lift truck and inserted into a steam autoclave. Steam at a pressure of about 15.8 kPa (23 psig) is used to heat the autoclave to about 110°C (230°F). The pressure in the cylinder is approximately 46 kPa (65 psig). The autoclave is equipped with pressure and electrical conductivity controls on the steam condensate

FIGURE 13.1. Schematic of the Fuel Fabrication Mainline Process

line to protect against overpressurization and escape of UF_6 . Should the pressure inside the UF_6 cylinder exceed a predetermined value, an alarm will be actuated. If the electrical conductivity of the steam condensate leaving the autoclave should exceed a predetermined value (as would occur if UF_6 were released from the cylinder into the autoclave), the heat is automatically shut off, the cascade feed line valve and a valve in the condensate line closes, and an alarm sounds. Under normal operating conditions, the only effluent from the feed equipment consists of the condensate from the steam-heated autoclaves. This effluent is discharged to the primary holding pond.

The ammonium diuranate (ADU) process is used for converting uranium hexafluoride to uranium dioxide (UO_2). This process is well established and is generally accepted in the industry. The ADU process consists of hydrolyzing UF_6 in water to form F_2 with NH_4OH to form ammonium diuranate, $(\text{NH}_4)_2\text{U}_2\text{O}_7$, (ADU). The ADU is then heated in the presence of steam and hydrogen to form UO_2 .

Eight ADU conversion lines are used to process five different isotopic enrichments simultaneously. Enrichment control is maintained throughout each conversion line. The important steps that take place in a typical ADU conversion line are described in the following discussion.

Vaporized UF_6 is fed, as a gas, to the ammonium diuranate (ADU) line. Water is mixed with the gaseous UF_6 to:

- form an aqueous solution of uranyl fluoride and hydrofluoric acid
- convert the gas into a more manageable form, a liquid, and,
- control very precisely the mass flow of uranium to the next operation.

The chemical reaction is:

Ammonium hydroxide is added to the uranyl fluoride to cause formation of solid precipitated particles of ADU. The ADU particles are suspended in the excess ammonium hydroxide solution as a slurry. It is here, in the precipitation step, that the basic physical properties of the final nuclear fuel are formed. Great care is taken to maintain close process control over the reactant streams and the product flow to the next operation. The chemical reaction for the precipitation step is:

After passing through a centrifuge, where the slurry is dewatered, the ADU is fed into a rotary calciner where the ADU is converted by heat and

hydrogen to uranium dioxide. The calciner is electrically heated. The calcining step is very important, as it also affects the chemical and physical properties of the uranium dioxide. This project is shown as:

The calciner reaction gases are passed through a water scrubber where ammonia gas is absorbed. This exhaust is then filtered through a HEPA filter assembly unit before it is discharged to the atmosphere. It is continuously monitored and counted for gross alpha content. The scrubber solution is mixed with the liquid waste from the ADU process (called quarantine solutions). This waste is analyzed for gross alpha content. If the total uranium concentration in the solution is found to be less than $3\text{E}-5 \mu\text{Ci/ml}$, it is discharged to the waste treatment facility. If greater than discharge limits, the solution is reprocessed to reduce the uranium concentration to acceptable levels, and then discharged to the waste treatment facility.

The bulk of the ammonia absorbed by the water scrubber is recovered for reuse in the ammonia recovery system and is described in further detail in Section 13.3.

13.2.3 Comminution, Blending and Packaging

The UO_2 from the calcination step is comminuted (pulverized) in a hammer mill, collected into batches for blending, and acceptable UO_2 powder is packaged in polyethylene canisters for transfer to the pellet area. Rejected UO_2 powder moves to the blender by means of a pneumatic transfer pipe (flexible hose).

13.2.4 Compaction, Granulation, Pelletizing, Boat Loading and Green Pellet Storage

This section describes the conversion of the UO_2 from a powder to the unfired fuel pellets.

Compaction

When the slug press requires material, a powder storage hopper releases powder to the pneumatic transfer system and the slug press is started, which in turn starts the granulator and classifier. During this time, the pellet press continues to operate until the uranium powder in its feed hopper reaches a low level.

When the slug press operates, it feeds powder into a die and compacts it into short wafers called slugs (about the size of a small coin). The slugs are conveyed to the granulator feed hopper by a mechanical conveyor.

Granulation

The slug conveyor, granulator and classifier run in response to demand from the pellet press. The granulator reduces the slugs to granules. The resulting granules are passed through the classifier, which screens them into oversize, acceptable size, and undersize particles. The oversize granules indicate a broken screen and the material is collected as dirty scrap, acceptable granules are transferred by a pneumatic conveyor to the pellet press feed hopper and undersize granules are returned for reslugging.

Pellet Pressing

Granulated powder is fed from the pellet press feed hopper into dies in the pellet press where it is pressed into pellets of a uniform density and size. The pellets are discharged to the boat loader. The level of granules in the feed hopper of the pellet press controls the classifier and granulator, stopping them on high level and starting them on low level.

Rejected pellets go to clean scrap. Samples of the pellets are extracted from the flow and checked for density after which they also go to clean scrap.

Boat Loading

Empty molybdenum boats arrive at the boat loading station from the sintering furnace complex into which pellets are stacked. The control system stops the pellet press if no empty boats are available or in the event the loader fails to discharge a full boat. Loaded boats are conveyed to a green pellet boat transfer station where the boat is picked up and placed in green pellet storage by a boat stacking and retrieving machine.

Green Pellet Storage

The green pellet boat storage unit is served by the green pellet stacking and retrieving machine. The storage unit is designed such that boats must be stored only in specific locations which form an array of slabs of favorable geometry less than a critical mass.

13.2.5 Sintering, Inspection and Pellet Storage

This section describes the firing of the ceramic pellets and their subsequent inspection and storage.

Sintering

When required, a boat loaded with green pellets is mechanically removed from green pellet boat storage, placed on the shuttle car pickup station, and then transported to one of five furnaces. Each furnace has space for storing

three boats of green pellets outside the furnace on the entrance feed conveyor. As necessary, a boat is conveyed into the furnace entrance air lock. The furnace operates at approximately 1700°C in a reducing atmosphere of forming gas (about 6% hydrogen and 94% nitrogen) at 5 to 10 cm water gage pressure (2 to 4 in.w.g.) above ambient pressure.

The airlock is purged with forming gas whenever a boat is inside. Upon command from the furnace control system, the inner door of the airlock opens and the boat moves from the airlock conveyor on to the preheat section conveyor. The inner airlock door is then closed. The boat moves forward on the preheat section conveyor until it is engaged by the walking beam conveyor. The walking beam conveyor then advances the boat through the heating section of the furnace in timed incremental steps. At the far end of the furnace the boat leaves the walking beam to be moved by the cooling section conveyor. The cooling section conveyor moves the loaded boat through the cooling section to the exit airlock conveyor in the exit airlock. On command, the inner door of the exit airlock closes, the outer door of the airlock opens and the boat moves out of the airlock onto the exit conveyor. Forming gas is introduced into the exit airlock whenever a boat is inside. When the boats reach the exit conveyor, they are safely cool.

The entrance feeders of all furnaces are located within restricted access enclosures having glove ports and view windows for access to equipment and components.

Inspection

All boats of sintered pellets discharged from any furnace are transported to the sintered pellet density inspection station by a shuttle car. The density is determined from the inverse of the volume/weight ratio of selected pellets, and the data is used to determine the disposition of pellets. Boats of under-fired pellets are returned for resintering, over-fired pellets are sent to clean scrap recovery, and boat loads of acceptable pellets are transported to the sintered pellet storage to await release to the pellet grinder as production demands require.

Storage

The sintered boat pellet storage is an enclosure having storage racks or compartments with a capacity to store approximately 135 loaded pellet boats.

13.2.6 Pellet Grinding, Inspection and Storage Grinding

Boats loaded with accepted sintered pellets are removed from storage by a stacking and retrieving machine and are conveyed to a diverter which directs them to either processing line, at the option of the operator. A boat unloading device in each line transfers pellets from the boat, aligns them, and directs them to a single-file conveyor which carries pellets to the grinder. Broken pellets and chips are removed from the boats after transfer

and collected as clean scrap. The conveyor delivers pellets in single file to the water-cooled grinder. Stopping of the grinder automatically stops the feed of pellets from the boat unloader so that excess pellets cannot flood or jam the system. Coolant water is pumped from a settling tank to the wheels of both grinders, collected, and pumped back to the settling tank. Surface water is removed from the pellets by drawing air, at high velocity, over them as they exit the grinder.

Inspection

The dimensional check station checks the diameter of pellets. This station rejects oversized diameter pellets and directs them to a collection container for transfer back to the grinder for regrinding. Undersized pellets are diverted to a clean scrap collection container. Acceptable pellets are conveyed to the chip inspection station, after which the pellets are mechanically conveyed and automatically loaded onto storage trays. The pellets are placed in grooves in the trays. One groove is loaded, then the loader indexes the tray to bring the next groove into the loading position. When a tray is fully loaded, it is transferred to the pellet dryer conveyor.

A tray holds approximately 900 pellets for a total pellet weight of 9.6 kg. The trays are used to facilitate handling, storage, retrieval and identification of pellet groups in the storage units. After inspection, the pellets are vacuum-dried and analyzed for moisture.

Storage

Tray loads of pellets are placed in one of two storage units where they are held until released for rod loading. The storage capacity is about 8 MgHM.

13.2.7 Fuel Rod Loading

Batches of empty fuel tubes, with bottom plugs welded in place, are removed from storage. These batches are placed in one of the two tube loading enclosures. A tube is loaded with pellets by positioning the upper end of the tube through a sealed port and locking it in place. A tray of pellets, removed from storage by the stacker, is placed on the tray support adjacent to the loading fixture. A row of pellets on the tray is aligned with the loading fixture and mechanically pushed into the tube. This operation is repeated until the tube is filled. The tube is then removed from the port seal and the open end is decontaminated. Following decontamination, the rod surface is checked with an alpha monitor to verify the removal of any contamination. If the rod cannot be decontaminated to within specified limits, the end is sealed with a suitable plastic bag which is taped in place, and the rod is sent to the rod repair and dismantling station.

The decontaminated tube is removed from the decontamination station and placed in the top end plug pressing station, a spring is inserted into the rod, and a top end plug is pressed into place.

The assembled rods are removed from the tube loading enclosure and transferred to the rod welding enclosure via a carrier. The rods are placed in the pre-weld storage section of the welding enclosure. One rod at a time is positioned in the girth welding machine. When the girth weld is completed, the weld is visually inspected and, if acceptable, the rod is transferred to the pressure welding machine and positioned in the chamber. The machine pressurizes the chamber with helium gas and the rod is seal welded. The weld is visually inspected, and the rod is transferred to the post-weld storage section where the rods are collected on carriers. The carrier is transferred to an airlock. The airlock is located in the wall between the manufacturing building and the rod inspection building. The carrier is passed through the airlock into the rod inspection area and stored until ready for testing and inspection.

13.2.8 Fuel Rod Testing, Inspection and Storage

Rods to be tested are removed from the airlock and preinspection storage in groups, and are placed in one of two vacuum chambers. A vacuum is pulled in the chamber, and the exhausted air is checked with a mass spectrometer to detect any leak as evidenced by the presence of helium.

The rods are gamma scanned individually to verify that pellets are of uniform composition, and that no pellets are missing.

The top plug welds of loaded rods are X-rayed in groups to examine the weld integrity. The bottom plug welds on empty tubes are X-rayed in the same manner.

Rods are given a final inspection, manually and visually, for straightness, quality of welds, for dimensional check of diameter and length, and are weighed.

13.2.9 Fuel Element Assembly and Shipping

Finished fuel rods are unloaded from storage racks or containers and inserted into appropriate fuel assemblies. 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).

(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.

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, a fine water spray is used on the rods during insertion to give some lubrication; in other cases, 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.

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 and held in storage until they are loaded into shipping containers for delivery to the reactor.

13.2.10 Fuel Rod Repair and Dismantling

Repairable or rejected fuel rods originate from the following inspection stations in the rod inspection and storage area: helium leak test, gamma scan, X-ray, and visual inspection. The repairable rods are those having a defect in the top end plug girth or seal weld, or those not filled properly with pellets. The rods are collected and transported manually to the rod repair and dismantling enclosures. The rod repair and dismantling operations are performed at two adjacent stations.

Repairable rods are depressurized at the first station. The top plug is cut off, the existing spring is removed, the rod end is decontaminated, a new spring is installed, and the repair plug is pressed into place. The rod is monitored for contamination and cleaned, if required, prior to being transferred to the second station. The rod is transferred to the adjacent welding and pressurizing station where the rod is placed in the welding machine and girth welded. The rod is then placed in the helium pressurization

chamber and the rod internally pressurized with helium and the small hole in the top plug seal welded. The repaired rods are transported to the helium leak test station in the rod inspection area.

Rejected rods are depressurized at the first station, the end plugs are cut off and the springs are removed in the same manner as for the repairable rods. The pellets are removed, and damaged pellets are collected in containers, and sent to the clean scrap feed hopper for recycle into the clean scrap supply. Pellets which appear undamaged are collected and transported to the pellet inspection station. The tubes from the rejected rods, together with end plugs and springs, are collected and transported for waste treatment.

13.2.11 Clean Scrap Recovery System (CSRS)

Clean scrap is collected at various fabrication steps in small, geometrically safe, transport containers and transported to the CSRS. In the CSRS the clean scrap is charged to the system in approximately 20 kg batches where it is size reduced in a roll crusher and subsequently processed by multiple oxidation reduction steps. Following the final reduction step, the material is transferred pneumatically in 20 kg batches to any one of three large storage vessels where successive batches are mixed together.

The CSRS is designed to treat the following types of material:

- off-density green pellets
- over-fired pellets
- grinder sludge
- pellet inspection rejects (nicked, undersize, cracked)
- rod repair pellets.

The collection container has an attached lid closure and a normally closed bottom valve for emptying. The bottom valve is provided with a blank-off to prevent accidental dumping. The container design is compatible with the conveyor system, which in turn insures maintenance of adequate spacing of containers during transport back to the head-end of the scrap recovery process. Each collection point has only one container accepting scrap. When filled, the outside surfaces are wiped clean, if necessary, and placed on the conveyor before another container may accept scrap.

Upon making connection between a clean scrap collection container and the roll crusher, the crusher is turned on. The container valve and crusher inlet valve are both opened and the contents emptied by gravity into the crusher. The material passes through rollers to break down sintered pellets so that the maximum particle size is reduced to about 6mm (0.25 in.). The crushed material is discharged to the oxidation reactor feed hopper. After the entire

batch has been processed, the crusher is shut off, the two valves are closed, and the container is separated from the crusher.

A dust collection shroud is attached to the crusher around the scrap container/crusher inter-connection to collect oxide dust which may be released at the time the equipment is separated. The exposed surfaces between the valves are cleaned after disconnection to prevent dispersal of oxide dust.

The oxidation reactor is charged with clean scrap from the feed hopper in batch quantities of approximately 20 kg. The reactor temperature is maintained by means of an electrical heating jacket and control system. Preheated air is introduced through the reactor to keep the scrap agitated and to obtain uniform exposure to the hot air. The material is held in the reactor under these conditions for a specified period of time, during which the UO_2 is oxidized to U_3O_8 powder. (Formation of the higher oxides results in an expansion that pulverizes the material.)

The exhaust air, partially depleted in oxygen, is taken from the top of the reactor through stainless steel sintered metal filters which retain the oxide powder within the reactor. Filters are prevented from loading up by giving a short blow-back pulse of air periodically to clear them. A controller is employed to provide the blow-back pulse, in sequence, to all of the several filters in the reactor head. Thus, air flow through the oxide bed is not greatly affected.

After completion of the initial oxidation, the product is transferred pneumatically to one of the two alternate reduction-oxidation-reduction reactors.

The reaction off-gases from all reactors pass through sintered metal filters and are received by a common off-gas header. To guard against loss of radioactive material in the event any one of the many filters in the reactors should develop a leak, a back-up sintered metal filter is inserted in the common off-gas header.

Three clean scrap storage vessels are used to receive the product from the reduction-oxidation-reduction (R-O-R) reactors. Each vessel is designed for a working capacity of 720kg of processed scrap. One vessel at a time is receiving processed product, another recently filled vessel is awaiting quality certification, and the third vessel is supplying material in batches as required to the blend station. Thus, the three vessels provide an uninterrupted supply of processed clean scrap available for return to the process stream.

As material is transferred pneumatically from the reactors, a pneumatic mixing operation is activated in the receiving storage vessel and is kept operating for about an hour. This procedure insures mixing of all the material delivered to the storage vessel to produce a uniform stock in the vessel. Once the vessel is filled and mixed, a sample is taken and analyzed for enrichment and for physical properties related to satisfactory pelleting.

Nitrogen is used for the transfer of hot product from the R-O-R reactors and for mixing operations in order to prevent reoxidation.

Rather large flow rates of N_2 gas are required to blend the product in the clean scrap storage vessels and for transfer of processed scrap from the R-O-R reactors to clean scrap storage. Therefore, a recirculating nitrogen system is incorporated. It is comprised of filters, a gas cooler, and instrumentation required for controlling system gas pressure through makeup and dump valves. Besides conserving gas, this system functions to remove residual heat from the product through its cooler.

13.2.12 Dirty Scrap Recovery System

Contaminated materials generated within the restricted access area may be dirty scrap that is oxide fuel which has become mixed with non-fuel material. Materials falling into this category are:

- contaminated UO_2 powder, pellets, and chips,
- sweepings,
- analytical and QC samples,
- liquid wastes from Analytical Services Facility (ASF), and
- filter elements from Liquid Waste Treatment and Liquid Effluent Treatment.

These wastes are placed in metal cans at the point of origin and transported to miscellaneous waste treatment where they are neutron scanned for uranium content. Those that are only slightly contaminated are packaged for offsite disposal as TRU-contaminated waste; the remaining material is subjected to Purex extraction to remove the uranium.

The process flow sheet is shown in Figure 13.2. The scrap is dissolved in HNO_3 acids (1) followed by filtration for particulate removal. This is followed by feed adjustment (2) using HNO_3 , leaving the dissolved wastes in a pH adjusted acid stream. The stream flows to a pulsed column (3) where it is contacted with organic: tributyl-phosphate (TBP) diluted by a paraffin-base solvent. The organic from the column bottom is stripped (4) and the values are concentrated (5) and enter into an ADU process similar to the head-end of the uranium fabrication plant as was described in Section 13.2.2. This involves a complexing with ammonia (6) to form the ADU precipitate (7), washing and drying and centrifugation. This is followed by air calcination and fed to clean scrap recovery.

13.2.13 Decontamination and Hot Repair

Equipment to be brought to the decontamination station is emptied of process materials, broken down, and decontaminated, to the extent practicable,

FIGURE 13.2. Dirty Scrap Recovery and Reconversion for the Fuel Fabrication Plant

while at its normally installed position. In the decontamination area, equipment to be repaired or discarded can be cleaned by vacuum cleaner or by flushing and washing with liquids, steam, etc. In the repair area, only vacuum cleaning can be done.

