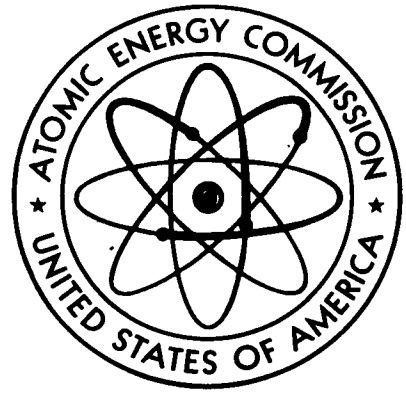
WASH-1248

Environmental Survey of the Uranium Fuel Cycle



April 1974

U.S. ATOMIC ENERGY COMMISSION
Fuels and Materials
Directorate of Licensing

DISCLAIMER

4/24/74

ENVIRONMENTAL SURVEY
OF THE
URANIUM FUEL CYCLE

ERRATA SHEET

Page S-11

Table S-3, Effluents - Radiological (Curies)

9th line from bottom - Change 4.4 to 6.0

7th line from bottom - Change 0.005 to 0.007

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Table S-3A

Change transuranics from waste management to 0.005

Change total transuranic emissions to 0.01

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Environmental Survey of the Uranium Fuel Cycle

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FUELS and Materials
Directorate of Licensing

PREFACE

In November 1972, the "Environmental Survey of the Nuclear Fuel Cycle" was published by the Fuels and Materials staff of the USAEC Directorate of Licensing. The purpose of this document was to establish a basis for those involved in licensing proceedings to provide informed consideration to the generic question of the environmental effects associated with the uranium fuel cycle in light-water-cooled power reactors.

Comments on the Environmental Survey were solicited in the Federal Register notice of a rule-making hearing which was held on February 1 and 2, 1973. The purpose of the hearing was to consider possible amendments to Appendix D of 10 CFR Part 50 to factor the environmental effects of the uranium fuel cycle into the cost-benefit analysis for individual light-water-cooled nuclear power reactors. The present document takes into account the written comments that were submitted in response to the Federal Register notice as well as recommendations for improvement in presentation offered during the hearings.

The Survey and rule-making are both limited to the uranium fuel cycle and the title of this document is being modified accordingly. The off-site environmental effects for each of the fuel cycle operations have been analysed and the data are presented in terms of the annual fuel requirements of a model 1000-MWe nuclear power reactor. Special efforts have been made to be conservative in estimating the nature and quantity of effluents ascribed to the amount of fuel needed for one year's operation of the model reactor. Where operating data were not available, approximations were made which tended to maximize the impact of the fuel cycle on the environment. All effluents, both radioactive and chemical were included. From a review of operations supplying material or utilities to each fuel cycle activity, only the generation of electrical energy for the isotope enrichment step was judged to cause significant environmental effects. The environmental effects of the coal-fired power plants used in the grids supplying the power were therefore included in the survey. These coal fired plants are the major source of gaseous effluents and use the bulk of the water for the entire fuel cycle.

The staff evaluation based upon the original edition of the Environmental Survey indicated that the environmental effects of the uranium

fuel cycle that are attributable to the model reactor were small. As a result of the comments and suggestions from interested parties, additional detailed data have been included or referenced in this revised edition of the Environmental Survey. It is important to note that this added material further supports and reinforces the staff's previous conclusions.

Changes that have been incorporated in this updated edition include the following:

1. The Waste Management Section has been enlarged and expanded to include the material presented in the testimony given during the hearings by Dr. F. K. Pittman, Director of the AEC's Division of Waste Management. Data on the proposed near term Retrievable Surface Storage Facility (RSSF) for above-grade storage of solidified high-level waste have been incorporated. Included is a reference preliminary design for the RSSF, based on existing technology, to demonstrate the validity of this concept. A brief discussion of the design with specific data relating to environmental effects, safety and accident analysis has been included.

2. The subject of "Contributions to the General Exposure" has been addressed in further detail in each basic step of the uranium fuel cycle and this separate category of analysis has been included.

   Previously, the potential exposure to the general public from minute quantities of radionuclides was considered for each step of the uranium fuel cycle. Investigation of this effect has been amplified in the present edition to include consideration of mechanisms for possible terrestrial concentration of nuclides from the fuel cycle.

3. The reprocessing chapter has been expanded by including data and evaluations from environmental studies of the off-site environs of the Savannah River Plant and the Hanford facilities This material has been included to provide information about the effects of the only long-term operations of fuel reprocessing plants. Data on the only commerically operated fuel reprocessing plant at West Valley, New York also have been summarized in this section to include data on this commercial plant. This report was published after the November 1972 Environmental Survey.

Neither the previous document, "Environmental Survey of the Nuclear Fuel Cycle", nor the present document, "Environmental Survey of the Uranium Fuel Cycle", is intended to be a detailed environmental

statement as defined in the National Environmental Policy Act of 1969 and Appendix D of 10 CFR 50 of the AEC's regulations. With the exception of the government-owned isotope enrichment plants and a few uranium mills in states having regulatory authority over such mills, all facilities considered in both documents have been the subject of detailed safety reviews by the staff and are operating under licenses issued by the AEC; they received individual environmental reviews under the AEC's regular policies and procedures governing such facilities. The information contained within both documents has been obtained from government and industry sources, and in some cases, from consultants. A detailed list of references, from which this information was obtained, is given at the end of each section of the survey.

The staff is grateful for the careful consideration given by all reviewers and users to the content of the Survey. Their contributions in the form of suggested improvements and detection of errors have helped to strengthen this document which serves as the technical basis for this important rule-making decision.

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SUMMARY

1. Background and Purpose

As part of the Federal licensing actions for individual nuclear power plants, detailed environmental statements are issued as public documents in conformance with the National Environmental Policy Act (NEPA) of 1969. These statements assess the environmental impact associated with the construction and operation of the specific nuclear power plant, as well as the transportation of radioactive materials to and from the plant. This document is an environmental survey of the nuclear fuel cycle which supports the individual nuclear power plants.

Detailed environmental reviews are carried out in the separate licensing actions for each individual fuel cycle facility involved in the handling of source material, or special nuclear material, and for production facilities. Most of the facilities discussed in this environmental survey were constructed and licensed by the AEC prior to the enactment of NEPA. Accordingly detailed assessments of environmental impact have not been carried out on facilities that predated the NEPA act. It is expected, however, that detailed environmental reviews on the fuel cycle facilities processing the bulk of the nation's fuel material will be accomplished within the next few years as a result of planned modifications and expansions of existing plants, and construction of new ones. This environmental survey is not intended in any way to replace or preclude these thorough and meticulous analyses of individual plants.

2. Scope

This survey assesses the environmental considerations related to the currently predominant uranium fuel cycle for uranium dioxide (UO_2) fueled, light-water moderated and cooled nuclear power plants (LWR). In the United States, about 99% of the electric power generated from nuclear fuel incorporates this fuel cycle and a large percentage of the plants that are under consideration for construction permits or operating licenses will utilize this fuel cycle. In addition, estimates of the nuclear generation of electric power indicate that this predominance of LWR use will prevail through most of the present decade. Alternative nuclear fuel cycles involving the fuel cycle for gas-cooled reactors, plutonium recycle in the present generation of LWR power reactors, and the fast breeder cycle will be considered in future documents.

The specific components comprising the LWR supporting fuel cycle are shown in Figure S-1 and include the following:

(a) Mining uranium ore.

(b) Milling and refining ore to produce uranium concentrates (U_3O_8).

(c) Production of uranium hexafluoride (UF_6) from uranium concentrates to provide feed for isotopic enrichment.

(d) Isotopic enrichment of uranium hexafluoride to attain reactor enrichment requirements using the gaseous diffusion process.

(e) Fabrication of nuclear reactor fuel including: converting UF_6 to uranium dioxide (UO_2), pelletizing, encapsulating in rods and assembling fuel elements.

(f) Reprocessing irradiated fuel and converting uranium to UF_6 for recycle through the gaseous diffusion plant for re-enrichment.

(g) Radioactive waste management of high level and other than high level wastes, including long-term storage of wastes.

(h) Transportation activities associated with moving materials to and from each of the above operations.

As discussed earlier, the environmental considerations relating to the construction and operation of the individual nuclear power plants, including transportation of radioactive materials to and from the power plant, are considered in detailed environmental statements in the separate licensing actions for each individual facility.

The manufacturing operations supporting the nuclear fuel cycle have been reviewed and those that have been judged to be relatively remote, indirect, and less significant contributors to the environmental impact of the nuclear fuel cycle have not been included in this statement. Typical operations in this category include production of commercial reagents such as sulfuric acid, hydrogen fluoride, ammonia, nitric acid, etc.

In many instances improvements in technology are available and plans are underway for incorporating these advances into production facilities However, the primary basis of the present survey is today's industry with only minimal allowances for advances that may be accomplished in the future. In line with Commission practice, standards and criteria relating to fuel cycle facilities are continually evaluated and modified

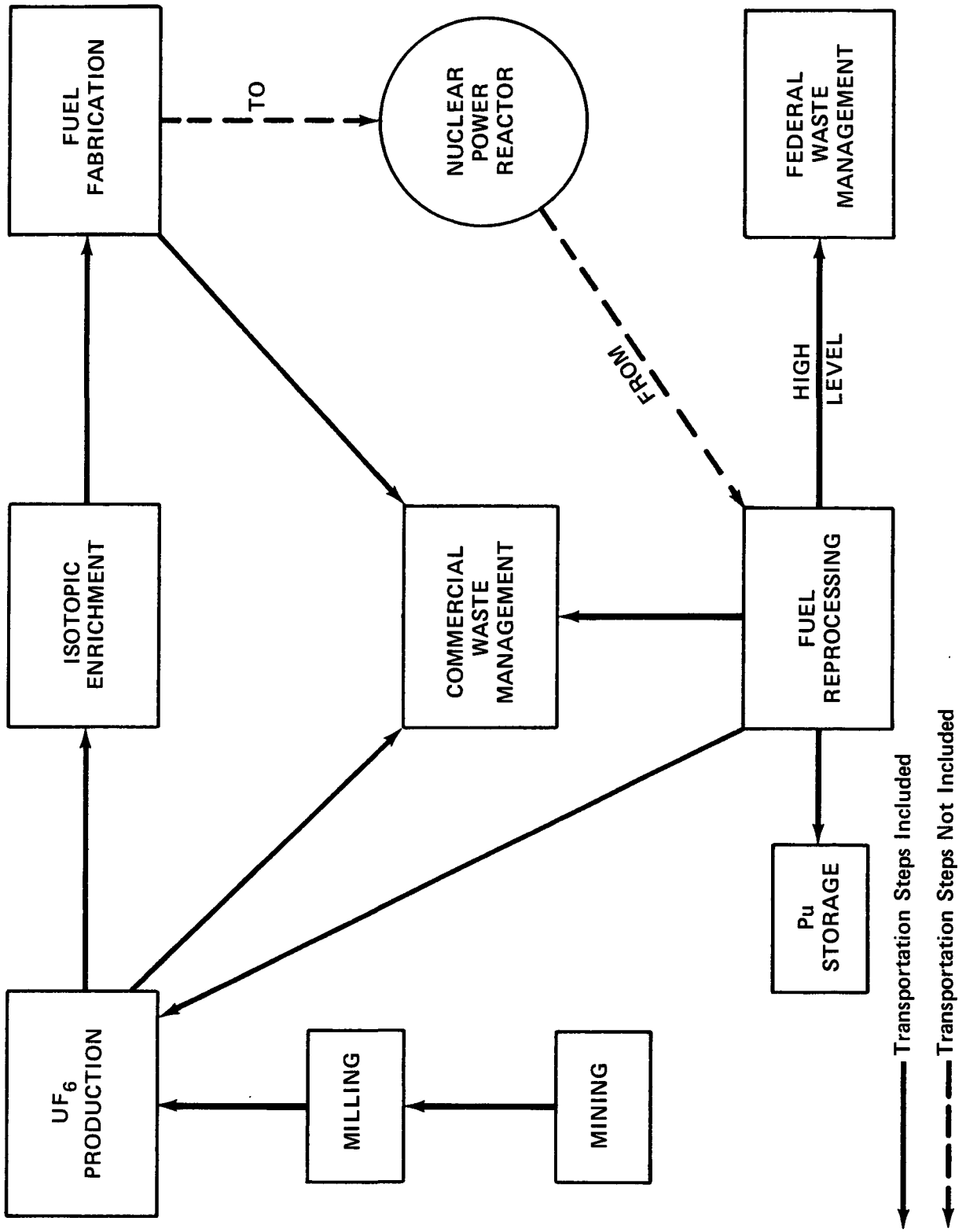

Figure S-1
URANIUM FUEL CYCLE – LIGHT WATER REACTORS
NO PLUTONIUM RECYCLE

as appropriate to reflect experience, changing technology, and expansion of the industry. Thus, future environmental evaluations should also reflect continuing changes and advances as they affect the current mode and level of operations.

3. Nuclear Industry Models

(a) Model LWR

A "model LWR" was developed to relate the environmental considerations of the supporting fuel cycle to the annual operation of a nuclear power plant using data from WASH-1139(71), Nuclear Power 1972-7000. In the development of this model, the requirements for each step of the fuel cycle have been reviewed for the current generation of 1000 MWe boiling water reactors (BWR) and pressurized water reactors (PWR). Both of these classes of LWR's utilize fuel in the form of sintered uranium dioxide pellets encapsulated in either stainless steel or zircaloy tubing. The maximum requirements in each step of the fuel cycle used to define the model LWR are listed in the first two columns of Table S-1 for both an initial core loading and an annual fuel reload together with fuel performance parameters used to define fuel requirements.

The useful life of LWR's has been estimated at between 30-40 years. For purposes of this analysis, a 30-year life has been conservatively assumed in defining the "annual fuel requirement" for the model LWR. The model LWR annual fuel requirement is defined as the sum of one initial core loading plus 29 annual reloads, averaged over the 30-year life of the plant, and is listed for each step of the fuel cycle in the third column of Table S-1. In discussing the environmental considerations of the nuclear fuel cycle steps in subsequent sections, resource use and effluent quantities have been related to this annual fuel requirement.

(b) Model Fuel Cycle Facilities

In some steps of the fuel cycle, numerous plants utilizing a wide variety of alternative processes and operations are involved. To evaluate environmental effects on a generic basis, a model fuel cycle facility for each component of the fuel cycle was defined.

Where industry has used one predominant method or one type of facility, that method or facility has been defined as the model facility. Where a single predominant operation has not been used, the mode of operation that imposes the most significant impact on

TABLE S-1

CHARACTERISTICS OF MODEL LWR (1000 MWe)
MAXIMUM FUEL CYCLE REQUIREMENTS

	Initial Core	Annual Reload	Lifetime Average Annual Fuel Requirement
Irradiation level (MWD_t/MTU) x 10^{-3}	24	33	33
Fresh fuel assay (wt% U-235)	2.6	3.2	3.2
Spent fuel assay (wt% U-235)	0.76	0.84	0.84
Ore supply (MT) x 10^{-3}	332	82.5	91
Yellowcake U_3O_8 supply (MT)	665	165	182
Natural UF_6 (MT)	840	250	270
Separative work (MT SWU)	304	110	116
Enriched UF_6 (MT)	200	47	52
Enriched UO_2 (MT)	152	36	40
Fuel loading (MTU)	134	32	35

Bases

Reactor plant load factor - 80%

Enrichment tails assay - 0.25%

No plutonium recycle

Reloads include recovered uranium

Losses of 1% each in fuel fabrication and reprocessing

MT = metric ton = 2205 lbs.
MTU = metric ton uranium
MT SWU = separative work units in metric tons

the environment has been selected as the model. In some cases, where the nature of the impact from two or more modes of operation differs significantly, the aggregate operation of all plants, normalized to an appropriate annual capacity, has been selected as the model fuel cycle facility. The model fuel cycle facilities are not intended to represent particular plants. However, the models were selected to be representative of the industry and to lead to conservative or pessimistic assessments of the environmental considerations.

In the case of mining, milling, fuel fabrication, and radioactive waste management, the above approach resulted in the adoption of representative individual facilities as the model facilities. The UF_6 production model is a composite of the total industry complex of two plants that are presently in operation. The isotopic enrichment model is the total government-owned, contractor-operated complex of three plants essentially as it exists today. The reprocessing model is a composite of the total industry complex of three plants as they are planned for operation in the middle of this decade. Table S-2 gives the annual capacity of each model fuel cycle facility and relates this capacity to the annual fuel requirement of the model LWR.

The lifetime of each model fuel cycle facility was estimated to relate the land use to the model LWR annual fuel requirement. These estimates are generally 20 years which are on the low side of the expected lifetimes, so that the resulting land use numbers are conservative.

4. Approach to the Assessment of Environmental Considerations

In this broad survey of environmental considerations, the nuclear fuel cycle is treated on a generic basis. This approach permits an overview of the entire industry without keying the study to particular plants and manufacturers. In order to compensate for the lack of specific detail, effluent concentrations, radiation dose rates, and human population densities appropriate to the model fuel cycle facilities are estimated in each section.

Whenever possible, the environmental considerations have been related to the annual operation of a model LWR. This has been accomplished by normalizing the land use, water use, fossil fuel use, and effluent releases (including chemical, radiological, and thermal) to the model LWR annual fuel requirement, defined above in part 3.a of this section. The summary tables in each section, and the main summary table in this section, present the environmental considerations on this normalized basis.

TABLE S-2

NUCLEAR FUEL CYCLE
CAPACITIES RELATIVE TO THE
ANNUAL FUEL REQUIREMENTS OF A MODEL LWR

	Fuel Cycle Plant Annual Capacity		Equivalent Number of Model LWR Annual Fuel Requirements
	Range	Model	
Uranium Mine (MT ore) x 10^{-3}	250-750	480	5.3
Uranium Mill (MT U_3O_8)	500-1100**	960	5.3
UF_6 Production (MTU)	5000-10,000	5000	27.5
Isotopic Enrichment (MT SWU)	6000-17,000	10,500*	90
UO_2 Fuel Fabrication (MTU)	300-1000	900	26
Spent Fuel Reprocessing (MTU)	300-1500	900	26

* Current operating level of industry and assumed model plant capacity
**Characteristic of about 70% of current facilities

It is recognized that the considerations presented in the summary tables may not adequately express the actual environmental impact of the fuel cycle. Accordingly, this information has been supplemented with concentrations and dose rates and compared with applicable and available standards.* These additional considerations are presented in the summary text in each section, as well as in the summary text in part 5 of this Section. Whereas the information presented in the summary table is normalized to the annual operation of a model LWR, it is unrealistic to express concentrations, dose rates, and postulated accident effects on this basis. Accordingly, these considerations are based upon the operation of the model fuel cycle facilities at the design throughput (from Table S-2).

A detailed environmental review of an industrial process effluents involves the consideration of three components. These are (1) a source term or rate of effluent release, (2) a dilution term, or dispersion of the effluent throughout the medium under consideration, and (3) a population term, giving the distribution of human beings or biota affected by the effluent. To evaluate environmental impact, these factors must be combined.

Estimates of effluent concentrations and radiation doses at the site boundaries of the model fuel cycle facilities are based upon experimental data or calculated values. Where measurements are available, these data have been used. In most cases, however, it has been necessary to calculate these quantities, based upon estimated release rates and a model for dispersion. For the fuel reprocessing step, detailed analyses have been made of atmospheric dispersion in conjunction with the NEPA review and the preparation of the detailed environmental statement for specific plants. Therefore for that step in the nuclear fuel cycle the discussion is based upon actual meteorological conditions at the specific sites. For other components of the fuel cycle, for which no such data were available, the model utilizes χ/Q values which are 1/10 of those given in AEC Safety Guide No. 3, as applicable for the model sites.

Where measured or estimated concentrations of chemicals in surface waters were available, these concentrations have been compared with the recommended criteria contained in the Water Quality Criteria "Green Book."** This volume represents the most comprehensive document

* Most commonly used Federal, State and international standards were utilized for both radiological and non-radiological effluents.

**Water Quality Criteria; Report of the National Technical Advisory Committee to the Secretary of the Interior; U. S. Federal Water Pollution Control Administration; Washington, D. C., April 1, 1968.

on water quality requirements, and is used as a basic reference by agencies engaged in water quality standards setting activities. The recommended criteria are for surface water which is to be subjected to normal water supply treatment prior to consumption as drinking water.

Airborne effluent concentrations have been compared with current EPA National Secondary Ambient Air Quality Standards,* where these are available. The secondary standards are designed to protect the public welfare from any known or anticipated adverse effects associated with the presence of air pollutants in the ambient air. For sulfur oxides, the secondary standard is 0.02 ppm, annual arithmetic mean, and for nitrogen dioxide it is 0.05 ppm annual arithmetic mean.

It is important to note that the discussion of environmental considerations in this document is confined to off-site effects; occupational health and safety of on-site workers are given major consideration by the AEC in detailed safety licensing reviews for individual facilities.

5. Summary of Environmental Considerations

The principal environmental considerations for each component of the nuclear fuel cycle, and the aggregate considerations, normalized to the annual fuel requirement of a 1000 MWe model LWR, are summarized for the nuclear fuel cycle in Table S-3. Table S-3A similarly summarizes the considerations for each step in the nuclear fuel cycle.

In the document, land commitments are described as "temporary" or "permanent." A "temporary" land commitment is a commitment for the life of the plant, or succeeding plants. On the abandonment or decommissioning of the plant, such committed land can be used for any purpose. "Permanent" commitments of land represent land that may not be released for use after plant shutdown and decommissioning.

(a) Use of Natural Resources

(1) Land

The temporary land commitment amounts to 63 acres per annual fuel requirement for the model LWR. More than 70% of this

*National Primary and Secondary Ambient Air Quality Standards, published by the Environmental Protection Agency, Federal Register, Volume 36, Number 84, April 30, 1971.

TABLE S-3

Summary of Environmental Considerations
for Uranium Fuel Cycle

(Normalized to Model LWR Annual Fuel Requirement)

	Total	Maximum Effect per Annual Fuel Requirement of Model 1000 MWe LWR
Natural Resource Use		
Land (acres)		
Temporarily committed	63	
Undisturbed area	45	
Disturbed area	18	Equivalent to 90 MWe coal-fired power plant
Permanently committed	4.6	
Overburden moved (millions of MT)	2.7	Equivalent to 90 MWe coal-fired power plant
Water (millions of gallons)		
Discharged to air	156	~ 2% model 1000 MWe LWR with cooling tower
Discharged to water bodies	11,040	
Discharged to ground	123	
Total	11,319	< 4% of model 1000 MWe LWR with once-through cooling
Fossil Fuel		
Electrical energy (thousands of MW-hr.)	317	< 5% of model 1000 MWe LWR output
Equivalent coal (thousands of MT)	115	Equivalent to the consumption of a 45 MWe coal-fired power plant
Natural gas (millions of scf)	92	< 0.2% of model 1000 MWe energy output
Effluents - Chemical (MT)		
[1]Gases (including entrainment)		
[2]SO_x	4,400	
NO_x	1,177	Equivalent to emissions from 45 MWe coal-fired plant for a year.
Hydrocarbons	13.5	
CO	28.7	
Particulates	1,156	
Other Gases		
F^-	0.72	Principally from UF_6 production enrichment and reprocessing. Concentration within range of state standards - below level that has effects on human health.

[1] Estimated effuents based upon combustion of equivalent coal for power generation.

[2] 1.2% from natural gas use and process.

TABLE S-3 (cont.)

	Total	Maximum Effect per Annual Fuel Requirement of Model 1000 MWe LWR
Effluents - Chemical (MT) (cont.)		
Liquids		
$SO_4^=$	10.3	From enrichment, fuel fabrication, and reprocessing steps. Components that constitute a potential for adverse environmental effect are present in dilute concentrations and receive additional dilution by receiving bodies of water to levels below permissible standards. The constituents that require dilution and the flow of dilution water are:
NO_3^-	26.7	
Fluoride	12.9	
Ca^{++}	5.4	
Cl^-	8.6	
Na^+	16.9	
NH_3	11.5	NH_3 - 600 cfs
Fe	0.4	NO_3 - 20 cfs
		fluoride - 70 cfs
Tailings Solutions (thousands of MT)	240	From mills only - no significant effluents to environment.
Solids	91,000	Principally from mills - no significant effluents to environment.
Effluents - Radiological (curies)		
Gases (including entrainment)		
Rn-222	75	Principally from mills - Maximum annual dose rate < 4% of average natural background within 5 miles of mill. Results in 0.06 man-rem per annual fuel requirement.
Ra-226	0.02	
Th-230	0.02	
Uranium	.032	
Tritium (thousand)	16.7	Principally from fuel reprocessing plants - Whole body dose is 4.4 man-rem per annual fuel requirements for population within 50-mile radius. This is < 0.005% of average natural background dose to this population. Release from Federal Waste Repository of 0.005 Ci/yr has been included in fission products and transuranics total.
Kr-85 (thousands)	350	
I-129	0.0024	
I-131	0.024	
Fission Products & Transuranics	1.01	
Liquids		
Uranium & daughters	2.1	Principally from milling - included in tailings liquor and returned to ground - no effluents; therefore, no effect on environment.
Ra-226	.0034	From UF_6 production-concentration 5% of 10 CFR 20 for total processing of 27.5^6 model LWR annual fuel requirements.
Th-230	.0015	

TABLE S-3 (cont.)

	Total	Maximum Effect per Annual Fuel Requirement of Model 1000 MWe LWR
Effluents - Radiological (curies) (cont.)		
Liquids (cont.)		
Th-234	0.01	From fuel fabrication plants - concentration 10% of 10 CFR 20 for total processing 26 annual fuel requirements for model LWR.
Ru-106	0.15*	From reprocessing plants - maximum concentration 4% of 10 CFR 20 for total reprocessing of 26 annual fuel requirements for model LWR.
Tritium (thousands)	2.5	
Solids (buried)		
Other than high level	601	All expect 1 Ci comes from mills - included in tailings returned to ground - no significant effluent to the environment, 1 Ci from conversion and fuel fabrication is buried.
Thermal (billions)	3,360	< 7% of model 1000 MWe LWR.
Transportation (man-rem)		
Exposure of workers and general public	0.334	

* Cs-137 (.075 Ci/AFR) and Sr-90 (.004 Ci/AFR) are also emitted.

TABLE S-3A

Summary of Environmental Considerations for Nuclear Fuel Cycle
Normalized to Model LWR Annual Fuel Requirement

Natural Resource Use	A Mining	B Milling	C UF_6 Prod.	D Enrichment	E Fuel Fab.	F Reprocessing	G Waste Management	H Transportation	Total
Land (Acres)									
Temporarily Committed	55	0.5	2.5	0.8	0.2	3.9	-	-	63
Undisturbed Area	38	0.2	2.3	0.6	0.16	3.7	-	-	45
Disturbed Area	17	0.3	0.2	0.2	0.04	0.2	-	-	18
Permanently Committed	2	2.4	0.02	0.0	0.0	0.03	0.2	-	4.6
Overburden moved (millions of MT)	2.7	-	-	-	-	-	-	-	2.7
Water (millions of gal.)									
Discharged to air	-	65	3.3	84	-	4.0	0.13	-	156
Discharged to water bodies	-	-	23.0	11,006	5.2	6.0	0.13	-	11,040
Discharged to ground	123	-	-	-	-	-	-	-	123
Total Water	123	65	26.3	11,090	5.2	10.0	0.26	-	11,319
Fossil Fuel									
Electrical energy (thousand MW-hr.)	0.25	2.70	1.70	310	1.7	0.45	.0077	-	317
Equivalent Coal (thousand MT)	0.09	0.97	0.62	113	0.62	0.16	.003	-	115
Natural Gas (million scf)	-	68.5	20.0	-	3.6	-	-	-	92

TABLE S-3A (cont.)

Summary of Environmental Considerations for Nuclear Fuel Cycle
Normalized to Model LWR Annual Fuel Requirement

Natural Resource Use	A Mining	B Milling	C UF_6 Prod.	D Enrichment	E Fuel Fab.	F Reprocessing	G Waste Management	H Transportation	Total
Effluents									
Chemical (MT)									
Gases (MT)									
SO_x	8.5	37.0	29.0	4,300	23	6.2	-	-	4,400
NO_x	5.0	15.9	10.0 (3)	1,130	6	7.1 (4)	-	2.6	1,177
Hydrocarbons	0.3	1.3	0.8 (2)	11	0.06	0.02	-	-	13.5
CO	0.02	0.3	0.2	28	0.15	0.04	-	-	28.7
Particulates	-	9.7	7.6	1,130	6	1.6	-	-	1,156
Other Gases									
F^-	-	-	0.11	0.5	0.005	0.11	-	-	0.72
Liquids									
$SO_4^=$	-	-	4.5	5.4	-	0.4	-	-	10.3
NO_3	-	-	0.1	2.7	23	0.9	-	-	26.7
Fluoride	-	-	8.8	-	4.1	-	-	-	12.9
Ca^-	-	-	-	5.4	-	-	-	-	5.4
Cl^-	-	-	0.2	8.2	-	0.2	-	-	8.6
Na^+	-	-	3.9 (5)	8.2	-	5.3	-	-	16.9
NH_3	-	-	-	-	10.0	-	-	-	11.5
Tailings Solutions (thousands)	-	240	1.5	-	-	-	-	-	240
Fe	-	-	-	0.4	-	-	-	-	0.4
Solids	-	91,000	40	-	26	-	-	-	91,000

(1) Estimated Effluents Based Upon Combustion of Equivalent Coal for Power Generation
(2) Combined Effluents from Combustion of Coal and Natural Gas and process tankage; contains 0.2 MT of Hexane
(3) 25% from natural gas use
(4) 77% from process
(5) Contains about 80% Potassium

TABLE S-3A (cont.)

Summary of Environmental Considerations for Nuclear Fuel Cycle
Normalized to Model LWR Annual Fuel Requirement

Natural Resource Use	A Mining	B Milling	C UF_6 Prod.	D Enrichment	E Fuel Fab.	F Reprocessing	G Waste Management	H Transportation	Total
Effluents (cont.)									
Radiological (curies)									
Gases (including entrainment)									
Rn-222	-	74.5	-	-	-	-	-	-	74.5
Ra-226	-	0.02	-	-	-	-	-	-	0.02
Tn-230	-	0.02	-	-	-	-	-	-	0.02
Uranium	-	0.03	0.0015	0.002	0.0002	-	-	-	0.032
Tritium (thousands)	-	-	-	-	-	16.7	-	-	16.7
Kr-85 (thousands)	-	-	-	-	-	350	-	-	350
I-129	-	-	-	-	-	0.0024	-	-	0.0024
I-131	-	-	-	-	-	0.024	-	-	0.024
Fission Products	-	-	-	-	-	1.0	-	-	1.0
Transuranics	-	-	-	-	-	0.004	-	-	0.004
Liquids									
Uranium & Daughters	-	2	0.044	0.02	0.02	-	-	-	2.1
Ra-226	-	-	0.0034	-	-	-	-	-	0.0034
Th-230	-	-	0.0015	-	-	-	-	-	0.0015
Th-234	-	-	-	-	0.01	-	-	-	0.01
Tritium (thousands)	-	-	-	-	-	2.5	-	-	2.5
Ru-106	-	-	-	-	-	0.15	-	-	0.15*
Solids (buried)									
Other than high level	-	600	0.86	-	0.23	-	-	-	601
Thermal (billions of Btu)	-	69	20	3200	9	61	1.0	0.03	3,360

* Cs-137 (0-075 Ci/AFR) and Sr-90 (0.004 Ci/AFR) are also emitted.

land is an undisturbed area or which may be withdrawn by fencing from active use by human habitation. The fencing also restricts migration of large animals. Approximately 18 acres are transformed from their original state by the construction of facilities. Less than 5 acres of land are permanently committed to the production of the annual fuel requirement for a model LWR.