Services provided for the decontamination area include the following:

1. a recirculating water flushing system with provisions for the addition of non-flammable reagents, degreasers
2. steam at 21 kPa (30 psig), provided by an independent steam generation system
3. compressed air from the plant system.

In addition, vacuum cleaners are provided in both the decontamination and repair areas, for use in operations for which dry cleaning is adequate. Within the cell areas, the permanently installed equipment and piping components are of fabricated stainless steel, insofar as is practicable.

The principal components of the recirculating flushing system are located in the decontamination area of the cell. The system includes two 100-gallon, geometrically favorable, tanks, whose contents can be pumped via nozzles or a spray-head for decontamination operations. The vessels are vented via an in-cell filter to the plant exhaust system. In operation, equipment to be decontaminated is treated using this system, plant water, steam, or air. Liquids drain to a geometrically favorable cell-floor sump from which they are pumped via cartridge-type filters to remove the oxide solids, and back to the tanks. The liquid is sampled and analyzed for uranium content to transfer to liquid waste treatment (LWT).

Following decontamination, components are normally repaired in the adjacent repair area, or they may be bagged out for offsite disposal. The repair area is provided with machine-shop equipment and other tools. Vacuum cleaning equipment is also available for dry cleaning. Liquids are not normally used in this area, although a geometrically favorable sump with sump pump is provided.

13.2.14 Analytical Services

The analytical services facility (ASF) is responsible for the analysis of feed materials, process streams, fuel product, and the destructive analyses on scrap materials.

Six sub-critical areas are maintained within the ASF, each having a fissile capacity limit of 290g of ^{235}U . All transfers between sub-critical areas are made pneumatically through the central material handling station (CMHS), with the exception of liquid waste. The CMHS will have exclusive control of all internal pneumatic transfers.

Samples are removed from the process stream and are placed in pretarred and precalibrated containers. The sample container is pneumatically transferred to the CMHS. A request for transfer and analysis, which includes the container and sample identification, the approximate weight and the nominal fissile content, is then forwarded to the ASF-CMHS.

A continuous material balance sheet is maintained at the CMHS and no transfers are permitted that could cause the fissile balance to exceed the approved criticality limits for that area. This condition is maintained by exclusive control of all transfers by the CMHS.

At the CMHS, sample material is subdivided into the predetermined proportions required to perform the necessary analyses. Each subsample is weighed and transferred to the sub-critical station responsible for the analyses requested. A continuous fissile balance is maintained at the CMHS for each sub-critical area. The CMHS is not permitted to transfer material to any sub-critical station in which the approved criticality limits would then be exceeded. Each sub-critical area may contain several glove boxes and hoods. Material movement within each sub-critical area is manual, either through tunnels or airlocks, and is not restricted with respect to criticality controls.

Liquid waste is vacuum transferred from hoods to the liquid waste pretreatment.

13.3 DESCRIPTION OF EFFLUENT PROCESSING AND WASTE MANAGEMENT SYSTEMS

Control of emissions of uranium, 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 airborne effluents, and in liquid and solid wastes.

13.3.1 Liquid Effluents Processing

A block diagram for the treatment of liquid effluents from the representative facility is shown in Figure 13.3. 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.

FIGURE 13.3. Process Flow Diagram - Liquid Effluent Treatment System for the UO_2 Fuel Fabrication Plant

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 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 close-loop cooling tower is pumped to the sanitary effluent lagoon. A significant amount of the water in these liquid effluents evaporates into the atmosphere. Tables 13.1 and 13.2 summarize the estimated routine chemical and radiological discharges, respectively (Westinghouse, 1975).

13.3.2 Airborne Effluents Processing

The treatment of airborne effluents at the plant is shown schematically in Figure 13.4. In cases where the potential for radioactive materials or significant chemicals does exist, treatment consists of water scrubbing 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 condensible 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. 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 routed to this latter bank of HEPA filters.

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:

TABLE 13.1. Average Yearly Water Chemical Effluents From
The Representative UO_2 Fuel Fabrication Plant

<u>Parameter</u>	<u>Concentration, mg/l</u>
	<u>1460 MgU/year</u>
Silver (Ag)	0.35
Iron (Fe)	2.10
Sodium (Na)	141
Calcium (Ca)	2328
Magnesium (Mg)	5.40
Manganese (Mn)	0.10
Molybdenum (Mo)	0.45
Nickel (Ni)	1.
Boron (B)	1.70
Chloride (Cl)	106
Phosphorus (P)	2.80
Kjeldahl (N)	534
Ammonia (NH_3)	9.40
Fluoride (F)	15.60
Sulfate (SO_4)	178
Sulfite (SO_3)	2.30
Sulfide (S)	trace
COD	247
BOD ₅	11.80
Phenols	trace
Oil and Grease	7.80
Hardness (as $CaCO_3$)	1005
Total Suspended Solids	15.60
Total Volatile Solids	1466
Total Solids	1122
Total Dissolved Solids	1093
pH	6.0

TABLE 13.2. Discharge Concentrations and Total Annual Release of Radioactivity in Liquid Effluent from the Representative UO₂ Fuel Fabrication Plant

<u>Radiation Component</u>	60 MgU/yr (Estimated)	
	<u>Concentration (pCi/l)</u>	<u>Total Release Rate (μCi/yr)</u>
alpha	1.22	384
beta	3.64	1140
gamma	0.14	44

FIGURE 10.A-5 PROCESS FLOW DIAGRAM-AIRBORNE EFFLUENT TREATMENT SYSTEM FOR THE REFERENCE UO₂ FUEL FABRICATION FACILITY

FIGURE 13.4. Process Flow Diagram - Airborne Effluent Treatment System for the UO₂ Fuel Fabrication Facility

- steam boiler combustion gases
- chemical and health physics laboratory ventilation
- calciner 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.

The efficiency of the scrubbers and HEPA filters is presented in Appendix 13, Table 13.A. Tables 13.3 and 13.4 present the estimated radiological and chemical releases from the various exhausts, respectively.

13.3.3 Waste Management

Waste materials are collected and stored prior to disposal, according to the following classifications: uranium contaminated or contamination-free, and combustible or noncombustible.

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.

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

TABLE 13.3. Airborne Uranium Releases from the Representative UO₂ Fuel Fabrication Facility^(a)

Effluent Release Point	Exhaust Area Flow Rate (ml/hr)	Effluent Discharge Rate (μ Ci/wk)
A. Furnace Exhausts	2.7E11	23.40
B. Conversion Process Exhausts	6.0E10	24.50
C. Calciner Combustion Gas	3.3E9	2.08
D. Air Compressor Room	1.7E10	1.66
E. Boiler Room Exhaust	1.7E10	2.84
F. UF ₆ Bay Rest Room Exhaust	3.4E8	0.02
G. Chem Lab Exhaust 2	1.7E9	0.72
H. Chem Lab Exhaust 6	3.9E9	2.32
I. H.P. Lab Exhaust	2.1E9	0.52
J. Incinerator Exhaust	3.8E9	<u>0.88</u>
	Total	71.94

(a) At 1460 MgU/yr operation reference Westinghouse 1975

(b) Also primary controlled air exhaust

TABLE 13.4. Average and Maximum Ammonia and Fluoride Gaseous Effluent Concentrations for the Representative UO₂ Fuel Fabrication Plant (Westinghouse 1975)

<u>Chemical</u>	<u>Exhaust Flow Rate at 1460 MgU/yr Rate (ml/hr)</u>	<u>Effluent Concentration Per Stack (mg/m³)</u>	
		<u>Average</u>	<u>Maximum</u>
Ammonia	6E10	1562	1872
Fluorides	6E10	1.45	1.73

their 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.

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 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 representative uranium fuel fabrication facility is given in Figure 13.5. At design capacity of 1460 MgU/yr., approximately 40 to 60 bales/day of combustible contaminated waste and 4 bales/day of noncombustible contaminated waste are generated as shown in Figure 13.6.

13.4 PLANT LAYOUT

The safety of a plant depends upon the processes conducted within the plant, the plant layout, its design and siting.

The representative facility is largely based on the Westinghouse Nuclear Fuel Columbia Plant, with an expanded design capacity of 1460 MgU/yr. Construction of the facility was begun in 1968 and completed in 1969. The plant was operated at about 800 MgU/yr in 1974, but has the capacity to operate at the expanded capacity of 1460 MgU/yr.

13.4.1 Site Description

The reference facility is assumed to lie on the generic site described in Section 8. The plant itself requires an area of 0.24 km² 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 exists around the total site to exclude the public, while a second fence, including a security entrance, surrounds the smaller plant area. The liquid effluents are discharged onsite into the river that flows through one corner of the site.

13.4.2 Facility Description

The reference facility, expected to operate for 40 years, consists of the fuel manufacturing building (main plant building), chemical storage area, machining area, waste ponds, offices, parking lot, and other outside equipment. Figure 13.7 shows the facility's layout. Approximately 81% of the main plant building (22,300 m² or 240,000 ft.²) is utilized for fuel manufacture, while 19% consists of offices, laboratories, and service areas. A separate building (4,645 m² or 50,000 ft.², not shown) on a concrete slab houses the machined components fabrication area. 4,645 m² (50,000ft²) of the

FIGURE 13.5. Overall Waste Management Operations for Representative UO_2 Fuel Fabrication Plant

APPROX RATE: 40 TO 60 BALES/DAY COMBUSTIBLE
4 BALES/DAY NONCOMBUSTIBLE

FIGURE 13.6. Waste Management Operations with Baled Materials for the Representative UO₂ Fuel Fabrication Plant

FIGURE 13.7. Layout of the Representative UO_2 Fuel Fabrication Facility

main plant building is the site of expansion in the production equipment. Other major buildings 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). Table 13.5 provides a list of major process equipment in the plant.

Except for the office/cafeteria wing, the reference facility is a two-to-three story, windowless, steel and prefabricated concrete slab structure with associated service and office buildings. The building has long, simple lines of rectangular interconnecting areas. The manufacturing plant and the offices are fully air conditioned.

Figure 13.8 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).

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, glove boxes, or other enclosures, and to be surrounded by operating areas. Each of the separate process areas is generally served by individual (filtered) ventilation systems, as the locations of the multiple small process stacks indicate (shown in Figure 13.9). Total ventilation flow for the facility is $6.5E9$ /day (160,000 cfm).

13.5 SAFETY-RELATED INFORMATION

This section discusses the pertinent safety-related information that can be used to help identify potential risks in operating a representative UO_2 fuel fabrication plant.

13.5.1 Operating and Maintenance Requirements

Approximately 1850 employees work at the facility in three shifts for around-the-clock operation. Parking space and facilities will be provided for up to 60 visitors. The estimated number of workers involved in several job types for the three shifts is presented in Table 13.6.

TABLE 13.5. Major Process Equipment Descriptions

PROCESS STEP	EQUIPMENT
Receiving	Fork Trucks UF ₆ Tank Storage
Conversion	Autoclaves Steam Supply Pressure Relief Valves Autoclave Controls Piping Hydrolyzing Bath Rotary Precipitate Screens Centrifuge Calciner H ₂ O Scrubber Conversion Off-Gas System Break-Through Instrumentation
Comminution, Blending	Hammermill Blender Packaging Equipment
Compaction, Granulation, Pelletization, Boat Loading and Green Pellet Storage	Slug Press Granulator Classifier Slug Conveyor Pneumatic Granule Conveyor Pelletizing Press
Compaction, Granulation, Pelletization, Boat Loading and Green Pellet Storage (Continued)	Pellet Conveyor Boat Loader Pellet Boats Green Pellet Boat Stacking and Retrieving Machine Green Pellet Storage Unit
Sintering Furnace, Boat Conveyors and Pellet Storage	Shuttle Car 1 Sintering Furnaces Rejected Pellet Boat Dumper Sintering Pellet Boat Stacking and Retrieving Machine Sintered Boat Pellet Storage

TABLE 13.5. (Cont.) Major Process Equipment Descriptions

PROCESS STEP	EQUIPMENT
Pellet Grinding Inspection and Storage	Bridge Crane Rectilinear Manipulator Boat Transfer Mechanism Boat Unloaders Pellet Conveyor System Pellet Grinder Sludge Collector and Dryer Dimensional Inspection Device Nick Inspection Device Tray Loading Device Trays Pellet Dryer Pellet Storage Unit Moisture Analyser Pellet Vacuum Drying System
Receiving, Cleaning and Storage of Tubes, Plugs and Springs	Tube Storage Racks Top Plug Storage Area Bottom Plug Storage Area Bottom Plug Press Bottom Plug Welder Pre X-ray Storage X-ray Inspection Post X-ray Storage Quality Check (QC) Bottom Plug Weld Inspection Airlock and Empty Tube Storage Spring Storage Area Rework Storage Area
Fuel Rod Loading	Loading Station Decontamination Unit Spring Loading and Top Plug Press Plug Welding Station
Rod Repair and Dismantling	Depressurizing and End Plug Cut-off Station Spring Removal and Rod End Ream Station Decontamination, Spring Insertion and Top Plug Pressing Station

TABLE 13.5. (Cont.) Major Process Equipment Descriptions

PROCESS STEP	EQUIPMENT
Girth Weld Station	Helium Pressurization and Pressure Welding Station Pellet Removal Station Tube Cut-Up Station
Rod Testing, Inspection, Storage and Shipping	Air Lock and Preinspection Storage Helium Leak Testing Equipment Helium Leak Test Storage Area Rod Assay and Gamma Scan Pre X-ray Storage X-ray Inspection Post X-ray Storage Physical Inspection and Weighing Rejected Rod Shielded Carrier Shielded Carriers Post Inspection Storage Inspected Rod Storage Inspected Rod Stacker Motorized Transfer Dolly Bridge Crane
Clean Scrap Recovery	Collection Containers Roll Crusher Oxidation Reactor Reduction-Oxidation-Reduction Reactors Storage Vessel

FIGURE 13.8. Main Building Floor Plan for the Representative UO_2 Fuel Fabrication Facility

FIGURE 13.9. Roof Plan and Process Stack Locations for the Representative UO₂ Fuel Fabrication Facility

TABLE 13.6. Number of Workers by Task and Shift for the UO₂ Fuel Fabrication Plant

<u>Job Type</u>	<u>No. of Workers at the Times Indicated</u>		
	<u>700 - 1600</u>	<u>1600 - 2400</u>	<u>2400 - 700</u>
Supervisory and Administration	78	57	57
Accounting	43	28	28
Secretarial	43		
Physical Protection	14	71	71
Unloading	57	57	57
Process Operation ^(a)	163	163	163
Assembly	71	71	71
Waste	43	43	43
Janitorial	28	28	14
Loading	43	43	
Maintenance	14	14	14

(a) Process personnel assist in major maintenance

Some equipment is expected to 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 m^3 (1,500,000 gal.) must be built every year.

13.5.2 Input/Output of Major Materials

Section 13.2 presented the process description and Section 13.4 presented the plant layout. A key parameter in a safety analysis is the throughput rates of key materials. Figure 13.10 is a general plant layout with process areas identified for keying to the material flows in the process. These material quantities and flow rates are provided in Figure 13.11 for an 8-hour shift in full production.

Overall input/output of radioactive materials for the facility is given in Table 13.7. The overall input of nonradioactive materials is given in Table 13.8. The nonradioactive materials in the airborne effluents, the liquid effluents, and the solid wastes from the plant are given in Tables 13.9, 13.10, and 13.11 respectively. For additional information, Table 13.12 summarizes the overall environmental impacts of the facility.

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, approximately 75% of which is recovered for reuse; and selected metal ions removed from the liquid effluents by precipitation as relatively insoluble sulfate salt wastes.

13.5.3 Inventory of Major Hazardous Materials at Plant Locations Having Safety-Related Importance

The radioactive material of primary concern with regard to hazard is uranium, particularly UF_6 . The quantities of uranium in various plant locations was given in Figure 13.11. The inventory values can be related to plant locations by referring to Figure 13.10.

13.5.4 Unit Operations Involved

This section identifies the unit operations for each step in the process flow schemes for the representative fuel fabrication facility. These are listed in Table 13.13.

13.5.5 Accident Driving Forces

Energy must be present to break any barriers that tend to reduce releases of radioactive materials as well as to drive the dispersion beyond the

LEGEND

1	CHEMICAL PROCESSING	10,11	GRID AREA
2	CHEMICAL LABORATORY AREA	12,13	ASSEMBLY AREA
3	PELLETIZING	14,15	ASSEMBLY AREA
4	SINTERING FURNACES	16	CAFETERIA
5,6,7	ROD LOADING	17	OFFICE AREA
8,9	X-RAY	18	UF ₆ RECEIVING
		19	PARKING
		20	MIXED OXIDE ASSEMBLY AREA

FIGURE 13.10. Building Floor Plan Showing Areas for Different Processes

FIGURE 13.11 Material Balance of the Uranium Fuel Fabrication Plant

TABLE 13.7. Overall Radioactive Materials Input/Output for Representative UO₂ Fuel Fabrication Facility

Material	Total Material (a)		U(a)(c)	Form		Fraction of (b)
	kg/day	g/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)

(a) Values are based upon one day operating at 100% capacity (5 MgU/day) 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.

KEY:

S = Solid

L = Liquid

G = Gas

NA = Not Available at this time

TABLE 13.8. Overall Nonradioactive Materials Input To The Representative UO₂ Fuel Fabrication Facility

Material	Total Material ^(a)		Chemical	Form		kg/day as 100%
	kg/day	lb/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	77%	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

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

Key: S = Solids
 L = Liquids
 G = Gas
 NA = Not available at this time

TABLE 13.9. Overall Nonradioactive Airborne Effluents From The Representative 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 ₁₂ 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 13.10. Overall Nonradioactive Liquid Effluents From
The Representative UO_2 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	$\text{H}_2\text{O}^{(c)}$	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 H_2O

Key: S = Solids
L = Liquids
G = Gas
NA = Not available at this time

TABLE 13.11. Overall Solid Waste From the Representative UO₂ Fuel Fabrication Facility

Waste Material	Form	Package	Total (a)		U Content (a)		Fraction of Plant Input
			lb/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 lb 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

TABLE 13.12. Overall Environmental Impacts From
Representative UO₂ Fuel Fabrication Facility

	<u>Quantity</u>	<u>Remarks</u>
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 Resource Use	1.9E4 kW-day/day	
	See Table 10.A-2	Also Special Maintenance requirements

TABLE 13.13. Unit Operations in the Representative
Fuel Fabrication Plant

Process Step	Unit Operations
Material Receiving	Unloading Tanks of Uranium Hexafluoride Unloading Fuel Hardware Receiving Miscellaneous Plant and Process Support Materials
Uranium Conversion	Vaporizing Hydrolyzing Precipitation Calination
Powder Preparation	Conmination Blending
Pellet Preparation	Compaction Granulation Pelleting Boat Loading Storage Sintering Inspection Storage
Fuel Rod Loading	Hardware Preparation Pellet Loading Rod Welding and Pressurization Rod Testing Storage
Fuel Element Assembly	Rod Withdrawal from Storage Rod Assembly Hardware Installation Assembly Inspection

TABLE 13.13. (Cont.) Unit Operations in the Representative
Fuel Fabrication Plant

Process Step	Unit Operations
Shipping	Preparation of Shipping Containers Installation of Fuel Elements
Waste Treatment	Waste Collection Clean Scrap Recovery Dirty Scrap Recovery Liquid Waste Treatment Compaction Concretizing Shipping
Analytical Services	Non-destructive Assay Chemical Assay Radiographic Assay

barriers. Such energies could be released by vehicle accidents, such as the delivery trucks, trucks picking up the finished product, and the fork-truck used for pallet handling. The forks themselves have been considered as possible penetrators of the shipping containers. Other external forces could include: an aircrash into the plant, tornado-accelerated missiles breaking into the plant, or a very severe earthquake that breaks the plant process lines, process cells and the outer building containment.