At any time, the total temporary land commitment required by the fuel cycle to support a 1000 MWe LWR is about 750 acres. The total permanent land commitment, assuming a 30-year reactor life, is about 140 acres.

To cast the land requirements into further perspective, a coal-fired power plant of 1000 MWe capacity requires the disturbance of approximately 200 acres per year for strip mining alone. The disturbed area for the nuclear fuel cycle amounts to approximately 18 acres per annual fuel requirement of a model LWR, which is less than 10% of the equivalent annual coal mining land commitment or equivalent to a 90 MWe coal-fired power plant fuel requirement.

(2) Water

Water is used in the nuclear fuel cycle both as a coolant and for process requirements. Water uses have been grouped into three categories based upon the method of return of the water to the biosphere. Water is evaporated into the air, discharged into water bodies or is returned to the ground.

The largest quantity of water involved is the 11 billion gallons required to remove the waste heat from the power stations supplying electrical energy to the enrichment step of the nuclear fuel cycle in the production of an annual fuel requirement. Assuming once-through cooling at these power stations, all of this water is returned to surface water bodies. An additional 319 million gallons of water are directly involved at the fuel cycle plants for cooling, process, and dewatering requirements, totaling 11.3 billion gallons of water moved in producing the annual fuel requirement for the model LWR.

In order to remove the waste heat from a 1000 MWe nuclear power plant on a once-through basis, approximately 300-400 billion gallons of water are pumped annually. Thus, the total demand for water in the components of the nuclear fuel cycle constitutes less than 4% of the water requirement of a 1000 MWe LWR.

The largest single direct dissipation of water by evaporation in the nuclear fuel cycle is for process cooling in the enrichment step. The gaseous diffusion plants evaporate approximately 84 million gallons of water to the atmosphere per model LWR annual fuel requirement. This constitutes approximately 54% of the 156 million gallons of water discharged to the atmosphere in the nuclear fuel cycle. As a point of reference, a 1000 MWe LWR utilizing cooling towers would evaporate approximately 7 billion gallons of water per year to the atmosphere or more than 40 times the evaporative use of water by the nuclear fuel cycle to produce the fuel for a year's operation.

The requirement for uranium mine drainage moves over 120 million gallons of water per model LWR annual fuel requirement. However, minimum depletion is involved, since the water is pumped from the bottom of the mine pit to the ground surface for return to ground water at some other location with some being returned to the atmosphere by evaporation.

(3) Other

The uranium enrichment component of the nuclear fuel cycle requires over 98% of the electrical energy required by the fuel cycle. The total electrical requirements are 317 thousand MW-hr for the annual fuel requirement of a model LWR. A 1000 MWe LWR would produce 7 million MW-hr in annual operation at a load factor of 80%. Thus the electrical requirements of the nuclear fuel cycle to produce fuel for this reactor are less than 5% of the energy produced by the reactor in a year's operation.

At present most of the electricity generated in the United States is produced in plants that burn fossil fuels. Assuming that coal comprises the bulk of fossil fuel utilization, the electrical energy requirements of the fuel cycle correspond to the consumption of 115 thousand MT of coal. A 1000 MWe coal-fired station consumes approximately 2540 thousand MT of coal annually. Thus, the nuclear fuel cycle for a model 1000 MWe LWR consumes about the quantity of coal required for a 45 MWe fossil-fueled plant.

Additionally, approximately 90 million scf of natural gas are consumed for process heat, most of which is used in the milling operation. This quantity of natural gas could be used to generate roughly 9,000 MW-hr of electricity, which is less than 0.2% of annual output of the model LWR.

(b) Effluents

(1) Chemical

(i) *Gaseous*

At present, most of the power plants that supply electricity to the fuel cycle operations burn coal. Consequently, the combustion products of coal comprise nearly all of the airborne chemical effluents attributable to the fuel cycle and approximate the effects from the operation of a 45 MWe coal-fired power plant for a year. The main contributor to these gaseous effluents is the uranium enrichment step, which consumes over 98% of the electrical energy required by the fuel cycle. The existing plants draw power from the grids of large utilities; thus, no single power supply source can be identified with the gaseous effluents. To the extent that power is supplied by nuclear power plants, the total quantity of sulfur dioxide, nitrogen oxides, hydrocarbons, carbon monoxide, and airborne particulates would be greatly reduced.

Fluorine is introduced into the fuel cycle during the UF_6 production step and is removed from the fuel material in the fuel fabrication step. As a result, fluorine becomes an airborne effluent from several steps of the nuclear fuel cycle. Although most of the fluorine gaseous wastes are effectively removed by scrubber treatment systems, approximately 0.7 MT per model LWR annual fuel requirement is released to the environment as an airborne contaminant. To put this quantity into perspective, the estimated fluoride emissions from four major industries are given in Table S-4. Assuming a nuclear power generation industry of 140 model LWR's by 1980, approximately 100 MT of gaseous fluorides would be released annually by the entire nuclear industry at that time. This constitutes about 0.1% of the total annual quantity of fluoride emissions from the total of the industries noted in Table S-4.

Despite the trivial nature of this effluent in comparison with other major industries, the airborne fluoride release from the nuclear fuel cycle could constitute a potential for adverse environmental impact. Measurements or calculations of airborne fluoride concentrations at the site

TABLE S-4

ESTIMATED FLUORIDE EMISSIONS
FROM MAJOR U. S. INDUSTRIES

Source	Emissions MT/yr.
Phosphate Industry (principally fertilizer manufacture)	17,000
Aluminum Manufacture	15,000
Steel Manufacture	39,000
Brick, tile, glass manufacture	19,000
TOTAL	90,000

boundaries of specific plants fall within the range of 0.005-2.0 $\mu g/m^3$. For perspective, these concentrations are well below the level of observed adverse effects on human health, and they span the range of existing state standards.* State standards are used for comparison because there are no applicable Federal Standards.

At uranium mills and UF_6 production plant sites, the combustion of natural gas for process heat is a source of nitrogen oxide release to the environment. Dispersion calculations indicate that annual mean NO_x concentrations are within the EPA air quality standards of 100 $\mu g/m^3$. That standard, according to the Environmental Protection Agency, is adequate to protect the public welfare from any known or anticipated adverse effects associated with the presence of oxides of nitrogen in ambient air.

(ii) Liquid

The largest quantity of liquid effluents, 240 thousand of waste solutions per annual fuel requirement, contains

*State of Washington: 0.5 $\mu g/m^3$
State of Pennsylvania: 5.0 $\mu g/m^3$

sulfuric acid and other spent chemicals from the milling processes. This waste liquor, however, is discharged to the tailings pond, and since it does not normally contaminate unrestricted ground or surface bodies of water, it does not actually become an effluent stream.

Significant quantities of a number of chemicals are discharged in liquid effluents from the UF_6 conversion, enrichment, fuel fabrication and reprocessing steps. The UF_6 conversion plant releases sulfates, fluorides, chlorides, sodium and potassium, ammonia, and iron in its liquid waste. After mixing in the adjacent river, the calculated increase in river water impurities does not exceed 4% under average conditions at the dry process plant. Measured concentrations of fluoride and nitrate downstream of the wet process plant show these concentration to be below surface water standards.

The concentrations of fluorides, nitrates, and ammonia contained in the liquid waste streams from the model fuel fabrication plant are a possible source of adverse environmental effect. Dilution of these constituents by the receiving body of water by 1-3 orders of magnitude may be required to achieve drinking water source quality, depending upon the flow rate of the receiving body of water, its upstream quality and its downstream use. Efforts are in progress to minimize these releases from existing plants.

The liquid effluent quantities from enrichment appear large but generally the chemicals do not constitute a potential for adverse environmental effect and are present at or near drinking water concentrations. The enrichment step contributes the largest total quantity of liquid contaminants, but the concentrations of potential contaminants in the effluent streams are generally within the range of permissible standards.* Additional dilution by about 700-1000 times by the receiving body of water decreases the concentrations well below acceptable levels. Treatment facilities are being planned to reduce the release of hexavalent chromium. The iron concentration, another restrictive species, is diluted to approximately 0.003 ppm in the receiving bodies of water, two orders of magnitude below the recommended criteria.

Fluoride and nitrate wastes are contained in the liquid effluents from UF_6 production plants, while nitrates, sodium, chloride, and sulfates are the principal contaminants in liquid effluents from fuel reprocessing operations. In both cases, dilution in receiving rivers is adequate to

*Water Quality Criteria, U. S. Department of the Interior, April 1, 1968.

reduce the incremental increase in concentration of these species to fractions of a ppm, and at least an order of magnitude below Water Quality Criteria, U. S. Department of the Interior, April 1, 1968.

(iii) Solid

The greatest bulk of solid materials is generated in the open pit mining and milling operations. The barren rock and earth overburden produced by the mine temporarily constitute a waste material, but are essentially returned to the barren mine as backfill and have not been considered as an effluent. The tailings from the mill are composed primarily of sandstone and clays and constitute the major quantity (91,000 MT) of solid waste from the fuel cycle. They are pumped as a slurry to the tailings pond, where they are permanently stored as solids in a chemical form similar to their original condition, but containing slightly less radioactivity, since uranium has been removed.

The 50 tons of ash generated by the hydrofluor UF_6 production process consists of nonvolatile fluorides. Since the ash residue contains traces of radionuclides, it is packaged and shipped for burial at a licensed commercial disposal site and thus does not become an effluent to the environment.

Most of the fluorine added to the fuel cycle during the UF_6 production step is removed and precipitated as CaF_2 in the fuel fabrication step. The 26 MT of precipitated calcium fluoride per annual fuel requirement, occupying a volume of approximately 11 cubic yards, may be buried in trenches on the site of the fuel fabrication plant and covered with backfill.

(2) Radiological

(i) Gaseous

The most significant gaseous radiological release from the fuel cycle derives from the fuel reprocessing step. Nearly all of the krypton-85, most of the tritium (in the model plant, 13% of the tritium is released directly to the watershed) minute quantities of radioiodine, other fission products,

and transuranic isotopes created in the nuclear reactor fuel are released as particulates to the atmosphere from the reprocessing plant operations. However, the estimated annual radiation doses from the model plant to an individual at the site boundary are approximately 2.5 mrem to the whole body, 4.2 mrem to the bone, 6.3 mrem to the thyroid, and 9.25 mrem to the outer layer of skin.

The long-term equilibrium buildup of Kr-85 in the atmosphere, due to one model 1000 MWe LWR, will eventually contribute approximately 120 man-rem annual whole body exposure to the entire population of the northern hemisphere (4 billion people). For comparison, the annual population dose to the same number of people from natural background radiation is approximately 500 million man-rem.

Tritium released from reactor fuel reprocessing can also increase the exposure of the world population. Dose to the U.S. population from the inventory of world wide reactor produced tritium is estimated to be 0.0006 millirem/yr.

Small quantities of uranium and its daughters are released to the atmosphere in several steps of the fuel cycle. Data are unavailable for the total quantity of activity released from the mining operation, but attempts to measure radon concentrations in an open-pit mine revealed no significant alpha concentrations. Estimates of the site boundary concentration of thorium-230 from the model mill are approximately 15% of the 10 CFR 20 limit. In all other cases, the concentrations of uranium and its daughters are estimated to range from 1-4% of the 10 CFR 20 limits for unrestricted areas.

(ii) Liquid

In the fuel reprocessing for a model LWR annual fuel requirement, approximately 2500 curies of tritium, 0.15 curies of ruthenium-106, .075 curies of Cs-137, and .004 curies of Sr-90 are released in the liquid effluent from the model plant.

Small quantities of uranium and its daughters are released in liquid effluents from each step of the fuel cycle. In the mining operation, several curies of activity are dissolved and suspended in the mine drainage water and returned to the ground. At the mill, approximately 2 curies of activity per annual fuel requirement are discharged in the tailings solution and thus are returned to the ground. In the remaining components of the fuel cycle, small quantities of radioactivity are released to receiving bodies of water. Offsite measurements in the vicinity of a UF_6 production plant indicate that annual mean radionuclide concentrations are maintained below 5% of the 10 CFR 20 limits. Estimates of the concentrations of radionuclides in effluent streams from enrichment and fuel fabrication plants indicate that concentrations are below 1% and 10% respectively of the 10 CFR 20 limits before dilution in receiving waters.

(iii) Solid

The most significant solid radiological waste consists of the fission products separated from the spent fuel of an annual fuel requirement in the reprocessing operation. These high level wastes will be stored onsite for a maximum of 10 yrs., and will ultimately be shipped, probably by rail, to a Retrievable Surface Storage Facility (RSSF). The RSSF will be established to store and manage high level solid wastes under constant surveillance for up to 100 years, or until such time as a more permanent Federal repository can be established. The facility will be designed to prevent the release of significant amounts of radioactive material to the environment under all credible environmental conditions and human actions. Therefore, such wastes will not be released as effluents to the environment.

The fuel element hulls and other fuel element parts contaminated with trace quantities of uranium, transuranics and fission products will be buried onsite at the reprocessing facility in a retrievable form and may be eventually shipped to the RSSF. Other low specific activity material, such as laboratory wastes, may be buried onsite or at a commercial burial ground.

Other than high activity solid wastes from UF_6 production, fuel fabrication, and reprocessing facilities amounting to a few curies per annual fuel requirement are packaged

and shipped by truck to a licensed commercial burial site. The geological and hydrological characteristics of these burial sites are such that little or no migration of radioactive material from the site is postulated. The burial sites are enclosed by fences and access is controlled.

The solid waste tailings from the milling operation, which contain most of the uranium daughter products originally in the ore (approximately 600 curies per annual fuel requirement), are slurried in the waste milling solutions. The solutions are pumped to the tailings retention pond and consequently the activity is contained onsite.

The public is exposed to a small amount of direct radiation exposure during the normal shipment of solid wastes. Approximately 600,000 people along the route of travel will receive a population dose of roughly 0.036 man-rem during the rail shipment of high level solid wastes from the fuel reprocessing plant site to the Federal storage facility. The population dose to approximately 200,000 people from the truck shipments of low specific activity solid wastes to commercial burial sites consists of roughly 0.011 man-rem. These dosages constitute less than 0.000006% of the natural background radiation.

(3) Thermal

Approximately 3.4×10^{12} Btu of waste heat are discharged to the biosphere in the production of a model LWR annual fuel requirement. For purposes of comparison, the waste heat from the annual operation of a 1000 MWe model LWR is approximately 50×10^{12} Btu. Thus, the thermal effluents from the supporting fuel cycle constitute less than 7% of the thermal release from the model LWR.

About 95% of the waste heat from the supporting fuel cycle originates in the uranium enrichment step. In this step, 1.6×10^{12} Btu are discharged to water bodies at the supporting electric power stations (assuming that the power stations that supply electricity to the gaseous diffusion plants utilize once-through cooling), 0.5×10^{12} Btu are discharged to the atmosphere through the stack at the electric power stations, and 1.1×10^{12} Btu are discharged to the atmosphere at the gaseous diffusion plants from cooling towers.

The operation of cooling towers leads to local misting and fogging under certain meteorological conditions. At the gaseous diffusion plants, however, this effect does not extend beyond the site boundaries. The impact of the thermal discharge to water bodies is difficult to estimate, since the power is drawn from the grids of large utility complexes and the heat is dissipated to a number of receiving bodies of water.

(c) Accident Considerations

The history of the nuclear fuel cycle to date indicates that accidents in fuel cycle facilities which could result in significant effects on the offsite environment are highly improbable. This record of the commercial nuclear fuel cycle industry has been accomplished by the consideration of safety as a controlling factor in all its functions. Each applicant in his license application is required to analyze potential conditions that could result in the release of radioactivity beyond the plant confines and by proper design, construction and operation to minimize such releases. As a further assurance, the Regulatory Staff performs a detailed independent safety evaluation of each commercial fuel cycle facility which includes at least the following elements:

(1) Site Analysis - Site conditions such as geography, meteorology, hydrology, and seismology are reviewed; in addition, maximum natural phenomena criteria are considered in the case of plutonium plants and reprocessing plants.

(2) Process Evaluation - The process flow sheet is reviewed in detail to identify potential effluents and safety problems during normal and abnormal operations.

(3) Structures and Systems - The building itself, including modules, layouts, etc., is reviewed for safety, emergency escape, limiting the spread of contamination and prevention and control of fires.

Systems - Ventilation, air cleaning, waste treatment, safety instrumentation and monitoring systems are analyzed for suitability under normal and abnormal conditions.

Equipment - The adequacy and reliability of the process and utility equipment are reviewed including the Quality Assurance (QA) on design, construction, installation, operation, and

maintenance. For plutonium conversion and fabrication facilities and for reprocessing plants, Appendix B of 10 CFR 50 covering QA requirements is a requirement.

(4) Radiation Safety and Nuclear Safety Programs - The review includes contamination control considerations, ventilation system performance, exposure assessment for workers and control of such exposure. Effluents and effluent treatment and monitoring systems for both liquid and gaseous streams leaving the plant are evaluated. Accident analyses that include consideration of criticality, radiation safety, and nonradiation safety problems are performed. In the fuel cycle plants handling special nuclear material, both liquid and solid systems are evaluated for criticality safety.

(5) Procedures - The licensee is required to have detailed operating and maintenance procedures. The training and testing programs for operators are reviewed. Particular attention is given to fuel reprocessing plant operators who are tested and licensed by the AEC. The licensee must provide a corporate hazard committee or some similar organization that has responsibility for review of new processes and plant changes. Safety audits of operations are required to be made by the licensee who must report the results of these audits.

Emergency plans are submitted by the licensee and are reviewed for adequacy and detailed coverage. Emergency plans are required for all the special nuclear material plants and for fuel reprocessing plants in accordance with licensing conditions or Appendix E of 10 CFR 50.

(6) Materials and Plant Protection Evaluation - In addition to the licensing functions of health and safety evaluation is the safeguards program of the applicant for the control of special nuclear material and the means by which he intends to protect those materials against theft, diversion, or sabotage.

In addition to requirements for care in design, construction, and operations of nuclear fuel cycle facilities, each licensee is required to report incidents to the cognizant AEC Regulatory Operations office which either have or threaten to cause any of the following types of events:

(i) Radiation exposure of individuals beyond stated limits.

(ii) Release of radioactive materials in daily averaged concentrations of more than 500 times limits specified in 10 CFR 20, Appendix B, Table II.

(iii) A loss of operations of any affected facility for a period of greater than one day.

(iv) Damage to property of over $1000.

The information in these reports is used as a basis for corrective action to prevent similar events from occurring in existing plants and is taken into account in the licensing actions on new or modified facilities of a similar nature. Such information is also evaluated to determine the need for new or modified standards and criteria.

The effectiveness of these measures to date is borne out by the fact that the incidents which have occurred in fuel cycle facilities in this country to date have neither resulted in significant injury nor endangered the health of any individual in the general public. Nevertheless, for each licensed operation of the fuel cycle, a series of potential accidents with environmental effects judged to range from trivial to serious have been postulated and evaluated in the safety analysis that is performed before the individual facility license is issued. Records to date indicate few if any of the routine type accidents involving special nuclear material have had any measurable effects on the environment. Thus, the review of accidents for this statement has been concentrated upon the most serious accidents that either have occurred or realistically can be postulated. The estimated radiological environmental effects of the most significant of these accidents are summarized in Table S-5 which lists the resulting calculated radiation exposure in unrestricted areas.

No criticality incident has occurred in the United States during the processing of low enrichment uranium.* Equipment design, system parameters, and administrative procedures in fuel cycle facilities handling enriched uranium require that two independent errors be necessary for the occurrence of an accidental criticality, reducing the probability of an accidental criticality event to an extremely low value. The resulting dose from such a highly unlikely criticality incident is considerably greater

* Although no such incident in the rest of the world is known to us, our information may be incomplete.

TABLE S-5

SUMMARY OF OFF-SITE
EXPOSURES FROM POSTULATED ACCIDENTS

Accident	Fuel Cycle Component	Calculated Off-Site Exposure (rem)	Principal Affected Organ
Criticality Incident*	Fabrication	6.6 1.3	Thyroid Whole-body
UF_6 Cylinder Rupture	UF_6 Production Enrichment	0.4	Bone
UF_6 Cylinder Rupture	Fabrication	0.1	Bone
Criticality Incident*	Enrichment	0.061 0.08	Thyroid External Neutron & Gamma (Whole-body)
Criticality Incident	Reprocessing	0.04	Thyroid
UF_6 Loadout System Leak	Reprocessing	0.01	Bone
Storage Pool Cooler Leak	Reprocessing	0.01	Bone

*Very improbable, has never occurred with low enriched uranium.

than the annual dose from background radiation; however, it is lower than the maximum annual dose permitted by 10 CFR 20 for occupational exposure.

A rupture or valve failure in a UF_6 cylinder is unlikely, but incidents of this nature have occurred in the past. An accident of this type could occur under varying conditions at a UF_6 plant, enrichment plant, or fuel fabrication facility. In estimating the offsite doses from this postulated accident, assumptions were made regarding the quantity released, the effectiveness of filters, and meteorological conditions. The calculated radiation doses are higher than the average annual dose from natural background radiation but are within the limits of 10 CFR 20 for unrestricted areas. The postulated accident at the UF_6 plant results in the highest offsite effects since it is assumed that the UF_6 cylinder malfunction occurs out-of-doors. Additionally, the fluoride release associated with the accident could result in some localized injury to plant life.

The accidents which were hypothesized for the mining, milling and waste management components of the fuel cycle do not result in significant offsite releases, or at worst entail limited decontamination efforts in the immediate vicinity of the site. The Federal facility for the interim storage of high level wastes will be designed to withstand all natural forces and man-created accidents so that there will be no significant release of radioactive materials to the environment outside of the facility.

It is estimated that 2.8 accidents involving truck shipments of non-enriched fuel cycle material could occur per thirty year lifetime of a model LWR. The low specific activity of the materials would limit the effects of a breach of containment to minor consequences. The likelihood of a criticality incident occurring during a truck shipment of fissile material is estimated to be infinitesimally small. Finally, it is estimated that 0.05 rail accidents involving the shipment of high level wastes to a Federal storage facility might occur per thirty year lifetime of a model LWR. Containers for high level waste must be designed and constructed to withstand accidents likely to be encountered in transport.

6. Overview of Total Nuclear Fuel Cycle

The environmental effects of the total nuclear fuel cycle have been estimated for mid-1972 and for the projected installed nuclear power generation capacity for 1979-1980. In mid-1972 approximately

10-12,000 MWe of nuclear electric generation capacity is estimated to be in operation in the United States. The projected installed nuclear electric generation capacity for 1980 is 140-150,000 MWe. Table S-6 summarizes industry demands and the number of plants for each fuel cycle step operating in 1972 and estimated required capacity and number of plants required to service the 1980 nuclear electric power generation industry. The environmental considerations for operations have been summarized in Tables 0-4, 0-5, 0-6, 0-7, 0-8, and 0-9. These data characterize the environmental effects of each individual fuel cycle plant. The environmental effects of the total fuel cycle may be obtained by combining the data in Table S-6 for the required number of plants with the corresponding information from Tables 0-4 through 0-9.

Uranium Mining

The existing uranium mining industry can produce about 30% more ore than is required by the nuclear electric generation capacity on-line today. By the end of the decade, the required mining rate must triple to meet the demand. Since the bulk of the known reserves are in New Mexico, Wyoming, Texas, Colorado and Utah, it is expected that the mines will be concentrated in that area. The only anticipated change in mining techniques is that a greater fraction of the ore mined in 1980 may come from underground mines, since a larger percentage of reserves are found at depths only amenable to underground mining.

Uranium Milling

The uranium milling industry is capable of supplying about twice today's nuclear power generation requirements of yellowcake; by 1980, the yellowcake demands are expected to quadruple. It is expected that the number of mills will more than double but it is likely that the technology employed will be similar to today's. The new mills are expected to be located in the Western States in the vicinity of mining operations.

UF_6 Production

It is anticipated that the 1980 requirements for UF_6 can be met by planned UF_6 conversion operations at the reprocessing plants and increases in the plant capacity of the existing facilities and by construction of several new UF_6 plants. No technological advance is forecast at this time.

TABLE S-6

TOTAL NUCLEAR FUEL CYCLE INDUSTRY

Types of Plants	1972 Plant Size Thousands of MT	1972 Annual Requirement Thousands of MT	1972 No. of Average Plants Required to Meet Power Demand	1980 (est.) Annual Requirement Thousands of MT	1980 (est.) No. of Average Plants Required to Meet Power Demand
Uranium Mines - Ore	250-750	4,500	10 (220)*	17,000	30-40
Uranium Mills - U_3O_8	0.5-1.1	9	12 (20)*	34	40-45
UF_6 Production - U	5-15	8	1+ (2)*	34**	3 Low Enriched Plants & 3-4 Natural Plants
Isotopic Enrichment SWU	7.5	5	1 (3)*	20	3
Fuel Fabrication - U	0.3-1.2	1.2	3+ (10)*	5.3	8-10
Fuel Reprocessing - U	0.3-1.5	0.2	1 (2)*	3	3-4

*Number in parenthesis is number of plants actually available.
**Including recycle of recovered U from reprocessing operations.

Nuclear Power Generation Basis: 10-12,000 MWe 1972
140-150,000 MWe 1980

Isotopic Enrichment

Planned improvements to the government owned complex of isotope enrichment plants will permit the existing plants to supply the amount of separative work required to service the 1980 installed nuclear electrical generation capacity. Since some of the electrical supply for the isotope separation plants is planned to come from nuclear power by 1980, it is estimated that there will be no increase in the gaseous chemical effluents from the enrichments plants despite a 70% increase in separative work capability.

Fuel Fabrication Plant

The fuel fabrication plant industry is presently serviced by 10 plants, some of which are not expected to be in use in 1980. A total of 8 to 10 production plants, having a combined throughput of over 5000 MTU of fuel per year, will be required to service the 1980 industry. There are new processes under development in the conversion portion of the fuel fabrication step of the fuel cycle. These new processes are expected to reduce substantially most of the chemical process effluents from fuel fabrication.

Fuel Reprocessing

Three fuel reprocessing plants either exist or are under construction in 1972. It is expected that one additional plant will be built and operating in 1980 to meet the reprocessing load. No major technological advances for these plants are predicted.

Waste Management

The volume of other than high level wastes, i.e., those which may be buried in commercial burial grounds, will increase in about the same ratio as nuclear generation capacity. It is expected that the existing burial grounds will be adequate to handle the 1980 volume of wastes. At the present time and through 1980 high level wastes may be stored at the fuel reprocessing plant site as liquids and solids. This onsite storage does not impose significant environmental effects.

It is expected that by 1980 the Retrievable Surface Storage Facility for storage of solidified high level wastes will be under construction. Hence, at some time after 1980, the high level wastes as solids will be transferred from the reprocessing plant to the Federal facility.

Transportation

At the present time, the transportation needs of the fuel cycle supporting the installed nuclear electric generation capacity can be met by about 1400 truck shipments per year on public highways. The movement of low specific activity material accounts for most of that total. By 1980, the number of truck shipments could exceed 16,000, however, the use of rail transport may reduce this volume of highway movements. The amount of material shipped will continue to be an inconsequential fraction of the total transportation industry.

A. URANIUM MINING

1. Summary

(a) General

Uranium mining in the United States is generally accomplished by one of two methods. Open pit mining, which accounted for 53% of the ore produced in this country in 1971, is used when the ore body lies under relatively friable material at depths up to several hundred feet. Underground mining is employed when the ore body is at depths greater than about 400 feet or when it lies under rock strata requiring a great deal of blasting.

Since the environmental effect is greater in open pit mining than in underground mining in terms of total volume of earth disturbed and since about half of the known ore reserves in the United States are located in relatively shallow sedimentary formations less than 400 feet deep,[1] an open pit mining operation in a western state was selected for the model uranium mining operation. The model mine has a capacity of 1600 metric tons (MT) of ore per day, which is equivalent to a yield of approximately 960 MT of U_3O_8 per year. This annual capacity is sufficient to supply 5.3 model LWR annual fuel requirements.

For this segment of the fuel cycle, a combined mine-mill complex was selected as the model since this represents a significant portion of the industry and is consistent with the current trend in the diverse uranium mining-milling industry.

(b) Environmental Considerations

The principal environmental considerations in the production of ore necessary to provide the annual fuel requirement for a model 1000 MWe LWR are presented in Table A-1.

(1) Use of Natural Resources

Land use data indicate that about one-third of the total land involved is disturbed for the actual mining operation, while the remaining two-thirds remains idle.[2] The disturbed land produces about 5400 MT of uranium ore per acre. Recent U.S. Bureau of Mines information

TABLE A-1

Summary of Environmental Considerations
For Uranium Mining
(Normalized to Model LWR Annual Fuel Requirement)

	Total
Natural Resource Use	
Land (acres)	
Temporarily committed	55
Undisturbed area	38
Disturbed area	17
Permanently committed	2
Overburden moved (millions of MT)	2.7
Water (millions of gallons)	
Discharged to ground	123
Fossil Fuel	
Electrical Energy (thousands of MW/hr.)	0.25
Equivalent coal (thousands of MT)	0.09
Effluents	
Chemical (MT)	
*Gases	
SO_x	8.5
NO_x	5.0
Hydrocarbons	0.3
CO	0.02

* Estimated effluent gases based upon combustion of equivalent coal for power generation, together with combustion of diesel fuel for mining equipment operation.

indicates that approximately 6100 MT of coal per acre are produced by strip mining.[3] However, taking into account the 35 to 40 times greater specific energy content of uranium ore,[4] on an equivalent power generation basis, 30-35 times more land is disturbed from mining coal.

The land permanently committed to uranium ore mining amounts to 2 acres for the annual fuel requirement for the model LWR.

Approximately 123 million gallons of water are pumped from the model uranium mine for the model LWR annual fuel requirement.[5] Although this amount of drainage temporarily lowers the local water table, the bulk of the water recycles through natural seepage and evaporation and eventually returns to the groundwater.

The electrical power consumed amounts to 250 MW-hrs for the annual fuel requirement. This is less than 0.1% of the power requirements for the entire fuel cycle.

(2) Effluents

The primary chemical gaseous effluents from the mining of uranium derive from the burning of fossil fuels for the required power and the use of diesel oil for driving mining equipment. The drainage water carries some suspended solids, but the suspended solids can be reduced by settling pond treatment and natural seepage. The primary solid waste material is the barren rock and earth overburden, the bulk of which is ultimately returned to the open pit as backfill.

Uranium and its daughters are released to the atmosphere when the ore body is exposed and broken up during either underground or open pit mining operations. The airborne radionuclides discharged from underground mines are rapidly diluted by forced air circulation and atmospheric dispersion to normal background levels at the site boundaries. Attempts by the Bureau of Mines to measure radon concentrations in existing open pit mines revealed no significant alpha concentrations.[6] Therefore, the concentrations of airborne radionuclides in unrestricted areas are expected to be undetectable.

Mine drainage water resulting from production necessary to supply the annual fuel requirement of the model LWR can contain as much as several curies of radioactivity.[7] This radiological liquid effluent results from dissolved and suspended uranium and its daughters. The activity is removed from the water and returned to the ground by ion exchange during seepage through the soil. When it is economically feasible, the uranium values are recovered from the mine water before it is discharged.[8]

(3) Accident Considerations

Flooding or collapse of mine walls could result in halting mining operations. During recovery, the required increased pumping rate might cause some increased concentration of suspended solids in the discharged mine water. However, due to the low (0.2% U content of the ore) concentration of radioactivity present, it is not likely that the water reaching unrestricted areas would be much different from natural springs in the vicinity.

Resumption of underground mine ventilation after a power failure would result in a transient condition during which higher than normal concentrations of radon would be discharged to the atmosphere. Such an occurrence is not expected to affect the off-site environment measurably.

Accidental releases of mine drainage waters from settling basins could result in the transport of solids containing uranium and its daughter products to nearby streams. Because of the small amounts and dilute nature of radioactive material involved, however, the effects on the environment would be insignificant.

An accidental fire in the mine involving large quantities of petroleum products is credible, but unlikely because of industrial safety precautions. A fire could release combustion products, but radioactive material releases would not be involved.

(4) Effect on the General Exposure

The BEIR report[9] and the US Environmental Protection Agency report, Estimates of Ionizing Radiation Doses in the United States 1960-2000,[10] both conclude that while

uranium mining activities increase the amount of surface uranium and its decay products, it does not cause measurable increases in environmental radioactivity outside the immediate vicinity of the mines.

2. Description of the Uranium Mining Industry

Domestic uranium mines have the capacity to produce about 8.2 million MT of ore per year,[11] but they are producing only 6.3 million MT per year.[12] About 70% of the uranium ore is produced in the States of New Mexico and Wyoming and an additional 17% in Colorado and Utah.[13] The population density in the four states encompassing most mining operations is 11.5 people per square mile.[14] Since uranium mines are usually located in particularly remote areas, the average population density within a fifty mile radius of a mine is approximately 5-10 people per square mile.[15]

Two methods - open pit mining and underground mining - produced more than 98% of the uranium in the United States in 1971. Open pit mining has a cost advantage over underground methods for ore deposits lying less than about 400 ft. below the surface, particularly when the overlying rock can be removed with little blasting. Underground operations are essential for deep deposits. A recent survey showed that 29 open pit mines of sizes ranging up to 700,000 MT per year produce about 53% of the total ore, while 193 underground mines of capacity ranging up to 230,000 MT per year produce most of the remainder.[16] The assay of uranium ore averages about 0.2 percent or 4 pounds of U_3O_8 per ton of ore.

Underground mining is characterized by service buildings, a head frame with a truck loading facility, a mine waste pile, and a flow of water pumped to surface drainage from underground sumps. The area occupied by the hoisting and loading facilities, shops, warehouse, changehouse, and office may be only a few acres, but the reach of underground openings may range to a mile or more. The volume of the mine waste pile can be equal to the volume of processed ore.

The groundwater which enters underground workings contains a variety of dissolved constituents, including radium, radon, and uranium. In the course of its travel from points of entrance to collecting sumps, the composition of this water is not significantly affected, although it is likely to release radon

to the mine air, and it may gain slightly in uranium content. In some underground mining, operators find that it is economically feasible to recover the uranium values from the waste water.

The volume of ventilating air discharged from underground uranium mines is large in comparison with other mines because of the necessity to dilute the radon gas emanating from the uranium ore. Fresh air is usually downcast through the production shaft and distributed through ore haulage ways, then discharged through vent holes or shafts at the extremities of the ore body and at intermediate locations. While the discharged mine air may contain significant total quantities of rock dust and radioactive gases, the large quantities of diluent air carrying these materials combined with natural dispersion in the atmosphere result in concentration levels at the site boundaries usually several orders of magnitude lower than the standards prescribed in 10 CFR 20. The mine air does not contain significant amounts of noxious gases or smoke nor do the mine air shafts intrude upon the landscape.

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 usually nearby and an assortment of heavy earth moving equipment is present. During much of the operating life of the mine, overburden is used for backfilling the mined out areas, thus minimizing haulage and the period of the physical and topographical impact of the operations. In the early stages of open pit mining, it is not possible to begin the restoration efforts until sufficient mined out area is exposed to permit the reclamation to proceed. During the later stages of mining and cleanup, the work of filling the final pit is not economic. The final pit areas are sometimes converted to small man-made lakes rather than attempting to achieve restoration to conditions similar to the surrounding region.

3. Description of the Uranium Mining Model

In line with three mine-mill complexes placed on stream recently, a 3000 acre open pit mining operation in a western state has been selected for discussing the environmental considerations of uranium mining. Open pit mining was selected because of its highly visible effects on the local environment. The model mine

produces about 1600 MT of ore per day for 300 days per year. At an assumed average U_3O_8 content of 0.2%, this is equivalent to about 960 MT of U_3O_8 per year. This annual capacity is equivalent to about 5.3 annual fuel requirements for the model LWR.

The ore body of the model mine lies at various levels from 100 to 450[17] feet below the surface in readily friable rock strata. It has about 10 years of productive mine life. The stripping ratio, yards of overburden to yards of ore body, may be as high as 50 to 1 at times, but is estimated to average about 30 to 1.[18] Topsoil will be stored for later reclamation of the mine area. The rate at which overburden is moved during the life of the mine averages about 9.5 million cubic yards per year.

As mining progresses, the overburden removed is used in backfilling the areas mined out earlier, so that nominally 120 acres remain open at any one time. The overburden storage at any time may amount to 19 million MT and cover about 250 acres during the active life of the mine. Table A-2 contains a summary of the model uranium mine characteristics and the relationship to the annual fuel requirements of the model LWR.

4. Environmental Considerations

(a) Use of Natural Resources

(1) Land

The land controlled in the model open pit uranium mining operation encompasses an area of approximately 3000 acres. The alternative use of the land in the region of the mine is usually animal grazing. Approximately one-third of the land is temporarily disturbed. After the operation is well developed, the pit area is approximately 120 acres. The surface area disturbed by excavation during the life of the mine averages 100 acres per year; an additional overburden storage area covers approximately 250 acres. Dusting and blowing associated with the excavated area is minimal because haulage ways are sprinkled to avoid such effects.

Most of the land occupied by the mine is reclaimed and restored before the site is abandoned. Ultimately, the operator grades and contours the piles of overburden remaining on the site to simulate the surrounding countryside. The final mined-out pit, encompassing

TABLE A-2

MODEL URANIUM MINE

Characteristics and Relationship to a Model LWR

	Model Mine Rates	Model LWR Annual Fuel Requirements	
Ore production (MT/day)	1600	Ore (MT x 10^3)	91
Yellowcake equivalent (MT U_3O_8/yr)	960	Yellowcake (MT)	182
Overburden moved (MT/yr x 10^6)	14	Overburden moved (MT x 10^6)	2.7
Water drainage (gal/min)	1500	Water drainage (gallons x 10^6)	123
Land disturbed (acres/yr)	100	Land temporarily disturbed (acres)	17

Mine Life Totals

Overburden moved	144,000,000 MT
stored	19,400,000 MT
Land disturbed	1000 acres
Covered by overburden storage	250 acres
Exclusion area	3000 acres

MT is metric tons (2205 pounds)

about 120 acres, may not be backfilled, but may instead be graded to reduce the slope of the side walls and allowed to fill with groundwater, forming a man-made lake. The lake may provide future recreational benefits usually unavailable in arid regions. However, permission to do this is within the purview of State land reclamation authorities.

Some uranium mines in the past have not backfilled their open pits to the extent described above. The currently effective and future state legislation on mined land reclamation will require improved performance by the mine operators. Colorado and Wyoming presently have such laws.

Natural reseeding by native plants and grasses and experimental plots of various alternative grasses are being studied by some mining companies in cooperation with State reclamation authorities. The objective of this research is to develop highly reliable methods for restoring the ecological balance in mined out areas while returning the site to stable conditions comparable and compatible with its surroundings.

For mines operated in conjunction with mills in non-agreement states, preservation of rare or endangered species is given consideration to minimize the effects of the operation on wildlife indigenous to the area. Recreational activities, historical monuments, or other unique features peculiar to a site are also considered when applicable.

(2) Water

Approximately 1500 gal/minute of water is pumped from the model mine to keep the mine dry while the ore is extracted. This quantity of mine drainage water is equivalent to 123 million gallons per model LWR annual fuel requirement. The water pumped from the mine temporarily lowers the local water table. The effect is limited to the immediate vicinity of the wells and sumps on the mining property. The water table returns to its normal level when pumping is discontinued. During the life of the mine, part of the water becomes runoff while the bulk recycles through natural seepage and evaporation.

Detailed chemical composition of mine water is not readily available. Humble Oil (Exxon) reports sampling wells and water holes in the Highland Mine-Mill Area and indicates the uranium content of the groundwater ranging from 0.07 to 7 x 10^{-10} µCi/ml. Arsenic is normally less than 0.05 ppm but one determination of 0.12 ppm was made. Selenium is normally less than 0.02 ppm but has ranged as high as 0.08 ppm. pH ranged from 6.2 to 8.0 and water contained 4.2 x 10^{-10} µCi/ml Ra-226 along with 9.9 x 10^{-8} µCi/ml Th-230. Total anions determined ranged from 4 to 20 meq/1. Radium-226 in the Humble mine water retention pond over the period April through November 1972 ranged from 0.05 x 10^{-8} to 0.64 x 10^{-8} µCi/ml.[19]

Utah International reports Ra-226 ranging from 2.3 to 4.8 x 10^{-9} µCi/ml, total alpha ranging from 5 to 5.5 x 10^{-4} µCi/ml, thorium ranging from <0.2 to 4.2 x 10^{-9} µCi/ml, and U ranging from 2 to 25 x 10^{-7} µCi/ml (mean 11 x 10^{-7} µCi/ml) in a few samples collected from their mine ditch (below the mine water settling ponds) over the period November 1962 to February 1972.[20]

Table A-3 contains data on radionuclide concentration mine water from the Homestake-Sapin mine[21] and from the Rio Algom mine in Moab, Utah.[22] The Homestake-Sapin analysis is for water discharged from an ion exchanger-column.

TABLE A-3

URANIUM MINE WATER COMPOSITION

	Activity, µCi/ml	
Radionuclide	Homestake-Sapin	Rio Algom
Nat U	1.2 x 10^{-7}	7.2 x 10^{-10}
Ra-226	1.12 x 10^{-7}	1.4 x 10^{-8}
Th-230	<2 x 10^{-8}	<2 x 10^{-8}
Po-221	<7 x 10^{-8}	--
Pb-210	0.05 x 10^{-7}	--
Pa-231	<9 x 10^{-9}	--
Gross alpha	5 x 10^{-7}	5 x 10^{-8}
Gross beta	3 x 10^{-7}	6 x 10^{-8}

Additional information on effluent water quality is contained in applications submitted to the U.S. Corps of Engineers in 1971 by a number of mines requesting permits for effluent discharges to navigable streams. Data extracted from a number of these applications are contained in Table A-4.

The water analyses show that mine drainage water tends to be slightly acidic to slightly alkaline, with high suspended solids. In only one case (Homestake-Sapin) is the Ra-226 content substantially above 10 CFR 20 limits for release to unrestricted areas; the other radionuclides reported individually are below 10 CFR 20 limits.

(3) Other

The model mine consumes approximately 1300 MW-hr. of electrical energy annually, primarly for the operation of dewatering pumps; in addition diesel fuel is consumed by the heavy earth moving equipment.

(b) Effluents

(1) Chemical

(i) Gaseous

The chemical gaseous wastes produced are the combustion products of petroleum used to fuel the heavy earth moving equipment. These are mostly CO, CO_2, SO_2 and unburned vapors of diesel fuel residues. The quantities involved in the typically remote mining location do not constitute a significant local air pollution factor.

Petroleum wastes such as oils, greases and solvents are accumulated from mining machinery operations. These are disposed of either by sale to a reclamation plant or by controlled burning with attention to wind direction and consideration for downstream effects. In remote areas, the burning of small volumes of petroleum products when winds are directed away from human habitation produces minimal impact on the environment.

(ii) Liquid

The largest liquid waste stream from open pit mining operations is mine drainage water. The required pumping rate for keeping the pit area workable is about

TABLE A-4

URANIUM MINE WATER COMPOSITION
(As Reported in Corps of Engineers Discharge Permit Applications)*

	OPEN PIT MINES		
Applicant	Kerr-McGee	Getty Oil	Utah Intl.
Mine Designation	--	KGS-JY-Mine	Shirley Basin
Mine Location	Shirley Basin, Wyoming	Shirley Basin, Wyoming	Shirley Basin, Wyoming
Flow rate, thousands pgd	460	1,440	2,880
pH	7.9	7.5	6.7-8.2
Alkalinity (as $CaCo_3$)	180	164	144-150
B.O.D. 5-Day	0	67	0-2
Chemical Oxygen Demand	2.4	0	0.8
Total Solids	612	840	850-1,275
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**	360	104	--
Beta Total**	168	77	--
Gamma Total**	N.D.	N.D.	--
U_3O_8**	--	--	140-1100

* Composition data given in mg/l unless otherwise specified.

** $\mu Ci/ml \times 10^{-9}$

TABLE A-4 (contd.)

URANIUM MINE WATER COMPOSITION

	UNDERGROUND MINES			
Applicant	Cotter Corp.	Union Carbide	Union Carbide	Union Carbide
Mine Designation	Schwartz-walder	Eula Belle	Martha Belle	Burro
Mine Location	Golden, Colorado	Uravan, Colorado	Uravan, Colorado	Slick Rock, Colorado
Flow rate, thousands gpd	72	69	47	25
pH	7.9	8.6	8.4	8.8
Alkalinity (as $CaCo_3$)	244	358	384	704
B.O.D. 5-Day	1	12	8	10.8
Chemical Oxygen Demand	10	<2	<2	11
Total Solids	1,220	730	3,103	1,790
Total Dissolved Solids	1,042	590	650	1,780
Total Suspended Solids	178	140	2,453	6
Total Volatile Solids	244	70.7	192	125
Ammonia (as N)	0.15	<0.10	<0.10	3.3
Kjeldahl Nitrogen	0.55	145	0.3	21.8
Nitrate (as N)	12.0	0.35	0.39	1.9
Phosphorus Total as P	0.4	0.2	0.4	0.15
Alpha-Total**	3.3			
Beta Total**	1.05			
Gamma Total**	3.3			

** $\mu Ci/ml \times 10^9$

1500 gpm. The water quality in the mine drainage water is reduced in comparison with local groundwater. It is turbid and frequently carries some suspended solids, rock, silicates and trace uranium ore, from the pit area. The quality of the water can be restored nearly to that of local springs by settling pond treatment.

(iii) Solid

The primary solid waste material produced by mining is the barren rock and earth overburden most of which is ultimately disposed of as backfill. The quantity of overburden that becomes airborne is minimized by watering the road surfaces. Used solid expendable stores, supplies, and trash are of relatively small volume and are burned or buried in earth fills on the site.

(2) Radiological

(i) Gaseous

Airborne radioactive effluents such as uranium bearing dusts and radon and its daughters are released to the atmosphere when an ore body is exposed and broken up during mining operations. Data concerning the total activity released during open pit mining are unavailable, and estimates of this quantity vary by orders of magnitude. However, attempts to measure radon concentrations by the Bureau of Mines in existing open pit mines revealed no significant alpha activity. Therefore, the concentrations of airborne radionuclides in unrestricted areas, at least 600 meters from the point of release, are expected to be undetectable.

(ii) Liquid

Dissolved and suspended uranium and its daughter products equivalent to several curies per model LWR annual fuel requirement are dissolved and suspended in mine drainage water.

(iii) Solid

The small quantity of uranium and its daughter products originally contained in the earth overburden are returned to the ground as part of the backfill material.

(3) Thermal

Except for the relatively insignificant thermal discharges from earth moving equipment, uranium mining does not release heat to the environment.

(c) Accident Considerations

Three accident categories, flooding, fire, and washout, were analyzed for potential environmental effects and all have apparently very slight potential for significant impact upon the off-site environment.

Flooding by natural causes is unlikely because uranium mines are generally located in semi-arid regions of the country. However, a failure of the mine drainage systems to dewater the mine area could occur because of a long term power loss or pump failure. This could lead to gradual flooding with groundwater rising to the level of the water table in the mine pit area. The recovery operations could require an increased rate of pumping operations which might result in some increase in suspended solid concentrations in the drainage water. However, the mineral concentrations in the water from a flooded uranium mine should not be significantly greater than that of natural mineral springs in the vicinity of the mines.

A power failure resulting in the temporary interruption of the ventilation system of an underground mine would result in some buildup of the radon concentration in the mine atmosphere. When the power is restored, the initial exhaust from the mine would contain a higher than normal concentration of radon. This transient condition, however, should have no measurable effect on the environment.

Because of the relatively large amount of suspended solids in the drainage water from some mining operations, the water is passed through settling basins before being released. Failure of a retention basin dike could result in the release of the water along with an appreciable amount of settled slimes to nearby streams. Although these solids may contain small amounts of uranium and its daughter products, such a release is not expected to have a significant effect on the environment.

The risk of fire is reduced by safety practices in the planning and design of uranium mines. Fire in an open pit mine is less hazardous to miners and fire fighters than in an underground mine. The combustible materials available are primarily petroleum products. An accidental fire involving 10-20,000 gallons of diesel oil would release combustion products into the environment, but no abnormal radioactive material releases would be involved. The accident would have an insignificant transient effect on the environment.

Although most mines are located in arid regions, heavy rains can cause washout of the sections of the mine, i.e., collapse of earth walls, etc. The washed out dirt, gravel and rocks will drain to the lowest mine area, and, when the mine is pumped out, the dirt may be suspended in the water. Hence, this accident is equivalent in impact to the flooding accident, although it may have a higher probability of occurrence.

(d) Contributions to the General Exposure

The radionuclides of interest in the mining operation are natural uranium and its daughters. Radon gas and its solid daughters may be released from the mine but are not expected to have any measurable effect beyond the mine boundary (see below).

Mine water may be used in an associated milling operation or discharged as runoff. Fine particles of ore and the soluble amounts of radionuclides may be distributed to the general environment in this way.

Neither radium nor uranium appears to concentrate in plants when the soil in which the plants are grown contains uranium or radium.[23] (The concentration factor given for radium is 0.01-0.1.)[24] In addition, soil, particularly clays, have large ionic adsorption capacities, so that radium and uranium can be removed from water by this natural process. See below for data on mine drainage water.

The BEIR report[25] and the US Environmental Protection Agency report, Estimates of Ionizing Radiation Doses in the United States 1960-2000,[26] both conclude that while uranium mining activities increase the amount of surface uranium and its decay products, it does not cause measurable increases in environmental radioactivity outside the immediate vicinity of the mines.

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B. URANIUM MILLING

1. Summary

(a) General

In the milling operation, uranium is extracted from the ore and is concentrated as a semi-refined product. The product commonly called "yellowcake", which is ammonium diuranate, can be any one of several uranium compounds. It will be called "yellowcake" throughout this survey.

Both mechanical and chemical processes are involved in the milling operation. Initially the ore is crushed and ground after which it is leached with either sulfuric acid or sodium carbonate solutions to extract the uranium values. The leach liquors are purified and concentrated by ion exchange or solvent extraction and the uranium is recovered by chemical precipitation with the solid product calcined, pulverized and drummed for shipment as "yellowcake."

As in a number of existing production complexes, the model mill, located adjacent to a uranium mine in a relatively remote western location, utilizes the acid leach process. The mill produces about 960 metric tons (MT) of uranium concentrate per year, a sufficient quantity to supply the annual fuel requirements for approximately 5.3 model LWR's.

(b) Environmental Considerations

A summary of the environmental considerations associated with the model uranium mill are given in Table B-1.

(1) Use of Natural Resources

Of the approximately 2.9 acres of total land usage attributable to the model LWR annual fuel requirement, approximately 2.4 acres are devoted to a pond for the permanent disposal of mill tailings. In effect, nearly the entire mass of ore processed by the mill ends up in the tailings pond. Although the model plant tailings pond area will be restored to resemble the surrounding terrain after the 20 years of plant life, the land will most likely be removed from further unrestricted use.

TABLE B-1

Summary of Environmental Considerations
For Uranium Milling

(Normalized to Model LWR Annual Fuel Requirement)

	Total
Natural Resource Use	
Land (acres)	
Temporarily Committed	0.5
*Undisturbed area	0.2
Disturbed Area	0.3
Permanently committed (Limited Use)	2.4
Water (Millions of gallons)[1,2]	
Discharged to air	65
Fossil Fuel[1]	
Electrical Energy (thousands of MW-hr)	2.7
Equivalent Coal (thousands of MT)	0.97
Natural gas (millions of scf)	68.5
Effluents	
Chemical	
**Gases[3] (MT)	
SO_x	37
NO_x (40% from natural gas use)	15.9
Hydrocarbons	1.3
CO	0.3
Liquids (thousands of MT)	
Tailings Solutions	240
Solids (thousands of MT)	
Tailings	91

* Major portion of undisturbed area for mills is included in mine land use.

** Estimated effluent gases based upon combustion of equivalent coal and natural gas for power and heat.

TABLE B-1 (Cont'd)

Radiological (Curies)[4,5]	
Gases (including airborne particulates)	
Rn-222	74.5
Ra-226	0.02
Th-230	0.02
U natural	0.03
Liquids[6]	
U & daughters	2
Solids[7]	
U & daughters	600
Thermal (billions of Btu's)	69

Process water, which contains waste milling solutions, also ends up in the tailings pond and is eventually dissipated primarily through evaporation.

The 65 million gallons of water which is redistributed in this way represents about 40% of the evaporative loss of water in the total fuel cycle.

The total electrical power consumed by the model uranium mill in producing the annual fuel requirement of yellowcake for a model LWR corresponds to less than 3 hours output of a 1000 MWe power plant.

Approximately 68.5 million scf of natural gas per model LWR annual fuel requirement are consumed to supply the necessary process and building heat. The largest single requirement is for drying and calcining the yellowcake product.

(2) Effluents

In addition to the gaseous effluent release associated with the generation of electric power required by the mill, small quantities of sulfuric acid fumes, kerosene, and dust are released to the atmosphere from the uranium mill processes. In all cases, the airborne concentrations of these contaminants are maintained well below EPA standards and deleterious effects on biota are highly unlikely.

Low level radiological airborne effluents consist of uranium and uranium daughter products. Conservative estimates of dispersion in the atmosphere predict site boundary concentrations in the range of less than 1% to 14% of the limits of 10 CFR 20.

Liquid and solid chemical and radiological wastes are discharged to the tailings retention pond; operating experience has indicated that no significant adverse effect on the off-site environment is involved. After the model plant is decommissioned, the pond area is graded, covered with earth, and restored for limited use.

Approximately 69 billion Btu of heat are required as process heat in the production of yellowcake for the annual fuel requirement of a model 1000 MWe LWR. Essentially all of this heat is discharged to the atmosphere. The effect on the environment will be undetectable except for some local fogging under certain meteorological conditions.

(3) Accident Conditions

A tailings dam failure through natural causes can be postulated but is unlikely. Tailings releases due to equipment malfunction or human error are not likely to have any appreciable environmental effect. The materials carried from the tailings pond or pipeline would be deposited through sedimentation over a relatively short distance. Recovery would be straightforward and all waste materials and contaminated soils could be either buried in place or returned to the tailings pond.

A postulated fire in a solvent extraction building is also credible, but the effects would be transitory and largely confined to a few hundred feet from the building. Recovery would require a radiation survey of the site and some limited removal or burial of contaminated soil, but it is unlikely to involve consequences greater than the temporary loss of operating capability.

(4) Contributions to the General Exposure

Population dose attributable to the uranium milling industry are expected to be relatively low. While uranium milling activities contribute to the content of radioactivity in the environment, it appears from available measurements that population doses from this source cannot be distinguished from background.[8]

2. Description of the Milling Industry

A uranium mill metallurgically extracts uranium from the ore by mechanical and chemical processing of the mineral into a semi-refined product sold in terms of its U_3O_8 content. Approximately twenty mills are operating in the United States

with a total annual capacity of 17,000 MT of U_3O_8. Mills vary widely in size, but an average output ranging from 500 to 1100 MT/year characterizes about 70% of today's facilities.[9]

Two alternative methods are employed for uranium milling operations in the United States. Mills use either the acid or the sodium carbonate leach process, depending upon the characteristics of the ore being processed. Aside from the expected differences in effluent chemical composition due to the reagents used and the higher concentration of impurities in the acid leach tailings liquor, other differences in the environmental effect of the two leach processes are produced. These include 3.5 times more water consumption and subsequent higher waste discharge volumes for the acid leach process. The alkaline leach process dissolves slightly more of the radium in the ore than does acid leaching. Thus the acid leach process discharges more of the radium with the tailings creating a slightly more radioactive solid waste.[10] Most of the ores are more amenable to the acid leach process and this method accounts for about eighty percent of yellowcake production.[11]

Because of important economic factors such as haulage costs, uranium mills are usually located near the source of ore. Based on the present uranium industry data and known ore reserves, a typical uranium mill is located in an arid, isolated region in one of the western states. The total population within a 50 mile radius is typically 60,000 people. The population density, approximately 5-10 people per square mile, is less than the average population density, 11.5 people per square mile, in the four state mining area of the western United States.[12]

3. Description of the Uranium Milling Model Plant

Since the acid leach process is the predominant chemical processing method, it has been selected as the model for describing the milling operation in the fuel cycle. Also, since in a number of existing mine-mill complexes the mill location is near the mine, the model mill selected is situated adjacent to the mine property. The ore source is an open-pit mine as described in the previous section on uranium mining and its production capacity is nominally 1600 MT of ore per day. The average assay of uranium content in the ore is about 0.2%.

Using these basic considerations for sizing the mill, about 960 MT of uranium concentrate are produced each year for the design life of the mill, which is taken to be 20 years. This annual capacity is equivalent to 5.3 annual fuel requirements for the model LWR.

The model uranium mill uses mechanical crushing and an acid-leach, solvent-extraction process, schematically shown in Figure B-1. The basic steps in the acid-leach process are:

(a) Ores are blended and crushed to pass through a 1-inch screen. The partially reduced ore is then wet ground in a rod or ball mill and is transferred as a slurry to the leaching tanks.

(b) The ore is contacted with sulfuric acid solution and an oxidizing reagent for leaching the uranium from the ore. The residues (tailings) are washed and the product liquor is pumped to the solvent-extraction circuit.

(c) In the solvent-extraction step, the uranium is purified and concentrated.

(d) The uranium is precipitated with ammonia and transferred as a slurry.

(e) Thickening and centrifuging separate the concentrate from residual liquids.

(f) The concentrate is calcined and pulverized.

(g) Packaging in 55 gallon drums readies the concentrate for shipment.

4. Environmental Considerations

(a) Use of Natural Resources

(1) Land

The model uranium mill occupies an area of about 300 acres, possibly within the claimed area of the adjacent mine. The mill site includes an ore storage and blending area; a crushing and sampling building; a mill building containing grinding equipment; a solvent extraction

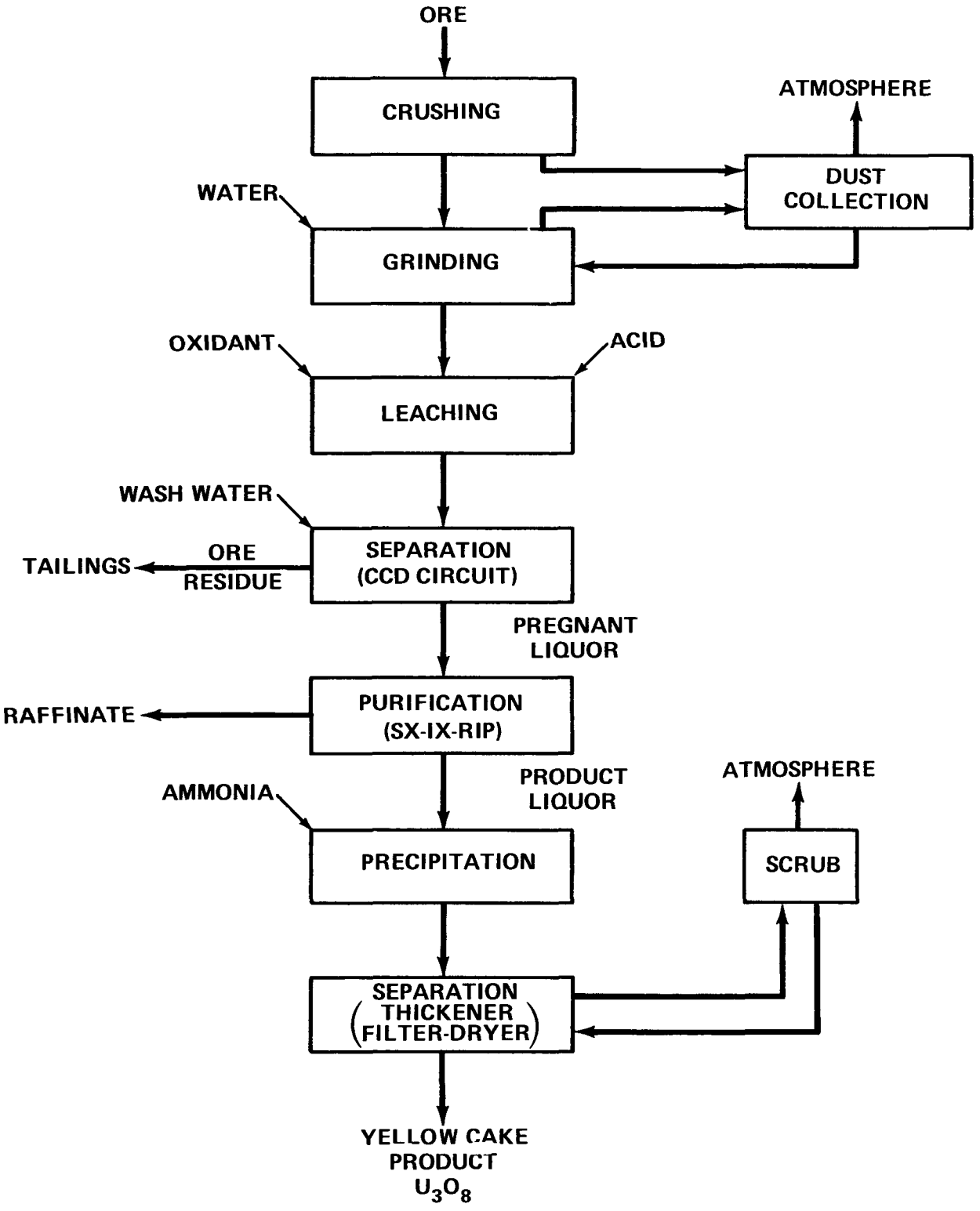

Figure B-1
URANIUM MILL – ACID LEACH PROCESS
SIMPLIFIED BLOCK FLOW DIAGRAM

building; thickeners; a tailings retention system of about 250 acres; a sewage treatment system; and several ancillary buildings used for offices and maintenance.