The incoming UF_6 , should it become heated, would have the internal energy needed for its dispersal. It also tends to react with moisture and form HF. Some failures which have been experienced with UF_6 containers are shown in Table 13.14.

The steam used for the autoclave provides energy for an accident, as do the chemical reactions used in the conversion to UO_2 . The centrifuge used to separate the slurry has some centrifugal energy. The calciner has energy for accidents and the hydrogen used in converting the ADU to UO_2 has explosive potential.

The uranium powder has little internal energy to either disperse itself or to break boundaries, but wind and building ventilation can provide the energy necessary to disperse the UO_2 powder if they have an unimpeded access to and from the powder. An example of this is the failure of a HEPA filter so that it allows release of particulate materials. Fortunately, few HEPA filter failures have occurred (Moeller 1975). Also, in the process of filtration, the particles agglomerate thereby reducing their dispersibility.

Other forces available within the plant are chemical reactions. Quantities of hydrogen gas are also used in the forming gas for the sintering furnaces. Should the mixing be improper and should oxygen also get into the mixture, an explosion becomes possible. The use of solvents in the process and analytical services is strictly controlled, but they do pose a possible fire and explosion energy source. A nuclear reaction might be possible in the wet conversion processes; it is certainly possible if highly enriched ^{235}U were received. Criticality has been particularly examined for the water-cooled furnaces, but the furnace geometry is such that it is very unlikely. The wet-scrap recovery uses the Purex process so there is some fire potential in the organic streams. There is also fire potential in the building electrical system wiring and in the waste collection, as there is in most manufacturing facilities.

13.5.6 Containment and Shielding Systems

Figure 13.12 shows the barriers protecting the public from the uranium and decay products. At receiving, the public is protected by the fact that the UF_6 is a solid material inside of a pressure vessel (OR-30A container). Once inside the plant, additional protection is afforded by the building and the ventilation and filtration system. The pressure vessel is placed in an autoclave and the UF_6 is gasified, converted into a liquid, precipitated and

TABLE 13.14. Summary of Accidental Releases of UF_6 (>5 kg Uranium)
from Feed Cylinders to Gaseous Diffusion Plant

Date	Quantity of Release		Cause of Accidental Release
	Uranium (kg)	UF_6 (lb)	
12- 1-52	92	300	Foreign material lodged in valve
6-28-53	31	101	Ruptured cylinder pigtail
7-15-53	460	1,500	Ruptured thermocouple
7-31-53	38	124	Ruptured cylinder pigtail
4- 9-54	40	130	Sheared cylinder valve stem
6-18-54	666	2,171	Sheared cylinder valve stem
3-15-55	414	1,350	Broken cylinder pigtail
11-28-55	15	49	Broken cylinder pigtail
3-10-56	63	205	Broken cylinder pigtail
10- 1-58	163	531	Failed cylinder end plug
3-19-59	45	147	Broken cylinder pigtail
11-17-60	3,077	10,033	Ruptured cylinder
3-17-66	8	26	Ruptured cylinder when cylinder dropped

Source: U.S. AEC, 1974

FIGURE 13.12. Pictorial of the Levels of Confinement Barriers

calcined to a powder, all while being confined by process lines and vessels, as well as the plant building. Once the powders have been formed into slugs, the size of the slug inhibits dispersion. The slugs are assembled and confined by the cladding and hardware, hence the confinement is product form, cladding and the building at this point. Finally, the fabricated fuel is shipped from the plant in licensed RCC-1 containers.

It should be noted that only during shipping is there a single barrier protecting the public from radioactivity. Even for this case the single barrier is quite strong and must pass stringent test requirements.

The HEPA filters are a high-reliability, Category I component used to allow air passage but to suppress the passage of radioactive particulates. High quality and stringent tests are required, but a few failures have occurred. Moeller (1975) has compiled data on air cleaning failures for the 8-year period 1966-1974 that have occurred at nuclear facilities. It should be noted that this time interval encompasses the implementation of 10CFR50 Appendix B on quality control, as well as the normal design rectification that occurs when failure modes are exhibited. Hence, the failures reported in Moeller may not reoccur. Erdmann et al. (1979), using data from Moeller and Burchsted et al. (1976), estimate the failure experience for 61 cm x 61 cm x 30 cm (2 ft. x 2 ft. x 1 ft.) HEPA filters as $1.1\text{E-}4/\text{HEPA-year}$ in wet processes and $1.0\text{E-}4/\text{HEPA-year}$ in dry processes.

There is essentially no shielding in the facility other than walls of conventional structural materials. All maintenance work is done by direct contact of the equipment by personnel wearing protective clothing. Operations are by direct contact except where operated remotely for automation purposes. (See also Section 13.5.7).

13.5.7 Degree of Hands-on Operation

Table 13.15 classifies the principal process steps according to the directness of exposure to radiation from the process material.

13.5.8 Product Form and Behavior

The radioactive material in the plant is gaseous (UF_6 at elevated temperature), liquid (ADU slurry or liquid waste), or solid (powder or pellets). Gaseous materials will penetrate the HEPA filters, a liquid release would only be airborne as a fine aerosol, and a solid release would only be airborne as a fine UO_2 powder.

Figure 13.13 shows the particle size distribution of UO_2 calcined at temperatures in the range of 800° to 1200°C . The particle size distribution for wet processes (such as the dirty-scrap recovery process) and dry processes (such as the powder operation) has been studied by Gonzales et. al. (1976) for several plants. Using these data and their measurements of HEPA filter penetration by particle size, penetration values were developed for the

TABLE 13.15. Classification of Process Steps by Directness of Exposure

Process Step	Type of Operation
Receiving, Handling and Storage of UF ₆	Contact with Shipping Containers
UF ₆ Vaporization, ADU Formation, Precipitation and UO ₂ Production	Remote ^(a)
Blending and Pellet Preparation	Remote ^(a)
Fuel Rod Loading and Welding	Contact
Testing and Inspection	Contact
Shipping	Contact
Scrap Handling	Contact
Dirty Scrap Recovery	Remote ^(a)
Clean Scrap Recovery	Remote ^(a)
Maintenance	Contact after Decontamination

(a) "Remote" in this case is the distance from the process materials to the automatic control systems. It is not through shielding walls.

FIGURE 13.13. Variation in Uranium Dioxide Particle Size Distribution for a Range of Calcining Temperature between 800 and 1200C

processes in this plant (see Appendix 13.). Dioctyl phthalate (DOP) tests are routinely performed on the filters to assure proper performance and the differential pressure measurement across the filters will alarm upon filter failure. Alarms in the stack air discharge will also be activated upon an unusual increase in radiation level, such as might accompany filter failure.

A further piece of safety information, useful in assessing safety in fuel fabrication, relates to the maximum stable density of an aerosol in a cell should an accident occur. A plot of this information is given later in Appendix 14. For particles in the range of 0.4 to 0.7 μ , this figure suggests a realistic concentration of about 1 g/m for a solid aerosol and about 3 mg/m for a liquid aerosol.

The uranium powder contains several uranium isotopes, as well as thorium decay products which grow back to 99% of secular equilibrium in 168 days. Thorium contributes to the activity about the same as ^{235}U , although most of the activity comes for ^{235}U . Table 13.16 presents the weight percent fractions of the significant isotopes. The weighted average activity is $3.3\text{E}-4$ Ci/g.

13.6 ALTERNATIVE PROCESS SCHEMES

The following alternatives are indicative of some variations in facilities that may be considered in near-future fuel fabrication plant designs.

13.6.1 Direct Conversion Fluidized Bed (DCFB)

The ADU process requires steam, wet process streams and calcination in the presence of hydrogen. An alternative is the DCFB process. This is a continuous flow process for converting uranium hexafluoride (UF_6) to UO_2 . This direct conversion process is currently beyond the advanced development stage and is a viable alternative to ADU. Figure 13.14 shows a flow diagram of the DCFB process.

The overall DCFB reaction can be described by the chemical equation:

Processing is carried out at elevated temperatures (550°C to 630°C) at slightly positive pressures in three gas-solid reactors in series: a primary converter, a fluoride stripper and a cleanup reactor. UO_2 product is recovered from a cooler-blender as a free flowing granular product and is milled, packaged and stored awaiting further processing.

The primary converter system consists of a reactant gas preheater, fluidized bed converter reactor, reactor furnaces and related instrumentation. UF_6 , hydrogen, and steam react in the fluidized bed of the reactor to form a

TABLE 13.16. Isotopic Composition of Uranium Dioxide

<u>Isotope</u>	<u>Wt. %^(a)</u>	<u>Ci/g^(a)</u>
^{238}U	95.78	3.3E-7
^{236}U	0.025	6.3E-5
^{235}U	4.15	2.1E-8
^{234}U	0.04	6.1E-3
^{234}Th	2.7E-9	2.3E4

(a) Assuming secular equilibrium with thorium daughter, based on highest enrichment

The diagram illustrates the Fluoride Volatilization Process (FVP) for converting UO_2 into UF_6 . The process begins with UO_2 from various sources (e.g., UO_2 container storage, UO_2 cylinder storage) being weighed and analyzed. It then moves through a series of heating stages (Preheater H-703, Heater H-705, Superheater H-706, Heater H-707, Heater H-708) where steam is added. The material is then transported through a cyclone and a primary converter (R-702) to a charging hopper. From there, it goes through a fluoride stripper (R-704) and a clean-up reactor (R-707). The resulting UF_6 is then transported through a product cooler/blender (R-709) and an isolation hopper to a discharge hopper. The UF_6 is then weighed and analyzed again before being packaged or sent to a waste pond. The process also includes a recycle stream for UF_6 and a final filter for the UF_6 product. Key components include: UO_2 cylinder storage, weigh and analyze, recycle, empty-educted cylinders, weigh, return to AEC, filter F709, header to scrubber, non-cond gases, separator tank C711, HF acid solution, heat exchanger, vent, quarantine tanks, measure sample and analyze, sample, P7130, P713A, exhaust (monitor), vented hood, UF_6 packaging, UO_2 container storage, weigh, sample and analyze, transfer internal or external, recycle (if required), steam, steam condensate, monitor and discharge, cyclone, primary converter R702, charging hopper, solids transport, fluoride stripper R704, clean-up reactor R707, product cooler/blender R709, isolation hopper, discharge hopper, vent, quarantine tanks, measure sample and analyze, sample, P7130, P713A, exhaust (monitor), vented hood, UF_6 packaging.

FIGURE 13.14. Flow Sheet of the Alternative Fluidized Bed (DCFB) Process

solid product consisting primarily of a mixture of UO_2F_2 and U_3O_8 . The solid reactant product is discharged from the bottom of the reactor and is transported as a dilute gas-solids phase to the top of the second reactor (fluoride stripper). The off-gas stream, consisting of excess steam and hydrogen and reaction product (HF), exits the top of the reactor and is used as the transport medium for the solid product.

The fluoride stripper system consists of a reactant gas preheater, reactor, reactor furnaces, internal filters and related instrumentation. Solids from the primary converter (UO_2F_2 and U_3O_8) enter the reactor and react with steam and hydrogen in the fluidized bed reaction section of the reactor. This reaction de-fluorinates approximately 83 percent of the entering UO_2F_2 and reduces approximately 85 percent of the entering solids to UO_2 . Solid product discharges into a fluidized transport pipe similar to that from the primary converter except that superheated steam constitutes the transport medium. Off-gases leave the system by passing through filters and flow to the wet scrubbing system.

The cleanup reactor system and reactions that occur therein are essentially the same as in the fluoride stripper system. The cleanup reactor provides a second stripping stage to complete the hydrolysis of UO_2F_2 and the reduction of U_3O_8 to UO_2 . Solid product is transported in dilute-phase fluidized flow to the cooler-blender by an inert carrier gas. Off-gases from this system follow the same path as those leaving the fluoride stripper.

The cooler-blender system consists of a vertical cylindrical vessel with external cooling coils and internal filters. UO_2 powder from the cleanup reactor is received continuously in the cooler-blender where it is cooled in an inert gas atmosphere. It is also blended with an inventory of material discharged in the course of approximately 8 hours of previous operations to minimize the effects of process variations. Cooler-blender product is discharged into an isolation hopper, purged with an inert gas, and transported in dilute-phase fluidized flow to the comminution system by a suitable carrier gas.

The comminution system consists of a mill feed hopper, mill and discharge bin. Milling, packaging and storage of the UO_2 product is very similar to that described for the ADU (ammonium diuranate) process.

A wet scrubber system is used to reduce pollutants in the waste off-gas stream to the lowest practicable levels. Each off-gas stream passes through a 5- μm sintered-Monel filter with a timed blow-back to keep the filter clean. A similar, back-up filter is also supplied in the main exhaust line to the scrubber. The gases are then passed through a direct contact, recirculating, venturi scrubber; then through a tangential demister or disengaging plenum; followed by a 25-centimeter diameter, packed column where the off-gases are scrubbed with water.

The scrubber liquid and resulting overflow to the process liquid waste quarantine tanks are maintained at a pH of about 7 by introducing aqueous ammonia to the scrubber reservoir.

Prior to release to the atmosphere, the gases pass through a demister, and finally HEPA filters. Filtered gases discharged to the atmosphere are continuously sampled, and are analyzed for airborne particulate radioactivity on a daily basis. Fluorides will be analyzed on a periodic basis.

The tangential demister or disengaging plenum and scrubber reservoir alternately overflow into one of three quarantine tanks. The contents of each quarantine tank are sampled and analyzed to assure the concentration is below acceptable levels before release to the Waste Treatment Facility for fluoride removal. A recirculating filter system with provision for pH adjustment and precipitation to remove the residual radioactivity is available if the concentration exceeds acceptable levels.

The value of DCFB is the elimination of the wet ADU process that could lead to a criticality incident. It is claimed to produce a more homogenous product and it reduces the possibility of a hydrogen explosion by eliminating a reducing calcination step. The disadvantages with DCFB are its complexity, the fact that it has not been proven on a commercial scale and that the fluoride stripping step is undesirable because of possible corrosion.

13.6.2 Powder Front End

Safety might be enhanced if UF_6 were not received at the plant to enable the processing to be as dry as possible.

If the enrichment plants were to convert the UF_6 to a UO_2 powder, the off-site transport of volatile UF_6 after enrichment would be eliminated and the UO_2 would be received and processed as a powder, and would enter the process at step 3, Figure 13.1. It can be argued that this would affect the safety concerns in the enrichment plant very little, since UF_6 is used throughout their operation. However, this would simplify and hence reduce the cost of a uranium fabrication plant, as well as eliminating a form of hazardous material. The enrichment plants would not have to use a heater to vaporize the UF_6 since it is already a gas in the diffusion process.

Should it be desired to eliminate the transportation of UF_6 , the conversion of U_3O_8 to UF_6 could take place at the front end of the enrichment process instead of in a conversion plant.

13.6.3 Dirty Scrap Recovery at Other Plants

The recovery of "dirty" scrap requires a small Purex process with the attendant accident possibilities associated with the process. As an alternative, the dirty scrap could be collected, assayed and shipped off-site to either a reprocessing plant or a MOX plant that already has a wet scrap

recovery facility to recover the uranium. The recovered uranium could enter the process stream at that plant rather than being returned. Such a concept would eliminate the scrap recovery process at the uranium fuel fabrication plant but would add the shipment of dirty scrap (co-location of the two plants would eliminate this off-site shipment step).

13.6.4 Pneumatic Transfer Air Recirculation

Some approximate calculations indicate that the extensive use of pneumatic powder transfer may result in loading of the prefilters and HEPA filter in a fairly short time. Filter loading can be reduced by recirculating the air used for pneumatic transfer. This process would reduce HEPA filter change-out frequency, and as a result decrease the number of times a possible release could occur due to a changeout.

13.6.5 Safeguards^(a) Considerations

The representative plant presented here was designed before the safeguards emphasis of the late 1970s, and some changes with respect to safeguards may be considered in future facilities. For example, it is recognized that an aerial attack by helicopter could be effective against the guard force and vital equipment. Therefore, the general plant layout may warrant review from this aspect. However, uranium enriched to less than 5% is not an especially attractive target for potential safeguards violators, both because of the amount of material that must be diverted and the difficulty of extracting the fissionable isotope. In this regard, this facility is similar to and probably better than a coprocessing flow sheet for a mixed oxide fuel fabrication plant discussed as an alternative in Section 14.6.2.

(a) Safeguards used in this sense refer to the protection of Special Nuclear Material (SNM defined in 10CFR71) from diversion to unauthorized purposes and to the protection of the public from radiological hazards from plant sabotage.

REFERENCES

Westinghouse Electric Corp., Applications dated 6/20/69, USAEC docket No. 70-1151, pp. 15-16.

Schneider, K.J. and T.J. Kabele 1979. "Descriptions of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles", PNL-2286, Pacific Northwest Laboratory, Richland, Washington.

USNRC, "Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors", NUREG-0002, August 1976.

USAEC, "Environmental Survey of the Uranium Fuel Cycle", WASH-1248, April 1974.

Westinghouse Nuclear Fuel Division, "Recycle Fuels Plant-License Application," (Anderson, S.C.), Docket No. 70-1432, July 1973.

Westinghouse Electric Corporation, Environment Evaluation for Westinghouse Nuclear Fuel Division, Columbia, South Carolina, March 1975.