When milling activities are terminated, the buildings and equipment can be removed from the site and the terrain essentially restored to its original state. The tailings pile can be graded, covered with earth and topsoil and seeded. Approximately 250 acres of the model plant site are involved. The current cost of such reclamation is estimated to be approximately $1000 per acre.

Where it has control over licensing, the U. S. Atomic Energy Commission will require mill operators to provide assurance that funds will be available for reclamation of the tailings area when mill activities are terminated. In addition, the Commission will require the operator to subject the land on which the tailings are stored to the following restrictions:

- The owner will not permit the exposure and release of the tailings material to the surrounding area.
- No structures which man or animals can occupy may be built on the covered surface.
- The covered surface may not be subdivided.
- No private roads, trails, or rights-of-way may be established across the covered surface.

It is expected that these restrictions will be binding on the applicant while it owns the land, and on successive owners thereafter, for a period of 50 years or until such time prior to the expiration of the 50-year period as government regulations are instituted to control disposition of uranium mill tailings.

(2) Water

The model mill requires approximately 1.15 million gal/day of process water. This water, which carries spent chemicals and solid waste tailings, is discharged to the tailings retention pond where it is dissipated, principally through evaporation.

(3) Other

Generally, natural gas is used as a source of process and building heat in the milling industry. The natural gas used for this purpose is approximately 68.5 million scf per model LWR annual fuel requirement.

The annual electric power requirements of the model mill are approximately 14,000 MW-hr. which is less than 1% of the electrical requirements of the total of the fuel cycle.

(b) Effluents

(1) Gaseous

(i) Chemical

Uranium milling operations release small quantities of a number of airborne chemical contaminants to the environment. The products of combustion from the natural gas are CO_2, nitrogen oxides, and water vapor. These gases are released from the process and heating boilers and will have very low particulate emissions. Sulfur dioxide and sulfuric acid fumes are released from the leach tank vent system in very low concentrations. Vaporized organic reagents, mostly kerosene, are released in small amounts from the solvent extraction ventilation system. Approximately 365 #/year of kerosene are released.[13]

Fugitive dust, primarily silica containing a small amount of uranium, may be generated by wind blowing across the ore stockpiles or exposed dry tailings. The amount of dusting from these sources, which are normally kept wetted down, is considered to be negligible in comparison to the process dust. The latter material is produced as a result of the ore crushing and grinding operations as well as in the yellowcake drying and calcining step. Although dust control facilities are provided, some small amount is discharged from the process dust collection system. Conservative estimates indicate that the dust concentration at the site boundary will be about .0012 mg/m^3 [14] or about 1.6 percent of the annual geometric mean allowed by the EPA National Primary Ambient Air Standard for particulate matter.[15]

Industry efforts are being directed toward controlling the concentrations of non-radioactive gaseous effluents so that they do not exceed the standards which have been established by the states or by the Environmental Protection Agency, whichever are governing for the particular situation. Allowable ambient concentrations of volatile sulfur and nitrogen compounds are shown in Table B-2.

TABLE B-2
Uranium Milling
EPA AMBIENT AIR STANDARDS[16]

Pollutant	Concentration	Basis
Sulfur dioxide	0.02 ppm	Annual arithmetic mean
Sulfuric acid fumes	4 micrograms/m^3	Maximum annual average*
Oxides of nitrogen	0.05 ppm	Annual arithmetic mean

*Wyoming State - Ambient Air Quality Standard.

The concentrations of airborne contaminants are maintained below these limits, since the effluents are usually diluted by dispersion in air by several orders of magnitude before they reach unrestricted areas. Based on the small quantities and low concentrations of effluents reaching unrestricted areas, harmful effects on local biota are highly unlikely. Moreover, buildup in the environment over the long term is unlikely in view of the chemical properties of the contaminants and their low concentrations.

(ii) Radiological

The radiological releases include airborne particulates and vapors. Uranium and uranium daughter products (thorium 230 and radium 226) are released from ore piles, the tailing retention system, and the ore crushing and grinding ventilation system in the form of dust. Natural uranium is released from the yellowcake drying and packaging operations as entrained solids. Radon gas is released from the leach tank vents, ore piles, tailings retention system and the ore reduction exhaust system.

The concentrations of airborne radioactive effluents released into the environment from processing operations are limited by dust collection systems. The estimated maximum release rates and conservative estimates of site boundary concentrations, considering all potential sources of airborne dusts, fumes and mists from the plant, ore pile and tailings system, are given in Table B-3. The site boundary concentrations for uranium, radium-226, and radon-222 are in the range of 1 to 4% of the limits given by 10 CFR 20. The concentration of thorium-230 is approximately 14% of the 10 CFR 20 Appendix B limit.

TABLE B-3
Uranium Milling
AIRBORNE RELEASES OF RADIOACTIVE MATERIALS

Radionuclide	Release Rate µCi/day	Site Boundary* Air Concentration µCi/ml
Uranium - natural	500	7.9×10^{-14}
Thorium 230	270	4.3×10^{-14}
Radium 226	270	4.3×10^{-14}
Radon 222	13×10^{5}	1.1×10^{-11}

*Distance to site boundary assumed to be 600 meters.

(2) Miscellaneous Solids

Solid wastes consisting of conventional trash (such as chemical containers, cardboard, paper, etc.) and sludges from the sanitary sewage treatment system are disposed of by controlled burning where permitted or in sanitary fills on the site.

(3) Tailings and Tailings Solution

The major chemical- and radiological-bearing stream leaving the milling process is the tailings slurry. This stream is a mixture of neutralized waste milling solutions and ore tailings. The slurry is pumped to a tailings retention pond system which uses an earthdam and local topographic features of the area to form the impoundment.

(i) Model Plant

The liquid effluent from the model mill consists of about 4300 MT per day of waste milling solutions, containing spent chemicals from the leaching, grinding, and washing circuits of the mill. The solutions, which have an initial pH of 1.5 to 2, contain the unreacted portion of the sulfuric acid used as the leaching agent in the mill process. The waste liquor contains various sulfates and some silica as the primary dissolved solids with trace quantities of metals and organic solvents. This liquor is discharged with the solids into the tailings pond, which is designed to prevent contamination of ground or surface water.

Concentrations of radioactive materials in the 4300 MT/day of waste liquor from the model milling plant are shown in Table B-4. Since the concentrations of Ra-226 and Th-230 are about an order of magnitude above the specified limits in 10 CFR 20, considerable effort is exerted to prevent any release of this material to the environment.

TABLE B-4[17]

Uranium Milling

CONCENTRATIONS OF RADIOACTIVE EFFLUENTS IN WASTE LIQUOR

Contaminant	Concentration
Uranium - natural	5×10^{-7} μCi/ml
Radium 226	1.9×10^{-7} μCi/ml
Thorium 230	1.2×10^{-5} μCi/ml

Approximately 1600 MT per day of solid waste tailings (slurried in about 4300 MT of waste milling solutions) are generated from the mill. The tailings are composed mostly of sandstone and clay particles.

The solid waste tailings contain about 85% of the radioactive materials originally in the ore.[18] During the annual operation of the model uranium mill, approximately 3200 curies of low level activity is carried with the tailings. While stored in the tailings retention pond, natural radioactive decay continues, resulting in further discharge of radioactive effluents to the atmosphere. The radon-222 generated in this manner, which is included in the release rates given in Table B-3, represents almost 100 percent of the total radon released in the milling operation and amounts to about 75 curies per annual fuel requirement.

The tailings retention pond has been constructed to prevent discharge of waste liquid and tailings into the surface water system and to minimize percolation into the ground. Monitor wells are provided to detect seepage as soon as it occurs and a collection system is provided to return any seepage to the pond. In the event of an increased concentration of impurities appearing in the monitor wells, corrective action directed toward locating and sealing the source of seepage would be required to prevent contamination of the ground water.

(ii) Industry Experience

The quantities of chemicals and dissolved radioisotopes discharged to tailings ponds varies with the ore and the recovery process.

An in-plant survey of a uranium mill utilizing the acid leach-solvent extraction process showed the composition for the solvent extraction raffinate stream given in Table B-5. Part of the stream is delivered directly to the tailings pond and part used to repulp washed sands and slimes which are also pumped to the pond.

The analyses of the sand-slimes tailing pond discharge from a mill using the acid leach-solvent extraction process for uranium recovery are given in Table B-6. This mill has a vanadium recovery circuit.

In this process, the solvent extraction raffinate was recycled to process while fresh water was used to repulp the barren solids for transfer to the tailings pond.

It can be seen that the tailings pond liquor tends to be quite acidic and not an attractive source of drinking water for animals or birds.

In 1966, data from 22 licensed mills covering 1045 samples collected from 161 sampling points were analyzed for Ra-226. The analyses showed 75% of the samples contained $<3 \times 10^{-9}$ μCi/ml; 19.2% contained $3 - 10 \times 10^{-9}$ μCi/ml; 4.4% contained $1 - 3 \times 10^{-8}$ μCi/ml; and, 1.4% contained more than 3×10^{-8} μCi/ml. These latter samples represented 6 mills at locations immediately adjacent to tailings piles. Analyses of seepages from tailings dams at 10 mills showed Ra-226 concentrations ranging from $0.4 - 3 \times 10^{-8}$ μCi/ml, with tailings pond liquors containing up to 1×10^{-6} μCi/ml of Ra-226.[19]

(iii) Colorado River Radium Content

Many uranium mills and mines are located on streams or rivers that are part of the Colorado River basin. The U. S. Department of Interior, FWPCA conducts and publishes periodic surveys of the radium content of the Colorado River Basin. Data for the period 1961-1968 show radium-226 concentrations at all reported stations to be below drinking water standards, except at one station in 1968. In that year, the mean annual Ra-226 concentration in the San Miguel River below Uravan was about 12% above drinking water standards.[21] Prepublication data for that station from 1970 to September 1971 show that the maximum Ra-226 concentration during that period did not exceed 50% of the drinking water standard.[22]

(4) Thermal

Approximately 50 million Btu are required hourly from the use of natural gas for generation of process heat. All of this heat is ultimately discharged to the atmosphere.

TABLE B-5

Uranium Milling
Solvent-Extraction Raffinate Composition[20]

Chemical Analysis
Concentration, mg/l (ppm)

Component	Raffinate	Sands-slimes slurry
Total acidity as $CaCO_3$	10,000	5,400
Mineral acidity as $CaCO_3$	9,000	3,500
Hardness as $CaCO_3$	1,850	1,550
Sulfate	12,600	10,000
Chloride	180	275
Iron	48	82
Manganese	17	7
Copper	0.2	0.2
Selenium	0	0
Sodium	1,400	800
Fluoride	12	13
Beryllium	2.4	2.1
Vanadium	0.06	0.03
Arsenic	11	17

Gross Radioactivity Concentrations

Activity in Total Sample ($\mu Ci/ml \times 10^9$)			
Undissolved,	Alpha	780	973,000
	Beta	680	1,052,000
Dissolved,	Alpha	5,900	14,000
	Beta	11,500	38,300
Activity in Undissolved Solids ($\mu Ci/g \times 10^9$)			
	Alpha	20,800	3,140
	Beta	18,000	3,400

Radium-226 Concentrations

Radium 226 in Total Sample ($\mu Ci/ml \times 10^9$)		
Undissolved	130	156,000
Dissolved	480	155
Ra-226 in Dry Undissolved Solids ($\mu Ci/g \times 10^6$)		
	3,500	505

TABLE B-6

Uranium Milling with Vanadium Circuit
Sand-Slimes Tailing Pond Discharge[20]

Chemical Analysis

Component	Concentration mg/l (ppm) Sample I	Sample II
Total Acidity, as $CaCO_3$	310	150
Mineral acidity as $CaCO_3$	10	0
Sulfate	7,600	1,300
Hardness, as $CaCO_3$	3,600	1,300
Chloride	2,280	415
Sodium	1,350	420
Fluoride	13	6
Vanadium	0.08	0.007
Arsenic	3	0
pH	3.8	6.0

Gross Radioactivity Concentrations

Activity in Total Sample ($\mu Ci/ml \times 10^9$)		
Undissolved,	Alpha	295
	Beta	336
Dissolved,	Alpha	320
	Beta	330

Activity of Dry Undissolved Solids ($\mu Ci/g \times 10^9$)	
Alpha	3,190
Beta	3,730

Radium-226 Concentrations

Concen. in Slurry ($\mu Ci/ml \times 10^9$)	
Undissolved	645
Dissolved	74

Concen. in Dry Undissolved Solids ($\mu Ci/g \times 10^6$)
690

(c) Accident Considerations

(1) Tailings Pond Accidents

The most likely types of accidents associated with uranium mill operations, of sufficient magnitude to have any significant effect on the off-site environment are inadvertent discharges of tailings to nearby rivers or streams or a major fire in a solvent extraction circuit.

Of the three modes of failure resulting in off-site releases of tailings, two are related to natural phenomena such as failure of a tailings dam due to flooding or failure due to an earthquake. Releases could also result from equipment failure, such as the rupture of a tailings distribution pipeline, or from operating errors, such as permitting the overflow of a tailings pond through inattention.

Failure of a tailings dam due to an earthquake is highly unlikely since most western mill sites are in the Zone One Seismic category, a region of "minor damage." Although an incident has been reported involving the release of about 2000 gallons of clear tailings liquid due to a break in a secondary tailings dike caused by unusually high runoff from melting snow, failure of a primary tailings dam by flooding is not considered to be a likely hazard. In addition to much of the industry being located in a semi-arid region, the risk of flooding is decreased further by locating the dams below areas of limited drainage, by providing cut-off dams and diversion ditches above the pond area and, by the standard practice of requiring that a 5-foot minimum free-board be maintained during operation of the tailings impoundment system.

If an operational or equipment failure accident occurred, it would probably not involve a sudden catastrophic failure of the dam. The stored sand and slimes would be somewhat resistant to flow and not readily transported by the water in the pond that is retained behind the low head dam. The flow of any leakage from a tailings line or from the tailings pond would be in the direction of the natural drainage course. The materials carried in the runoff would be rapidly deposited by sedimentation

over a relatively short distance. Liquids would flow down the natural drainage system for an indeterminate distance until depleted by seepage and evaporation.

In the event of a tailings release, the recovery action would be relatively uncomplicated. The affected drainage system would be surveyed and waste solids and contaminated soils could be removed and buried or returned to the tailings impound system. The residual environmental impact, if any, would be small.

Several years ago, tailings dike failures occurred. On evaluation of the dike construction, it was determined that dike strengthening was required. Mills having dikes similar in construction to those that failed were required to strengthen the dikes. New mills were required to use the new construction standards.

Table B-7 contains a summary of tailings accidents from 1959 to 1971 assembled from U. S. AEC Compliance files.[23]

(2) Other Accidents

The solvent extraction circuit, where several thousand gallons of solvent (mostly kerosene) containing as much as several thousand pounds of natural uranium are used in the refining process, represents a potential for a serious fire. Aside from a large volume of intense smoke characteristic of a petroleum fire, the effect on the environment from the radiological or chemical contamination standpoint would not be significant beyond a few hundred feet from the source. The recovery action could require that the surrounding area be surveyed for uranium and some contaminated soils removed or buried.

Two large fires occurred in 1968 in two separate mills involving solvent extraction circuits where damages amounted to three hundred thousand dollars in one case and almost a million dollars in the other.[24,25] While from two to three thousand pounds of uranium were present in the circuits at the time of the fires, investigations showed that in neither case was there an appreciable release of uranium to the unrestricted environment and essentially complete recovery of the uranium was expected.

TABLE B-7

URANIUM MILL TAILINGS RELEASES

Date	Mill & Location	Incident
8/19/59	Union Carbide Green River, Utah (Concentrator) Tailings Dike Failure	Tailings dam washed out; Ca. 15000 T sands lost to Browns Wash and Green River due to flash flood; No increase in dissolved Ra was noted in river.
8/22/60	Kerr-McGee Shiprock, N. M. Raffinate Pond Dike Failure	240,000 gal. of raffinate released into San Juan River; $\sim 50 \times 10^{-8}$ μCi/ml Ra-226; river samples collected several days after release showed no increase in Ra-226 background; river at Medicine Hat (100 mi. downstream of plant) showed 0.36×10^{-9} μCi/ml Ra-226 on 8/30/60.
12/6/61	Union Carbide Maybell, Colo. Tailings Dike Failure	Ca. 500 T solids released from tailings area; 200 T reached unrestricted area; no liquid reached any flowing stream. "The presence of these tailings (off-site) does not constitute a hazard, as there are no persons living in the area, nor is there any drinking water taken from surface or ground water in the near vicinity."
6/11/62	Mines Development, Inc. Edgemont, S. D. Tailings Dike Failure	200 T solids washed into Cottonwood Creek and some carried 25 mi. into Angostura Reservoir.
8/17/62	Atlas-Zinc Minerals Mexican Hat, Utah Tailings line failure	Est. 280 T solids + 240 T liquids released from broken tailings discharge line into draw 1.5 mi. from San Juan River. Calculated concentration of river water would have been below 10 CFR 20 MPC.

TABLE B-7 (Cont'd)

6/16/63	Utah Construction Riverton, Wy. tailings dike precautionary release	Material released by 2 ft drainage cut made to prevent cresting due to heavy rains; material released below 10 CFR 20 values.
11/17/66	VCA Shiprock, N. M. Raffinate line failure	Est. 16000 gal of liquid lost because of break in raffinate line; material spread over 1/4 acre; break occurred 1 mile from San Juan River with some small amount reaching river.
2/6/67	Atlas Corp. Moab, Utah Auxiliary decant line failure	Overflow from main tailings pond overflowed aux. decant system; 440,000 gal. lost; average Ra-226 concentration was 5.5×10^{-8} μCi/ml.
7/2/67	Climax Uranium Grand Junction, Co. Tailings dike failure	Dike failure of unapproved retention system released ca. 1-10 acre-ft of waste liquid into Colorado River; No indication that Ra conc. in river exceeded 10 CFR 20 limits.
11/23/68	Atlas Corp. Moab, Utah Tailings distribution pipe break	35000 gal of tailings slurry lost; effluent flowed down drywash and then 1/2 mile to Colorado River; river flow sufficient to give 10,000: 1 dilution; most solids settled out in drywash; measurements of river downstream of plant immediately after release and at 4 hr. intervals in 24 hr. following release showed U, Ra 226, Th-230 below 10 CFR 20 limits.
2/16/71	Petrotomics Shirley Basin, Wy. Secondary tailings dike failure	2000 gal. of liquid lost to unrestricted area; break in dike of effluent sump; spill frozen in place.
3/23/71	Western Nuclear Jeffrey City, Wy. Tailings line - dike failure	Break in sand tails slurry line caused a dike failure allowing sand tails to flow for 2 hr. into natural basin adjacent to tailings site on licensee's property; fence extended to make this area restricted.

It was demonstrated that carbonaceous material, primarily the soot, which had settled out in areas adjacent to the solvent extraction building as a result of the fire contained less than 0.02% U_3O_8 and that this material could have been contaminated with uranium dust deposited prior to the time of the fire. In one case it was established that the fire was started by sparks from a welding operation while in the other, the exact cause was unknown but was believed to have been electrical arcing.

Additional incidents included a small fire causing $5,000 damage which occurred in a uranium mill's drying and packaging area. This fire was caused by the unattended use of an open flame. In another mill, actually a decommissioned mill, a fire was caused by a cutting torch. The company has instituted industrial safety requirements that all personnel involved in cutting operations must have fire-fighting equipment nearby. No off-site environmental effects occurred.

Other minor mishaps such as overflows from process tanks, failure of process lines, failure or misoperation of off-gas filtration or scrubbing equipment or even large spills of reagents such as sulfuric acid or kerosene from storage tanks are credible accidents that may occur in uranium mill operations as in any chemical process industry. The probability of these types of accidents having any significant effect on the off-site environment is negligible.

(d) Contributions to the General Exposure

The radioactive materials of interest in the uranium milling operation are natural uranium and its daughters. In the milling process, some fraction of the radium and thorium in the ore may be dissolved and appear in the liquid impounded in the tailings pond. The major effluents from the milling process come from dust. Two mills have liquid effluent streams and there can be seepage or accidental discharges from tailings ponds. In the south Texas uranium producing district, run off from surface contamination, ore stockpile, and open pit mines can contribute to measurable radium content in surface streams.

Radium is known to adsorb on clays and other soils,[26] and thorium is readily adsorbed.[27] Radium can be absorbed by plants from soil, but the concentration is 1-2 orders of magnitude less in the plant than in the soil.[28]

"Estimates of Ionizing Radiation Doses in the United States 1960-2000" states the isotopes of interest from milling activities are primarily Ra-226 and Rn-222. Studies made at active and inactive mill sites with covered and uncovered tailings showed no significant radiation exposure to the public from these sources.[29]

Population dose attributable to the uranium milling industry is expected to be relatively low. While uranium milling activities contribute to the content of radioactivity in the environment, it appears from available measurements that population doses from this source cannot be distinguished from background.[30]

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C. URANIUM HEXAFLUORIDE PRODUCTION

I. Summary

(a) General

The U_3O_8 concentrate extracted from the ore must be converted to the volatile compound uranium hexafluoride (UF_6) for enrichment by the gaseous diffusion process. Two processes are used for UF_6 production. The hydrofluor process consists of continuous successive reduction, hydrofluorination and fluorination of the ore concentrates followed by fractional distillation of the crude uranium hexafluoride to obtain a pure product. The second method employs a wet chemical solvent extraction step at the head end of the process to prepare a high purity uranium feed prior to the reduction, hydrofluorination and fluorination steps. Roughly equal quantities of UF_6 feed to the enrichment plants are produced by each method.[1]

The nature of the effluents from the two processes differs. The bulk of the impurities entering with the crude uranium feed are rejected from the hydroflur process as solids; in the wet process, the bulk of the yellow cake impurities is contained as dissolved solids in a raffinate stream. The model UF_6 production plant is assumed to produce 1/2 of its output by the hydrofluor process and 1/2 by the wet solvent extraction process so that its environmental effect properly reflects the average industry effect. Approximately 10,000 MT of uranium are processed to UF_6 annually by the two commercial plants. The model plant consists of a 5000 MTU plant, which is representative of about 1/2 of the currently operating industry, and is capable of supplying the annual fuel requirements of 27.5 model LWR's.[2]

(b) Environmental Considerations

Table C-1 gives the principal environmental considerations in the production of UF_6 related to the model LWR annual fuel requirement.

(1) Use of Natural Resources

The temporary commitment of land for UF_6 production amounts to approximately 4% of the total used for the entire fuel cycle. Roughly 10% of the land is disturbed, and about 1% is permanently committed for waste storage.[3]

TABLE C-1

Summary of Environmental Considerations
For Uranium Hexafluoride Production
(Normalized to Model LWR Annual Fuel Requirement)

	Total
Natural Resource Use	
Land (acres)	
Temporarily committed	2.5
Undisturbed area	2.3
Disturbed area	0.2
Permanently committed	0.02
Water (millions of gallons)	
Discharged to air	3.3
Discharged to water bodies	23.0
Total	26.3
Fossil Fuel	
Electrical energy (thousands of MW-hr)	1.7
Equivalent coal (thousands of MT)	0.62
Natural gas (millions of scf)	20
Effluents	
Chemical (MT)	
Gases	
*SO_x	29
**NO_x	10
**Hydrocarbons	0.84
*CO	0.2
F^-	0.11
Liquid	
F^-	17.5
$SO_4^=$	4.5
NO_3^-	.1
F^-	8.8
Cl^-	.2
***Na^+	3.4
NH_3^+	1.6
Fe	.04
Solids (MT)	40

Radiological (curies)	
Gases	
Uranium	0.00015
Liquids	
Ra-226	0.0034
Th-230	0.0015
Uranium	0.044
Solids (buried)	
other than high-level	0.86
Thermal (billions of BTu's)	20

* Effluent gases from combustion of equivalent coal for power generation.[6]
**From the combustion of coal and natural gas and process vents, hydrocarbons include 0.2 MT/yr of hexane from wet process portion of model plant.
***Contains 80% potassium.

The amount of water use associated with the model uranium hexafluoride process is approximately 2.4 million gallons per day.[4] About 150,000 gallons per day are used in the wet solvent extraction step as process water of which about 20,000 gallons ultimately are discharged as raffinate.[5] The remaining water use is primarily for process coolant. About 90% of this source is returned to the river from which it came. The remainder is redistributed through evaporation from holding ponds. The model use rate is assumed to be about one half of the industry use rate which is largely dependent upon the assumption that cooling requirements are about the same using either production process.[7]

The electrical energy used, or the equivalent fossil fuel used, is small when related to the remainder of the fuel cycle. About 20 million scf of natural gas are consumed per model LWR annual fuel requirement.[8]

(2) Effluents

A number of process off-gases are generated in the preparation of UF_6 from crude uranium feed. Most of these are combustion products but some are volatilized solids and gases evolved during calcining and fluorination. Several off-gas treatments are applied to minimize the concentrations of airborne effluents released to the environment. Fluorides and oxides of nitrogen are the more significant sources of potential adverse environmental impact. Historically, analyses of airborne concentrations of fluoride as HF in air and concentrations in forage in the vicinity of a wet solvent extraction plant indicate fluoride levels below those expected to cause deleterious effects on human health or grazing animals. Long term observation of an area within a 7-mile radius of a hydrofluor plant has not revealed any adverse effects attributable to fluoride releases from the plant.[9]

There are two major aqueous waste streams associated with UF_6 production. Many of the contaminants in this liquid waste are in the raffinate stream from the solvent extraction process which is not released to the environment but held indefinitely in sealed ponds. The second stream is made up mostly of cooling water and dilute scrubber solutions which represent the bulk of

the water use. Some of these aqueous effluents are treated with calcium to precipitate calcium fluoride and diluted with all remaining clear water effluents from the plant before they are released. The solid calcium fluoride is recovered from settling ponds, packaged and ultimately buried.[10]

Analyses of water samples taken to measure the amounts of fluoride and nitrate concentrations in the vicinity of wet process UF_6 production plant showed concentrations of 0.1 ppm and 0.3 ppm respectively which are within the 1968 Department of Interior recommendations for drinking water sources.[11] About 0.014 mCi per day of natural uranium is released from the plant in ventilation exhaust air as dusts and volatile UF_6.[12] Radioactivity in liquid effluents, originating primarily from natural uranium, is continuously monitored and has averaged less than 2×10^{-6} μCi/ml or less than 10% of the applicable 10 CFR 20 limit for water effluents to the unrestricted area over the history of an existing UF_6 production plant.[13] Radioactivity in the solid ash residue from fluorination is largely from thorium and amounts to about 0.86 Ci per annual fuel requirement for the hydrofluor process.

(3) Accidents

The accidents considered were industrial incidents which might be associated with UF_6 production. Summary assessments are presented of a solvent extraction fire, a ground level release of UF_6 from a failed cylinder, a raffinate pond dike failure and an evaporator rupture.[14] No credit was taken for mitigating design features. No accidents having an environmental effect have occurred to date.

(4) Contribution to General Exposure

Although conversion operations contribute to the radioactive content of the environment, the incremental exposure is small relative to natural background.

2. Description of the Uranium Hexafluoride Production Industry

A key step in the nuclear fuel cycle is the conversion of uranium ore concentrates (U_3O_8) to the volatile uranium hexafluoride (UF_6) which is suitable for feed to a gaseous diffusion uranium enrichment plant. There are two processes employed for producing uranium

hexafluoride from the uranium feed. One is the dry hydrofluor method which processes the concentrates directly in a succession of fluidized bed reactors followed by fractional distillation. The wet method precedes the conversion to UF_6 with a solvent extraction step designed to purify the U_3O_8 feed. Roughly equal quantities of UF_6 for fueling the commercial reactor industry are produced by each method. Plants using each process have been constructed and operated with sufficient capacity to process at least 5000 metric tons per year of uranium into uranium hexafluoride.

The range of population density in the vicinity of the two existing UF_6 production facilities is 35-60 people per square mile.[15] The region surrounding the plant using the dry hydrofluor process is the more densely populated.

The UF_6 conversion processes remove essentially all of the impurities and produce a highly purified UF_6 product for use as fuel to the isotopic enrichment facility. The dry hydrofluor process eliminates impurities either as volatile compounds or as solid constituents of ash.[16] The major amount of the volatile impurities are removed from the off gases by caustic scrubbers. The wet solvent extraction method separates impurities by extracting the uranium values in an organic solvent leaving other constituents in the aqueous phase.[17] Both plant design bases stipulate virtually complete recovery of uranium values, total utilization of fluorine, and high utilization of a number of the other main reactants, such as hydrogen, hydrogen fluoride and ammonia.

There is also a uranium recovery process of carbonate leach, precipitation, and ammonium sulfate wash, that is a part of the dry process.

The dry hydrofluor process is depicted schematically in Figure C-1, and consists of the following operation:

(a) Pre-process handling, weighing, sampling and storage;

(b) Roasting and fluidized-bed reduction of the U_3O_8 with cracked ammonia to UO_2;

(c) Fluidized-bed hydrofluorination with anhydrous HF to a crude UF_4;

(d) Fluidized-bed fluorination with elemental fluorine to crude UF_6;

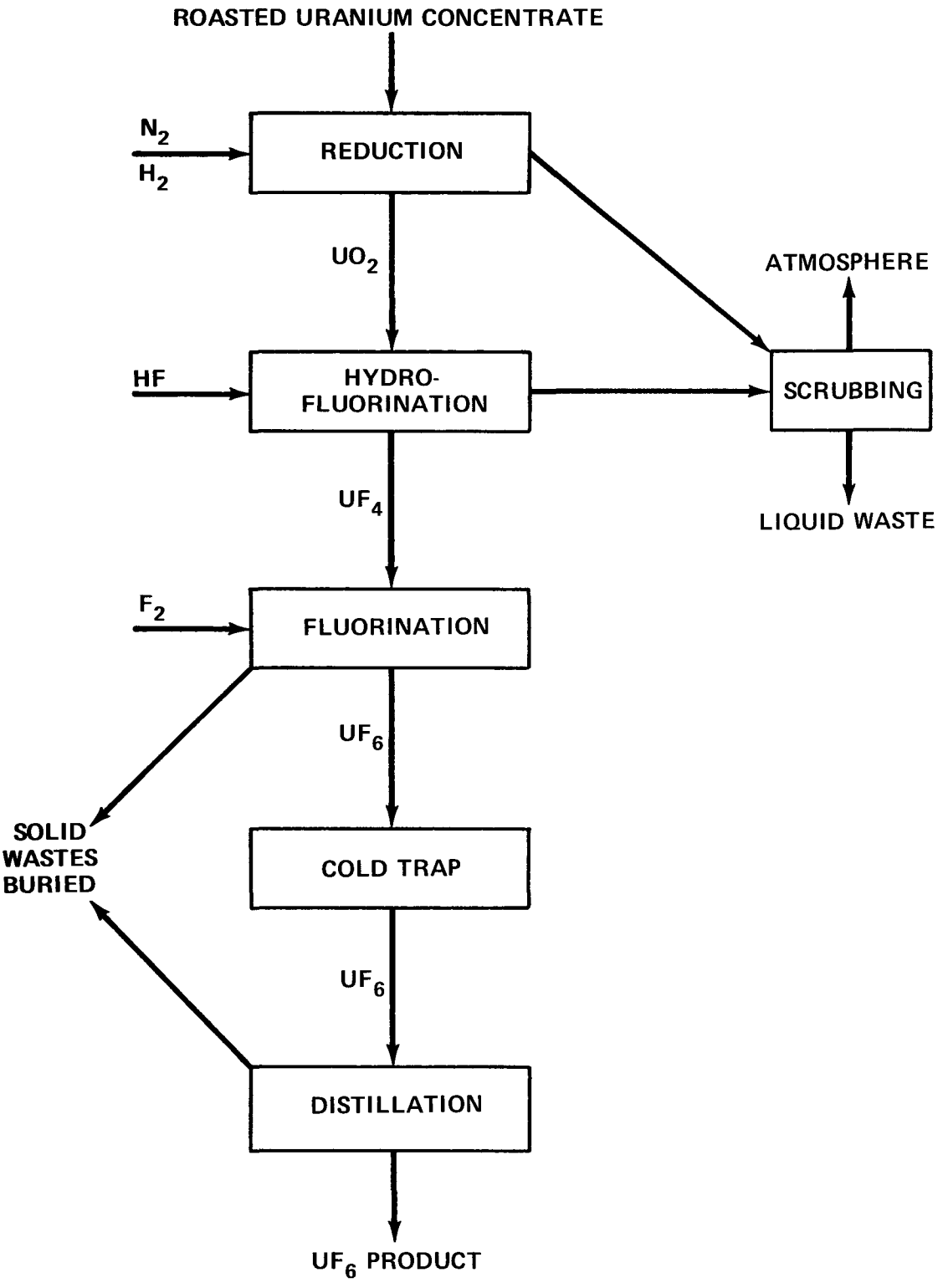

Figure C-1
UF_6 PRODUCTION – DRY HYDROFLUOR PROCESS
SIMPLIFIED BLOCK FLOW DIAGRAM

(e) Fractional distillation to refined UF_6. The distillation step removes volatile fluorides generated in the fluorination step; these fluorides are predominantly molybdenum and vanadium fluorides. The uranium recovery process is also used on incoming high sodium ores, as well as all solid process wastes generated in the process.

In the dry process, the volatile fluorides are separated from the uranium product by taking advantage of relative differences in volatility. These impurities leave the process as solid wastes after treatment.

The second process, a wet chemical solvent extraction method followed by denitration, reduction, hydrofluorination and fluorination in fluidized bed reactors, is depicted in Figure C-2. This method consists of the following operations:

(a) Pre-process handling, weighing, sampling and storage;

(b) Digestion in hot nitric acid;

(c) Countercurrent solvent extraction with TBP in Hexane;

(d) Reextraction of uranium as uranyl nitrate solution;

(e) Calcining to UO_3;

(f) Fluidized-bed reduction with cracked ammonia to UO_2;

(g) Fluidized-bed hydrofluorination in a two stage countercurrent reactor to UF_4 using anhydrous HF;

(h) Flame reactor fluorination to UF_6 by reaction with elemental fluorine. fluorine.

Both of the UF_6 production processes result in products of high purity. The principal difference between the two methods is that the wet process starts with a solvent extraction step to purify the ore concentrate before fluorination, whereas the dry process converts the concentrate to UF_6 in fluidized bed reactor stages and as a final step purifies the UF_6 by fractional distillation.

3. Description of the Model Uranium Hexafluoride Production Plant

The effluents from the two methods of UF_6 production differ substantially. The bulk of the impurities entering with the yellowcake is rejected from the dry hydrofluor process as solids from the fluorination tower in the act process, the bulk of the yellowcake impurities is contained in dissolved solids in the raffinate.

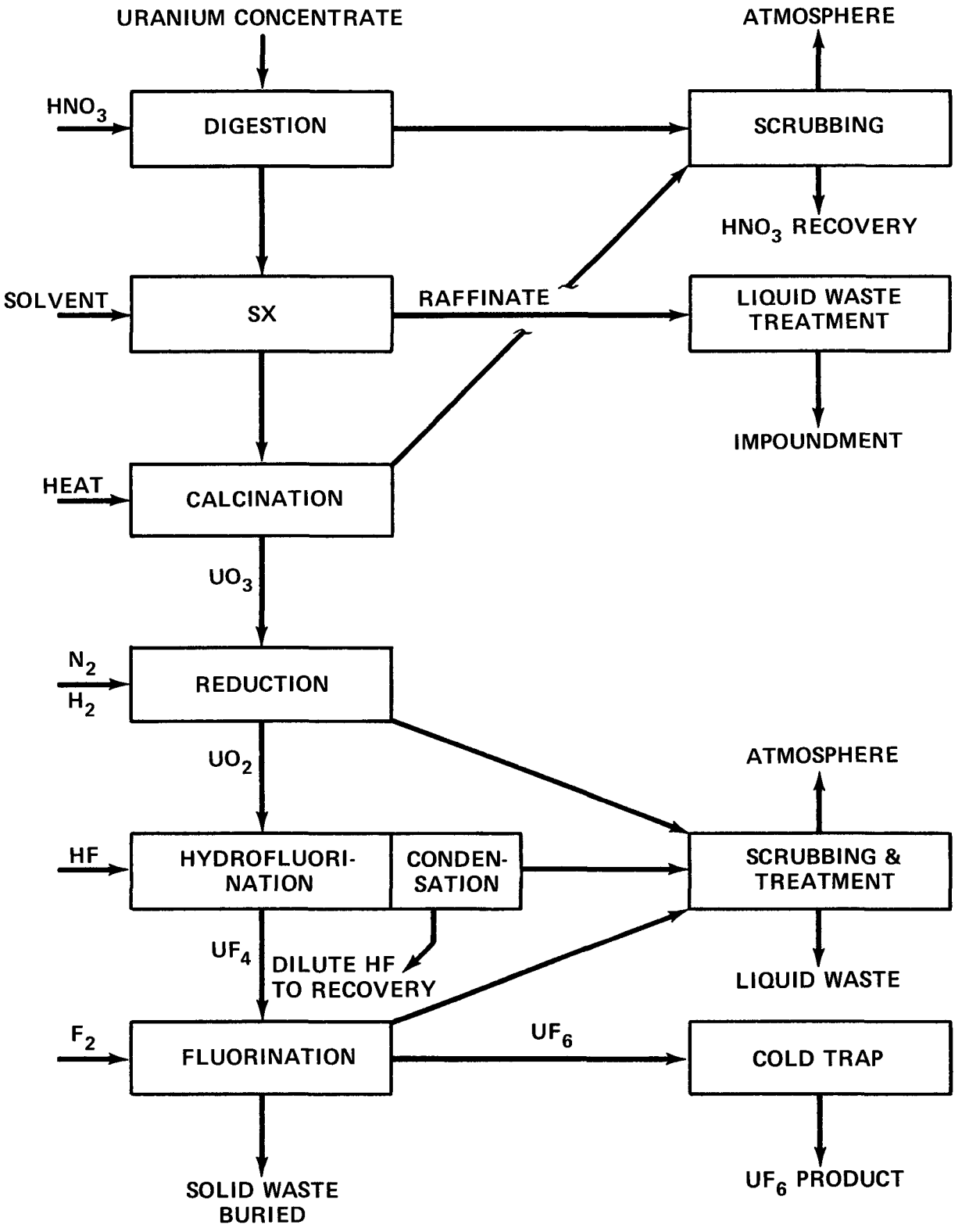

Figure C-2
UF_6 PRODUCTION – WET SX – FLUORINATION
SIMPLIFIED BLOCK FLOW DIAGRAM

Because the UF_6 used by the commercial reactor industry is produced in about equal quantities by the two methods, the UF_6 production plant model consists of a hybrid plant. The model is assumed to produce 1/2 its output by the hydrofluor process and 1/2 by wet solvent extraction. It considers the resources used and effluents from both processes.

To meet domestic requirements, the industry produces roughly 10,000 metric tons of uranium as hexafluoride annually.[18] The model plant is taken to be half of the industry capability or about 5000 MT per year (27.5 model LWR annual fuel requirements) and has an expected life of about 20 years.

4. Environmental Considerations

(a) Use of Natural Resources

(1) Land

The model UF_6 production plant is built on about a 1400 acre site in a developing industrial area. The previous use of the land was agricultural.[19] The site was selected with consideration for minimized impact on local recreation, historical factors, and adjacent farming activity in the area. The supporting services are modern and complete, providing power, water, and transportation.

During the operating life of the plant approximately 100 acres of the site are disturbed for roads, fills, and structures.[20] It is expected that most of the disturbed area can ultimately be restored to its original condition with some difficulty encountered in the case of building foundations, slabs, and underground storage facilities. Accordingly, it is conservatively assumed that about 10 acres of land are permanently committed. This can be expressed as about 2.5 acres temporarily committed per annual fuel requirement of which about 0.2 acre is disturbed. Additionally about 0.02 acre per annual fuel requirement is the estimated area permanently committed.

(2) Water

The rate of water use for a UF_6 production plant is not unusual for industrial use. The wet solvent extraction process uses water for reagent makeup and the aqueous phase of the solvent extraction step. Both methods require water for the process cooling systems, and both return cooling water to natural receiving bodies of water.[21]

In both cases, a site near a river provides a reliable water supply and permits final discharge of treated liquid wastes and coolant water. Some of the liquid process wastes, such as the raffinate from the wet solvent extraction process, are retained indefinitely. Others are treated in holding ponds, sampled, and diluted with other clear aqueous plant effluent streams before being discharged.[22]

The UF_6 production industry uses about 4.8 million gallons of water per day for all purposes, 87% of which is returned to surface waters.[23] The wet solvent extraction process takes in about 26.4 million gallons per model LWR annual fuel requirement produced.[24] Of that amount, 21.2 million gallons are discharged to a river after treatment with lime to reduce the fluoride content and dilution with all other clear water effluents. The remaining water is either discharged to the air as cooling tower losses or other evaporation losses or discharged to the raffinate holding pond.[25]

The dry hydrofluorination-fluorination process for UF_6 production uses water predominantly as coolant. About 26.2 million gallons are used during the production of one model LWR annual fuel requirement.[26] The industry model uses about 26.3 million gallons of water for all purposes during the manufacture of UF_6 for an LWR annual fuel requirement. Of that about 23.0 million are discharged to surface water bodies and 3.3 million gallons are discharged to air.

(3) Other

The model UF_6 production plant consumes about 2100 MW-hrs of electrical energy per model LWR annual fuel requirement. This is equivalent to the power produced by a thermal plant burning 760 MT of coal and represents less than 0.7% of the electrical energy consumed by the fuel cycle in support of the model LWR. Additionally, the UF_6 production plant consumes 20 million scf of natural gas for process heat during the production of an annual fuel requirement.[27]

(b) Effluents

(1) Chemical

(i) Gaseous

The manufacture of uranium hexafluoride produces off-gases such as hydrogen, hydrogen fluoride, hydrogen sulfide, volatile metallic fluorides of uranium, silicon, vanadium and molybdenum and oxides of nitrogen.

The following off-gas treatments are applied to process systems at the wet process plant to minimize the impact of potential airborne effluents:[28]

1. Absorption towers are used to scrub out oxides of nitrogen recovering nitric acid for reuse in the process;

2. Hydrogen is burned, forming water before it is released;

3. Hydrogen fluoride is condensed and the resulting dilute hydrofluoric acid is recycled to a supplier for reprocessing;

4. Hydrogen sulfide is burned, producing SO_2, most of which is scrubbed out in a caustic scrubber solution.

The diluent used for the tributyl phosphate solvent is hexane, a reasonably volatile solvent. It is released to the atmosphere from tank vents.

The fluoride release rate associated with the wet process is about 10 kg per day from the plant stack of a plant operating at design capacity. This is equivalent to 0.11 MT of fluoride released per annual fuel requirement. Analyses for fluoride in air in the vicinity of the wet process UF_6 plant historically indicate concentrations averaging less than 2 ppb, well below the concentrations at which deleterious effects have been reported. Fluoride concentrations in forage have been observed as high as 10 ppm.[29] The generally accepted threshold for fluorosis in foraging animals after relatively long exposure (2-3 years) is 30-40 ppm.[30]

The following off-gases from dry hydrofluor process are all scrubbed with potassium hydroxide in addition to the other indicated treatments to minimize air-borne effluents from the process:[31]

1) Off-gases from the reduction reactor are filtered and scrubbed with water.

2) The hydrofluorination reactor off-gas treatment system consists of filters and water scrubbing.

3) Effluents from the fluorination reactor cold trap system are passed through a KOH-saturated coke box.

4) Hydrogen from the fluorine generation plant.

Most of the oxides of nitrogen attributable to UF_6 production are related to power requirements or natural gas burned. The NO_x in the gaseous effluent from the process is that which is emitted from the nitric acid absorption tower used in the solvent extraction-fluorination process and boilers.[32] The estimated release during the manufacture of one annual fuel requirement by the solvent extraction-fluorination process is 1.2 metric ton. The calculated NO_x emission as a combustion product of natural gas is about 2.7 metric tons per annual fuel requirement produced. The concentration of nitrogen oxides in air at the point of release from the UF_6 plant is estimated at 82 ppm.[33] Taking into account dilution by the atmosphere, it is estimated that the concentration at the site boundary is about 10 ppb, well within the annual EPA air quality standard of 100 $\mu g/m^3$ for the oxides of nitrogen.[34] At these concentrations, no discernible health or environmental effects are expected.

The calculated rate of SO_2 release to the atmosphere from the hydrogen reduction burner is about 22 kg per day based on the design and operating data available for such installations.[35] The amount of SO_2 released by the model UF_6 plant during the

production of an LWR annual fuel requirement is about 240 kg. The calculated concentration at the site boundary is about 0.4 ppb or 1.3% of the EPA air quality standard.[36]

(ii) Liquid

The model plant releases spent scrubber solutions, after some treatment, and treated cooling water to the adjacent river. The liquid effluent consists of the combined waste streams from the dry and wet process plants. The liquid effluent stream contains sulfate, nitrate, fluoride, chloride, sodium, potassium, ammonium, and iron.

Levels measured in receiving streams in the vicinity of a plant using the wet solvent extraction-fluorination process have been 0.1 ppm fluoride and 0.3 ppm nitrate downstream from the plant.[37] These concentrations are within the 1968 Department of Interior Surface Water Criteria for Public Water Supplies, 0.8 to 1.7 mg/l for fluorides and 10 mg/l for nitrates in bodies of water used as sources of drinking water.[38]

The dry process fluoride liquid waste discharge is diluted by a factor of about 10,000 under average conditions, and about 1,500 under minimum flow (1968) conditions. The calculated increases in concentrations under average conditions in the river downstream of the plant are as follows: 0.6% for fluoride, a limiting species; 4% for ammonia; less than 1% for the constituents given in Table C-1.[39] Developmental work is being carried out at the dry process plant to reduce the amount of fluoride in the liquid waste.

The raffinate liquid generated in the wet UF_6 process amounts to 3.2×10^6 gallons/yr (at 2500 MT/yr). This liquid is variable in composition, containing large amounts of dissolved solids,[40] as well as soluble radionuclides. This raffinate stream is neutralized and impounded until a permanent method of disposal is developed. Neutralization results in precipitation of some uranium and daughter products (see below).

(iii) Solid

The major part of the chemical solid effluents originates in the hydrofluor process as nonvolatile ash and consists of iron, calcium, magnesium, copper and other nonvolatile fluorides.[41] The quantity of ash produced by hydrofluorination amounts to approximately 0.1 ton per metric ton of product or 18.2 metric tons per annual fuel requirement.[41] The ash containing nonvolatile fluorides is continually removed from the process and reacted with fresh fluorine to recover the uranium.[43] The final ash residue, containing traces of uranium daughters is packaged and consigned for burial as solid waste at a licensed commercial waste burial site.[44] No similar volume of solid ash waste is produced by the wet solvent extraction fluorination process. Treatment of scrubber effluent from the wet process plant produces calcium fluoride solid wastes.

(2) Radiological

(i) Gaseous

The quantity of natural uranium in exhaust ventilation from all process sources associated with the wet solvent extraction-fluorination approximates 0.014 mCi per day (about 41 g) or 0.00015 Ci per annual fuel requirement for a model LWR.[45] This does not constitute a potential for a significant environmental effect. The calculated concentration of natural uranium in air at the site boundary using conservative meteorological assumptions is about 7×10^{-16} µCi/ml, which is less than 0.1% of the 10 CFR 20 limit.

(ii) Liquid

The cooling water stream from either the wet or dry UF_6 process, together with dilute scrubber effluents is released to the river near the plant. The average concentration of uranium in the liquid effluent from one plant for the first 10 months of 1972 was 8.4×10^{-7} µCi/ml (∿ 4% of MPC).[46] The raffinate liquid generated in the wet UF_6 process

is impounded. Of the soluble radionuclides present in the neutralized raffinate pond, only radium is present in amounts exceeding 10 CFR 20 limits.[47] After two years of operation of the wet process UF_6 facility, the total sludge collected in the ponds was estimated to contain about 7600 kg of uranium.[48] The sludge also contains short lived daughters in secular equilibrium with U-238, and the radium and Th-230 entering with the yellowcake feed.

Tentative plans for the ultimate disposal of the raffinate call for increasing the evaporation of the water, and disposal of the sludge by either burial at a licensed burial ground or reprocessing at a mill to recover the uranium with transfer of the waste material to the mill tailings pond.

(iii) Solid

The estimated quantity of radioactivity in solid wastes from the dry hydrofluor portion of the model plant is given in Table C-2. The total activity involved is approximately 24 curies per year or 0.86 Ci per annual fuel requirement. The activity is contained in the ash residue which is packaged and consigned for burial at a licensed commercial disposal site.[49] Some other low activity solid wastes in insoluble form are buried. Typical materials in this classification would be contaminated drums. Less than 1000 pounds per year of such waste material is generated.[50] This is equivalent to about 16.5 kg per annual fuel requirement.

(3) Thermal

Approximately 20 billion Btu of process heat is dissipated during production of the UF_6 for the model LWR annual fuel requirement. Most of the heat is used in calcination and is discharged to air in the vicinity of the solvent extraction process. Much of the process heat load from the production of UF_6 is discharged to the environment by evaporation from holding ponds or cooling towers. The cooling water used in the wet process is elevated in temperature by approximately 5°F prior to its discharge to a receiving river.[51] The thermal load from the dry hydrofluorination process is similarly discharged to air and to a receiving river.

TABLE C-2

Radioactivity in Solid Wastes
Hydrofluor Section of Model Plant
(2500 MT/yr UF_6)

Activity Source	Annual Activity Ci/yr
Uranium -234, -235, and -238	1.7
Short-lived daughter products in equilibrium with natural uranium	1.7
Decayed separated daughter products	.25
Thorium 230	18
Radium 226	1.8

Basis: 0.1% Uranium loss

0.2% of radium in ore enters process with yellowcake

2.0% of Th-230 in ore enters process with yellowcake

Solids cooled one year before burial.

(c) Accident Considerations

To the extent practicable, accidents are minimized or mitigated by design features and operating procedures in UF_6 production plants. Engineered handling equipment, automatic safety features, and procedural controls reduce the likelihood of accidents. The training and experience of personnel add further to the safety of operations and precondition action to promptly mitigate the consequences of accidents. The effectiveness of these measures is demonstrated by the fact that there have been no accidents to date that have had any offsite environmental effects.

Several accidents associated with UF_6 production have a potential for offsite effects. The following five have been described and analyzed:[52]

- A fire in the solvent extraction (SX) operations;
- A valve failure or rupture of a hot UF_6 cylinder;
- A waste retention pond rupture;
- A UNH evaporator failure;
- An acid tank rupture.

Accidents involving elemental fluorine releases are not addressed because essentially no fluorine is stored.[53] It is prepared as needed and used in process.

The SX building can be considered as 2 operating parts. The first is the solvent rework section where most of the organic solvent used in the process, hexane, is stored and prepared for use. The other is the solvent extraction section where the uranium purification process is carried out.

Fire in the solvent rework section might involve burning as much as 7000 gallons of hexane and may be considered a typical industrial accident. A fire on the solvent extraction side of the operation might involve columns containing uranium and its radioactive daughter products. The SX units contain both organic and aqueous streams. The organic stream, TBP-hexane, preferentially extracts uranium. The amount of loaded solvent which might be involved could be about 2500 gallons containing as much as 1800 pounds of uranium.[54] The radioactive material present would be low specific activity natural uranium and daughter products.

The fire could involve a spill of the contents of an extraction column which would result in a pool of burning hexane floating on the aqueous phase, all of which would be retained by concrete curbing, a structural feature of the SX building.[55]

The fire would normally be suppressed by an automatic water-foam deludge system but, assuming that system failed to operate, the natural uranium carried in smoke would be largely confined to the building, plating out on all surfaces with smoke particulates. Traces carried out of the plant in smoke might deposit in the vicinity of the building. It is unlikely that there would be measurable uranium deposition beyond the plant site. The consequences of fire accidents would result in no significant radiological consequences offsite and could constitute a localized cleanup problem with operational losses rather than a potential environmental effect.

A second accident considered which can be associated with the UF_6 production operations is a rupture or valve failure of a hot cylinder (nominally 14 ton) of UF_6. The accident is assumed to occur out-of-doors during handling or transfer before the valve production has been installed. The assumed failure is the loss of a valve which results in a hold in a hot cyclinder of UF_6 causing an estimated release of 9200 lbs of natural UF_6. Table C-3 shows the calculated radiation dose to organs of interest and the concentration of fluoride downwind from the point of release assuming no mitigating effects and the person exposed remained in the path for the duration of the release.[56]

TABLE C-3

CONSEQUENCES OF NATURAL UF_6 CYLINDER FAILURE

Distance (meters)	Exposure (rem) Kidney	Bone	Hydrogen Fluoride mg/m^3
1000	0.1	0.4	10

In the accident described the toxicity of the uranium, the chemical toxicity of the fluorides (HF and UO_2F_2) and the radiation dose to bone could all be considered safety questions.

An individual would not be likely to remain in the path of the uranium - HF cloud for the full duration of the release since the smell of HF would be perceptible and the calculated concentration of HF is about 40% of the level which causes eye and respiratory discomfort.[55] It should be recognized that corrective action like spraying with water would tend to cool the cylinder and rapidly deplete the HF-UO_2F_2 cloud.[58] The environmental effects of such a release could result in some localized foliar lesions on plant life in the path of the HF but inconsequential permanent damage. The HF intake by an individual exposed for the duration of the release would be about 20 mg. (Less than 1% of lethal dose to man.)[59]

The waste retention pond is peculiar to the solvent extraction-fluorination production scheme. The raffinate containing uranium, radium-226 and thorium is stored in the sealed impoundments. If a dike failure occurred and the contents were released, there might be some potential for a significant environmental insult.

The raffinate ponds contain liquid and sludges. The radioactive material in a neutralized pond is primarily in the settled sludges with only about 2% of the total activity present in the liquids.[60]

A catastrophic failure of a large retention pond dike might release as much as 8 million gallons of contaminated water. The contaminated water would contain radionuclides in the concentrations indicated in Table C-4.[61]

TABLE C-4

RADIONUCLIDES IN LIQUID WASTE POND

Radionuclide	Concentration (μCi/ml)
Ra-226	1×10^{-6}
Th-230	1×10^{-8}
Uranium	1.2×10^{-7}

The minimum monthly flow of the river adjacent to the existing wet process UF_6 facility (based on daily readings from October 1968 to September 1971) was 275 million gallons per day (11.5 MGH).[62] This flow would be expected to provide sufficient dilution to reduce concentrations of radionuclides to below the

maximum permissible concentrations. The chemical content of the raffinate pond could be sufficiently toxic to cause localized fish kills in the plume until river flow has completely diluted the material. Such effect would be of short duration and temporary in its effect on the local fish population.

The UNH evaporator at a solvent extraction plant might contain about 2000 gallons of high specific gravity uranyl nitrate. Adjacent to this could be an equal volume of product stored in a surge tank. Both of these would be installed in a curbed area capable of containing the total volume of both vessels.

A spill might occur as the result of a line break or a valve failure. If the UNH material did leak, it would be caught and retained in the curbed area and only mists and sprays would be released beyond the immediate area with no significant release to the environs offsite. All of the activity involved is associated with freshly separated uranium of low specific activity.

Historically, only one explosion has been associated with evaporator operation and that was due to a "red oil" reaction. The "red oil" type of reaction can occur when the temperature exceeds 226°F. This is prevented by continuous venting to the atmosphere and limiting temperatures to a maximum of 225°F.[63]

When large quantities of acid are stored at any industrial facility there is some likelihood of a spill or leak. For UF_6 production both nitric acid and hydrofluoric acid may be stored in large quantities. Of these, HF poses the greater problem in the event of a leak. Design features, structures and practices are aimed at reducing the incidence and consequences of such accidents. It is common practice to install acid storage tanks in curbed areas with sufficient volume to contain the entire volume of the storage vessel. In addition, the curbed area may contain crushed limestone providing a quantity in excess of that required to neutralize all of the acid available.

In the handling of HF, to assure added capability to drain a leaking storage vessel, the retention of one empty tank car onsite as a standby vessel is often utilized.

In the extremely unlikely event of a catastrophic failure of an acid storage tank there could be some release of vapor and spray in the immediate area of the storage yard. The duration of the release would be relatively short and would not constitute a potential insult to life forms beyond the area in close proximity to the storage facility.

The ultimate consequences of an acid spill would amount to an operational loss requiring cleanup and repair including replacement of the reacted crushed limestone.

Other accidents and incidents of far less potential for offsite effects may occur in UF_6 production facilities as in any other manufacturing operations. Typical events in the general safety classification of industrial accidents might be equipment failures, valve and piping ruptures, gland leaks, joint breaks, loss of services or utilities, and material spills.

In one instance of record[64] a valve bonnet failed in a line from a vaporizer tank in the distillation area of a plant making UF_6 by the dry hydrofluor process and released 90-95 pounds of uranium as UF_6 into a basement level room. In the ensuing action to freeze or recover the UF_6 with vacuum and effect repairs 2 employees were injured by exposure to HF and UO_2F_2. No effects of uranium or fluoride which might have been released to the environment were reported. Air sampling equipment at the site boundary measured a peak concentration of 1.65×10^{-12} μCi/cc, which is less than the 10 CFR 20 limit for unrestricted areas.

The potential exists for similar accidental releases in plants whenever a joint is broken to perform maintenance or pipe ends are left plugged while out of service. These kinds of operational faults are characteristically dealt with by "clean up", repair, replacement or, less frequently, when a relatively higher risk occurs, redesign. All cases of this kind are well within the design capability of the system ventilation scrubbers, dryers and high efficiency filters which reduce the potential for any release to the environment and effectively prevent deleterious consequences offsite.

The production of fluorine for use in process is essential to UF_6 production. With operations of this kind there is a recognized potential for fluorine fires. These fires are readily stopped by valving off or shutting off the fluorine supply.

The plant design provides off-gas cleanup facilities to prevent releases of HF, fluorine or UF_6 to the environment. HF from the hydrofluorination system is condensed or scrubbed with water and recycled to the process while any residual fluorine from the fluorination system is reacted with hydrogen to form HF and scrubbed from the gas stream. Off-gases from the UF_6 cold traps may be scrubbed with water or caustic solutions or passed through sodium fluoride filled traps to eliminate atmospheric contamination.

The evolution of hydrogen in electrolytic cells is a recognized explosion hazard which is minimized by operating with a high rate of flow through systems with no surge capacity. Hydrogen released from electrolytic systems is commonly burned and discharged as water vapor.

In fluidized bed reactors, the equipment can leak HF, burn out, or fail in service. Potential operational failures are anticipated and treated routinely with a minimum of operating down time and no inordinate release of toxic materials to the environs. The offgas cleanup systems are designed for more severe design basis accidents and have ample capacity for coping with these relatively minor accidents.

Loss of refrigeration to cold traps in the load out systems poses no particular threat to the environment because secondary condensers backed by offgas scrubbers and redundant particulate filters effectively prevent release of UF_6 to the environs.

One incident involving U_3O_8 handling at the head end of the UF_6 production process has been recorded.[65] The operator of a mechanical drum dumper attempted to empty a nonstandard short drum containing U_3O_8 concentrates. In the process of doing so he spilled 250 pounds of yellowcake requiring cleanup operations on three floors of the process building. There was no release of uranium to the environment.

(d) Contributions to the General Exposure

The isotopes important to the UF_6 conversion process are the naturally occurring members of the U-235 and U-238 decay chains. Different recovery rates for the different chemical members of the chain may result in relative concentrations of

the uranium daughters different from that found in uranium ore. Data on terrestrial concentration factors for uranium are given in Chapters A and B.

The wet UF_6 conversion process head end operations are similar to those of a mill using solvent extraction; the reduction, hydrofluorination, and fluorination steps may release radioactivity in small amounts to the atmosphere and to the river serving the plant. The dry hydrofluor process produces solid wastes containing uranium, and releases some radioactivity to the atmosphere and the local river.

Although conversion operations contribute to the radioactive content of the environment, the incremental exposure is small relative to natural background.

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D. URANIUM ENRICHMENT

1. Summary

(a) General

Isotopic enrichment of uranium is necessary to provide fuel for a light-water moderated nuclear reactor. The concentration of U-235 in natural uranium is about 0.7% and the enriched uranium content for the current generation of reactors is 2-4%. About 116,000 kg of separative work units (SWU's)* are required to prepare enough uranium for the annual requirements of a model LWR.

The facilities are large in size because a large number of separation stages are required to attain the necessary enrichment. Based upon the use of existing equipment, about 1700 stages are needed to produce 4% enriched UF_6.

The present plant facilities are owned by the United States and operated by private industry under contracts with the AEC. There are three facilities currently operating in the country. The model considered for this study is the entire complex appropriately scaled to the model LWR.

(b) Environmental Considerations

The major environmental considerations associated with uranium enrichment, normalized to model LWR annual fuel requirement, are tabulated in Table D-1.

(1) Use of Natural Resources

Uranium enrichment requires less than one acre of land per model LWR annual fuel requirement which is less than 2% of the temporary land commitment required for the total fuel cycle. None of this land is permanently committed.

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* A separative work unit (SWU) is a measure of the effort expended to separate a quantity of uranium of a given assay into two components, one having a higher percentage of uranium-235 and one having a lower percentage. Separative work is generally expressed in kilogram units to give it the same dimensions as material quantities.

TABLE D-1

Summary of Environmental Considerations
for Uranium Enrichment

(Normalized to Model LWR Annual Fuel Requirement)

	Total
Natural Resource Use*	
Land (acres)	
Temporarily committed	0.8
Undisturbed area	0.6
Disturbed area	0.2
Permanently committed	0.0
Water (millions of gallons)	
Discharged to air (at GDP's)	84
Discharged to water bodies (at GDP's)	6
Discharged to water bodies (at power plants)	11,000
Fossil Fuel	
Electrical Energy (thousands of MW-hr)	310
Equivalent coal (thousands of MT)	113
Effluents	
Chemical (MT)	
Gases (from coal-fired power plants)	
**SO_x	4,300
**NO_x	1,130
**Hydrocarbons	11
**CO	28
F^-	0.5
**Particulates	1,130

TABLE D-1 (Cont'd)

Summary of Environmental Considerations
for Uranium Enrichment

(Normalized to Model LWR Annual Fuel Requirement)

	Total
Effluents (cont'd)	
Liquids (from GDP's)	
Ca^{++}	5.4
Cl^{-}	8.2
Na^{+}	8.2
$SO_4^{=}$	5.4
Fe	0.4
NO_3^{-}	2.7
Radiological (Curies)***	
Gases	
Uranium	0.002
Liquids	
Uranium	0.02
****Thermal (billions of Btu's) (from coal-fired power plants & GDP's)	3,200

*Based on 20 year life of GDP.
**Estimated effluent gases based upon combustion of equivalent coal for power generation, assuming 100% load factor.
***Based on four percent isotopic enrichment.
****Approximately 67% of this heat is discharged by the electric generating plants servicing the model enrichment plant, assuming 100% load factor coal-fired plant.