APPENDIX

TABLE 13.A. Efficiency of Process Gas Scrubbers

<u>Scrubber</u>	<u>Quantity</u>	<u>Location</u>	<u>Type</u>	<u>Efficiency</u>		
				<u>Chemical</u>		<u>Particulate</u>
S-2A S-2B	(2)	Plant Air Effluent	High Energy Venturi Cyclone	70-85%	(NH ₃ , HF)	90% (By Weight)
S-3	(1)	Vessel Vent Header	Packed Tower	90%	(NH ₃ , HF)	
S-1	(2)	Scrap Recovery	Venturi	90%	(NH ₄ F)	
Calclner Reaction Gas Effluent	(10)	Calclners	Venturi	75-80% 75-90%	(NH ₃) (HF)	90%
Incinerator Effluent	(1)	Incinerator	Impingment	75-85%	Acids	95%
DCFB	(1)	DCFB Off-Gas	Venturi	98%	(HF)	
	(1)	DCFB Off-Gas Scrubber	Packed Tower	97% 99%	(NH ₃) (HF)	

TABLE 13.B. Fractional Penetration of Wet-Process Polydisperse Aerosol Through HEPA Filters

Particle Size Range AMAD (μm)	Reference Wt. Fraction of Total	Penetration Fraction Through One HEPA Filter $\times 10^{-6}$
< .12	0.04	36 $\pm$ 36
0.12 - 0.22	0.1	54 $\pm$ 50
0.22 - 0.44	0.3	71 $\pm$ 59
0.44 - 0.96	0.36	64 $\pm$ 57
0.96 - 1.54	0.1	39 $\pm$ 33
> 1.54	0.1	30 $\pm$ 30

Distribution Weighted Mean 5.8 E-5

TABLE 13.C. Fractional Penetration of Dry-Process Polydisperse Aerosol Through HEPA Filters

Particle Size Range AMAD (μm)	Reference Wt. Fraction of Total	Penetration Fraction Through One HEPA Filter $\times 10^{-6}$
< .12	-	36 $\pm$ 36
0.12 - 0.22	0.0001	54 $\pm$ 50
0.22 - 0.44	0.002	71 $\pm$ 59
0.44 - 0.96	0.038	64 $\pm$ 57
0.96 - 1.54	0.10	39 $\pm$ 33
> 1.54	0.86	30 $\pm$ 30

Distribution Weighted Mean 5.8 E-5

14.0 FUEL REFABRICATION

The representative UO_2 - PuO_2 fuel refabrication facility is typical of current technology, and is modeled primarily on the design of the Westinghouse Recycle Fuels Plant (RFP), a proposed large-scale plant with the capacity in the range of 0.55 to 1.1 Mg of $(\text{UO}_2\text{-PuO}_2)/\text{day}$, or 200 to 400 Mg of $(\text{UO}_2\text{-PuO}_2)/\text{year}$ (WRFP ER, 1973). No sizeable UO_2 - PuO_2 fuel refabrication operation exists at this time.

14.1 SUMMARY

The plant chosen for this analysis ships 200 Mg/yr of mixed oxide fuel (MOX), having approximately the same reactivity as about 3% enriched uranium fuel (see Section 13) to nuclear power plants. The PuO_2 powder is received in special shipping containers in 2.2 kg quantities while the UO_2 powder is received in 55-gallon (208-liter) drums. The material is blended, compressed and fired to form small ceramic pellets. These pellets are loaded into zirconium tubes to form fuel rods, and the rods are assembled to become fuel elements, to be shipped to the power plant purchasing the fuel. The plant includes clean scrap recycle, dirty scrap treatment and recycle, and waste and effluent treatment. The plant is designed to protect the workers and public from radiation and actinide ingestion through the use of shielding, controlled air-flow, and filtration of air before exhaust. No radioactively contaminated liquid effluent is discharged from the plant. Ancillary activities within the plant concern physical security, material accountability, scrap recovery, waste preparation and packaging and test maintenance.

The representative plant presented here is based primarily on the proposed (W) plant, Anderson, South Carolina (Westinghouse, 1973). This material was significantly supplemented by material from Schneider and Kabele (1979) and several other sources referenced in the text. The estimates for the personnel distribution by task were made from experience and engineering judgment.

The plant inventory may be 600 kg of PuO_2 powder. A small fraction of this is stored in L-10 shipping containers and stored in the vault. Other fractions are in unloading and blending, but the bulk is in a storage hopper. Once the PuO_2 is mixed with the UO_2 to achieve the correct equivalent enrichment and formed into fuel pellets, it is no longer highly dispersible. Approximately 260 employees work at the facility in 3 shifts, and there is provision for up to 30 visitors. Most of the people are present during normal working hours, dropping to about 69 people on the 2400 to 0700 hours shift. Unit operations in the plant are, first: material receiving - unloading pallets holding PuO_2 in L-10 containers, and drums of slightly enriched or natural UO_2 , the necessary hardware to construct fuel pins and elements. The next major step is powder preparation, consisting of powder unloading, blending, and storage. Next is pellet preparation, consisting of compaction, granulation, pelleting, boat loading, sintering, and inspection. Then comes fuel rod loading, consisting of hardware preparation, pellet loading, rod welding, pressurizing, testing; and finally the fuel element assembly,

consisting of rod assembly, hardware installation, inspection, and shipping. Necessary ancillary activities are waste treatment consisting of: collection clean scrap recovery, dirty scrap recovery, liquid waste treatment, compaction, concretizing, and shipping. The analytic services provide the necessary product control through non-destructive assay, chemical assay, and radiographic analysis.

Material containment is immediately provided by the process vessels, which are contained in thick concrete shielding cells that are in the manufacturing building. All airflow is from the lowest radiation levels (normal access) to the highest levels (restricted access). All air from plutonium containing areas is filtered three times through HEPA (high efficiency particulate air) filters. The timely remote operations are: blending and pelletizing and dirty and clean scrap recovery. Plutonium unloading is a glove box operation. The other questions, such as fuel loading and welding, are contact operations. Plant maintenance is contact, but only after suitable decontamination has taken place.

The basic radiological safety concerns of the Fuel Refabrication Facility are associated with the high toxicity and high mobility of plutonium powder. Its alpha particle emission causes the particles to exhibit much greater mobility than inert particles of the same size. The activity also gives rise to concern regarding self-heating in the large storage hoppers, possibly causing an exothermic reaction of UO_2 by forming U_3O_8 . In principle this could lead to plant fires. However, these are suppressed by cooling and careful control over all combustibles, such as process solvents, hydraulic fluid, etc. Another source of accident-causing energy is a large amount of fissile material that could possibly cause a nuclear criticality accident. The inclusion of the wet scrap recovery process increases the possibility of organic fires and nuclear criticality accidents. The scrap recovery could be conducted in a reprocessing facility where such is the main process.

External events that can degrade the multiple plant barriers are: aircrashes, earthquakes in excess of the design basis, tornadoes capable of generating missiles that would penetrate the multiple protection, and floods that could remove radiological material by water transport. Some other types of external events, such as forest fires, are mitigated by siting considerations.

Spills, failed glove box gloves, and blow-back on the instrumentation sampling lines are examples of accidents that may affect the plant workers in addition to those cited above that affect the public.

Besides the obvious physical barriers, other barriers are the product powder size distribution, which strongly affects HEPA filtration efficiency and stable aerosol densities. Several plant and process alternatives are discussed, such as coprocessing of the uranium and plutonium powders that could be mixed at the reprocessing plant, colocation of the reprocessing and refabrication plants, dirty scrap recovery at the reprocessing plant,

pneumatic transfer air recirculation, remote maintenance, and a coprecipitation front end.

14.2 MAINLINE PROCESS DESCRIPTION

A criterion used in selecting a model plant for risk analysis is the representativeness of the model plant to the plants used in the anticipated fuel cycle. This model plant represents a considerable scale-up over existing plants; hence, it would not be wise to seek a larger plant. The more details known about the plant and process, the more accurately a risk analysis reflects the risk of a facility. In this regard, the detailed analysis that has gone into this plant design enhances its usefulness as a model.

Figure 14.1 provides a schematic of the mainline plant processes. Each box in the schematic contains a number that keys it to the subsection where the process step is discussed (e.g., box 1 is discussed in Section 14.2.1).

14.2.1 Material Receiving and Storage

The PuO_2 is shipped by truck to the plant in two 2.2 kg containers which are contained within a L-10 Class B container (see Section 19) as required for this class of radioactive material (10CFR70). Four L-10 containers are shipped on a pallet. A fork-lift truck is used to unload the pallets and transport them to the storage vault where the material is stored until needed for the process.

The UO_2 is shipped by truck in 55-gallon drums on pallets (one drum per pallet). The trucks are unloaded at the unloading dock by a fork-lift truck. The drums are transferred to the uranium storage area until required by the process.

The fuel rod and fuel element hardware is shipped in hermetically sealed packages by truck, unloaded at the dock by a fork-lift truck, and transferred to the rod assembly area where it is stored in its shipping containers until required.

14.2.2 Fuel Material Unloading

This section describes the handling and storage of the incoming shipments of uranium and plutonium powder.

Plutonium Dioxide Powder

As required by the process flow, the L-10 containers are transported from the vault on a manually-propelled dolly, fitted with motor-driven screw jacks to the unloading station which consists of four compartments.

The L-10 container is moved into compartment 1, and the lid assembly is removed and surveyed for any potential contamination. All exposed surfaces of the open L-10 are surveyed. The bagged vermiculite is then removed and a

Note: The number (x) in each box refers to the section 14.2.x number.

FIGURE 14.1. Fuel Refabrication Mainline Process Schematic

further survey is conducted. The vent valve cover and pressure vessel flange are removed, and the L-10 is surveyed again and decontaminated if necessary. The L-10 assembly is then jacked up so that the top of the opened drum mates to a seal around an opening to compartment 2. When the seal is made, as observed by visual inspection, the external container of the L-10 will complete the confinement barrier. The door to compartment 1 is then closed. Compartment 1 is basically a hood assembly and contains a negative pressure with respect to the surrounding work area.

In compartment 2, a hoist clamp is manually connected to a lifting lug of a large can. This large sealed can contains two sealed cans of PuO_2 . The can assembly is lifted out of the L-10 pressure vessel, moved by the hoist along a monorail, and lowered through a port into compartment 3. After disconnecting the hoist clamp from the can assembly, the port connecting compartment 2 to compartment 3 is closed. The empty L-10 shipping container in compartment 1 is sealed and returned to storage.

Remote handling is utilized in compartment 3 by using manipulators. The large outer can is opened using a can cutter. The two inner cans, containing a total of approximately 4.5 kg PuO_2 , are individually weighed. The top of each can is removed by a mechanical can-opener. A pneumatic transfer tube is inserted into an open can of powder and the contents are transferred to PuO_2 bulk storage vessels. When powder transfer is completed, each empty can, with lid, is reweighed to obtain a tare weight. Reweighing the empty cans allows a comparison to be made against the shipper's weights and also ensures that all the powder has been removed during transfer. Each empty can will then be cleaned to remove any residual powder adhering to the inner walls. The cleaned empty cans are checked by a gamma scanning device and transferred into compartment 4.

When the drum in compartment 3 is ready for removal, the bag is sealed, disengaged from the port, surveyed for alpha contamination, and the drum lid is replaced, sealed and transferred by dolly to the miscellaneous waste treatment (MWT) system for the appropriate handling.

A drumming station is located beneath compartment 4. The cleaned empty cans are transferred to this section for compaction. The small compactor compresses cans prior to transfer to the lined 55-gallon drum. This drum station is primarily used for compacting cans; however, defective equipment items with gross quantities of PuO_2 removed may be placed in the drum. The drum is then surrounded by a hooded shroud with air flow into the limited access area from the nonrestricted access area to control release of radioactivity. When the drum is filled, the bag containing the contents is sealed, the drum lid is replaced and sealed and the closed drum is then transferred by dolly to the drum scanning station in the miscellaneous waste treatment area. In this manner, the PuO_2 powder is transferred from the shipping containers to be contained within the process vessels and piping within the process cells, which in turn are inside the secondary containment afforded by the plant building.

Maintenance outside of the unloading equipment is routine. Maintenance of any unloading equipment outside the unloading station is routine. Minor equipment repair may be accomplished inside the unloading station as contact maintenance through gloves. Contact maintenance is limited to compartments 1, 2, and 4 of the unloading station. Remote maintenance will be required in compartment 3. Provision is made for removal of defective equipment to drums.

Uranium Dioxide Powder

UO₂ powder is received in sealed 55 gallon drums. The drums are weighed and placed in storage as described. When production demands require, UO₂ powder is removed from the shipping drums and transferred to the UO₂ transfer hopper via a pneumatic conveyor. The UO₂ transfer hopper serves as storage for UO₂ powder outside the restricted access area. The transfer hopper is equipped with a high-powder-level alarm to indicate when it is full, a low-level alarm to indicate that more drums of UO₂ should be introduced into the system, and a low-low-level alarm that prohibits discharge of UO₂ powder from the transfer hopper.

14.2.3 Powder Blending

Powder blending is performed by accepting powder from three types of hoppers: UO₂, PuO₂, and MOX coming from recycled materials. Careful control is necessary to assure product specification and uniformity.

The plutonium powder is pneumatically transferred from the unloading station to one of three storage vessels, each capable of holding 170 kg of PuO₂. As one vessel receives the powder, the last-filled vessel is being analyzed, and the third is supplying powder in batches to the blending station. (During the pneumatic transfer of powder, mixing and aeration by low pressure dry air is taking place.) The storage vessel selected for discharge supplies powder to the PuO₂ feed hopper until the high-level trip indicates an amount of material equal to approximately 120% of that required for a batch of mixed-oxide blend.

Similar to the plutonium feed, the uranium feed receives UO₂ powder from the transfer station. This is transferred by pneumatic conveyor to the UO₂ transfer hopper which stores the powder outside of the restricted access area (all of the plutonium handling is inside the restricted access area). This hopper has a high-level alarm to indicate that it is full, a low-level alarm to call for more material, and a low-low-level alarm prohibiting discharge of the UO₂ powder when it is tripped.

The mixed-oxide-recovered powder is transferred from one of three storage vessels to the mixed-oxide feed hopper with similar interlocking controls to those on the plutonium and uranium hoppers; except that the isolation valves on each of the powder feed systems are actuated remotely by the batch control system.

After the feed hoppers of each component are charged, the respective weigh hoppers will be allowed by the interlocks to operate if:

- the blender has operated since the last-fill discharge cycle
- the positive discharge shutoff is closed
- the weight hopper calibration cycle has been completed.

When it is necessary to recharge the blend hopper, feeders supplying the three types of powder start at full speed, but go to slow and then stop on the required amount. After the weigh hoppers are charged, the operator may initiate blender charging under programmed control only if each weight hopper contains the required amount of powder. Blender charging begins with aligning and connecting inlets to the UO₂ and MOX weigh hoppers. If this alignment is not correct, interlocks prevent discharge. (Plutonium alone cannot be discharged.) Following the completion of blender loading with these materials, the blender is rotated 180° and aligned with the plutonium weight hopper, and the plutonium is loaded. With the blender inlet and outlet valves closed, the blender drive motor is energized for the required number of blending revolutions. This operation is followed by gamma scanning to verify blend uniformity.

Upon completion of acceptable blending, the powder is transferred to one of nine storage silos by passing through a reduction mill. The powder is sampled during this transfer at the reduction mill output. A metal cylindrical carrier containing the powder is transferred by the conveyance system to the analytical services facilities for analysis. If the blend is rejected, it is transferred to clean scrap recovery; if accepted, to slugging.

When a sub-blend of mixed oxide powder is uniformly blended and ready for release from the blender, one of nine mixed oxide silos is selected for storage. The diverter valves in the pneumatic conveyor which route the powder from the powder reduction mill are positioned for flow to the selected silo. The blender discharge is aligned and coupled with the reduction mill feeder. The blender discharge valve is opened and the reduction mill drive and the mill feeder drive are actuated for a time interval, as required to completely empty the contents of the blender and mill. The discharged milled mixed oxide powder is transferred to the silo via a pneumatic conveyor. The completion of the powder batch transfer is confirmed by the indication of a weigh cell system which is part of the silo.

14.2.4 Compaction, Granulation, Pelletizing, Boat Loading and Green Pellet Storage

This section describes the processes that prepare the MOX for firing the ceramic fuel pellets.

Compaction

When the slug press requires material, a powder storage silo of released powder is selected. The diverter valve in the transfer line is positioned to permit transfer from the silo to the slug press feed hopper. Once the pneumatic transfer system has been activated and powder is being transferred, the slug press can be started, which in turn starts the granulator and classifier. During this time the pellet press continues to operate until its feed hopper reaches its low level. When the slug press operates, it feeds powder into a die and compacts it into short wafers called slugs. The slugs are conveyed to the granulator feed hopper by a mechanical conveyor.

Granulation

The slug conveyor, granulator, and classifier run in response to demand from the pellet press. The granulator reduces the slugs to granules. The resulting granules are passed through the classifier, which screens them into over-size, acceptable sizes, and under-size particles. The over-size granules indicate a broken screen and the material is collected as dirty scrap, acceptable granules are transferred by a pneumatic conveyor to the pellet press feed hopper, and under-size granules are returned for re-slugging.

Pellet Pressing

Granulated powder is fed from the pellet press feed hopper into dies in the pellet press where it is pressed into pellets of a uniform density and size. The pellets are discharged to the boat loader. The level of granules in the feed hopper of the pellet press controls the classifier and granulator, stopping them on high level and starting them on low level.

Rejected pellets go to clean scrap. Samples of the pellets are extracted from the flow and checked for density after which they go to clean scrap.

Boat Loading

Empty molybdenum boats arrive at the boat loading station (from the sintering furnace complex), and pellets are stocked in the boats. The control system stops the pellet press if no empty boats are available or in the event the loader fails to discharge a full boat. Loaded boats are conveyed to a green pellet boat transfer station, where the boat is picked up and placed in green pellet storage by a boat stacking and retrieving machine.

Green Pellet Storage

The green pellet boat storage unit is served by the green pellet stocking and retrieving machine. The storage unit is designed such that boats must be stored only in specific locations which form an array of slabs of favorable geometry less than a critical mass.

14.2.5 Sintering, Inspection and Pellet Storage

This section describes the firing process followed by inspection and storage preparatory for precision grinding.

Sintering

When required, a boat loaded with green pellets is mechanically removed from green pellet boat storage and placed on the shuttle car pickup station and then transported to one of five furnaces. Each furnace has space for storing three boats of green pellets outside the furnace entrance air lock. The furnace operates at approximately 1700°C in a reducing atmosphere of forming gas (about 6% hydrogen and 94% nitrogen at 5 to 10 cm water pressure (2 to 4 in.w.g.) above ambient pressure.

The air lock is purged with forming gas whenever a boat is inside. Upon command from the furnace control system, the inner door of the air lock opens and the boat moves from the air lock conveyor on to the preheat section conveyor. The inner air lock door is then closed. The boat moves forward on the preheat section conveyor until it is engaged by the walking beam conveyor. The walking beam conveyor then advances the boat through the heating section of the furnace in timed incremental steps. At the far end of the furnace the boat leaves the walking beam to be moved by the cooling section conveyor. The cooling section conveyor moves the loaded boat through the cooling section to the exit air lock conveyor in the exit air lock. On command, the inner door of the exit air lock closes, the outer door of the air lock opens and the boat moves out of the air lock onto the exit conveyor. Forming gas is introduced into the exit air lock whenever a boat is inside. When the boats reach the exit conveyor, they are safely cool.

The entrance feeders of all furnaces are located within restricted access enclosures having glove ports and view windows for access to equipment and components.