The process cooling water requirements of the model enrichment plant involve the evaporation of 84 million gallons of water per model LWR annual fuel requirement. This amounts to 54% of the evaporative use of water in the fuel cycle. An additional 6 million gallons of water per model LWR annual fuel requirement are discharged to water bodies at the enrichment plants.

The additional water used for cooling by power stations supplying electrical energy to gaseous diffusion plants, assuming once-through cooling, is approximately 11 billion gallons discharged to water bodies per annual fuel requirement.

Uranium enrichment requires approximately 98% of the electrical energy consumed in the entire fuel cycle. About 310,000 MW-hr of electrical energy are utilized in the production of enriched UF_6 for the model LWR annual fuel requirement. The thermal-electric system providing power for the diffusion plants is fossil-fueled and must burn about 113,000 MT of coal to meet this demand. In perspective, the electrical energy produced by the model 1000 MWe nuclear station annually (at 80% load factor) amounts to about 22 times the energy consumed to produce an annual fuel requirement.

(2) Effluents

The primary source of environmental impact associated with the enrichment of uranium is related to the gaseous effluents from the coal-fired stations used to generate the required electric energy. Waste gas emissions, including particulates, of approximately 6600 MT are associated with the production of an annual fuel requirement. This is equivalent to the gaseous effluents released annually by a 45 MWe coal-fired plant.

Also related to the power requirements of the enrichment plant is the discharge of heat into the environment at the sites of individual electric generation plants. Since the power is drawn from the grids of large utility complexes, the environmental impact is difficult to

evaluate. The heat rejection at the enrichment plant site is largely to the atmosphere, and although occasional misting and fogging results within the site from the operation of cooling towers, the thermal impact is insignificant.

Small quantities of airborne fluoride are generated at the diffusion plants. Measurements in unrestricted areas indicate concentrations which are below the range for which deleterious effects have been observed. In addition, oxides of nitrogen and sulfur are released at the diffusion plants. Conservative estimates of the offsite concentrations of these contaminants yield levels which are below EPA standards. Furthermore, the total quantity of these effluents is insignificant in comparison with the combustion products generated by the supporting electric power plants.

A number of chemical species are present in the liquid effluent stream from the plant. Calcium, chloride, sodium, and sulfate ions are major constituents of this stream. Chromate is,however, the limiting species. The concentrations of chemicals undergo considerable dilution before reaching the river. With water treatment to reduce chromium concentrations, additional dilution within the receiving river reduces all incremental concentrations resulting from the discharge to a small fraction of the recommended permissible water quality standards.

Small fractions of a curie of uranium in gaseous and liquid effluents are introduced into the environment which result in concentrations in offsite, air and water media which are less than 2% of the limits of 10 CFR 20.

(3) Accident Considerations

Accidents involving an explosion or fire, and a nuclear criticality incident were considered. A fire or explosion could release gaseous and liquid chemicals into the

environment, but compartmentation by cells limits the total quantities that could be involved in one accident, and the distance to unrestricted areas enhances dilution of concentrations.

A criticality incident in the low-enrichment portions of a diffusion plant is highly improbable. Detailed evaluations of cascade equipment under normal and contingency operations have indicated the inherent nuclear safety of the cascade:

- Where the integrity of the diffusion equipment is not breached, criticality cannot occur in unmoderated uranium hexafloride in the U-235 concentration range involved in light water reactor fuel.

- Criticality is possible in the moderated state; however, accumulation of the necessary quantity of fissile material in a nuclearly favorable configuration is required. Nuclear evaluations have indicated that the abnormal operating contingencies necessary to produce such a situation make the possibility of a criticality condition extremely unlikely.

Should a criticality incident occur at low enrichment, it would be a thermal system. The yield from a typical solution or thermal accident has been in the order of 10^{17} fissions. Except in the immediate vicinity, accidents of this magnitude have resulted in minimal contamination.

(4) Contributions to the General Exposure

The isotopes of interest in the enrichment plants are U-234, U-235, and U-238, and naturally occurring daughters. It is unlikely that diffusion operations significantly increase levels of exposure in the general population.

2. Description of the Uranium Enrichment Industry

Natural uranium contains about 0.7% of the fissionable isotope, Uranium-235. Light-water nuclear power reactors, however, utilize

uranium that is enriched in U-235 to the range of 2-4%.[1] Gaseous diffusion is the technology that has been developed in this country for performing the enrichment operation.[2]

The average velocities of gas molecules at a given temperature depend upon their masses. The gaseous diffusion process is based upon the principle that the rate at which a gas escapes through a small hole in a containment vessel is proportional to the speed of the gas molecules. The enrichment of uranium is accomplished by combining this principle with the use of a porous barrier through which the gas molecules diffuse. Using volatile uranium hexafluoride as the gas, the maximum theoretical enhancement in the isotopic content for a single stage is a factor of 1.0043.[3] This degree of enhancement is multiplied by using a large number of stages, or a cascade. The existing plants would utilize approximately 1700 stages to produce material of 4% U-235.[4] The gas flow through the cascade is provided by compressors driven by electric motors. The compression of gas generates heat which is discharged into the environment. In addition to the enriched UF_6 product, the gaseous diffusion plants produce UF_6 depleted in U-235 called tails. The current assay of the tails is 0.25% U-235. This material is stored as solid UF_6 in cylinders at the plants for future uses.[5]

The U. S. gaseous diffusion plants (GDP's) which are owned by the government and operated under contract with private industry, are located at three sites. The Oak Ridge, Tennessee, and Paducah, Kentucky, enrichment plants are operated by Union Carbide Corporation, Nuclear Division; the plant at Portsmouth, Ohio, is operated by the Goodyear Atomic Corporation.[6] Distances from each site to nearby cities and to UF_6 production plants are shown in Table D-2.[7] The distances to fuel fabrication plants are shown in Table D-3.[8]

The Oak Ridge and Portsmouth plants were built on sites originally chosen for their remote location, low population density, and generally marginal utility as agricultural land. The Paducah plant was built on a government-owned site previously occupied by an ordnance works.[9] The population density in the vicinity of the gaseous diffusion plants ranges from 30 to 40 people per square mile, the region within a 50 mile radius of the Oak Ridge plant having the highest population density, primarily because of

TABLE D-2[12]

DISTANCES TO GASEOUS DIFFUSION PLANTS

FROM NEARBY POPULATION CENTERS AND UF_6 PRODUCTION PLANTS

Gaseous Diffusion Plant	Population of Nearby Cities			UF_6 Production Plants, miles	
	City	Miles	Population	Allied Chemical Metropolis, Ill.	Kerr-McGee Sequoyah, Okla.
Oak Ridge	Oak Ridge, Tenn.	13	28,000	275	800
	Knoxville, Tenn.	30	170,000		
Paducah	Paducah, Ky.	16	31,000	20	500
Portsmouth	Waverly, Ohio	12	5,000	400	900
	Portsmouth, Ohio	20	28,000		

TABLE D-3[13]

PROCESSORS OF URANIUM FUEL MATERIALS AND
DISTANCES TO DIFFUSION PLANTS

Fuel Processor	Distance in miles from: Oak Ridge	Paducah	Portsmouth
Babcock and Wilcox, (NUMEC subsidiary) Apollo, Pa.	450	600	250
General Electric Co., Wilmington, N. C.	400	650	500
Gulf-United Nuclear Fuels, Hematite, Mo.	400	150	400
Jersey Nuclear Co., Richland, Wash.	3000	2500	3000
Kerr-McGee Corp., Oklahoma City, Okla.	800	500	900
Nuclear Fuel Services, Inc., Erwin, Tenn.	150	300	300
Westinghouse Electric Corp., Columbia, S. C.	250	500	450

the contribution from Knoxville, Tennessee.[10] The existing plants were built during the period 1943 to 1955. Major features of the model complex, such as land area requirements, a listing of plant systems and their capacities, and operations personnel are given in Table D-4.[11]

Due to the unusually large requirements for continuous floor area, gaseous diffusion plants have been built on reasonably flat land capable of sustaining a bearing load of at least 2500 pounds per square foot. Sites have been chosen for ready access to abundant and inexpensive electric power and an adequate water supply for process cooling. The site exclusion areas provide a buffer zone averaging approximately 800 meters to the nearest site boundary.[15]

Cooling water is obtained from the Clinch River at the Oak Ridge plant, the Ohio River at the Paducah plant, and from the Scioto River and subterranean wells at the Portsmouth plant. The bulk of the process heat load, however, is rejected to the atmosphere via forced-draft cooling towers. Water for the three plants is required at the rate of approximately 23 million gallons per day at present power levels.[16] Make-up water is required to replace cooling tower evaporation and windage losses, and blowdown losses. Blowdown is the removal of a portion of the recirculating cooling water containing concentrated dissolved salts to prevent their build-up in the system. At a production capacity of 10.5 million separative work units annually, the electric power load of the existing plants is approximately 3250 megawatts (MW).

Power for the gaseous diffusion plants is drawn from the grids of three utilities: Tennessee Valley Authority (in quantity subject to contract), Ohio Valley Electrical Corporation (up to 1900 MWe), and Electric Energy, Incorporated (up to 735 MWe). These utilities generate power primarily in large coal-fired stations.[17] The power is supplied to the diffusion plants through multiple-line rights-of-way carrying 27 lines. Typical rights-of-way for single high voltage transmission lines are 150 to 200 feet in width depending on the transmission voltage and are occupied by steel towers at 1200 to 1400-foot intervals. The rights-of-way extend from the plant boundary back to a substation on the supplier's transmission grid.

TABLE D-4[14]

CHARACTERISTICS OF GASEOUS DIFFUSION PLANT COMPLEX

1.	LAND USE (Acres)	1,500
	Buildings	
	Process	270
	Auxiliaries and Support	80
	Warehouse and Storage	25
	Roadways and Parking Lots	20
	Storage Yards	30
2.	PLANT SYSTEMS	
	Process - Present Conditions, millions SWU/yr	10.5
	1980 Conditions, millions SWU/yr	27.7
	Electric Switchyards - Present Power Load, MWe	3,250
	1980 Projected Load, MWe	7,380
	Steam Plant (thousands of pounds/hour)	1,000*
	Recirculation Water System (millions of gallons per day)	1,350*
	Fire Protection Water System (thousands of gallons per minute)	53
	Water (Chemical) Treatment Plant (millions of gallons per day)	85*
	Nitrogen Plant (standard cubic feet per minute)	440*
	Dry Air Plant (thousands of standard cubic feet per minute)	60*
3.	PERSONNEL ASSOCIATED WITH DIFFUSION PLANT COMPLEX OPERATIONS AND MAINTENANCE (Does not include research and development personnel)	3,000

*Maximum or design capacity of this system.

Facility support functions represent a large part of the overall plant activities. Each of the gaseous diffusion plants has its own electrical distribution, air, water, and nitrogen systems, as well as individual maintenance, decontamination, and uranium recovery facilities.

To reach the production capacity level of 27.7 million SWU per year in 1980, as quoted in Table D-4, an extensive program of process improvement and upgrading will have to be completed. The program involves modifications to existing equipment and facilities with very little new construction required.[18]

3. Description of the Model Enrichment Plant

The existing GDP complex described in the previous section is used as the basis for the uranium enrichment model plant. The entire complex was chosen because all three sites are similar and the composite model realistically represents the enrichment component of the fuel cycle. The model plant, which is assumed to have a lifetime of 20 years, does not include the uranium hexafluoride or uranium metal conversion facilities which are operated in support of government programs.

The production capacity of the model plant is given in Table D-5, and is related to the annual requirements of the model 1000 MWe LWR. The upgraded capacity of the complex in the year 1980 is included for comparison purposes. It is seen that the percentage of the present gaseous diffusion plant complex which is assignable to the Model LWR annual fuel requirement is 1.1% of the present capacity.*

4. Environmental Considerations

(a) Use of Natural Resources

(1) Land

The requirements of continuous diffusion through hundreds to thousands of stages render the gaseous diffusion plants

* It should be noted that these considerations are for purposes of establishing a conceptual model. In actuality, the existing production capability of the diffusion plants is only partially devoted to the commercial production of LWR fuel.

TABLE D-5

GASEOUS DIFFUSION PLANT
TOTAL CAPACITY
AND RELATION TO MODEL LWR
ANNUAL FUEL REQUIREMENT

Year	Total Production Capacity, MT SWU/yr	Model LWR Annual Fuel Requirement Mt SWU	Portion of Production Capacity Required, %
1972 (Model)	10,500	116	1.1
1980	27,700	116	0.4

among the largest industrial facilities in the world. Of the total 1500 acres devoted to the combined sites of the complex, 425 acres have been disturbed for buildings, roadways, or storage facilities. The temporary commitment of land over the projected life of the plant is less than one acre per annual fuel requirement. Essentially, none of the land is permanently committed, that is, cannot be returned to some active use after the plant life is expended.

(2) Water

The operation of cooling towers used to dissipate the waste heat from the plant results in approximately 84×10^6 gallons of water evaporated to the atmosphere per model LWR annual fuel requirement. The high rate of water evaporation may result in localized misting and fogging within the site under certain meteorological conditions. This condition does not occur external to the plant sites. Six million gallons of water are also released to water bodies at the various sites. Additionally, assuming once-through cooling about 11 billion gallons of water would be discharged to surface water bodies from power stations supplying electrical energy for a model LWR annual fuel requirement.

(3) Other

The enrichment step in the fuel cycle is the largest single user of electrical energy in the fuel cycle. The model enrichment plant consumes approximately 310×10^3 MW-hrs of electricity to produce the annual fuel requirement for the model LWR.

Since at present the electricity is generated primarily in coal-fired stations, this is equivalent to the consumption of approximately 113×10^3 MT of coal.

(b) Effluents

(1) Chemical

(i) Gaseous

The primary source of environmental impact associated with the enrichment of uranium is related to the generation of the required electric power. At present, the

supply of electricity comes primarily from coal-fired stations. The characteristics of a typical existing power plant are given in Table D-6.[19] Based upon the data in Table D-6, the emission rates of effluents from a typical 1000 MWe coal-fired power station and the quantities of effluents emitted by the power plant in support of the production of an annual fuel requirement for a model LWR are given in Table D-7.[20] Since the power for the diffusion plants is drawn from the grids of large utility complexes, an individual point source cannot be identified with the contaminant emissions.

The plant complex itself vents gases from the process and auxiliary systems containing fluorides, sulfur dioxide, and nitrogen oxides. Based upon process release data from 1970 and the use of coal for power generation, the magnitudes of these effluents attributable to the support of a model LWR annual fuel requirement are:[22]

i) Nitrogen oxides - 8.0 MT

ii) Fluorides - 0.2 MT

iii) Sulfur dioxide - 14.4 MT

Measurements of the airborne fluorides in unrestricted areas around the Oak Ridge plant indicate monthly average concentrations between 0.4 and 1.5 ppb which are below the range for which deleterious effects have been observed, and are within the maximum concentration of 1.5 ppb allowed by the State of Tennessee over a 30 day period. Estimates of the dispersion of nitrogen oxides and sulfur dioxide yield offsite concentrations of 0.0032 and 0.0043 ppm, respectively. These concentrations are within the range of the EPA annual mean standards of 0.05 ppm for nitrogen oxides and 0.02 ppm for SO_2.[23]

Chemical discharges to the environment are expected to decrease as planned programs for further pollution control are implemented.[24]

(ii) Liquid

The major sources of liquid chemical effluents from the diffusion plants are the following:[25]

TABLE D-6

CHARACTERISTICS OF A TYPICAL
COAL-FIRED POWER PLANT[21]
(100% Load Factor)

Electrical Efficiency	33%
Heat Rate	10,300 (Btu/hr)/kw
Heat to Cooling Condensers	5,300 (Btu/hr)/kw
Heat to Stack and Elsewhere	1,600 (Btu/hr)/kw
Heat Value of Coal	13,000 Btu/lb
Coal Use Rate	363 MT/hr
Sulfur Content of Coal	2%
Ash Content of Coal	8%
Type of Firing	Pulverized Coal
Particulate Emission Rate	22 lb/MT of coal

TABLE D-7

MODEL GASEOUS DIFFUSION PLANT
POWER GENERATION EMISSION DATA

(Assumed Coal-Fired Power Plants at 100% Load Factor)

Effluent	Emission Rate for 1000 MWe Coal-Fired Power Plant	Total Effluents in Support of Uranium Enrichment by Diffusion Plants for One Model LWR Annual Fuel Requirement*
Coal Burned	363 MT/hr	113,000 MT
Particulates	3.6 MT/hr	1,130 MT
SO_2	13.8 MT/hr	4,300 MT
NO_X	3.6 MT/hr	1,130 MT
CO	0.09 MT/hr	28 MT
Hydrocarbons (as methane)	0.04 MT/hr	11 MT
Aldehydes (as formaldehyde)	2 lb/hr	0.3 MT
Heat**	1,570 MW	486,000 Mwhr

* Assuming 310 x 10^3 MW-hrs. of electrical energy is required for the enrichment of the annual fuel requirement for the model LWR.

** Released to condenser cooling water.

1. Blowdown water from the process cooling system (from the water treatment plant or cooling towers), containing sulfates, sodium, calcium, and hexavalent chromium;

2. Liquid wastes from process cleanup operations, containing fluorides, nitrates, and iron;

3. Liquid wastes from auxiliary production facilities, containing fluorides, nitrates, chlorides, iron and ammonia;

4. Condensate and blowdown from the onsite steam plant which results in an alkaline stream containing sodium and phosphorous; and

5. Sanitary water plant and sewage treatment plant effluent containing chlorine.

The estimated quantities of chemical contaminants and concentrations in an effluent stream associated with the enrichment of a model LWR annual fuel requirement are given in Table D-8. The data are derived from the Oak Ridge plant; however, they are taken to be representative of the complex. Chromium is the present limiting polluting species at plants using chromium for water treatment. Plans are underway to reduce chromium in the effluent stream to the values given in table D-8. The liquid effluents generated in support of the model LWR annual fuel requirement are represented by the hypothetical 45 x 10^6 gallon stream.

The last column of Table D-8 compares the estimated concentrations with recommended permissible water quality criteria contained in a report to the U. S. Department of the Interior.[27]

In most cases, the estimated concentrations in the effluent stream are within the recommended permissible criteria. Taking into account the factor of about 700 additional dilution available in the receiving water, the concentrations of all chemical contaminants are significantly below the permissible water quality criteria.

TABLE D-8

GASEOUS DIFFUSION PLANT
COMPLEX
ESTIMATED QUANTITIES OF
CHEMICALS IN LIQUID EFFLUENTS*[26]

Effluent	Amount Released in Support of Enrichment for One Model LWR Annual Fuel Requirement, MT	Concentrations in Effluent Stream, ppm	1968 Department of the Interior Water Quality Permissible Criteria, ppm
Ammonia	0.18	1	0.5
Cadmium	trace	<0.004	0.01
Calcium	5.4	30	--
Chlorides	8.2	45	250
Chromium (Hexavalent)	0.002**	<0.05**	0.05
Copper	0.01	.07	1.0
Fluorides	0.18	1	0.8-1.7
Iron	0.41	2	0.3
Nickel	0.04	0.2	--
Nitrates	2.7	15	10
Phosphorous	0.06	0.3	--
Sodium	8.2	45	--
Sulfate	5.4	30	250
Zinc	0.04	0.2	5

*Multi-stream data expressed as an analysis of a single representative hypothetical 45 x 10^6 gal. stream (normalized to the requirements of a model 1000 MWe LWR).

**Hexavalent chromium quantity and concentration based upon use of water treatment system for chromium removal.

(iii) Solid

Liquid effluents from equipment clean-up are collected in holding ponds. The sludge collected in this manner is a solid effluent that contains soil runoff from groundwater and small quantities of precipitated metals and other settlable solids. The amount of solids attributable to the plant operations is less than 1 MT per annual fuel requirement and is buried onsite requiring less than 0.01 acre.

These solids accumulate in a holding pond before they are removed and buried. The liquid overflow from this holding pond is analyzed and represents the major source of the ionic impurities listed in Table D-8.

It is unlikely that groundwater will leach any more material from the solids when they are buried. If any material were leached, it would have the approximate relative composition shown in Table D-9.

(2) Radiological

(i) Gaseous

Small quantities of uranium are vented from the process and auxiliary systems of the model enrichment plant. Based upon data from 1971, the amount of airborne uranium discharged in support of the model LWR annual fuel requirement is approximately 0.7 kg.[28] A conservative estimate of the offsite concentration is 6×10^{-14} μCi/ml, less than 2% of the limits of 10 CFR 20.

(ii) Liquid

Uranium is released in liquid wastes from process cleanup operations and from auxiliary production facilities. Based upon data from 1970, the quantity of uranium in liquid effluents for the support of the model LWR annual fuel requirement is approximately 8 kg.[29] A conservative estimate of the concentration in the effluent stream indicates an activity of 9×10^{-8} μCi/cm^3, approximately 0.2% of the limits of 10 CFR 20. This is further reduced by a factor of approximately 700 in the receiving body of water.

(iii) Solid

The sludge collected in holding ponds for containing liquid effluents from equipment clean-up will contain a detectable amount of radioactivity in very dilute concentrations in the other materials of the sludge. Since this material is retained onsite in an immobile condition it is not considered as a solid effluent.

(3) Thermal

The largest source of waste heat released to the environment in support of uranium enrichment is related to the generation of the required electric power. Using the data in Table D-6, approximately 2100 x 10^9 Btu are dissipated to the environment from electric power stations for the production of a model LWR annual fuel requirement. Assuming that the power stations supplying electricity to the gaseous diffusion plants utilize once through cooling, 77% of this heat is discharged to water. However, since the power for the diffusion plants is drawn from the grids of large utility complexes, the heat is dissipated to a number of receiving bodies of water.

In the model plant itself, approximately 310 x 10^3 MW-hrs. of electrical energy is degraded to heat in support of the annual fuel requirement for the model LWR. Of a total of 1100 x 10^9 Btu, approximately 10% is rejected to the atmosphere by the plant process ventilation system and an additional 5% is rejected to the atmosphere by process auxiliaries.[30] The remaining heat passes via cooling towers to the atmosphere through the process of water vaporization.*

(c) Accident Considerations

The potential accidents that have been studied for the GDP complex have been fire, explosion, criticality, and unintentional release

*Less than 0.1% of the waste heat is dissipated to water bodies via cooling tower blowdown.

of UF_6 to the atmosphere. The few incidents that have occurred testify to the effectiveness of the process design, operating procedures, administrative controls and emergency procedures adopted by the industry.

(i) Non-nuclear explosion and/or fire might result in the release of some gases or liquid chemicals and chromate-treated water from sprinkler systems, the evolution of heat and steam, and the necessity for replacement construction. Extensive effects are not expected because of the distances between buildings and distances from operating facilities to local streams and unrestricted areas.

(ii) Criticality Incident

Uranium is handled for the most part in the gas phase at low enrichment, conditions where criticality incidents are least likely to occur. Operations in which uranium-bearing solutions and solids are processed at U-235 enrichments above 1.0% require equipment design and operating controls for mass or volume which meet nuclear safety criteria. In the event of a highly improbable nuclear incident, it is expected that most of the materials, if releases occurred, would be contained in the equipment or the building with only minor contamination and clean-up beyond the place where it occurred.[31] The consequences of any particular release might be considered proportional to the quantity of UF_6 emitted and the specific enrichment condition.

(iii) Release of UF_6

Accidental releases of UF_6 can lead to potential exposure at the plant boundary to both radioactive materials and hydrogen fluoride.

A list of all accidental releases of more than 5kg of U at one of the gaseous diffusion plants is given in Table D-9.[32] It can be seen that there has been less than one accident/year over the past 20 years, and in the last 10-12 years, only one incident released more than 5 kg U.

Estimates of the offsite exposure resulting from a criticality burst of 5×10^{17} fissions and the release of 3077 kg of natural UF_6 have been made. The accidents are independent and are assumed not to occur simultaneously. Table D-10 summarizes the results.

The criticality incident causes exposures at the plant periphery that are about 10% of those from a similar criticality incident at a fuel fabrication plant, because of the greater distance to the site periphery. (See Chapter E). The exposures resulting from the release of natural UF_6 are similar to those from the release of natural UF_6 at the model UF_6 conversion plant (see Chapter C for a more detailed analysis of the accidental release of natural UF_6.)

A release of enriched UF_6 at the diffusion plant is possible. Although the exposure per microcurie of enriched uranium inhaled is greater than that per microcurie of natural uranium, the amount of enriched uranium might be released in a cylinder rupture is smaller than the amount of natural uranium. Natural UF_6 is shipped in 14 T cylinders, whereas 3% enriched material is shipped in 2-1/2 T cylinders. Estimated maximum release of UF_6 from a 2-1/2 T cylinder is about 700 kg. The exposure at the plant boundary areas ponding to the release of 700 kg of 3% UF_6 is about 50% of the exposure resulting from the release of 3000 kg of natural UF_6. The HF concentration would be about 3 mg/m^3. The release of enriched UF_6 is a less severe accident than the release of natural UF_6.

(d) Contributions to the General Exposure

The isotopes of interest in the enrichment plants are U-234, U-235, and U-238, and naturally occuring daughters. The high purity of the UF_6 feed and

TABLE D-9

MATERIAL RELEASES (UF_6) INVOLVED IN FILLING OR FEEDING CYLINDERS

Date	Quantity (kg U)	Reason
12-1-52	92	Foreign Material Lodged in Valve
6-28-53	31	Ruptured Pigtail
7-15-53	460	Thermocouple Well Rupture
7-31-53	38	Ruptured Cylinder Pigtail
4-9-54	40	Sheared Cylinder Valve Stem
6-18-54	666	Cylinder Valve Stem Sheared
3-15-55	414	Broken Cylinder Pigtail
11-28-55	15	Broken Pigtail
3-10-56	63	Broken Cylinder Pigtail
10-1-58	163	End Plug of Cylinder Failed
3-19-59	45	Broken Pigtail
11-17-60	3,077	Ruptued Cylinder
3-17-66	8	Cylinder Dropped, Causing Rupture

TABLE D-10

ESTIMATED EXPOSURE AT SITE BOUNDARY
RESULTING FROM POSTULATED ACCIDENTS

Accident*	Organ of Greatest Exposure	Organ Dose (rem)
Criticality incident	whole body	0.08
UF_6 (natural) release	bone	0.44
	HF exposure	11 mg/m^3

* Bases
800 meters to boundary
All noble gases and 50% of halides released in criticality accident
ground level releases
3077 kg of natural UF_6 released

product, and the nature of the process mean that only minor amounts of these materials will be released to the atmosphere. Estimates of offsite exposures are less than 2% of 10 CFR 20 limits. It is unlikely that these activities would significantly increase levels of exposure in the general population.

REFERENCES

1. The Growth of Nuclear Power: 1972-1985, WASH-1139 (Rev. 1) (December 1971), page 10, table 8.

2. Proceedings of the Technical Briefing and Preproposal Conference on Industry Participation in Uranium Enrichment, ORO-690; (May 17, 1972) Vol. 4, page 4, paragraph 2.

3. AEC Gaseous Diffusion Plant Operation, USAEC, ORO-684 (January 1972) page 3, paragraph 2.

4. ORO-684; page 9, table 2, axial stages only.

5. Data on New Gaseous Diffusion Plants, USAEC, ORO-685, (April 1972) page 27, item 6, paragraph 3, and page 29, Figure 16.

6. ORO-684; page 7, paragraph 1.

7. See Reference 12, below, relating to Table D-2.

8. See Reference 13, below, relating to Table D-3.

9. Master Plan for Paducah Plant, AEC, Paducah, Kentucky (May 1968) page 4.

10. Road Atlas, Rand McNally (1971) Map of Tennessee, pp. 42-43.

11. Environmental Impact of Gaseous Diffusion Plants, Study for Division of Regulation, UCC-ND (May 11, 1972) page 5, Table II.

12. A. Distances

    1. From Diffusion Plants to Population Centers:

        a. Oak Ridge Operations, USAEC:ORO, Oak Ridge, Tennessee, 1969; ORGDP to Oak Ridge, page 22; Paducah Plant to Paducah, page 63; Portsmouth Plant to Portsmouth, page 65.

        b. Tennessee Highway Map; ORGDP to Knoxville.

        c. Ohio Highway Map; Portsmouth Plant to Waverly.

2. From Diffusion Plants to UF_6 Production Plants:

Road Atlas, Rand McNally (1971); pp. 2-3.

B. Populations

Road Atlas, Rand McNally (1971)

Knoxville - page 110
Oak Ridge - page 110
Paducah - page 106
Waverly - page 109
Portsmouth - page 109

C. Location of UF_6 Production Plants:

The Nuclear Industry, USAEC, WASH-1174-70 (1970) pp. 50-51.

13. A. Location of Fuel Materials Processors

The Nuclear Industry, WASH-1174-71 (1971) Table II-6, page 39.

B. Distance from Diffusion Plants to Fuel Materials Processors

Road Atlas, Rand McNally (1971) pp. 2-3.

14. Environmental Impact of Gaseous Diffusion Plants, p. 5, Table II.

15. Plot Plan of Security Fences, Guard Posts, Badge Portal, and Gates, Drawing No. S-S-24410B, Revision 6 (March 25, 1966).

16. ORO-684, page 9, Table 1 (Water Treatment Max. Capability).

Same as Reference 14, page 6, top of page.

17. Steam-Electric Plant Construction Cost and Annual Production Expenses, 22nd Annual Supplement, FPC-209, Federal Power Commission (January 1971) TVA plants listed on pages 120 to 123.

In addition, OVEC's Kyger Creek and Clifty plants and EEI's Joppa plants which also serve the diffusion plants are all coal-fired plants located on the Ohio River.

18. ORO-684; page 21, paragraph 3.

19. "Power Plant Emissions," Correspondence from J. F. Wing to Wayne L. Smalley, March 20, 1969.

20. Ibid.

21. Ibid.

22. Nitrogen Oxides, Fluorides, and Sulphur Dioxide: Based on unpublished data taken at the Oak Ridge Gaseous Diffusion Plant.

23. Letter, W. C. Hartman (UCND) to R. G. Jordan (UCND), "ORGDP Review of AEC. Calculations for Draft Generic Statement, January 23, 1973.

24. Environmental Impact of Gaseous Diffusion Plants, Study for Division of Regulation, UCC-ND (May 11, 1972) page 13, paragraph 4 (based on best judgment of pollution control personnel).

25. Ibid., page 11, Section C.

26. A. Diffusion Plant Effluent Data of Table D-8: Obtained from data sheets maintained by the Pollution Control Department, ORGDP.

B. Permissible Criteria: See reference 27, below.

27. Water Quality Criteria: Report of the National Technical Advisory Committee to the Secretary of the Interior; U. S. Federal Water Pollution Control Administration, Washington, D.C. (April 1, 1968).

28. Paducah Data: Radioactive Effluent Monitoring and Control, UCC-ND-168, 1970.

Oak Ridge Data: Ibid.