Inspection

All boats of sintered pellets discharged from any furnace are transported to the sintered pellet density inspection station by a shuttle car. The density, as determined from the inverse of the volume/weight ratio of selected pellets, is measured and the data is used to determine the disposition of pellets. Boats of under-fired pellets are returned for resintering, over-fired pellets are sent to clean scrap recovery, and boat loads of acceptable pellets are transported to the sintered pellet storage to await release to the pellet grinder as production demands require.

Storage

The sintered boat pellet storage is a shielded enclosure having storage racks or compartments with a capacity to store approximately 135 loaded pellet boats.

14.2.6 Pellet Grinding, Inspection and Storage

This section describes the firing process followed by inspection and storage preparatory for precision grinding.

Grinding

Boats loaded with accepted sintered pellets are removed from storage by a stocking and retrieving machine, and are conveyed to a diverter which directs them to either processing line, at the option of the operator. A boat unloading device in each line transfers pellets from the boat, aligns them, and directs them to a single-file conveyor which carries pellets to the grinder. Broken pellets and chips are removed from the boats after transfer and collected as clean scrap. The conveyor delivers pellets in single file to the water-cooled grinder. Stopping the grinder automatically stops the feed of pellets from the boat unloader so excess pellets cannot flood or jam the system. Coolant water is pumped from a settling tank to the wheels of both grinders, collected, and pumped back to the settling tank. Surface water is removed from the pellets by drawing air, at high velocity, over the pellets as they exit the grinder.

Inspection

The dimensional check station measures the diameter of pellets. This station rejects over-sized diameter pellets and directs them to a collection container for transfer back to the grinder for regrinding. Under-sized pellets are diverted to a clean scrap collection container. Acceptable pellets are conveyed to the chip inspection station, after which the pellets are mechanically conveyed and automatically loaded onto storage trays. The pellets are placed in grooves in the trays. One groove is loaded, then the loader indexes the tray to bring the next groove into the loading position. When a tray is fully loaded, it is transferred to the pellet dryer conveyor.

A tray holds approximately 900 pellets for a total pellet weight of 9.6 kg. The trays are used to facilitate handling, storage, retrieval, and identification of pellet groups in the storage units. After inspection, the pellets are vacuum-dried and analyzed for moisture.

Storage

Tray loads of pellets are placed in one of two storage units where they are held until released for rod loading. The storage capacity is about 8 MgHM.

14.2.7 Fuel Rod Loading

Batches of empty fuel tubes, with bottom plugs welded in place, are removed from storage. These batches are placed in one of the two tube loading enclosures. A tube is loaded with pellets by positioning the upper end of the tube through a sealed port and locking it in place. A tray of pellets, removed from storage by the stacker, is placed on the tray support adjacent to

the loading fixture. A row of pellets on the tray is aligned with the loading fixture and mechanically pushed into the tube. This operation is repeated until the tube is filled. The tube is then removed from the port seal and the open end is decontaminated. Following decontamination, the rod surface is checked with an alpha monitor to verify the removal of any contamination. If the rod cannot be decontaminated to within specified limits, the end is sealed with a suitable plastic bag which is taped in place, and the rod is sent to the rod repair and dismantling station.

The decontaminated tube is removed from the decontamination station and placed in the top end plug pressing station, a spring is inserted into the rod, and a top end plug is pressed into place.

The assembled rods are removed from the tube loading enclosure and transferred to the rod welding enclosure via a shielded carrier. The rods are placed in the pre-weld storage section of the welding enclosure. One rod at a time is positioned in the girth welding machine. When the girth weld is completed, the weld is visually inspected and, if acceptable, the rod is transferred to the pressure welding machine and positioned in the chamber. The machine pressurizes the chamber with helium gas and the rod is seal welded. The weld is visually inspected, and the rod is transferred to the post-weld storage section of the glove box, where the rods are collected on carriers. The carrier is transferred to an air lock. The air lock is located in the wall between the manufacturing building and the rod inspection building. The carrier is passed through the air lock into the rod inspection area and stored until ready for testing and inspection.

14.2.8 Fuel Rod Testing, Inspection and Storage

This section describes the quality assurance testing of the completed fuel rods and their storage before assembly.

Testing and Inspection

Rods to be tested are removed from the air lock and pre-inspection storage in groups, and are placed in one of two vacuum chambers. A vacuum is pulled in the chamber, and the exhausted air is checked with a mass spectrometer to detect any leaks as would be evidenced by the presence of helium.

Rods are gamma scanned individually to verify that pellets are of uniform composition, and that no pellets are missing.

The top plug welds of loaded rods are X-rayed in groups to examine the weld integrity. The bottom plug welds on empty tubes are X-rayed in the same manner.

Rods are given a final inspection manually and visually for straightness, quality of welds, dimensional check of diameter and length, and are weighed.

Storage

After final inspection, the fuel rods are placed in one of four shielded storage compartments. Each pair of compartments is arranged so a stacker operating in a center aisle can store or retrieve channel carriers (containing rods) on modular racks which are located on both sides of the aisle. When carriers enter or leave the storage area, a shield door automatically uncovers an opening at one end of the aisle to allow pass-through.

14.2.9 Fuel Element Assembly and Shipping

Finished fuel rods are unloaded from storage racks or containers and inserted into appropriate fuel assemblies. 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
- 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) will 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) will contain $\text{UO}_2\text{-PuO}_2$ fuel pellets and the remaining rods will contain UO_2 fuel pellets.

Information on the design of mixed oxide fuel assemblies for large, modern LWRs is largely proprietary. PWRs are assumed to use mixed oxide fuel in separate and distinct fuel assemblies. For BWRs, it is 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, UO_2 fuel rods.

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, a fine water spray is used on the rods during insertion to give some lubrication; in other cases, 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.

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 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. The BWR fuel assemblies are assumed to be shipped in Model RA-1 shipping packages.

14.2.10 Fuel Rod Dismantling and Repair

Repairable or rejected fuel rods originate from the following inspection stations in the rod inspection and storage area: helium leak test, gamma scan, X-ray, and visual inspection. The rods are collected and transported manually in shielded carriers to the rod repair and dismantling enclosures. 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 correction of 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.

The repairable rods are those having a defect in the top end plug girth or seal weld, or those not filled properly with pellets. Repairable rods are depressurized in the first glove box. The top plug is cut off, the existing spring is removed, the rod end is decontaminated, a new spring is installed and the repair plug is pressed into place. The rod is monitored for contamination and cleaned, if required. Decontamination of repaired rods with new springs and repair plugs is performed in a separate isolated portion of the first glove box, prior to transference to the second glove box. The rod is transferred through the air lock to the adjacent welding and pressurizing glove box where the rod is placed in the welding machine and girth welded. The rod is then placed in the helium pressurization chamber, internally pressurized with helium, and the small hole in the top plug seal welded. The repaired rods from the second glove box are transported in a shielded carrier to the helium leak test station in the rod inspection area.

Rejected rods are depressurized in the first glove box, and end plugs are cut off and the springs are removed in the same manner as for the repairable rods. The pellets are removed, and damaged pellets are collected in containers and sent to the clean scrap feed hopper for recycle into the clean scrap supply. Pellets which appear undamaged are collected and transported to the pellet inspection station in the restricted access area via conveyor and manipulator. Scrap metal from cut-up rejected tubes, swabs and other waste, and salvaged pellets are placed in containers and are transported by conveyor from the first glove box into the restricted access area, for material recovery and waste disposal.

14.2.11 Clean Scrap Recovery System (CSRS)

Clean scrap is collected at various fabrication steps in small geometrically safe transport containers and transported within the restricted access area to the CSRS. In CSRS the clean scrap is charged to the system in approximately 20 kg batches where it is size reduced in a roll crusher and subsequently processed by multiple oxidation-reduction steps. Following the final reduction step, the material is transferred pneumatically in 20 kg batches to any one of three large storage vessels where successive batches and any mixed oxide material returned from the pelleting supply storage vessels are mixed together.

The CSRS is designed to treat the following types of material:

- off-density green pellets
- over-fired pellets
- grinder sludge
- pellet inspection rejects (nicked, undersize, cracked)
- rod repair pellets

A collection container has an attached lid closure and a normally closed bottom valve for emptying. The bottom valve is provided with a blank-off to prevent accidental dumping. The container design is compatible with the restricted access area conveyor system which in turn insures maintenance of adequate spacing of containers during transport back to the head-end of the scrap recovery process. Each collection point will have only one container accepting scrap. When filled, the outside surfaces are wiped clean, if necessary, and placed on the conveyor before another container may accept scrap.

Upon making connection between a clean scrap collection container and the roll crusher, the crusher is turned on. The container valve and the crusher inlet valve are both opened and the contents emptied by gravity into the crusher. The material passes through rollers which break down sintered pellets so that the maximum particle size is reduced to about 0.6 cm (0.25 in.). After the entire batch has been processed, the crusher is shut off, the two valves closed and the container is separated from the crusher. A dust collection shroud is attached to the crusher around the scrap container/crusher inter-connection to collect oxide dust which may be released at the time the equipment is separated. The exposed surfaces between the valves are cleaned after disconnection to prevent dispersal of oxide dust. The crushed material is discharged to the oxidation reactor feed hopper.

The oxidation reactor is charged with clean mixed oxide scrap from the feed hopper in batch quantities of approximately 20 kg. The reactor temperature is maintained by means of an electrical heating jacket and control

system. Preheated air is introduced through the reactor to keep the scrap agitated and to obtain uniform exposure to the hot air. The material is held in the reactor under these conditions for a specified period of time during which the UO_2 is oxidized to U_3O_8 powder. (Formation of the higher oxides results in an expansion that pulverizes the material.) The PuO_2 remains unchanged chemically.

The exhaust air, partially depleted in oxygen, is taken from the top of the reactor through stainless steel sintered metal filters which retain the oxide powder within the reactor. Filters are prevented from loading up by giving a short blow-back pulse of air periodically to clear them. A controller is employed to provide the blow-back pulse, in sequence, to all of the several filters in the reactor head. Thus, air flow through the oxide bed is not greatly affected.

After completion of the initial oxidation, the product is transferred pneumatically to one of the two alternate reduction-oxidation-reduction reactors.

The reaction off-gases from all reactors pass through sintered metal filters and are received by a common off-gas header. To guard against loss of actinides in the event any one of the many filters in the reactors should develop a leak, a back-up sintered metal filter is inserted in the common off-gas header.

Three clean scrap storage vessels are used to receive the product from the reduction-oxidation-reduction reactors. Each vessel is designed for a working capacity of 720 kg of processed scrap. One vessel at a time is receiving processed product, another recently filled vessel is awaiting quality certification, and the third vessel is supplying material in batches as required to the mixed oxide blend station. Thus, the three vessels provide an uninterrupted supply of processed clean scrap available for return to the process stream.

As material is transferred pneumatically from the reactors, a pneumatic mixing operation is activated in the receiving storage vessel and is kept operating for about an hour. This procedure insures mixing of all the material delivered to the storage vessel to produce a uniform stock in the vessel. Once the vessel is filled and mixed, a sample is taken and analyzed for enrichment level and for physical properties related to satisfactory pelleting. Nitrogen is used for the transfer of hot product from the reduction-oxidation-reduction (R-O-R) reactors and for mixing operations in order to prevent reoxidation.

Rather large flow rates of N_2 gas are required to blend product in the clean scrap storage vessels and for transfer of processed scrap from the R-O-R reactors to clean scrap storage. Therefore, a recirculating nitrogen system is incorporated. It is comprised of filters, a gas cooler, and instrumentation required for controlling system gas pressure through makeup and dump valves. Besides conserving gas, this system, through its cooler, has the

function of removing residual heat from the product as it leaves the reactors and of removing the autogeneous heat generated by the plutonium while in storage.

14.2.12 Dirty Scrap Recovery System

Contaminated materials generated within the restricted access area may be dirty scrap that is mixed-oxide fuel which has become mixed with non-fuel material. Material falling into this category is:

- contaminated MO_2 and PuO_2 power, pellets, chips
- sweepings
- analytical and quality control samples
- liquid wastes from analytical services facility
- filter elements from liquid waste treatment and liquid effluent treatment.

These wastes are placed in metal cans at the point of origin and transported to miscellaneous waste treatment where they are neutron scanned for plutonium content. Those that are only slightly contaminated are packaged for offsite disposal as TRU-contaminated waste; the remaining material is subjected to Purex extraction to remove both the uranium and plutonium.

The process flow sheet is shown in Figure 14.2. The scrap is dissolved in HNO_3 -HF acids followed by filtration for particulate removal. This is followed by feed adjustment using aluminum nitrate to complex the fluoride, leaving the dissolved wastes in a pH-adjusted acid stream. The stream flows to a pulsed column where it is contacted with organic: tributyl-phosphate (TBP) diluted by a paraffin-base solvent. The organic from the column bottom is stripped and the values are concentrated and go to clean scrap for conversion to PuO_2 - UO_2 by the reduction-oxidation-reduction process described in Section 14.2.11.

14.2.13 Decontamination and Hot Repair

Equipment to be brought into the decontamination cell is emptied of process materials and is broken down and decontaminated to the extent practicable while at its normally installed position or in the restricted access area (RAA). Equipment is transferred to the cell by means of the RAA second floor crane and is lowered into the decontamination cell area through an 2.4-meter-square (8-foot-square) hatch which is provided with a remotely removable cover.

In the cell, equipment components for decontamination and/or repair can be moved between areas and can be positioned within the cells by means of motorized carts on a system of tracks with 2.4-meter-diameter (8-foot-diameter), 4.5 Mg capacity turntables. In addition, both cell areas are

FIGURE 14.2. Dirty Scrap Recovery and Reconversion for Model 200 Mg Mixed-Oxide/Year Fuel Refabrication Plant

provided with 4.5 Mg overhead cranes and with manipulators. Glove ports and shielded viewing windows, for use in the maintenance operations, are located at key positions along the cell walls. Television cameras and periscopes are also provided for viewing. Controls for all internal mechanisms, tools and other services are provided outside the cell.

Services provided for the decontamination area include the following:

- a recirculating water flushing system with provision for addition of non-flammable reagents, degreasers
- steam 21 kPa (30 psig), provided by an independent steam generation system
- compressed air from the plant system.

In addition, vacuum cleaners are provided in both the decontamination and repair areas, for use in operations for which dry cleaning is adequate. Within the cell areas, the permanently installed equipment and piping components are of fabricated stainless steel, insofar as practicable.

The principal components of the recirculating flushing system are located in the decontamination area of the cell. The system includes two 380-liter (100-gallon), geometrically favorable tanks whose contents can be pumped via nozzles or a spray head, for decontamination operations. The vessels are vented via an in-cell filter to the plant exhaust system. In operation, equipment to be decontaminated is treated using this system, plant water, steam, or air. Liquids drain to a geometrically favorable cell-floor sump from which they are pumped through cartridge-type filters to remove the oxide solids before going back to the tanks. The liquid is sampled and analyzed for Pu prior to transfer to liquid waste treatment (LWT).

Following decontamination, components are normally repaired in the adjacent repair area, or they may be bagged out for offsite disposal. The repair area is provided with machine shop equipment and other tools. Vacuum cleaning equipment is also available, for dry cleaning. Liquids are not normally used in this area, although a geometrically favorable sump with a sump pump is provided.

Bag-out of equipment for disposal is accomplished via a 2.4-meter diameter (8-foot-diameter) bag-out hatch in the ceiling adjacent to the decontamination and repair cell. Equipment is transported from the cell, using the RAA second-floor crane, and is inserted through the bag-out hatch into a bag suspended below. The bagged equipment is removed from the area on dollies or fork-lift truck.

For bringing in new equipment, the operations just described are performed in reverse order.

4.2.14 Analytical Services

The analytical services facility (ASF) is responsible for the analysis of feed materials, process streams, fuel product and the destructive analysis on scrap materials.

The sub-critical areas are maintained with the ASF, each having a fissile capacity limit of 290g of plutonium. All transfers between subcritical areas are made pneumatically through the central material handling station (CMHS), with the exception of liquid waste, which is vacuum transferred from hoods to the liquid waste pretreatment. The CMHS has control of all internal pneumatic transfers.

Samples are removed from the process stream and are placed in pretared and precalibrated containers. The sample container is pneumatically transferred to the CMHS. A request for transfer and analysis is then forwarded to the ASF-CMHS which includes the container and sample identification, the approximate weight and the nominal fissile content.

A continuous material balance sheet is maintained at the CMHS, and no transfers are permitted that would cause the fissile balance to exceed the approved criticality limits for that area. This condition is maintained by exclusive control of all transfers by the CMHS.

At the CMHS, sample material is subdivided into the predetermined proportions required to perform the necessary analyses. Each sub-sample is weighed and transferred to a sub-critical station responsible for the analyses requested. A continuous fissile material balance is maintained at the CMHS for each sub-critical area. The CMHS is not permitted to transfer material to any sub-critical station that causes the approved criticality limits to be exceeded. Each sub-critical station may contain several glove boxes and hoods. Material movement within each sub-critical area is manual, either through tunnels or air locks, and is not restricted with respect to criticality controls.

For an annual production rate of approximately 200Mg/yr, an estimated 200 grams of plutonium could be processed through the ASF per week.

14.3 DESCRIPTION OF EFFLUENT CONTROL PROCESSING AND WASTE MANAGEMENT SYSTEMS

The control of plutonium and its radioactive decay daughters in the effluents and wastes from the representative mixed-oxide fuel fabrication facility is the major concern, while control of uranium is secondary. The control of plutonium as well as americium, thorium and uranium involves both liquid and airborne effluent control, and liquid and solid waste management. Some nonradioactive effluents are also controlled to some degree.

14.3.1 Liquid Effluent Processing

The processing of liquid effluents in the representative facility is shown in Figure 14.3, excluding the sanitary effluent control. Separate collection and pre-treatment 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 (38 $\pm$ 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 radioactivity and is pumped through a filter to a potentially contaminated quarantine tank (3800 $\pm$ or 1000 gal.). Provision is made, however, to pump the wash water through a filter back to the smaller potentially contaminated sump tank (800 $\pm$ 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 (760 $\pm$ or 200 gal.) provides retention capacity while the contents of the larger tank (2300 $\pm$ or 610 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 $\pm$ or 1000 gal.) for discharge to the sanitary treatment system and eventual discharge to the river.

If the alpha activity exceeds the maximum permissible discharge limit, the liquid is transferred from the larger sump tank to a treatment tank (2300 $\pm$ or 610 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 $\pm$ or 1000 gal.) for deactivation treatment. The filters are mounted inside an enclosure to collect particulates that may be present. Spent filter cartridges are transferred to the miscellaneous waste treatment system.

Deactivation treatment is accomplished by passing the contaminated solution through absorption-adsorption ion exchange beds at a controlled flow rate to a deactivation product tank (3800 $\pm$ or 1000 gal.). If product analysis shows that the deactivation treatment successfully reduced the contamination level to 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.

The primary chemicals in the liquid effluent from the plant are PO_4 , NO_3 , SO_4 , Cl and Na ions. The first two chemicals are plant nutrients; however, in the estimated quantities shown in Table 14-1, plant growth will not be stimulated because the quantities are too small.

It is also estimated that the plant will release $4.7\text{E}-8\mu\text{Ci/cc}$ (Westinghouse, 1973) and $1.9\text{E}-6\mu\text{Ci/cc}$ of alpha and beta emissions, respectively, from plutonium in the water discharge.

FIGURE 14.3. Process Flow Diagram: Liquid Effluent Treatment System for the Mixed-Oxide Fuel Fabrication Facility

TABLE 14.1. A Comparison of Ambient Chemical Concentrations in the Plant Discharge and Receiving Waters with Estimated Concentrations Due to MOX Plant Operation

Chemical	Concentration, mg/l						
	Plant Discharge Concentration	In East Branch Creek		In Weems Creek			
		No (a) Discharge	Plant Discharge, 0.33 cfs	No (a) Discharge	Plant (b) Discharge 13.25 cfs	Plant (c) Discharge 4 cfs	Plant (d) Discharge 0.94 cfs
PO ₄	1.27	0.1	0.19	0.1	0.10	0.10	0.13
NO ₃	15.7	0.23	2.91	0.32	0.38	0.54	1.33
SO ₄	0.7	<1.0	0.97	<1.0	1.0	2.0	0.99
Cl	6.2	6.0	6.0	6.0	6.0	6.0	5.0
Na	17.3	1.25	1.37	1.0	1.13	1.24	1.59
Total dissolved solids (TDS)	100.4	31.0	36.3	53.0	56.7	57.3	58.2

- (a) Ambient conditions based on February 1973 survey.
 (b) February 22, 1973 flow conditions.
 (c) Summer conditions - no natural flow in East Branch.
 (d) Drought conditions - no natural flow in East Branch.
 (e) 1 cfs = 28.3 l/sec.

14.3.2 Airborne Effluent Processing

The treatment of airborne effluents from the mainline processes in the representative facility is shown schematically in Figure 14.4. The following paragraphs discuss airborne effluent control for individual mainline process steps:

PuO₂ Unloading and Storage

The exhaust air from the pneumatic conveying system moves 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 moves through another bank of sintered metal filters, prefilters, and HEPA filters before discharging to the plant exhaust system. The exhaust air from airjet 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 facility information is not clear.) Vent air from the UO₂ transfer hopper is prefiltered, HEPA-filtered and discharged to the normal access area atmosphere. Vent air from the UO₂ feed and weight hoppers, the PuO₂ feed and weight hoppers, the UO₂-PuO₂ feed and weight 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 filtered through a sintered metal filter and then discharges to the UO₂-PuO₂ pneumatic conveying system exhaust for further filtration.

FIGURE 14.4. Process Flow Diagram: Airborne Effluent Treatment System of the Mainline Process for the Representative Mixed-Oxide Fuel Refabrication Facility

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, and 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 passed through a sintered metal filter, a backup sintered filter, a prefilter, and a HEPA filter, and discharged to the plant exhaust system. All air exhausted from the manufacturing building passes through a minimum of two HEPA filters before discharge to the environment.

To minimize and restrict radioactive contamination within the facility, three zones of confinement are provided. The outer zone, or normal access area (NAA), 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 normal access area (NAA). The second zone, or limited access zone areas (LAA), is used only for sampling and maintenance access to the third zone. The third zone, or restricted access area (RAA), includes glove box interiors, decontamination and repair cell interiors, and process lines and powder fabrication equipment. These latter areas possess the highest level of 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 release to the environs. Recirculation of air in the normal access area amounts to about $1.1\text{E}9$ m^3/day (27,000 cfm), in the limited access area about $2.4\text{E}8$ m^3/day (6,000 cfm), and in the restricted access area about $2.9\text{E}8$ m^3/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, thereby 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 14.5. The caustic gas scrubber scrubs out contaminants in the airborne releases from two fume hoods, various glove box vents, oven and furnace off-gases from the miscellaneous waste treatment roasting glove box, and an acid tank vent.

The continuous discharge of low-level radioactivity through the process building ventilation system is estimated from the experience obtained from operation of the pilot plant plutonium fuel fabrication facilities located at Cheswick, Pa. The Cheswick facility has a ventilation and filtration system very similar to that proposed for the representative facility. The number of stages of filtration and the flow rate per filter are the same. Furthermore, the glove box design is expected to be comparable or superior for the representative facility compared with the Cheswick facility. The overall air flow rates are also comparable on a scale up basis ($400\text{ m}^3/\text{min}$ at Cheswick vs $900\text{ m}^3/\text{min}$ for the FRFP). Thus, the experience gained from measurements of air discharge activity levels at Cheswick should be directly applicable to the expected release rates at this representative facility.

Measurements of gross alpha activity concentration levels at the ventilation exit of the Cheswick plant over the past several years have shown the average levels to be less than the detectable level of $5.4\text{E}-14$ $\mu\text{Ci}/\text{cc}$ of alpha activity. By using this value and the design air volume flow rate of $900\text{ m}^3/\text{min}$ (32,000 cfm), the total plutonium alpha activity release to the atmosphere is conservatively calculated to be $4.0\text{E}-6$ $\mu\text{Ci}/\text{sec}$ of mixed plutonium isotopes.

14.3.3 Waste Management

The radioactive contamination of greatest concern in waste materials is plutonium contamination. The waste management process at the representative facility is summarized in Figure 14.6. Radioactive waste materials are those contaminated with plutonium or uranium which is not planned to be recovered.

HEATING, VENTILATING, AND AIR CONDITIONING SYSTEM

FIGURE 14.5. Process Flow Diagram: Airborne Effluent Treatment for the Supporting Process for the Representative Mixed-Oxide Fuel Refabrication Facility

LIQUID WASTE TREATMENT SYSTEM (LWT)

MISCELLANEOUS WASTE TREATMENT SYSTEM (MWT)

▲ AIRBORNE EFFLUENT TO TREATMENT

NOTES:

(a) SOME SOLID WASTES AND EQUIPMENT CAN NOT BE DRUMMED AND REQUIRE SPECIAL TREATMENT

(b) NOT ALL THESE PROCESSES MAY BE UTILIZED FOR ANY ONE TYPE OF MATERIAL

FIGURE 14.6. Overall Waste Management Operations for the Representative Fuel Refabrication Plant

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 scrap recovery operations via the miscellaneous waste treatment system.

Wastes are received alternately in one of two solidification feed tanks. When one tank is filled, the incoming stream is diverted to the alternate tank. The contents of the full tank are mixed, sampled and assayed for verification of plutonium concentration. Waste from the full tank is batch-transferred to the cement mixing operation. The cement mixture is transferred to 55-gallon drums. After solidification, the drums are sealed, surveyed for surface contamination, and transferred to a shipping container overpack for storage and ultimate shipping.

If, after 24 hours in which the contents have been allowed to solidify, there is still free liquid present, the liquid is moved back into the solidification head tank by means of a capillary tube and jet orifice. After the free liquid is removed, the drum is handled in the following manner: the bag is sealed, removed from the port and tucked into the top of the drum, and the drum lid is installed. When it has been determined that the exterior of the drum is free of alpha contamination, the drum is then transferred to storage for ultimate shipment to off-site transuranic waste disposal facilities.

Miscellaneous Waste Treatment

Miscellaneous waste includes all potentially contaminated and contaminated materials generated within the manufacturing building which are excluded from the liquid waste treatment (LWT) and the liquid effluent treatment (LET) systems. This includes a very wide variety of materials with respect to plutonium content and physical description. Typical waste materials are:

- wipe rags and paper
- gloves from glove ports
- plastic bags, bottles, tubing, sheet materials
- metallographic lab mounts, grinding and polishing wastes
- filter elements, both air and liquid
- absorption bed cartridges
- surgical gloves

- blotter paper
- discarded protective clothing
- solvents
- spent lubricants
- waste basket paper
- scrap hardware - tools, equipment

The plutonium content of these materials may range from trace quantities to recoverable amounts, depending on how the material was used in the plant. In general, waste generated within the restricted access areas (RAA) is expected to have measurable amounts of contamination. Those materials which were directly associated with process equipment decontamination may require separation steps to be taken in order to concentrate the recoverable plutonium. On the other hand, wastes generated in the limited access area (LAA) and normal access areas (NAA) may have little or no plutonium contamination and are only suspected of potential alpha contamination. All of these waste materials must have their plutonium content identified and are separated into either a recoverable or a disposable category. Disposable materials are packaged for shipment and offsite disposal. The miscellaneous waste generated in RAA is placed in metal cans at the point of origin. The cans are sealed after filling. Material which does not fit into the 3.8-liter (1 gallon) cans requires special handling.

All these materials are transported to the MWT area. The treatment system consists of glove boxes having specialized functions and is all interconnected with an enclosed conveyor system. The conveyor system is connected to the second floor level of the RAA.

The first step in processing is to classify all incoming material into potentially recoverable or disposable categories by gamma scanning. Low-level disposable waste is measured by a precision gamma scan measurement to determine the amount of plutonium present. Then it is transferred to the drumming station where the material is loaded into a 55 gallon drum, compacted, and the drum is sealed. Hardware and other non-compressible materials are packed into drums separately and the drums are sealed. Loaded and sealed drums are gamma surveyed and checked to assure that external surface contamination is below allowable limits; they are then transported to the loading dock and placed in a shipping overpack.

Waste containing potentially recoverable quantities of plutonium is first checked with a neutron counter to determine more precisely the Pu content, sorted as to physical makeup, and then routed to glove boxes equipped to perform appropriate separation and concentration treatment. Treatments available include roasting, shredding, washing, precipitation and filtering, solidification, and mechanical separation. Some types of waste may require

several separation and concentration treatments. After processing is complete, the Pu waste concentrate becomes dirty scrap, and is crushed, mixed, and loaded into 1 liter metal cans and sealed. Each batch of mixed scrap is assayed for Pu content. These cans are then given an identification number, and sent to dirty scrap storage on the 2nd floor of the RAA.

The facility has the capability to store all the dirty scrap generated during the first three years of operation. Over that period, about 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. The low-level waste residue, shredded plastics, gloves, and etc. are sent to the drumming station and drummed with other disposable waste. The low-level contaminated aqueous waste is pumped to the LWT system for solidification. The small amount of organic liquid which requires disposal is filtered, collected, sampled and transferred to a 55 gallon drum containing an absorbent and placed in a shipping overpack for disposal.

Dry waste generated in the LAA and NAA has little or no Pu contamination. This material is collected in plastic bags and monitored for verification that no significant contamination is present. The material is placed in drums and introduced to the drum compactor where it is prepared for disposal. No dry waste material will be allowed to leave the manufacturing building other than through the MWT.

Large items, such as 61 cm x 61 cm x 30 cm (24 in. x 24 in. x 12 in.) HEPA filters, require individual handling and treatment.

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.

14.4 PLANT LAYOUT

This section summarizes the description of the site, the facility, and its hardware. This information is to assist in deriving the safety-related information in Section 14.5.

14.4.1 Site Description

The representative facility is assumed to lie on the 4.7 km² generic site described in Section 8. The facility itself (within the inner security fence) requires an area of 0.073 km² of 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 facility area and includes a security entrance. The liquid effluents (nonradioactive only) from the plant are assumed to be discharged onsite into the river that flows through the generic site.

14.4.2 Facility Description

The representative mixed oxide fuel fabrication facility is principally modeled after the proposed Westinghouse Recycle Fuels Plant (Schneider and Kabele, 1979). The facility is capable of producing mixed oxide BWR and PWR fuel assemblies at 200 to 400 Mg ($\text{UO}_2\text{-PuO}_2$)/yr at fully expanded production. The 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.

The facility contains approximately 11,150 m² (120,000 ft.²) of building area. The permanent physical structures, including the buildings, parking lots, and roads occupy about 0.032 km² (8 acres). The access road requires about 0.02 km² (5 acres), while the landscaped area involving grass, shrubs, and trees occupies about 0.065 km² (16 acres).

The facility consists of a main manufacturing plant, an office arrangement, and conventional support and maintenance services as shown in Figure 14.7. The main structures associated with the fuel fabrication process are shown in Figures 14.8, 14.9, and 14.10, including four reinforced concrete buildings: 1) the manufacturing building, 2) the rod inspection building, 3) the feed materials and personnel control building, and 4) the electro-mechanical equipment building. The manufacturing building has a total floor area of 6466 m² (69,600 ft.²) and is the only building that houses dispersible forms (i.e., nonpelletized) of PuO_2 . 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 (Figures 14.11 and 14.12) is basically an "L" shaped, two-level building. It is structurally separated from the other main buildings and 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.

The rod inspection building is a single-level building, containing facilities for cleaning tubes, for inspecting loaded sealed fuel rods, offices, and a storage/shipping area. Additional detail on layout of the manufacturing and rod inspection buildings is given in Figures 14-11 and 14-12.

The feed materials and personnel control building is a rectangular two-level structure. The first floor contains rooms for personnel lockers,

FIGURE 14.7. Layout of the Representative Fuel Refabrication Facility

FIGURE 14.8. Floor Plan for Basement of $\text{UO}_2\text{-PuO}_2$ Manufacturing Building

(a) REQUIRED FOR PRODUCING 400 Mg OF MIXED OXIDE/YEAR

FIGURE 14.9. Floor Plan for First Floor of $\text{UO}_2\text{-PuO}_2$ Manufacturing Building

FIGURE 14.10. Floor Plan for Second Floor of Mixed-Oxide Manufacturing Building

FIGURE 14.11. Physical Layout for Second-Floor Level of Representative Mixed-Oxide Fuel Refabrication Plant

FIGURE 14.12. Physical Layout for First-Floor Level of Representative Mixed-Oxide Fuel Refabrication Plant

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. 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. The forming gas facility consists of permanent cylinders for hydrogen, trailer-mounted hydrogen cylinders, and the cryogenic nitrogen supply tank. The reference facility is expected to operate for 40 years.

The process area descriptions and major process equipment descriptions are summarized in Tables 14.2 and 14.3, respectively.

14.5 SAFETY RELATED INFORMATION

Safety related information for a plant is primarily concerned with the confinement barriers, the driving forces for dispersing material, the hazardous materials and their form, and the worker and public population at risk.

14.5.1 Operating and Maintenance Requirements

Approximately 260 employees work at the facility in 3 shifts for around-the-clock operation 7-days/week. Parking space and facilities are provided for up to 30 visitors. The estimated number of workers involved in several job types for the three shifts is presented in Table 14.4.

Maintenance of most of the process equipment is done by direct contact with the equipment, but with workers protected by special coverings and special air breathing equipment. Restricted time of exposure during maintenance is frequently encountered due to radiation fields (see also Section 14.5.7).

14.5.2 Input/Output of Major Materials

Section 14.2 presented the process description and Section 14.4 presented the plant layout. A key parameter in a safety analysis is the throughput rate of materials. In Figure 14.13, the process step identification is keyed to the main product and waste material quantities and flow rates for an 8-hour shift in full production.

**TABLE 14.2.a. Major Process Area Descriptions - Representative
UO₂-PuO₂ Fuel Refabrication Facility**

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 m²)	NA	NA	(1)	L = 5.5, W = 1.5	NA	NA
Liquid effluent treatment	16 x 9.1 x 5.5 (140 m²)	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 m²)	NA	NA	NA	NA	NA	NA
1st Floor	68 x 55 x 6.1 (3000 m²)	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 m²)	NA	NA	NA	NA	NA	NA
Dark room	3.4 x 3.1 x 6.1 (10 m²)	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 m²)	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 17 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 m²)	Reinforced concrete walls	NA		(46 cm thick walls, 20 cm thick floor slab)		NA
PuO₂ storage	7.1 x 7.0 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 m²)	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 m²)	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
				Same as for Room # 1			
Filter room #2	31 x 8.8 x 5.8	NA	NA	NA	NA	NA	NA

**TABLE 14.2.b. Major Process Area Descriptions - Representative
UO₂-PuO₂ Fuel Refabrication Facility**

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 Cage & 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	A	NA
Garage	13 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

(#)Numbers in () indicate types of enclosures and numbers following indicate quantity.
NA = Not available at this time.

TABLE 14.3.a. Major Process Equipment Descriptions - Representative
 UO_2 - PuO_2 Fuel Refabrication Facility

Equipment	Location	No.	Size, m LxWxH: (each)	Material	Others	Process Duty or Capacity (each)	Other Factors
<u>PuO_2 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>PuO_2 Storage:</u>							
PuO_2 storage vessel	NA	1	NA	NA	NA	170 kg Pu	NA
Transfer Piping	NA	NA	NA	NA	NA	NA	NA
<u>Powder Blending & UO_2 Unloading:</u>							
UO_2 drum weighing & dump station	Feed material receiving & storage	-	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	NA	-	NA	NA	NA	1.4 m ³	Dust-tight, remotely activated
Double sequencing isolation valve	At RAA barrier	-	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	NA	Two speed electric
UO_2 weigh hopper	RAA	1	NA	SS	NA	0.14 m ³	Dust-tight
PuO_2 pneumatic conveyor	NA	NA	NA	NA	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

TABLE 14.3.b. Major Process Equipment Descriptions - Representative
UO₂-PuO₂ Fuel Refabrication Facility

Equipment	Location	No.	Size, m LxWxH (each)	Material	Others	Process Duty or Capacity (each)	Other Factors
<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) 1 pellet boat 1 pellet boat	Molybdenum heating elements NA NA
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 crane	RAA	1	NA	NA	NA	4545 kg	NA
Recline 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 Mechanical device, checks pellet diameters
Dimensional inspection device	RAA	2	NA	NA	NA	NA	Optical scan
Nick inspection device	RAA	2	NA	NA	NA	NA	NA
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

TABLE 14.3.c. Major Process Equipment Descriptions - Representative
 UO_2 - PuO_2 Fuel Refabrication Facility

Equipment	Location	No.	Size, m LxWxH (each)	Material	Others	Process Duty or Capacity (each)	Other Factors
Receiving, Cleaning and Storage of Tubes, Plugs and Springs:							
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
Fuel Rod Loading:							
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 - 1-OK 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
Rod Repair and Dismantling:							
Depressurizing and end plug cut-off station	Glovebox in RAA	1	NA	NA	NA	10-25 PWR rods	NA
Spring removal and rod end ream station	Glovebox in RAA	1	NA	NA	NA	10-25 PWR rods	NA
Decontamination, spring insertion and top plug pressing station	Glovebox in RAA	1	NA	NA	NA	NA	NA
Girth weld station	Glovebox in RAA	1	NA	NA	NA	NA	NA
Helium pressurization and pressure welding station		1	NA	NA	NA	NA	NA
Pellet removal station	Glovebox in RAA	1	NA	NA	NA	NA	NA
Tube cut-up station	Glovebox in RAA	1	NA	NA	NA	NA	NA
Rod Testing, Inspection, Storage and Shipping:							
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
Clean Scrap Recovery:							
Collection containers	Various locations	NA	30.3 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
vessels	RAA	3	NA	NA	NA	720 kg	NA

TABLE 14.4. Number of Workers by Task and Shift

<u>Job Type</u>	<u>No. of Workers at Time of Day Shown</u>		
	<u>700 - 1600</u>	<u>1600 - 2400</u>	<u>2400 - 700</u>
Supervisory and Administration	11	8	8
Accounting	6	4	4
Secretarial	6		
Physical Protection	2	10	10
Unloading	8	8	4
Process Operation ^(a)	23	23	23
Assembly	10	10	10
Waste	6	6	6
Janitorial	4	8	2
Loading	6	6	
Maintenance	2	2	2

(a) Process personnel assist in major maintenance.