Portsmouth Data: Radioactive Effluents, Portsmouth Gaseous Diffusion Plant, (1970), GAT-R-575, June 28, 1971.

29. Same as reference 27, above.

30. ORO-685; page 64, paragraph 3.

31. WASH-1192, Operational Accidents and Radiation Exposure Experience Within the USAEC (1971), Section 2, Criticality Accidents. A review of Section 2 shows that contamination due to criticality accidents has generally been contained in the area of the excursion.

32. Private Communication, R. G. Jordan, Union Carbide Corporation, Nuclear Division.

E. FUEL FABRICATION

1. Summary

(a) General

The feed material for the fabrication of fuel for the model LWR is UF_6 enriched from 2 to 4% in the U-235 isotope. The UF_6 is converted to UO_2 and the UO_2 is formed into pellets and sintered to achieve the desired density. Finished pellets are loaded into Zircaloy or stainless steel tubes, fitted with end caps and welded. The completed fuel rods are assembled in fixed arrays to be handled as fuel elements.

A representative model fuel fabrication plant has been defined which uses the conventional ammonium diuranate process for conversion of UF_6 to UO_2. The capacity was chosen as 3 MTU per day, a large plant by present industry standards, resulting in an annual production of approximately 26 model LWR annual fuel requirements.

(b) Environmental Considerations

The environmental considerations arising from the fabrication of a model LWR annual fuel requirement are summarized in Table E-1 and in the following discussion:

(1) Use of Natural Resources

The land use for the model fuel fabrication plant is essentially temporary; almost all of the land disturbed by the fuel fabrication operations can be ultimately reclaimed for other uses. The temporarily committed land use of 0.2 acre and the fossil fuel consumption of 620 MT of coal for the supply of power represent less than 1% of the utilization of these natural resources for the total fuel cycle. The natural gas consumption is about 1/7 of that of the UF_6 production process.

The water demand is approximately 5.2 million gallons, most of which is used to cool equipment and is returned to the biosphere after a holding period of days to weeks. The water required is less than 2% of that used by the other fuel cycle operations.

TABLE E-1
Summary of Environmental Considerations
For Fuel Fabrication
(Normalized to Model LWR Annual Fuel Requirement)

Natural Resource Use	Total
Land (acres)	
Temporarily committed	0.2
Undisturbed area	0.16
Disturbed area	0.04
Permanently committed	0
Water (Millions of gal.)	
Discharged to water	5.2
Fossil Fuel	
Electrical energy (thousands of MW-hr)	1.7
Equivalent coal (thousands of MT)	0.62
Natural gas (millions of scf)	3.6
Effluents	
Chemical (MT)	
Gases	
*SO$_x$	23
*NO$_x$	6
*Hydrocarbons	0.06
*CO	0.15
F^-	0.005
Liquids	
**N as NH_3	8.4 ($\sim$ 10 MT NH_3)
**N as NO_3	5.3 ($\sim$ 23 MT NO_3^-)
Fluoride	4.1
Solids	
CaF_2	26 ($\sim$ 13 MT F^-)
Radiological (curies)	
Gases	
U	0.0002
Liquids	
U	0.02
Th-234	0.01
Solids (buried)	
Uranium	0.23
Thermal (billions of Btu's)	9

* Effluent gases from combustion of coal for power generation.

(2) Effluents

The most significant effluents from the standpoint of potential environmental impact are chemical in nature. Nearly all of the airborne chemical effluents result from the combustion of fossil fuels to produce electricity to operate the fabrication plant.

The only significant airborne chemical effluent from the process operations of the fabrication plant is fluorine as fluorides. The fluorine introduced into the fuel cycle during the UF_6 production phase becomes a waste product during the production of UO_2 powder. The gaseous fluorine wastes generated are effectively removed from the air effluent streams by water scrubber systems and result in a site boundary concentration of roughly 20% of the most restrictive of a reference state's standard, 0.5 $\mu g/m^3$.

The most significant chemical species in liquid effluents are nitrogen compounds that are generated from the use of ammonium hydroxide in the production of UO_2 powder and from the use of nitric acid in scrap recovery operations. The nitrogen concentrations in liquids released from the waste holding ponds are about 420 mg/liter in the form of ammonia and 280 mg/liter in the form of nitrates. The limiting concentration is that of ammonia and is about three orders of magnitude above that of drinking water. Depending on the nature of the receiving stream and its downstream uses, the nitrogen releases could constitute a significant impact on the environment.

Water from the scrubber systems is combined with process liquid wastes and treated with lime to form a calcium fluoride (CaF_2) precipitate, which is removed by filtration. The 26 MT of CaF_2 filtered from the liquid per model LWR annual fuel requirement has a volume of about 11 cubic yards and may be retained onsite.

The small percentage of fluorine which is not removed by the lime treatment is released from the liquid waste

holding ponds at a concentration of about 200 mg/liter, about two orders of magnitude above the concentration allowed by drinking water standards.

The quantities of radionuclides released in the effluent gases and liquids result in concentrations of radioactive material in both media that are less than 1% and 10% respectively of the 10 CFR 20 limits at the site boundary. The uranium listed in Table E-1 as Radiological Effluents - Solids is contained in the CaF_2 solid wastes at a concentration of about 0.01 μCi/g. Because of the low concentration, this does not constitute a radiological hazard.

The thermal load carried by the cooling water is dissipated to the air when the water passes through the liquid waste holding and treatment ponds before it is released offsite.

(3) *Accident Considerations*

Special design and operating precautions are taken to prevent the occurrence of accidents; hence they have a low probability of occurrence. These precautions have been successful, in that there have been no accidents to date that have had an off-site environmental effect.

Three accidents that could have significant off-site effects were analyzed: the rupture of an overfilled UF_6 cylinder which releases soluble uranium and hydrogen fluoride; an explosion in a furnace which releases uranium in an insoluble form; and a criticality accident which creates direct neutron and gamma radiation and releases fission products.

The hypothetical UF_6 release results in radiation doses of about 100 mrem to the bone and about 25 mrem to the kidneys over a 2 hr. period at the site boundary. These doses would be less than the annual whole body dose from natural background. The HF concentration at 100 meters is estimated to be about 3.5 mg/m^3, which is 75% greater than the threshold limit value for occupational exposure of 8 hours per day but is less than the single exposure concentration capable of causing temporary discomfort.

The hypothetical criticality accident that has never occurred with low enriched uranium in the history of the fuel cycle industry in the United States could result in a whole body dose of about 1.3 rem and a thyroid dose from radioiodine of about 6.6 rem in unrestricted areas. This accident has a very low probability of occurrence and the resulting doses are less than the maximum acceptable annual doses specified in 10 CFR 20 for occupational exposure.

The hypothetical furnace explosion could result in a radiation dose of about 0.024 mrem to the lungs, which is several orders of magnitude less than the statistical variation in the yearly dose from natural background radiation.

(4) Contribution to General Radiation Exposure

The isotopes of importance in fuel fabrication are U-234, U-235, U-238, and Th-234 and Pa-234, all naturally occurring radioisotopes. Non-uranium members of the U-238 chain beyond Pa-234 are not present (< .01% of secular equilibrium).

In the publication, "Estimates of Ionizing Radiation Doses in the United States 1960-2000," the U. S. Environmental Protection Agency states:[1]

> "It is unlikely that [fuel fabrication] activity would increase levels of exposure and in the general environment. Similar activities at government facilities discussed below contribute no significant population doses."

2. Description of the Fuel Fabrication Industry

Ten commercial plants licensed by the AEC are presently capable of performing all or part of the fuel fabrication operation. Three of the plants use enriched UF_6 as feed material and produce completed light water reactor fuel assemblies. Four other plants use enriched UF_6 as feed material for producing UO_2 powder or UO_2 pellets. The other three plants use UO_2 powder or UO_2 pellets as feed material and produce completed fuel assemblies. Table E-2 summarizes the plant locations and operations. Table E-3 summarizes site size and the demography at each plant location. The average population density listed in the table is an estimate based on the surrounding counties within a 50 mile radius of the site.

TABLE E-2

LWR FUEL FABRICATION PLANTS[2]

Licensee	Plant Location	Plant Feed Material	Plant Product
Babcock & Wilcox	Lynchburg, Va.	UO_2 Pellets	Fuel Assemblies
Combustion Engineering	Windsor, Conn.	UO_2 Powder	Fuel Assemblies
General Electric	Wilmington, N.C.	UF_6	Fuel Assemblies
Gulf United Nuclear	Hematite, Mo.	UF_6	UO_2 Powder or Pellets
Gulf United Nuclear	New Haven, Conn.	UO_2 Pellets	Fuel Assemblies
Jersey Nuclear	Richland, Wash.	UF_6	Fuel Assemblies
Kerr-McGee*	Crescent, Okla.	UF_6	UO_2 Powder or Pellets
Nuclear Fuel Services*	Erwin, Tenn.	UF_6	UO_2 Powder or Pellets
NUMEC	Apollo, Pa.	UF_6	UO_2 Powder or Pellets
Westinghouse	Columbia, S.C.	UF_6	Fuel Assemblies

*Kerr-McGee and Nuclear Fuel Services data are from USAEC Regulatory files.

TABLE E-3

FUEL FABRICATION PLANTS

SITE SIZE AND DEMOGRAPHY

Plant Location	Site Size, Acres	Population Density[3] people/sq. mi.	City	Population of nearby Cities[4]	Distance (Miles)
Babcock & Wilcox[5] Lynchburg, Va.	506	40	Lynchburg	54,000	4
Combustion Eng.[6] Windsor, Conn.	532	620	East Granby	3,500	3
			Windsor	22,500	5
General Electric[7] Wilmington, N.C.	1650	50	Castle Hayne	700	2
			Wilmington	46,000	8
Gulf United Nuclear[8] Hematite, Mo.	150	300	Hematite	<2,500	3/4
			St. Louis	622,000	33
Gulf United Nuclear[9] New Haven, Conn.	76*	620	Hartford	158,000	9
			New Haven	138,000	0
Jersey Nuclear[10] Richland, Wash.	160	20	Richland	26,000	3
Kerr-McGee[11] Crescent, Okla.	1000	110	Crescent	1,600	5
			Oklahoma City	363,000	30
Nuclear Fuel Services[12] Erwin, Tenn.	58	110	Erwin	4,700	1-1/2
			Johnson City	33,800	13
NUMEC[13] Apollo, Pa.	5	420	Apollo	<2,500	0
			Pittsburgh	520,000	25
Westinghouse[14] Columbia, S.C.	1140	140	Columbia	113,500	8

*Shared by manufacturing and research divisions of Olin Corporation and naval reactor fuel operations of United Nuclear Corp.

The combined production capacity of these plants exceeds present reactor requirements and those projected over the next 2-3 years.

However, because of the increasing reactor fuel demands after this period and the fact that contracts for reactor fuel are negotiated several years in advance, plans are now being made by the fabrication industry for substantial expansion of production capacity over the next five years. Much of this increased capacity will be achieved through expansion of existing plants. A few new plants are expected with the probable shutdown of some of the older, less efficient plants. It is estimated that there will be about 8 plants at the end of the decade, each designed to use enriched UF_6 as the feed material to produce completed fuel assemblies.

The processing technology used for fuel fabrication can be divided into three basic operations: chemical conversion of UF_6 to UO_2; mechanical processing including pellet production and fuel element fabrication; and recovery of uranium from scrap and off-specification material. The most significant potential environmental impact results from UF_6 to UO_2 conversion and chemical operations in scrap recovery.

The currently dominant method for UF_6 to UO_2 conversion is a wet process which involves the use of ammonium hydroxide to form an intermediate ammonium diuranate (ADU) compound prior to final conversion to UO_2. Alternative dry processes to the conventional ADU process for conversion of UF_6 to UO_2 have been developed.[15] These proprietary processes offer the potential of lower capital and operating costs as well as waste management advantages.

3. Description of the Model Fuel Fabrication Plant

The model fuel fabrication plant has a capacity of 3 MTU per day and operates 300 days per year. By today's standards, this is a large plant capable of producing 26 annual fuel requirements for the model LWR. The model plant lifetime is taken to be 20 years.

The plant operations are based on currently dominant industrial practices using the conventional ADU process for conversion of UF_6 to UO_2. Of the processes currently in use or in development, the ADU process appears to create the greatest waste management problems. The feed material for the plant is UF_6 enriched from 2-4 percent in the

U-235 isotope. The UF_6, a solid at normal ambient temperature, is received in sealed 2-1/2-ton cylinders from the gaseous diffusion plant.

The process steps involved in making UO_2 powder are as follows and are shown in Figure E-1.

(a) Vaporization of the UF_6 is accomplished in a steam or electrically heated cabinet and the gaseous UF_6 is piped to a column or tank where it is reacted with water;

(b) Hydrolysis results from the reaction of the UF_6 with water forming a UO_2F_2 solution;

(c) Precipitation of ammonium diuranate (ADU) is accomplished by adding ammonium hydroxide;

(d) The ADU slurries are concentrated by centrifuging or filtering.

(e) The ADU is calcined by heating; and

(f) Reduced to UO_2 powder in a reducing atmosphere (hydrogen).

The mechanical operations involve the following principal steps:

(a) Pretreatment of UO_2 powder by comminution, compaction and granulation to desired size distribution;

(b) Pelletizing;

(c) Sintering of the pellets in a reducing atmosphere;

(d) Grinding to finished dimensions;

(e) Washing and drying the pellets;

(f) Loading the pellets into fuel rods and welding the end caps;

(g) Assembling fuel rods to form finished fuel elements.

Much of the off-specification material revealed by the frequent testing and inspection procedures associated with the operations can be recycled into the fabrication line with rather minimal reprocessing. However, some of this material must be processed through a scrap recovery cycle involving the following principal steps.

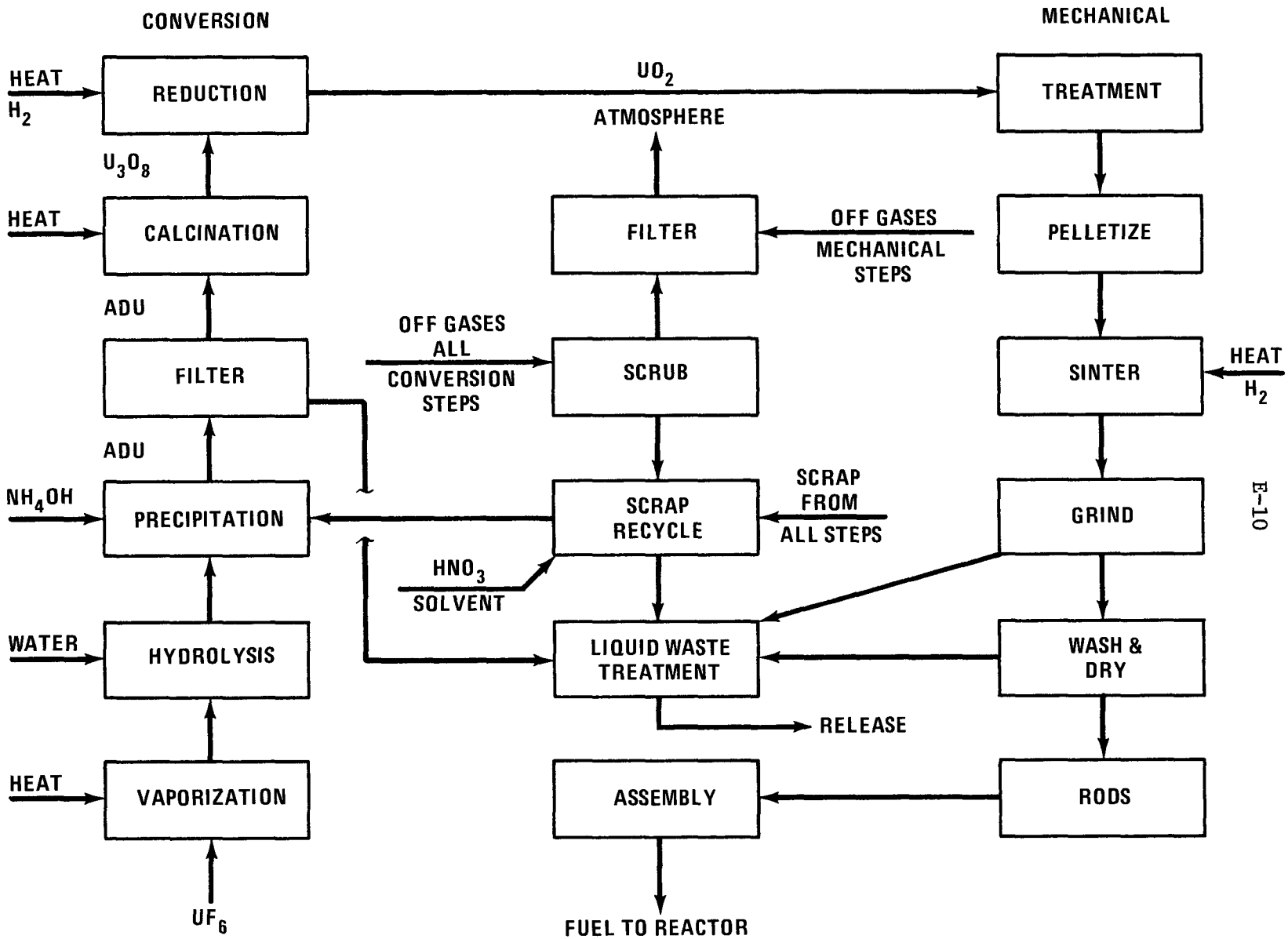

Figure E-1
FUEL FABRICATION – ADU PROCESS
SIMPLIFIED BLOCK FLOW DIAGRAM

(a) Dissolution of the uranium in nitric acid, forming uranyl nitrate;

(b) Purification of the uranium through solvent extraction;

(c) Reconversion of uranium to a form suitable for return to UO_2 production.

A plant of the size of the model plant can be expected to have an incinerator to reduce the volume of combustible scrap contaminated with low levels of radioactive material.

4. Environmental Considerations

(a) Use of Natural Resources

(1) Land

The model fuel fabrication plant is assumed to be located on a site of nominally 100 acres using about 20 acres for plant and ancillary service areas and providing a buffer zone of at least 100 meters to the nearest site boundary. All of this land is capable of reclamation after fuel fabrication operations cease. The most difficult land to reclaim for other uses would be that used for holding ponds or lagoons, which would represent only a few acres. The temporarily committed land is equivalent to about 0.2 acre per model LWR annual fuel requirement, with 0.04 acre actually disturbed.

As shown in Table E-3, the actual area held by fuel fabricators as plant site and adjacent holdings ranges from a few acres up to a few thousand acres, but fabrication plant sites need not inherently be large. Even for a 1,000 acre site the temporarily committed land for an annual fuel requirement would be less than 5% of that committed by the rest of the fuel cycle.

The external appearance of the plant is typical of that of many industrial buildings consisting of a 2-story, windowless, steel or pre-fabricated concrete slab structure of, perhaps, 100,000 square feet with associated service and office buildings.

(2) Water

The model plant requires about 450,000 gallons of water per day.[16] This is equivalent to 5.2 million

gallons of water per annual fuel requirement. Most of this water is required for cooling of process equipment and does not come into contact with uranium or process chemicals during operation. The cooling water is used to dilute the liquid process wastes prior to release off-site.

Although the water required to operate the model fabrication plant could influence the location of the plant, it should not constitute a significant environmental impact. The daily water requirement of the 3 MTU fabrication plant is less than 0.05% of that used by a model LWR.

(3) Other

The power required to operate the model fuel fabrication plant is approximately 6 MWe.[17] The electrical energy required to produce an annual fuel requirement is 1,700 MW-hr, corresponding to the consumption of approximately 620 MT of coal. This is only about 1/2% of the electrical energy requirements of the enrichment plant in the supply of an annual fuel requirement.

Additionally, the plant consumes approximately 3.6 x 10^6 scf of natural gas for process heat in the fabrication of the annual fuel requirement.[18] This is 4% of the natural gas consumed by the total nuclear fuel cycle.

(b) Effluents

(1) Chemical

(i) Gaseous

The chemical process off-gas contains some of the fluoride associated with the UF_6 conversion operations. The treatment of gaseous effluents by scrubbing and demisting reduces the average fluoride concentration to approximately 0.1 ppm in the air released from the stack.[19] The average concentration at the nearest site boundary, assumed to be about 100 meters from the stack and using conservative meteorological conditions, is approximately 1 x 10^{-4} ppm (about 0.1 $\mu g/m^3$). This compares favorably with the most limiting

ambient air quality standard for fluoride of 0.5 $\mu g/m^3$ currently imposed by the State of Washington, a state which has recently published fluoride standards for air and forage.[20]

Most of the airborne chemical effluents result from the combustion of fossil fuels to produce electricity to operate the fabrication plant. As previously stated, the power consumed by the fabrication plant is about 1/2% of that consumed by the remainder of the fuel cycle operations during the production of an annual fuel requirement.

(ii) Liquid

Water from the air effluent scrubber systems contains most of the fluoride released during operation. The liquid effluent from the UF_6 to UO_2 conversion process contains ammonia and the liquid effluent from the scrap recovery operations contains nitrates and ammonia. The effluent stream is treated with lime to form a calcium fluoride precipitate, and released to a holding pond or lagoon.[21] The CaF_2 solids may be removed by filtration or by setting in the lagoon during the holding period.

The volume of contaminated liquid waste streams is approximately 25,000 gallons per day. It is combined with about 425,000 gallons per day of process cooling water in the holding ponds prior to release offsite.[22]

The aqueous effluent stream from the lagoons carries about 730 pounds per day of fluoride, about 1600 pounds per day of nitrogen in the form of ammonia, and about 1000 pounds per day of nitrogen in the form of nitrates.[23] This results in about 4.1 MT of fluoride, 8.4 MT of nitrogen as ammonia, and 5.3 MT of nitrogen as nitrate per annual fuel requirement. The concentrations released from the lagoon are about 200 mg/liter of fluoride, 280 mg/liter of nitrogen in the form of nitrates and 420 mg/liter of nitrogen in the form of ammonia.

As a point of reference for the chemical contaminants, the April 1, 1968 report on Water Quality Criteria by the National Technical Advisory Committee to the Secretary of the Interior recommends the following surface water criteria for public water supplies: for fluorides, 0.8 to 1.7 mg/l, depending on the ambient air temperature; for nitrogen as nitrate, 10 mg/l; and for nitrogen as NH_3, 0.5 mg/l.[24] Thus, the effluents may have chemical concentrations above these recommended levels for drinking water supplies. The limiting release is that of ammonia and would require reduction in ammonia concentration by three orders of magnitude to reach recommended levels for surface water. Present commercial fuel fabrication plants release liquids into streams with flow rates as low as 5 cfs and rivers with flow rates as high as 7000 cfs.[25] Depending upon the flow rate of the receiving river, the quality of the river upstream of the fabrication plant outfall, and the desired use of the river downstream of the plant, the release of nitrogen could constitute a significant impact on the environment.

(iii) Solid

The calcium fluoride precipitate from the liquid waste stream can be retained onsite. The total quantity produced by the model plant is 680 MT per year, or about 26 MT per annual fuel requirement. The 26 MT has a volume of about 11 cubic yards and requires a very small volume for onsite retention.[26]

(2) Radiological[27]

(i) Gaseous

Process offgases from the UF_6 conversion and scrap recovery dissolution operations are passed through scrubber solutions, demisters and then

through a high efficiency particulate air (HEPA) filter before release to the atmosphere. Exhaust air from enclosures, equipment and areas where the UO_2 powder is handled is drawn through HEPA filters before release. Off-gases from the incinerator are treated by a scrubber-demister or a bag filter followed by a HEPA filter. The treatment of air effluents in each case is sufficiently effective to reduce average annual uranium concentrations to less than 3.8×10^{-12} μCi/cc at the point of release from the stack or vent, the approximate 10 CFR 20 limit for release to unrestricted areas corresponding to the enrichment being processed. For an assumed ventilation flow rate of approximately 10^5 cfm, this corresponds to an annual airborne activity release from the model plant of approximately 0.005 Ci. The average annual concentrations at the site boundaries, using realistic meteorological assumptions, are estimated to be less than 0.1% of the applicable 10 CFR 20 limit.

Thorium 234, discussed in detail in the following section on liquids, is not a problem, since the limiting 10 CFR 20 concentration for airborne Th-234 is 300 times greater than for U-238.

(ii) Liquid

The thorium daughters of uranium are separated from the uranium product at the milling plant. However, the thorium-234 daughter of uranium-238, with a half-life of 24 days, grows back into 99% of secular equilibrium in approximately 168 days.

During scrap recovery operations, some thorium can be preferentially separated from the uranium during solvent extraction and appear in the raffinate solution. The use of a raffinate holding pond permits some radioactive decay of the Th-234; most of the Th-234 present is that which is in radioactive equilibrium with

U-238. It is assumed that the activity due to Th-234 in liquid effluents is 50% of the uranium activity, or more than twice the equilibrium activity of Th-234 at this enrichment.

It is estimated that the activity released from the ponds is approximately 20 mCi from uranium, 10 mCi from Th-234, and 10 mCi from Pa-234 per annual fuel requirement. The average concentrations at the point of release from the pond are about 1×10^{-6} μCi/ml of uranium, 5×10^{-7} μCi/ml of Th-234, and 5×10^{-7} μCi/ml of Pa-234. These concentrations are less than 10% of the 10 CFR 20 limits for release to an unrestricted area.

(iii) Solids

The CaF_2 solids retained onsite contain about 0.23 curie of uranium per annual fuel requirement. The concentration of uranium is about 0.01 μCi/g of solid. Based on the solubility of CaF_2, any uranium leached out of the solids with CaF_2 would be present in the leachate at concentrations of about 10^{-3} of MPC, which is so low as to be insignificant as a potential radiation hazard.

Other solid wastes contaminated to low levels with uranium are sent to a licensed commercial burial ground. As previously mentioned, it is probable that the bulk of these wastes are incinerated and thus the volume shipped is considered insignificant. The uranium activity shipped is about 25 mCi per annual fuel requirement.

(3) Thermal

Approximately 9×10^9 Btu of heat are generated in the fabrication of the model LWR annual fuel requirement. The thermal load of the process cooling water is dissipated to the atmosphere in the holding ponds and has no adverse effect on the environment.[28]

(c) Accident Considerations

Accidents of varying degrees of severity may occur in fuel fabrication plants, but the nature of the operations and the controls employed make it unlikely that any significant impact outside the confines of the plant would result from an accident. This conclusion is supported by past experience of the industry. Typically, occurrences such as loss of electrical power, pump-valve-piping leaks, inadequate ventilation of enclosures, and spills of UO_2 powder have trivial consequences. These incidents and others such as filter failures, minor fires, UF_6 releases in the plant, and inadvertent release of liquid wastes have occurred or might occur in the lifetime of the plant. These can result in consequences which are undesirable, such as increased exposure of employees, damage to equipment and loss of operating time, but which have negligible impact on the environment.

Incidents of the type noted above are a matter of record. Plugged exhaust filters, vent lines, exhaust ducts, or exhaust scrubbers have caused inadequate air flow from process equipment or enclosures.[29] The lack of proper air flow caused excessive airborne concentrations in working areas, but did not involve abnormal releases outside the plant. Similar inplant airborne releases have occurred from gasket failures,[30] improper operating conditions,[31] and improper operating procedures resulting in major spills outside of ventilated enclosures.[32] Higher than normal occupational exposures have occurred when operators have attempted to repair malfunctioning equipment without supervision by radiation safety personnel.[33]

One unusual occurrence was the rupture of the stainless steel bowl of a grinder sludge centrifuge.[34] The accident did not result in over-exposure to employees or in a significant release from the plant, but was reported to the USAEC because 10 CFR Part 20 requires reporting of all accidents resulting in property damage in excess of $1000. The value of the centrifuge exceeded this amount.

The Commission has received a verbal report of a leak in the retention dam of a liquid waste lagoon, resulting in the loss of an estimated 1.4 million gallons. All liquids flowed into a lake on the licensee's property, the discharge from which is controlled by the licensee. The uranium concentration of the water released was less than 10% of the 10 CFR Part 20 limits for release to an unrestricted area. The greatest potential hazard from an uncontrolled release of waste water from a lagoon is the ammonia content and the hazard is a function of the flow rate of the receiving stream. The normal release of 450,000 gallons per day with 420 mg/liter of nitrogen in the form of ammonia requires dilution by approximately 600 cubic feet/sec of ammonia-free water to meet recommended levels for drinking water supplies. An accidental release would contain approximately the same concentration of ammonia, but would require greater dilution if the volume released exceeded normal operating releases.

An explosion occurred in an ion exchange resin column in 1967, but did not result in personnel overexposure or release of airborne radioactivity from the plant in excess of 10 CFR 20 limits.[35] The explosion was caused by improper blending of concentrated nitric acid and water, resulting in excessively concentrated acid entering the column. Improvements in operating parameters and protective systems have significantly decreased the probability of a similar occurrence.

The AEC has received numerous verbal reports of minor UF_6 leaks, resulting from such things as plugged transfer lines, improper line connections and fittings, and defective valves, none of which resulted in significant releases outside the plant. One significant UF_6 release has been reported.[36] A valve on a newly installed unit was inadvertently left open resulting in approximately 100 pounds of UF_6 released from the process equipment during a period of fifteen to twenty minutes. A cloud of uranyl fluoride was released from the building. The only adverse effect was minor skin burns around the

exposed neck area of an employee who reentered the vaporization area to determine the source of the leak. No property damage resulted from the incident and subsequent environmental sampling and testing showed that the release had no discernible effect on the environs.

Three accidents of a potentially greater severity but having a very low probability of occurence have been postulated and evaluated for the model plant. These are a rupture in a hot UF_6 cylinder, which releases hydrogen fluoride and soluble uranium; an explosion in a reduction furnace, which releases uranium in an insoluble form; and a criticality accident, which creates direct neutron and gamma radiation and releases fission products. It was assumed that an individual could be exposed at the centerline of the plume, 100 meters from the plant.

It is hypothesized that a 2.5 ton UF_6 cylinder is received that has been overfilled with UF_6 or contaminated with some foreign gas or vapor, such that overpressurization occurs upon heating in spite of the protective interlock system. It is assumed that the cylinder ruptures and that no immediate corrective action is taken. Approximately 700 kg of UF_6 are released into the vaporization room in about 35 minutes, after which the contents of the cylinder cool to the solid state. The material released into the room would be exhausted through a scrubber system, a high efficiency particulate air (HEPA) filter and out the stack. Upon release, UF_6 becomes hydrolized from contact with water vapor in the air and with the scrubber system, forming UO_2F_2 and HF. It is further assumed that the HEPA filter becomes plugged with hydrolized UF_6, destroying the negative pressure differential and allowing UF_6, UO_2F_2, and HF gas to seep from the building. It is assumed that this results in 1% of the uranium and 10% of the HF which escaped from the cylinder being released from the building at essentially ground level.