FIGURE 14.13. Material Quantities and Flows in an 8-Hour Shift for 200 Mg/Year

14.5.3 Inventory of Major Hazardous Materials at Plant Locations Having Safety-Related Importance

The hazardous material of primary concern in this facility is plutonium, with uranium being of lower concern. The quantities of these materials in the various locations in the facility were given in Figure 14.13.

14.5.4 Unit Operations Involved

This section identifies the unit operations for each step in the process flow schemes for the representative fuel fabrication facility. These are listed in Table 14.5.

14.5.5 Accident Driving Forces

Energy must be present to cause accidents and to break barriers as well as to drive the dispersion beyond the barriers. Such energies are available at the receiving dock in the form of the truck providing the deliveries and picking up the finished product and in the fork-truck used for pallet handling. The forks themselves have been considered as possible penetrators of the shipping containers. Other external forces could be an aircraft crash into the plant, tornado-accelerated missiles breaking into the plant or a very severe earthquake that breaks the plant process lines, process cells or the outer building containment.

The product powder has little internal energy to either disperse itself or break boundaries, but wind and building ventilation can provide the energy necessary to disperse the PuO_2 powder, if it has an unimpeded access to and from the powder. An example of air dispersion is the possible failure of the HEPA filter so that it releases the entrapped particulate. Fortunately, there have been few HEPA filter failures; furthermore, in the process of filtering, the particles agglomerate, thereby reducing their dispersibility.

Other forces available within the plant are chemical reactions. Quantities of hydrogen gas are used in the forming gas for the sintering furnaces. Should the mixing be improper and oxygen also get into the mixture, an explosion becomes possible. The use of solvents in the process and analytical services is controlled but it does pose a possible fire and explosion energy source. A nuclear reaction is also possible if the PuO_2 powder could be changed in geometry and moderated. This possibility has been particularly examined regarding the water-cooled furnaces, but the geometry is such that it is very unlikely. The wet scrap recovery uses the Purex process, so there is some fire potential in the organic. There is also fire potential in the building electrical system wiring and in the waste collection, as there is in most manufacturing facilities.

These possibilities are explored further in the preliminary hazard analysis taken from Fullwood et al (1980) and presented in the Appendix.

TABLE 14.5 Unit Operations in the Representative
Mixed-Oxide Fuel Fabrication Plant

<u>Process Step</u>	<u>Unit Operations</u>
Material Receiving	Unloading Pallets Holding Plutonium Dioxide Powder Shipping Containers Unloading Pallets Holding Drums of Uranium Dioxide Powder Unloading Fuel Hardware Receiving Miscellaneous Plant and Process Support Materials
Powder Preparation	Pu Powder Unloading U Powder Unloading Pu Powder Storage U Powder Storage Blending MOX Powder Storage MOX Powder Feed
Pellet Preparation	Compaction Granulation Pelleting Boat Loading Storage Sintering Inspection Storage
Fuel Rod Loading	Hardware Preparation Pellet Loading Rod Welding and Pressurization Rod Testing Storage

TABLE 14.5 (Cont.)

<u>Process Step</u>	<u>Unit Operations</u>
Fuel Element Assembly	Rod Withdrawal from Storage Rod Assembly Hardware Installation Assembly Inspection
Shipping	Preparation of Shipping Containers Installation of Fuel Elements
Waste Treatment	Waste Collection Clean Scrap Recovery Dirty Scrap Recovery Liquid Waste Treatment Compaction Concretizing Shipping
Analytical Services	Non-Destructive Assay Chemical Assay Radiographic Assay

14.5.6 Containment and Shielding Systems

Figure 14.14 shows the barriers protecting the public from the actinides. It is seen that there is a high level of redundant protection. The top of the figure begins with the L-10 shipping container. The PuO₂ is contained within a 0.1mm (0.004 in.) polyethylene bag contained within double cans. This is contained within a 12.7cm (5-inch) schedule 40 pipe having a welded cap on one end and a wrought iron screw cap on the opening end (the 2-R container). This is contained within a double 55 gallon drum using a clamping ring to seal the lid.

The transition of the PuO₂ from shipping container to process equipment is described in considerable detail in Section 14.2.2. It is clear from the description that great care is taken to insure the level of protection is not reduced during the transition. From this point the material is confined within glove boxes, process vessels or pneumatic transfer lines. The equipment is of stainless steel construction. The physically weakest areas are the glove boxes and pneumatic transfer lines where the PuO₂ is mobile, but these are within process cells of 50 cm concrete thickness. The ducting is constructed of 1.27 cm (0.5-inch) stainless steel tubing which is also the material of the HEPA filter enclosure.

The HEPA filters themselves may be one of the weakest barriers in the system, although they are a high-reliability, Category I component used to allow air passage but to suppress the passage of radioactive particulates. Although high quality and stringent tests are required, some failures have occurred. Moeller (1975) has compiled data on air cleaning failures for the 8-year period 1966-1974 that have occurred at nuclear facilities.

It should be noted that this time interval encompasses the implementation of 10 CFR 50 Appendix B on Quality Control, as well as the normal design rectification that occurs when failure modes are exhibited. Hence, the failures reported in Moeller may not recur. New failures could occur but should have lower probabilities of occurrence.

14.5.7 Degree of Hands-On Operation

Table 14.6 classifies the principal process steps according to the direction of exposure to radiation from the process material.

14.5.8 Product Form and Behavior

Of the material in the plant, the plutonium is the primary hazard. However, not all of this plutonium is an inhalation hazard. Estimates of the health effects must consider information regarding the retention fraction.

Figure 14.15 shows the particle size distribution of PuO₂ calcined at temperatures in the range of 800° to 1200°C. The particle size distribution for wet (such as the dirty-scrap recovery process) and dry (such as the powder operation) has been studied by Gonzales et al. (1976) for several plants.

FIGURE 14.14: Pictorial of the Levels of the Confinement Barriers

TABLE 14.6. Classification of Process Steps
by Directness of Exposure

Process Step	Type of Operation
Receiving, Handling and Storage of UO_2 and PuO_2 Shipping Containers	Contact with Containers
UO_2 Unloading	Semi-Contact ^(a)
PuO_2 Unloading	Remote ^(b)
Blending and Pellet Preparation	Remote
Fuel Rod Loading and Welding	Contact
Testing and Inspection	Contact
Shipping	Contact
Scrap Handling	Contact
Dirty Scrap Recovery	Remote
Clean Scrap Recovery	Remote
Maintenance	Contact after Decontamination

(a) Drums are handled by standard methods using a dumper. Operators do not normally contact the powder but extreme caution is not used.

(b) Glove box operation.

FIGURE 14.15. Variation in Plutonium Dioxide Particle Size Distribution for a Range of Calcining Temperature Between 800 and 1200°C

Using these data and their measurements of HEPA filter penetration by particle size, penetration values were developed for the processes in this plant. (See Appendix.) Tests with dioctyl phthalate (DOP) aerosols are routinely performed on the filters to assure performance and to assure that the differential pressure measurement alarms upon failure of the filters. Alarms in the stack air discharge are also activated on any unusual increase in radiation level, such as might accompany filter failure.

A further piece of safety information useful in assessing safety in fuel refabrication relates to the maximum stable density of an aerosol in a cell should an accident occur. A plot of this information is given in the Appendix. For particles in the range of 0.4-0.7mm, the plot suggests a realistic concentration of about 1 g/m³ for a solid aerosol and about 3 mg/m³ for a liquid aerosol.

This activity of plutonium is from 5 isotopes. Table 14.7 presents the fraction of these isotopes and their activity assuming high burnup. The weighted mean activity of these isotopes is 13 Ci/g. The burnup, flux level and short time from discharge are very conservative.

14.6 ALTERNATIVES TO THE REPRESENTATIVE CONCEPT

The following alternatives are indicative of some variations in facilities that may be considered in near-future fabrication plant designs.

14.6.1 Co-precipitation

The fuel refabrication plant described here accepts oxide powders and produces powder blends of the appropriate homogeneity and reactivity. It is well known that homogeneous powder blending is more difficult than liquid blending. An alternative to the powder process is co-precipitation of a mixture of uranium and plutonium nitrate solutions. If these are subsequently calcined to produce a mixed oxide powder, this is the COPRECAL process developed by General Electric (Dotson 1980). The product could arrive at the plant as separate nitrate solutions for blending at the plant, or the powders could be renitrated back to aqueous solution form, or the refabrication plant could be co-located and receive the separate or mixed (co-processed) nitrate streams directly from the reprocessing plant. The precipitant is ammonium dioxide. The precipitation process is carried out in a continuous-flow, stirred-tank reactor in which the following reactions take place:

1. $\text{Pu}(\text{NO}_3)_4 + 4\text{NH}_4\text{OH} \rightarrow \text{Pu}(\text{OH})_4 + 4\text{NH}_4\text{NO}_3$
2. $3\text{UO}_2(\text{NO}_3)_2 + 7\text{NH}_4\text{OH} + \text{H}_2\text{O} \rightarrow (\text{UO}_2)_3 \cdot \text{NH}_3 \cdot 5\text{H}_2\text{O} + 6\text{NH}_4\text{NO}_3$
or $2\text{UO}_2(\text{NO}_3)_2 + 5\text{NH}_4\text{OH} \rightarrow (\text{UO}_2)_2 \cdot \text{NH}_3 \cdot 3\text{H}_2\text{O} + 4\text{NH}_4\text{NO}_3$
3. $\text{HNO}_3 + \text{NH}_4\text{OH} \rightarrow \text{NH}_4\text{NO}_3 + \text{H}_2\text{O}$

Precipitation is accomplished using the "reverse strike" method, wherein

TABLE 14.7. Isotopic Composition of Plutonium Dioxide^(a)

<u>Isotope</u>	<u>Fraction</u>	<u>Curies/gm</u>
²³⁸ Pu	0.018	16.9
²³⁹ Pu	0.593	0.061
²⁴⁰ Pu	0.239	0.22
²⁴¹ Pu	0.111	114.0
²⁴² Pu	0.039	0.0039

(a) 120 days after discharge, once-through PWR fuel, 33,000 MWD/Mg exposed to a flux of $2.9\text{E}13$ n/cm²-sec.

mixed nitrate solution is initially added to a pool of ammonium hydroxide. Both nitrate and hydroxide are then continuously added to ensure that precipitation always takes place at high pH to eliminate the need for pH control and for filtration.

Calcination takes place in a fluidized bed using nitrogen gas and an elutriative inert bed of Inconel shot. The advantages of the inert bed are: high heat transfer, uniform product, low scrap generation, and a drain for ready inventory. An in-bed jet grinder is used to minimize the buildup of large particles.

The calcination of the slurry follows these reactions:

4. $\text{Pu}(\text{OH})_3 + \text{PuO}_2 + \text{H}_2\text{O}$
5. $(\text{UO}_3)_3 \cdot \text{NH}_3 \cdot 5\text{H}_2\text{O} + 3\text{UO}_3 + \text{NH}_4\text{OH} + 4\text{H}_2\text{O}$
6. $2\text{NH}_4\text{NO}_3 + 2\text{N}_2 + 4\text{H}_2\text{O} + \text{O}_2$
7. $4\text{NH}_4\text{OH} + 3\text{O}_2 + 2\text{N}_2 + 10\text{H}_2\text{O}$

This mixed oxide product from the calciner is processed in a reduction/stabilization step to produce ceramic-grade mixed oxide which should meet all pellet fuel fabrication requirements. This process reduces the UO_3 portion of the mixed oxide calciner product to UO_2 . The UO_2 is then reoxidized slightly at 700-800°C.

The stabilization portion of the process is accomplished by contacting the powder with CO_2 while the powder is still at the reduction temperature. If this stabilization is not performed, the UO_2 may oxidize to U_3O_8 upon exposure to air, rendering the mixed oxide unsuitable for fuel fabrication. A brief summary of the value/impact of this process is:

<u>VALUE</u>	<u>IMPACT</u>
More homogeneous powder. Reduction in powder inventory. Simplification of the mixing. Reduction in dusting and dust loading of the HEPA's. This should increase HEPA life and reduce HEPA maintenance costs and exposure as well as possible accidental releases during changeout.	Introduces a wet process into an otherwise dry process. Requires different staffing. Since present regulations prohibit liquid plutonium nitrate shipment, the process is only possible if the refabrication plant is co-located close enough that the transfer can be made onsite, possibly by pipe transfer. Pipe transfer raises some earthquake problems and would require double pipes. There may be safeguards implications.

14.6.2 Other Considerations

Other alternatives that might be considered are pneumatic transfer of

PuO₂ or PuO₂-UO₄, remote maintenance, alteration because of safeguards considerations, and dirty scrap recovery with co-location of fuel cycle elements. These are discussed briefly below.

Pneumatic Transfer Air Recirculation

Some approximate calculations indicate that the extensive use of pneumatic powder transfer will result in loading of the prefilters and first HEPA filter in a fairly short time. Further examination of this point should be made. A brief summary of the value/impact of such a change is:

VALUE

The value is to reduce the amount of dust (PuO₂ & UO₂) laden air that challenges the HEPA filters. This reduces costs for HEPAs, cost of filter changeout, radiation exposure for changeout and possible accidental releases during changeout.

IMPACT

This would add extra costs for the air recirculating equipment. The dust may abrade the recirculating equipment. Extra ducts and hoses will be needed.

Remote Maintenance

The type of plant used as an example here is appropriate for processing the first recycle of plutonium, but second and higher cycles would most likely require considerable changes. It is expected that remote processing/manufacture and remote maintenance would be required for such a plant. Much of the processing/manufacture is already remote so the major changes would come in the receiving and handling of PuO₂, in rod fabrication and in assembly. The shielding would probably need to be thicker. However, the plant maintenance concept would have to be considerably changed to go to remote maintenance, and this could well change the entire plant layout and operating concept, such as to a canyon type processing area, to facilitate remote servicing. The alternative is to design and construct first recycle plants capable of handling plutonium from later recycles. A brief summary of the value/impact of such a change is:

VALUE

The representative plant may not meet the principle of ALARA for occupational exposure. Remote maintenance would reduce occupational exposure and simplify decommissioning. It would probably result in a higher plant availability and reduction of radiological exposure.

IMPACT

This adds considerably to the cost of a plant because of the canyon structure and remote maintenance equipment. Future robotic developments could change this to all cell-like structure with robot maintenance, but the cost will still be higher than contact maintenance.

Safeguards (a) Considerations

The model plant presented here was designed before the safeguards emphasis of the late 1970's, and some changes with regard to safeguards may be considered in future facilities. For example, it is recognized that an aerial attack by helicopter could be effective against the guard force and vital equipment. Therefore, the general plant layout may warrant review from this aspect. For such a consideration in general, the vital equipment and PuO_2 in the form of a ceramic powder could be made less accessible, such as locating it in a basement.

The transportation of PuO_2 powder may represent an important safeguard risk (Westinghouse 1973, Schneider and Kabele 1979). Thus, the co-location of the reprocessing plant with the refabrication plant could essentially eliminate this risk as well as the risks of sabotage and diversion in this transportation link. Co-location has the additional advantage of reducing the quantity of PuO_2 powder necessary to be stored at the refabrication plant. (This quantity is still sufficient to construct a nuclear device, thus it may be desirable to keep UO_2 and PuO_2 mixed at all times.)

If used, the practice of "co-processing" must be performed in the reprocessing plant that serves the refabrication plant. When co-processing is used, the quantity of material that must be diverted to construct a nuclear device is about 90 kg, instead of approximately 5 kg of PuO_2 . Furthermore, a rather difficult Purex-type of separation is needed to separate the uranium from the plutonium of any diverted material, and the mixture is not useful as weapons material. Neither of these concepts has been proposed for commercial nuclear fuel production. There are no technical problems associated with co-location. Co-location has not been seriously considered primarily because the companies that do the reprocessing and refabrication are different. Coprocessing, however, would require considerable development. The following is a qualitative value impact discussion of this alternative.

-
- (a) Safeguards used in this sense refers to the protection of Special Nuclear Material (SNM defined in 10CFR71) from diversion to unauthorized purposes and to the protection of the public from radiological hazards from plant sabotage.

VALUE

The value of this alternative is the practical elimination of diversion of SNM by stealth. It applies to the steps of reprocessing, PuO_2 transportation and fuel refabrication.

IMPACT

This constitutes a major change in the back end of the fuel cycle and has not been demonstrated on a commercial scale, hence further process development and pilot work is needed. It is not apparent that this change would add substantially to the costs of the fuel cycle. It might reduce costs in that some of the purification steps are eliminated. It crosses over institutional boundaries in that reprocessing, transportation and fuel reprocessing are each normally performed by different companies. Without analysis, it is not apparent that either public or worker, routine or accident risks would be adversely affected.

Dirty Scrap Recovery

A further advantage of co-locating a reprocessing and a refabrication plant is that the dirty scrap (non-nuclear fuel contaminated) may be separated from its contaminant in existing facilities in the reprocessing plant instead of a small-scale Purex operation in the fuel refabrication plant (FRP). The following is a qualitative value/impact discussion of this alternative.

VALUE

The value of this alternative is that the FRF with this change becomes a completely dry process. This simplifies staffing and eliminates or reduces the possibility of several potential accidents such as criticality, and solvent fire. It would seem to result in a cost reduction due to the flow sheet simplification. It simplifies the off-gas treatment and probably reduces the chemical and radiological atmospheric discharge. It eliminates an area of safeguards implications because it might be possible for an operator to separate Pu and U in the Purex process.

IMPACT

The impact is a complication in material control. An accurate assay of the SNM is required before it could be shipped as dirty scrap. More scrap will probably accumulate than if it were processed on site.

REFERENCES

- Dotson, L.M., et al. 1980. Technical Development of the COPRECAL Co-Conversion Process. A.I.Ch.E. 89th National Meeting, Portland, Oregon.
- Fullwood, R., et al. 1980. Working Paper for a Radiological Accident Probability/Consequence Analysis of a Mixed Oxide Fuel Fabrication Plant. SAI/SR-224-80-PA, DRAFT. Palo Alto, California.
- Gonzales, M., et al. 1976. Performance of Multiple HEPA Filters Against Plutonium Aerosols. LA-6546.
- Moeller, D.W. 1975. "Problems in Nuclear Air Cleaning Systems". Nuclear Safety 16(4).
- Schneider, K.J. and T.J. Kabele. 1979. Descriptions of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles. PNL-2286. Pacific Northwest Laboratory, Richland, Washington.
- Westinghouse Electric Corp. 1973, Docket 70-1151.

APPENDIX 14

TABLE 14.A. Fractional Penetration of Dry-Process Polydisperse Aerosol Through Various HEPA Filter Stages

Particle Size Range AMAD (μm)	Reference Wt. Fraction of Total	Penetration Fraction Through HEPA Filter One	Penetration Fraction Through HEPA Filter Two	Estimated Penetration Fraction Through HEPA Filter Three
		$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$
<.12	-	36 $\pm$ 36	200 $\pm$ 220	200
0.12 - 0.22	0.0001	54 $\pm$ 50	82 $\pm$ 31	246
0.22 - 0.44	0.002	71 $\pm$ 59	92 $\pm$ 24	276
0.44 - 0.96	0.038	64 $\pm$ 57	126 $\pm$ 82	378
0.96 - 1.54	0.10	39 $\pm$ 33	24 $\pm$ 19	24
>1.54	0.86	30 $\pm$ 30	4.2 $\pm$ 2	4.2
Distribution Weighted Mean		5.8 E-5	5.2 E-10	1.2 E-13

14.61

TABLE 14.B. Fractional Penetration of Wet-Process Polydisperse Aerosol Through Various HEPA Filter Stages

Particle Size Range AMAD (μm)	Reference Wt. Fraction cf Total	Peretration Fraction Through HEPA Filter One $\times 10^{-6}$	Penetration Fraction Through HEPA Filter Two $\times 10^{-6}$	Estimated Penetration Fraction Through HEPA Filter Three $\times 10^{-6}$
<.12	0.04	36 $\pm$ 36	200 $\pm$ 220	200
0.12 - 0.22	0.1	54 $\pm$ 50	82 $\pm$ 31	246
0.22 - 0.44	0.3	71 $\pm$ 59	92 $\pm$ 24	276
0.44 - 0.96	0.36	64 $\pm$ 57	126 $\pm$ 82	378
0.96 - 1.54	0.1	39 $\pm$ 33	24 $\pm$ 19	24
>1.54	0.1	30 $\pm$ 30	4.2 $\pm$ 2	4.2
Distribution Weighted Mean		5.8 E-5	5.7 E-9	1.7 E-12

FIGURE 14.A. Mass Concentration of Solid and Liquid Particles in Aerosols

TABLE 14.C. MOX Fabrication Plant Preliminary Hazard Analysis (a)

SYSTEM/ SUBSYSTEM	POTENTIAL ACCIDENTS	CAUSAL FACTORS	BARRIERS	CHARACTERISTIC SOURCE TERMS	SIGNIFI- CANCE
Receiving Dock	Pu Container Leaking Upon Receipt	Improper Assembly and Test	4 Barriers	Ceramic Grade Powder 8 Microns Mean A.E.D.	Low
	Pu Container Punctured During Receiving	Improper Use of Fork Truck for Handling Pu - Administrative Violation	Extremely Diffi- cult to Put a Fork Through the 2R Pipe with Cushioning		Very Low
	Dropped Container Pinned Between Truck and Dock	Improper Handling	Very Doubtful That a Truck Could Crush a Pu Container to Cause a Release		Very Low
	Truck Fire	Worker Smoking for Example	Trucks Would Probably be Diesel. Containers are Designed for 1475°F, 30 min. Fire Tests Show Resistance at Higher Tempera- tures		Very Low
	Tornado	Tornado Strike During Unloading	Pu Containers Are Very Resistant. Tornado Warning May Speed Unload- ing so That the Pu is in the Vault at Strike Time.	Ceramic Grade Powder 8 Microns Mean A.E.D.	Low
	Flooding	Flooding During Unloading	No Effect. Sealing to Keep Pu in, Keeps Water Out		Very Low
	Earthquake	Earthquake During Unloading	Containers are Designed for Much Higher "G" Load- ings than Earth- quakes. Building Collapse Could Damage Some Containers.		Low

TABLE 14.C. (cont.)

SYSTEM/ SUBSYSTEM	POTENTIAL ACCIDENTS	CAUSAL FACTORS	BARRIERS	CHARACTERISTIC SOURCE TERMS	SIGNIFI- CANCE
Storage Vault	Criticality	Flooding	Building Sited and Designed to Preclude	Agglomerated Ceramic Powder, Fission Gases, Neutrons	Very Low
	Air Crash with Possible Fire	Aircraft Accident	Seismic Category 1 Vault can be Penetrated by Only Fast or Large Aircraft Spill is Limited to Only a Few Containers	Ceramic Powder	Low
	Tornado	Natural Occurrence	Each Container Category 1 Wall Designed for 360 mph Winds and Certain Missiles		Low
Plutonium Unloading	Shipping Container Falls From Lift Plat- form	Improper Container Loading Collapse of a Wheel or Support Structure	Three Barriers are Remaining and 2R Container	Ceramic Powder 2.2 kg Pu/CAN	Very Low
	Leak in Pneumatic Transfer Line	Wear and Abrasion of Transfer Line	Glove Box, RAA, LAA Walls, 3 HEPA Filter Stages		Low
	Blocked Transfer Line	Improper Moisture in Powder Line is Blocked but Pu is not Dispersed	Tube and Above		Very Low
	Spill of Can After Opening	Improper Insertion of Pneumatic Transfer Tube Transfer Tube Overturns Can Occur	Glove Box, RAA, LAA Walls, 3 HEPA Filter Stages		
	Fire in Drum-Out Station	Improper Intro- duction of Solvents	Administrative Barriers to Solvents RAA, LAA Walls, 3 HEPA Filter Stages		Low
	Spill of Plutonium Outside of Glove Box During Maintenance Tornado, Earth- quake, Flooding, Air Crash	Failure or Inability to Completely Remove Pu from Parts for Disassembly	ADM and Health Physics Control Rare Need for Decontamination Maintenance This location is a Modest Source in Case of these Occurrences	Agglomerated Pu Powder 2.2 kg Pu/CAN	Low Very Low

TABLE 14.C. (cont.)

SYSTEM/ SUBSYSTEM	POTENTIAL ACCIDENTS	CAUSAL FACTORS	BARRIERS	CHARACTERISTIC SOURCE TERMS	SIGNIFI- CANCE
Hopper Loading and Storage	Failure of Transfer Line	Powder-Caused Abrasion Pipe Stress or Vibration	RAA, LAA Walls, 2 Stages of HEPA Filters Transfer Cutoff on Failure Detection	Transfer-In In Batches of 2.2 kg Transfer-Out Until Closure of Isolation Valve	Modest
	Collapse of Pu Hopper Supports or Hopper Con- tainer Body	Design or Fatigue	Quality Control Over Design	170 kg of Ceramic Grade Pu in One of 3 Vessels	
Blending and Storage	Pneumatic System Failure	Wear, Abrasion	3 HEPA's	Ceramic Powder	Very Low
Pressing	Hydraulic Fluid Fire	Seal Failure Improper Fluid	3 HEPA's	Coarse Powder	Very Low
Sintering	Hydrogen Explo- sion in the Sintering Furnace	Improper Oxygen Explosion; Mixing Valve Failure	Same	Coarse Powder	Very Low
	Dust Spill	Mechanical Failure	Same	Coarse Powder	Very Low
	Criticality	Water-Cooled Furnace Modera- tion Extremely Diffi- cult for 3-4% Enrichment to go Critical	Same	Neutrons, Iodine, Gamma Rays, and Nobles	Very Low
	Release During Maintenance	Improper Procedures	Same	Coarse	Very Low
Grinding	Abnormal Grinder Operations	Loss of Coolant	3 HEPA's	Dust-like Powder	Very Low
Several	Solvent Fire	Procedural Error	Same	Coarse	Very Low
Rod Loading or Repair	Dropped Pellets	Error	Same	Coarse	Very Low
Improper Welding	Dispersed MOX	Error	Same	Dust-Like Powder	Very Low

TABLE 14.C. (cont.)

SYSTEM/SUBSYSTEM	POTENTIAL ACCIDENTS	CAUSAL FACTORS	BARRIERS	CHARACTERISTIC SOURCE TERMS	SIGNIFICANCE
Fuel Shipping	Dropped Rod	Error	1 HEPA	Coarse	Very Low
Clean Scrap Recovery	Criticality	Procedural Errors	3 HEPA's	Neutrons, Iodine, Nobles, and Gamma	Very Low
	Hydrogen Explosion in ROR Reactors	Oxygen Release in Reaction - Improper Ventilation	3 HEPA's	Coarse	Very Low
	Spill of MOX Scrap	Error	3 HEPA's	Coarse	Very Low
Dirty Scrap Recovery	Solvent Fire	Leak, Operating Errors	3 HEPA's	Coarse	Very Low
	Red Oil Explosion	Loss of Temperature Control	3 HEPA's	Wet Process	Low
	Resin Fire and Explosion	Administrative Control Nitration of Filter	3 HEPA's	Wet Process	Low
Analytical Service Facility	Solvent Fire in Glove Box	Procedural Error	3 HEPA's	Wet Process	Very Low
Final Filter Failure	Release of Plutonium Trapped in Final Filter	Unknown	None		

GLOSSARY

The symbols for metric units and the prefixes used with the metric units are defined below. A definition of acronyms and abbreviations used in this study are also listed. Common terms covered in standard dictionaries and commonly used chemical symbols are not included.

Prefixes Used With Metric Units

<u>Prefix</u>	<u>Abbreviation</u>	<u>Factor</u>
giga	G	10^9
mega	M	10^6
kilo	k	10^3
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

Symbols for Metric Units

<u>Symbol</u>	<u>Name</u>
$^{\circ}\text{C}$	degree celsius
Ci	curie
d	day
g	gram
h, hr	hour
J	joule = $1 \text{ N}\cdot\text{m}$
L	liter
m	meter
<u>M</u>	gram-mole/liter
min	minute
N	Newton = $1 \text{ kg}\cdot\text{m}/\text{s}^2$
Pa	Pascal = $1 \text{ N}/\text{m}^2$
R	Roentgen
rem	roentgen equivalent man
s	second
W	Watt = $1 \text{ J}/\text{s}$
yr	year

Definition of Acronyms and Abbreviations

AP:	Activation product
ADU:	Ammonium diuranate
AEC:	Atomic Energy Commission
AFR:	Away from reactor (spent fuel storage)
ALARA:	As low as reasonably achievable
AOFP:	All other fission products
ASHRAE:	American Society of Heating, Refrigeration, and Air Conditioning Engineers
ASME:	American Society of Mechanical Engineers
BCL:	Battelle-Columbus Laboratories
BWR:	Boiling water reactor
CCD:	Countercurrent decantation
CFR:	Code of Federal Regulations
CH-TRUW:	Contact-handled transuranic waste
DF:	Decontamination factor
DOT:	Department of Transportation
DOE:	Department of Energy
EPA:	Environmental Protection Agency
ERDA:	Energy Research and Development Administration
FP:	Fission product
FFP:	Fuel fabrication plant
FRP:	Fuel reprocessing plant
GESMO:	Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors, NUREG-0002
HC:	Hydrocarbons
HEPA:	High-efficiency particulate air
HLW:	High-level waste
HLLW:	High-level liquid waste
HTGR:	High temperature gas-cooled reactor
HVAC:	Heating, ventilation, and air conditioning
IAEA:	International Atomic Energy Agency
ILW:	Intermediate level waste
INEL:	Idaho National Engineering Laboratory
K_{eff} :	Effective neutron multiplication factor
LA:	Lower actinides
LANL:	Los Alamos National Laboratory
LLW:	Low-level waste
LLNL:	Lawrence Livermore National Laboratory
LMFBR:	Liquid metal fast breeder reactor
LWR:	Light water reactor
MOX:	Mixed oxide (U and Pu)
MOX-FFP	Mixed oxide fuel fabrication plant
NG:	Noble gases
NA:	Not available
NDT:	Non-destructive testing
NEG:	Negligible

NRC: Nuclear Regulatory Commission
NWTs: National Waste Terminal Storage Program
ORNL: Oak Ridge National Laboratory
PNL: Pacific Northwest Laboratory
PWR: Pressurized water reactor
RHO: Rockwell Hanford Operations
RH-TRUW: Remote-handled transuranic waste
SAI: Science Applications, Inc.
SHLW: Solidified high-level waste
SNM: Special nuclear material
SNL: Sandia National Laboratories
SURF: Spent unprocessed fuel
SVFP: Semi-volatile fission products
SWU: Separative work units
TBP: Tri-butyl phosphate
TRU: Transuranic nuclide
TRUW: Transuranic waste
UBC: Uniform Building Code
ULA: Uranium plus low actinides
UNH: Uranyl nitrate hexahydrate
WSEP: Waste solidification engineering prototypes

FUEL CYCLE RISK ASSESSMENT RESEARCH PROGRAM (B2402)

DISTRIBUTION LIST

1. NRC Standard Distribution GF
2. Division of Risk Analysis (18)
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

C. C. Eng (10)
J. C. Belote
S. Bernstein
3. Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

K. G. Steyer
4. Division of Facility Operations (2)
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

F. Forscher
M. T. Jamgochian
5. Division of Fuel Cycle and Material Safety (5)
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

P. Loysen
A. T. Clark
J. E. Ayer
F. D. Fisher
J. P. Colton

6. Battelle Pacific Northwest Laboratories (25)

P.O. Box 999

Richland, Washington 99352

R. E. Rhoads
P. M. Daling
C. A. Geffen
T. B. Powers
W. E. Bickford
P. J. Pelto
A. M. Schreiber
L. D. Williams
T. D. Chikalla
R. E. Nightingale
R. C. Liikala
R. M. Fleischman
R. J. Sorenson
M. K. White
D. A. Dingee
A. M. Platt
K. J. Schneider (5)
N. M. Burleigh
Technical Information
Publishing Coordination
Fuel Cycle Library

7. Battelle Columbus Laboratories (8)

505 King Avenue

Columbus, Ohio 43201

W. H. Goldthwaite
P. Baybutt (3)
N. F. Miller
K. R. Yates
W. J. Zielenbach
W. E. Vesely

8. Nestor Ortiz (2)

Sandia National Laboratories

Division 4413

Albuquerque, New Mexico 87185

9. Ralph Fullwood (2)

Science Applications, Inc.

5 Palo Alto Square, Suite 200

Palo Alto, California 94304

10. Joseph McSweeney
M&M Nuclear Consultant
1221 Avenue of the Americas
New York, New York 10026
11. U.S. Department of Energy (6)
Headquarters
Washington, D. C. 20545

M. J. Lawrence
W. Ballard
F. Coffman
K. Laughan
O. P. Gormley
C. Bastin
12. N. J. McCormick
University of Washington
Seattle, Washington 98185
13. H. J. Wingender
NUKEN GmbH
PO Box 110080
D-6540 Hanau 11
Federal Republic of Germany
14. Dr. K-E Maass
Hahn-Meitner-Institut
fur Kernforschung Berlin GmbH
1 Berlin 39 - Wannsee
Glienicke Strasse 100
Federal Republic of Germany
15. U.S. Department of Energy (2)
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

M. J. Plahuta
J. J. Schreiber

16. Battelle Columbus Laboratories (2)
ONI/ONWI
505 King Avenue
Columbus, Ohio 43201

S. Goldsmith
R. J. Hall

17. Risk Assessment Program (2)
IAEA
Vienna International Center
P.O. Box 100
A-1400 Vienna, Austria

18. M. J. Steindler
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

19. J. L. Russell
U.S. Environmental Protection Agency
Office of Radiation Programs
AW - 459 EPA
401 M Street, S.E.
Washington, D. C. 20560

20. R. F. Williams
Electric Power Research Institute
P.O. Box 10412
Palo Alto, California 94303

21. Westinghouse Hanford Company (2)
P.O. Box 1970
Richland, Washington 99352

A. G. Blazewitz
M. Carlson

22. Hiroshi Mizuta
Institute for Nuclear Safety
Mita Kokusai Bldg.
Mita 1-4-28, Minato-Ku
Tokyo 108, Japan

NRC FORM 335 (7-77)		U.S. NUCLEAR REGULATORY COMMISSION BIBLIOGRAPHIC DATA SHEET		1. REPORT NUMBER (Assigned by DDC) NUREG/CR-2873, Vol. 1. PNL-4306	
4. TITLE AND SUBTITLE (Add Volume No., if appropriate) Nuclear Fuel Cycle Risk Assessment: Descriptions of Representative Non-Reactor Facilities Sections 1-14				2. (Leave blank)	
7. AUTHOR(S) KJ Schneider, Coordinator; WE Bickford, PM Daling, CA Geffen, TB Powers, NE Miller, KR Yates, WR Zielenbach, RE Pepping, LE Duda, RR Fullwood				3. RECIPIENT'S ACCESSION NO.	
9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) Pacific Northwest Laboratory PO Box 999 Richland, WA 99352				5. DATE REPORT COMPLETED MONTH: July YEAR: 1982	
12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) Division of Risk Analysis Office of Nuclear Regulatory Research U.S. Nuclear Regulatory Commission Washington, DC 20555				DATE REPORT ISSUED MONTH: September YEAR: 1982	
13. TYPE OF REPORT Technical				PERIOD COVERED (Inclusive dates) 6/1/81 - 7/30/82	
15. SUPPLEMENTARY NOTES				14. (Leave blank)	
16. ABSTRACT (200 words or less) <p>This report, the first from the NRC's Fuel Cycle Risk Assessment Program, defines and describes fuel cycle elements that are being considered in the program. One type of facility (and in some cases two) is described that is representative of each non-reactor element of the fuel cycle. The descriptions are based on real industrial-scale facilities that are current state-of-the-art, or on conceptual facilities where none now exist.</p> <p>The fuel cycles considered in this report are for Light Water Reactors with once-through flow of spent fuel, and with plutonium and uranium recycle. Representative facilities for the following fuel cycle elements are described for uranium (or uranium plus plutonium where appropriate): mining, milling, conversion, enrichment, fuel fabrication, mixed-oxide fuel refabrication, fuel reprocessing, spent fuel storage, high-level waste storage, transuranic waste storage, spent fuel and high-level and transuranic waste disposal, low-level and intermediate-level waste disposal, and transportation. For each representative facility the description includes: mainline process, effluent processing and waste management, facility and hardware description, safety-related information (the emphasis of this report) and potential alternative concepts for that fuel cycle element.</p>					
17. KEY WORDS AND DOCUMENT ANALYSIS Nuclear Fuel Cycle, Facilities Descriptions, Nuclear Safety, Risk Assessment, Safety Characteristics				17a. DESCRIPTORS	
17b. IDENTIFIERS/OPEN-ENDED TERMS					
8. AVAILABILITY STATEMENT Unlimited				19. SECURITY CLASS (This report) Unclassified	
				21. NO. OF PAGES	
				20. SECURITY CLASS (This page) Unclassified	
				22. PRICE \$	