If the hypothetically exposed individual at 100 meters remained in the center of the plume for 2 hours, he would receive a dose of about 100 mrem to the bone and about 25 mrem to the kidneys. This is less than the annual whole body dose from natural radiation.[37] The HF concentration at 100 meters would be about 3.5 mg/m^3. This is 75% greater than the threshold limit value of 2 mg/m^3 for occupational exposure of 8 hours per day recommended by the American Conference of Governmental Industrial Hygienists. This is a maximum allowable concentration, but is only 14% of the single exposure concentration which might result in temporary conjunctival and respiratory discomfort.[38]

UO_2 pellets are sintered in furnaces with a reducing atmosphere of hydrogen. The operation is carefully controlled to prevent the development of an explosive atmosphere. It is hypothesized that these controls fail and an explosion occurs in one of the furnaces. The explosive force would not be sufficient to destroy the furnace, but uranium could be blown out of the ends. It is assumed that the furnace contains 30 kg of uranium, all in the form of UO_2 pellets, and that all of the uranium is blown out. It is unlikely that any of the uranium would be released from the plant, but it is hypothesized that 0.3 kg of the uranium is drawn into the air exhaust system. Assuming a building filter efficiency of 99.9%, the calculated radiation dose to an individual at the site boundary, 100 meters from the release point, would be about 0.024 mrem to the lungs which is inconsequential.

Nuclear criticality safety at fuel fabrication plants is based on a double contingency policy. Equipment design, systems parameters, and administrative procedures are such that two independent errors must occur to create an accidental critical excursion. Conservatism in the assumptions regarding manual

operating conditions further increases the margin of safety. To the extent practicable, particularly when working with solutions, equipment is designed to be safe by geometry or with fixed nuclear poisons. A criticality accident has never occurred during processing of low enriched uranium in the United States. The probability of such an event is not subject to reliable quantitative prediction.

It is hypothesized that a uranium solution is accidentally transferred into a vessel of unsafe geometry and that the resultant excursion yields 5×10^{17} fissions. The direct neutron and gamma radiation at the site boundary, 100 meters from the plant, could result in a dose of 1.3 rem. It is assumed that 50% of the iodine released and all of the noble gases released escape from the building, and that exposure occurs at 15 minutes after the burst. The radioactive plume would not contribute significantly to the 1.3 rem whole body dose from direct radiation. The dose to the thyroid from the iodine radioisotopes would be about 6.6 rem. These doses are less than the maximum annual doses permitted by 10 CFR 20 for occupational exposure.

(d) Contribution to General Radiation Exposure

The isotopes of importance in fuel fabrication are U-234, U-235, U-238, and Th-234 and Pa-234, all naturally occurring radioisotopes. Non-uranium members of the U-238 chain beyond Pa-234 are not present (< .01% of secular equilibrium).

In the publication, "Estimates of Ionizing Radiation Doses in the United States 1960-2000," the U. S. Environmental Protection Agency states:[39]

> "It is unlikely that [fuel fabrication] activity would increase levels of exposure in the general environment. Similar activities at government facilities discussed below contribute no significant population doses."

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F. IRRADIATED FUEL REPROCESSING

1. Summary

(a) General

Fuel reprocessing recovers the unused fissile material and separates the fission products from the spent fuel discharged by the power reactor. By the middle of the 1970's, three reprocessing plants, with an estimated combined annual capacity of 2700 MTU may be in operation in the United States. The three reprocessing plants are generally similar in regard to process technology, all using mechanical means for cladding destruction and adaptations of the Purex process for a part or all of the separations.[1]

The collective operation of the three plants, normalized to an annual capacity of 900 MTU/yr, is selected as the model reprocessing plant. This capacity is equivalent to the annual fuel requirements of approximately 26 model LWR's.

(b) Environmental considerations

The major environmental considerations associated wtih irradiated fuel reprocessing, normalized to a model LWR annual fuel requirement, are summarized in Table F-1 and as follows:[2]

(1) Use of Natural Resources

The temporary land use of 3.9 acres comprises roughly 6% of the land use for the total fuel cycle. About 95% of this land use is a fenced in buffer zone and is not disturbed. Less than 0.03 acre per annual fuel requirement is permanently committed. The water use of 10 million gallons comprises about 3% of the water use for the total fuel cycle. Approximately 40% of the water is redistributed through evaporation. The electrical energy requirement of 450 MW-hr. comprises approximately 0.15% of the consumption of electrical energy in the total fuel cycle and is equivalent to the output of the model LWR for less than 1/2 hr.[3]

The fuel reprocessing component of the nuclear fuel cycle contributes significantly to the conservation of natural resources. The values recovered from the spent fuel can be measured in terms of about 30,000 MT of conserved uranium ore and bred and recovered fissile material worth $1.75 million per model LWR annual fuel requirement.[4]

TABLE F-1

Summary of Environmental Considerations For Irradiated Fuel Reprocessing
(Normalized to Model LWR Annual Fuel Requirement)

	Total
Natural Resource Use	
Land (acres)	
Temporarily committed	3.9
Undisturbed area	3.7
Disturbed area	0.2
Permanently committed	0.03
Water (millions of gallons)	
Discharged to air	4.0
Discharged to water	6.0
Total	10.0
Fossil Fuel	
Electrical energy (thousands MW-hr)	0.45
Equivalent coal (thousands MT)	0.16
Effluents	
Chemical (MT)	
Gases	
*SO_x	6.2
**NO_x	7.1
*Hydrocarbons	0.02
*CO	0.04
F-	0.11
Liquids	
Na^+	5.3
Cl^-	0.2
$SO_4^=$	0.4
NO_3^- (as N)	0.2

*Estimated effluent gases from combustion of equivalent coal for power generation.

**23% of total is estimated effluent gas from combustion of equivalent coal for power generation.

TABLE F-1 (contd.)

Effluents	
Radiological (Ci)	
Gases (including entrained matter)	
Tritium (thousands)	16.7
Kr-85 (thousands)	350
I-129	2.4×10^{-3}
I-131	2.4×10^{-2}
Fission products	1.0
Transuranics	4×10^{-3}
Liquids	
Tritium (thousands)	2.5
Ru-106	0.15
Cs-137	0.075
Sr-90	0.004
Thermal (billions of Btu's)	61

(2) Effluents

The total radioactivity of airborne radioactive effluents from fuel reprocessing is large (about 65% of the airborne radionuclides) in comparison with the remainder of the fuel cycle. Assuming that all of the Kr-85 and most of the tritium (87%) produced in the nuclear power plant fuel is released to the air during the fuel reprocessing step, the estimated annual whole-body exposure at the site boundary from gaseous effluents is less than 3% of the natural background radiation throughout most regions of the country.[5]

Nearly all of the fission products created in the nuclear reactor are removed from the uranium in the fuel reprocessing step. The activity of the fission products 150 days after discharge from the model reactor is reduced by radioactive decay to roughly 150 megacuries per model LWR annual fuel requirement.[6] The high-level wastes containing most of this radioactivity are stored as liquids in carefully designed, built and monitored tanks, within vaults, at the fuel reprocessing site for up to 5 years after separation. Eventually they will be converted to inert solids, and will be shipped to a Retrievable Surface Storage Facility within 10 years after separation, and thus isolated from the environment.[7]

Only one of the three plants, Nuclear Fuel Services, comprising the irradiated fuel reprocessing industry discharges radionuclides directly to the watershed. According to measurements made in 1971, the maximum concentrations of tritium and Ru-106 released from processing 69MT of fuel did not exceed 4% of 10 CFR 20 annual average concentration limits in off-site waters.[8] If this plant operated at 300 MT fuel/year, the tritium concentration in off-site waters could reach about 15% of 10 CFR 20 limits. With improved Ru-106 recovery, off-site concentrations of this isotope would be about 0.4% of 10 CFR 20 limits.

Oxides of nitrogen and fluorides are the most significant gaseous chemical effluents from the fuel reprocessing plant. However, the estimated concentrations of NO_x at the site boundaries are more than two orders of magnitude

below the 100 $\mu g/m^3$ EPA standard, and the predicted concentrations of fluorides are within the most restrictive State standard of 0.5 $\mu g/m^3$.[9] One of the plants comprising the irradiated fuel reprocessing industry releases chemicals to off-site waters. The incremental increase in concentrations in the receiving waters is roughly 1 ppm or less, a negligible amount for the chemical species involved.

Some heat, much of it originating from the decay of fission products in stored high level wastes, is discharged to the atmosphere. This thermal effluent amounts to slightly over 1% of that for the total fuel cycle.

(3) Accident Considerations

Fuel reprocessing plants are designed to assure adequate margins of safety to prevent accidents, and to assure that acceptable protection systems will function reliably to mitigate the consequences of accidents if they should occur as a result of multiple failures of systems or procedures that are provided to prevent accidents. A broad spectrum of accidents are analyzed, which range from minor process leaks or spills of radioactive material within the plant and/or its laboratory to credible major accidents such as, but not limited to, criticality incidents, solvent fires, hydrogen explosions, ion exchange resin fire, and typical accidents related to the handling and storage of radioactive materials. Credible accidents are treated as if they might occur during the life of the plant (irrespective of their low probability of occurrence) and the environmental consequence of the release of chemical or radioactive material that might result if the accident should occur is analyzed.[10]

The most significant accidental off-site exposure could result from an accidental criticality incident in these plants. If such an event were to occur, an individual at the site boundary could receive a dose to the thyroid of approximately 40 mrem.[11] In general, other postulated accidents could result in off-site exposures of 10 mrem to the bone of individuals near the site boundary via inhalation and ingestion of fission product and transuranic radionuclides dispersed into the atmosphere by accidental

releases. It is significant to note, however, that in more than 25 years of fuel reprocessing experience using similar processes at government owned plants, there has been no accident that has resulted in the release of significant radioactivity to the off-site environs. Based upon the extensive safety measures instituted in new commercial facilities, at least as good a safety record is expected.

(4) Contributions to the General Exposure

The reprocessing plants described in this chapter release all of the noble gases (predominantly Kr-85) and all of the available tritium present in the uranium dioxide fuel 150 days after shut down. A small fraction of the iodine isotopes, and small amounts of mixed fission products and actinides are also released. In the case of NFS, some part of the release is in a low level liquid waste stream.

Kr-85 and H-3 can increase the exposure of the general population. U. S. EPA estimates whole body annual exposure from all reactor produced Kr-85 will be about 0.003 mrem/person in 1980,[12] compared to about 100 mrem/person from natural background. The H-3 produced in all reactors world-wide is estimated to give an annual dose of 0.0006 mrem/person in 1980.[13]

The annual exposure to the population within a 50-mile radius of the model reprocessing plant is estimated to be 167 man-rem, corresponding to 6 man-rem/annual fuel requirement. The average annual dose/person within the 50-mile radius is about 0.055 mrem/person.[14]

2. Description of the Irradiated Fuel Reprocessing Industry

Irradiated fuel reprocessing recovers usable fissile material from spent reactor fuel elements. During the operation of a reactor, the buildup of fission products and depletion of fissile material requires that the operator replace between one-fifth and one-third of the fuel elements annually and redistribute the other partially spent fuel in the reactor core. The discharged fuel elements contain about one-third of the uranium-235 that was in the fuel prior to irradiation, and the fissile plutonium that was produced from uranium-238 during irradiation. At present, the recovered uranium-235 is recycled in reactor reload fuel. In the future, the bred plutonium may be used as LWR reload fuel or as fuel in liquid metal fast breeder reactors. At present, the plutonium is isolated and stored.

There are economic and technical considerations which favor recovery and recycle of fissile material from the spent fuel elements. The net value of the residual fissile material, allowing for costs associated with reprocessing, waste disposal, and transportation services, is approximately $50,000 per ton of irradiated fuel. Based on 35 metric tons of uranium reprocessed per year in support of a model 1,000 MWe LWR, the reclaimable fissile material has a net worth of about $1.75 million dollars. These economic savings are reflected in lower electric power costs. The recovered fissile material from an annual fuel requirement also represents the conservation of natural resources equivalent to approximately 30,000 MT of uranium ore.[15]

At present there are three fuel reprocessing plants in operation or being constructed in the United States. One plant has been in operation since 1966, but is presently shut down. Another is nearly completed and will be ready for operation in 1974. The third plant is in an early stage of construction and scheduled for operation in late 1976. The three plants have a combined design capacity to meet the projected needs for fuel reprocessing services until late in the 1970's.[16]

The first commercial fuel reprocessing plant, the Nuclear Fuel Services (NFS) facility, can process irradiated light-water power reactor fuels at the rate of 1 MTU/day. In anticipation of the need for additional commercial services, NFS is giving consideration to increasing the plant's capacity to 900 MTU/year (3MTU/day).

The second commercial fuel reprocessing plant, the Midwest Fuel Recovery Plant (MFRP), will be ready for operation in 1974. It has a design capacity of approximately 300 MTU/yr.

The Barnwell Nuclear Fuel Plant (BNFP), which will be the third irradiated fuel reprocessing plant, is in its early stages of construction. It is scheduled to begin operating in late 1976, and will have sufficient capacity to process 1500 MTU/yr.

Each of these plants is located on a relatively large, remote site. Site location, size and demography data for each plant are given in Table F-2. In general, the three fuel reprocessing plants are similar in respect to process technology. All plants utilize mechanical means for breaking up the fuel elements and chemical systems for recovering special nuclear material which are adaptations of the Purex process, for which the technology and risks are well defined. However, specific methods applied for mechanically disassembling the fuel elements, dissolving fuel materials, and applying separation technology to recover fissile materials differ somewhat from plant to plant. A simplified block flow diagram for the plant is given in Figure F-1.

TABLE F-2

IRRADIATED FUEL REPROCESSING PLANTS
SITE DATA AND DEMOGRAPHY[17]

Plant and Location	Site Size, Acres	Population Density people/sq. mi.	Population of Nearby Cities		
			City	Population	Distance, Miles
Nuclear Fuel Services, West Valley, N.Y.	3350	90	Buffalo	463,000	28
			West Valley	<1,500	4
Midwest Fuel Recovery Plant-Morris, Ill.	890*	150	Morris, Ill.	8,000	8
			Joliet, Ill.	79,000	15
			Aurora, Ill.	74,000	27
Barnwell Nuclear Fuel Plant - Barnwell, S.C.	1700**	35	Barnwell, S.C.	4,500	7.5
			Aiken, S.C.	16,000	26
			Augusta, Ga.	60,000	33

* Adjacent to the Dresden nuclear reactor site of 2,230 acres.
** Adjacent to AEC Savannah River Plant exclusion area.

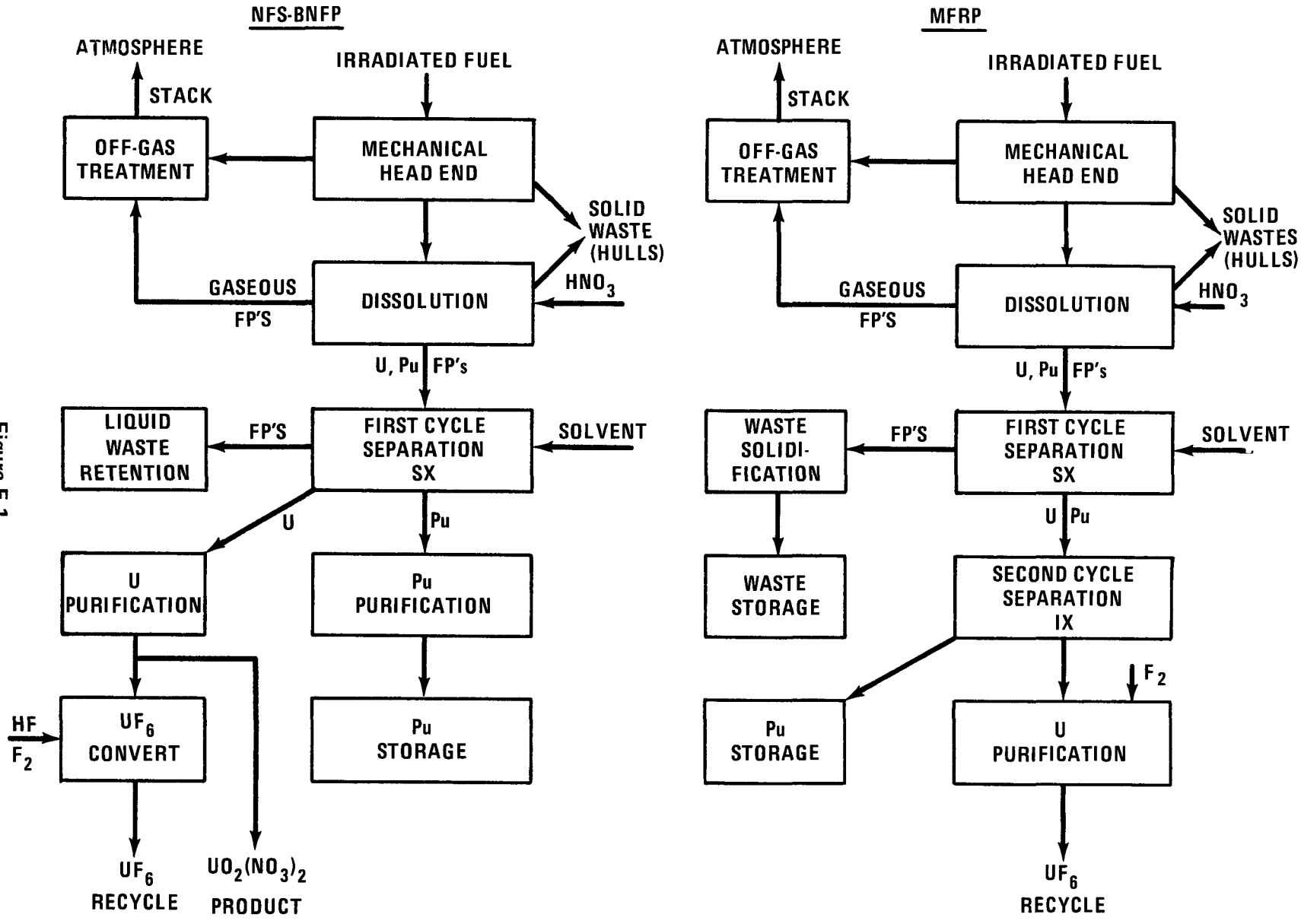

Figure F-1
FUEL REPROCESSING
SIMPLIFIED BLOCK FLOW DIAGRAM

Spent fuel element assemblies are received at the reprocessing plant via truck or rail in heavily shielded shipping casks. The assemblies are spaced arrays of sealed tubular rods containing UO_2 pellets which have been partially transformed into PuO_2, fission product oxides, and gases by irradiation. The tubes encapsulating the fuel are made of zircaloy or stainless steel.

After storage to permit short half-life radionuclides to decay (150 days), the fuel elements are chopped into short pieces, exposing the metal oxides. The metal oxides are leached by hot nitric acid, leaving behind the chopped tubing (hulls). The hulls are soaked in hot nitric acid and water to assure that essentially all of the uranium, transuranics and fission products have been removed. The nitric acid solution, containing uranium, transuranics and fission products, is adjusted chemically and processed through solvent extraction and ion exchange systems. These process steps separate the fission products, uranium, and plutonium, from each other. The purified uranium product is converted to uranium hexafluoride (UF_6) and is shipped to the gaseous diffusion plant for reenrichment. The purified plutonium product will be stored pending conversion to PuO_2 for use in future plutonium recycle or breeder reactor fuel elements (MFRP also recovers and stores neptunium).

In fuel reprocessing technology today, there are two classes of radioisotopes, noble gases and tritium, most of which are released from the fuel to the environs.

Noble gases - Krypton 85 is the dominant noble gas present after 150 days cooling (>99.9% of the noble gas activity comes from Kr-85). It is released quantitatively from the fuel.

The continuous release of all Kr-85 formed in a 1000 MWe reactor can contribute 120 man-rem/year to the entire population of the northern hemisphere; natural background contributes 400 million man-rem/yr. Thus there does not appear to be any significant increase in background from Kr-85 release for many years to come. There is ongoing research sponsored by the U.S. AEC devoted to developing a method for removing Kr-85 from reprocessing off-gases.

Tritium - The behavior of tritium in LWR fuel has been the subject of ongoing study.[18] Tritium can react with Zircaloy

to form a solid zirconium compound. It has been reported that from 30-60% of the total tritium formed in the fission process remains with the zirconium hulls. No data are available on the leaching of tritium from zirconium by nitric acid.

A substantial fraction of the remaining tritium in the fuel remains with the high level liquid waste, but will eventually be released when that waste is solidified. Hence all tritium in the fuel that does not tritide will eventually be released from the reprocessing plant.

In the case of NFS, it has been found that about 40% of the tritium from the plant is released in a low level liquid stream.[19] It has been assumed in this survey that 100% of the tritium formed in the fuel is released in reprocessing.

In the reprocessing operation, certain other radioisotopes are released from the plant stack in small amounts after treatment. Iodine, other fission products, and transuranics may be released. All gaseous effluents are discharged to the atmosphere via off-gas treatment and filtering systems which are designed to remove over 99.9% of the radioactive iodine gas, the radioactive fission products and transuranic particulates.

Of the three commercial reprocessing plants built or being constructed, only NFS has a low level radioactive liquid effluent. In the past, NFS has released tritium, ruthenium, strontium, and cesium isotopes, as well as small amounts of other isotopes; NFS has installed a low level waste treatment system designed to improve the quality of the low level waste discharged (i.e., reduce its radioactivity level). Accounting for creek dilution, values offsite for cesium and strontium have been assumed to be less than 0.1% of MPC.

The major waste systems for each of the three plants are described in Table F-3.

TABLE F-3

IRRADIATED FUEL REPROCESSING PLANTS
MAJOR WASTE SYSTEMS*

Plant	Gaseous Effluents	Liquid Wastes		Solid Wastes[3]
		High-Level	Other Than High-Level	
NFS	To atmosphere via Iodine Scrubber, HEPA filters, 61 meter stack	Stored onsite as neutralized liquid in tanks in vault[1]	Tritium and Ru-106 controlled release to creek, other isotopes <0.1% of 10 CFR 20 in off-site waters	Stored onsite in drums in impervious clay deposits
MFRP	To atmosphere via Iodine Scrubber, sand filter, 91 meter stack	Converted to solid. Stored onsite in containers under water in storage basin	Stored onsite in tanks in vault as immobile salt cake	Stored onsite in underground lined vault
BNFP	To atmosphere via Iodine Scrubber, HEPA filters, 100 meter stack	Stored onsite as acidic liquid in tanks in vault[2]	Stored onsite in tanks in vault	Stored onsite in underground concrete drums

(1) Plans underway to add tanks for storage of high-level liquids in acidic conditions with ultimate conversion to solids for transfer to a Federal storage facility.

(2) Plans for solidification of high-level liquid wastes for transfer to the Retrievable Surface Storage Facility.

(3) All facilities ship other than high-level solid wastes to commercial burial grounds for long-term storage, with the exception of hulls and fuel hardware which are stored onsite as indicated above.

*The information on this table has been compiled from Safety Analysis Reports from the facilities.

Each plant has provisions for complete containment of high-level liquid wastes in high integrity tanks in vaults or as an immobile solid as shown in Table F-3. The plans vary somewhat, but all result in total retention of the high-level wastes with no release to the environment. Within five years all high-level liquids will be converted to solids and within ten years will be transferred to a Federal storage facility for long-term confinement.[20] Solid waste materials such as hulls and fuel hardware are stored onsite in underground vaults, concrete containers or in impervious soil.[21] Other low-specific activity solid wastes are packaged and shipped to commercial burial grounds for long-term storage. There will be essentially no release of solid radioactive wastes to the offsite environment from any plant.

Plans are under way or under consideration for all three of the plants to process the recovered uranium values to hexafluoride to be recycled through the gaseous diffusion plants. Uranium hexafluoride production results in some nonradioactive chemical effluents of fluoride bearing compounds. The recycled uranium can represent as much as one-third to one-fourth the amount of natural feed to the enrichment operation, so that the potential impact of the fluorination operation at the reprocessing plant corresponds to a fraction of the total environmental impact associated with UF_6 production.

Pending development of a future market for the plutonium product recovered by reprocessing nuclear power reactor spent fuel, the fuel reprocessors tentatively plan to store the plutonium product for the utilities as part of their services. The plutonium product can be stored safely in special containers and facilities specifically designed for this purpose. The storage of plutonium product at the reprocessing site has been considered in licensing safety evaluations and with respect to the environmental impact of irradiated fuel reprocessing as a whole.

By 1975, the annual quantities of plutonium recovered by reprocessing nuclear power reactor spent fuel will be in the range of 2-3 metric tons; by 1980 about 15 metric tons; and will increase more rapidly thereafter.[22] The feasibility of using about 3 weight percent plutonium in a mixed plutonium-uranium oxide fuel for LWR's has been demonstrated.[23] However, the prospective utilization of such plutonium recycle fuel is somewhat uncertain since the actual timing and the extent to which the recovered plutonium

will be recycled is an economic matter to be considered by each utility. Moreover, although several firms have indicated plans to provide production-scale, mixed oxide fuel fabrication plants by 1975 or 1977, the present capability for fabricating such fuel is limited. Accordingly, pending development of the plutonium recycle economy, limited means for storing the recovered plutonium product inventory will be provided at the three reprocessing plants.

The New York State Atomic and Space Development Authority (ASDA) has constructed a plutonium storage facility, for the above purpose, at its Western New York Nuclear Service Center, West Valley, New York.[24] This facility is specifically designed to eliminate the possibility of any significant radiation exposure, criticality incident, or other accidents that might be related to the storage of plutonium in sealed containers. It can store 2 metric tons of plutonium as nitrate in a nitric acid solution. The plutonium nitrate solution is contained as follows: (a) in a 10-liter polyethylene bottle, (b) that is sealed within a 304 L stainless steel 14-gauge tubular capsule, (c) which is inserted in an eight-inch thick annulus of reinforced concrete with seven-inch thick reinforced concrete bottom and top cover disks, and (d) all of the above are contained within a sealed steel drum. Approximately 1000 such containers can be stored in this facility. Similarly, General Electric Company and Allied-Gulf Nuclear Services plan initially to store Class 1 shipping containers of plutonium nitrate solution within respective protective areas of the MFRP and BNFP.[25]

As the rate of plutonium generation increases due to additional LWR's being placed in operation, other more economical means could be provided for the storage of the larger inventories of recovered plutonium product. At that time, bulk quantities of plutonium nitrate solutions could be stored in vessels within confinement structures specifically designed and constructed for that purpose, or the plutonium nitrate solution could be converted to plutonium dioxide, a solid, which can be sealed in containers and stored in vaults specifically designed and constructed for that purpose. The timing for the start of use of recovered plutonium and the rates for either recycle or storage will be dependent upon an analysis of many changing factors. At this time it is not feasible to make firm projections concerning use of recycle plutonium in LWR's beyond the indication that some recycle may be accomplished by the end of this decade.

On February 1, 1973, the AEC published new proposed requirements for measures of protection of licensed fuel reprocessors against acts of industrial sabotage.[26] All reprocessing plants are required to provide protection systems to detect unauthorized access to special nuclear materials, i.e., plutonium. Buddy systems, television coverage, perimeter lighting, fencing, and communication with local law enforcement agencies are among the systems that may be required at reprocessing plants.

3. Environmental Studies of the Effects of Reprocessing Plants

As stated previously, the United States Government has operated fuel reprocessing plants for over 25 years, with major facilities at Hanford (Richland), Washington and Savannah River (Aiken), South Carolina. Another reprocessing plant is located in Idaho.

NFS, operated from 1966 through 1971, is the only plant in the United States that operated commercially.

Since the normal operations of a reprocessing plant result in the release of some radioisotopes to the environment, a review of the published environmental surveys from the Hanford off-site vicinity, Savannah River Plant off-site vicinity, and the NFS plant vicinity is presented below. It should be pointed out that both Hanford and Savannah River sites contain nuclear facilities, specifically reactors, which may have released radioactivity. In addition, both sites may be larger than commercial reprocessing plants, and the fuel exposure may be significantly different than would be experienced by commercial fuel.

(a) Savannah River Plant - This plant, operated for the AEC by EI du Pont de Nemours and Company occupies 312 square miles in South Carolina. Production areas include fuel preparation area, five reactors, two fuel separations areas, and a heavy water plant. Only three reactors are now operating.

There has been a continuous monitoring program since 1951, before plant startup, to determine the concentration of radioactive materials in a 1200 square mile area outside the plant.

Semiannual reports of the environmental monitoring are published, and are entitled "Effect of the Savannah River Plant on Environmental Radioactivity."

Reports for the period July 1963 - June 1971 were reviewed.[27] Milk has been sampled at four dairies within a 25 mile radius of the SRP over the entire period. Generally, the iodine 131 concentration was below the sensitivity of the analysis over the entire period, and was consistent with U.S. Public Health Service data over most of the United States. (In July - Dec. 1964, the SRP dairy analyses showed <11 pCi/l of I-131, whereas USPHS showed <10 pCi/l for the Atlanta, Georgia, Charlotte, N. C., and Charleston, S. C., milk sheds.)[28] Sr-90 and Cs-137 concentrations over the same period were consistent with USPHS values over most of the United States. Tritium in milk, usually at about 0.1% of applicable concentration guides, was ascribed to SRP operations. At SRP, the reactors are the major sources of tritium.

Radioactivity on vegetation (Bermuda grass) was also analyzed at the plant perimeter and a 25 miles radius. Gamma emitter concentration, ascribed to fallout, was lower in 1971 than in 1963; alpha emitters were of the same order of magnitude (0.2 pCi/g) in 1971 and in 1963.[29]

Analyses of algae and fish in the Savannah River are given. In 1971, du Pont reported that "Radioactive materials in fish flesh continued to be far below levels considered significant from a health standpoint."[30] Data for fish for Jan. - June 1970 are given in Table F-4.[31]

The radioactivity level of the Savannah River upstream and downstream of the plant are reported. The average concentration of any isotope did not exceed 4% of MPC over the entire period, and toward the latter portion, did not exceed 0.5% of MPC. In recent years, Beaufort County, S. C., has received some of its drinking water from the Savannah River, drawn about 90 miles south of the plant. Tritium in the water contributes about 0.17 mrem/yr to an individual drinking 1.2 liters/day. (The reactors are the source of the tritium.) Communities near the SRP obtain water from

TABLE F-4

RADIOACTIVITY IN SAVANNAH RIVER FISH, JAN.-JUNE, 1970
pCi/g (wet weight)

Location	Number of Fish Assayed		Type of Sample	^{137}Cs				$^{89,90}Sr$	
				Bream[a]		Catfish[b]		Bream and Catfish	
	Bream	Catfish		Max	Avg	Max	Avg	Max	Avg
Above SRP boundary	18	75	Bone	-	-	-	-	23	12
			Flesh	25	3.2	15	3.6	-	-
Adjacent to SRP	14	27	Bone	-	-	-	-	21	13
			Flesh	18	6.3	21	6.6	-	-
Below SRP at Highway 301	89	22	Bone	-	-	-	-	9	8
			Flesh	20	4.5	11	4.9	-	-

[a] Shellcracker, bluegill, and redbreast (Lepomis).

[b] Predominantly yellow cat (Ictalurus).

deep wells or surface streams. There is no evidence that SRP contributed to the radioactivity of public water supplies of towns around the plant, since the alpha and beta emitter concentrations in 1971 were essentially the same as before the plant started up.[32]

(b) Hanford - Operators of the Hanford site have prepared environmental surveys of the vicinity annually for a large number of years. Hanford contains reactors, fuel reprocessing plants, and isotope recovery facilities; as well as fuel fabrication and plutonium processing. Until fairly recently, the reactors operated with once-through cooling water, resulting in the addition of radionuclides from the reactor to the Columbia River. Beginning in 1971 only one production reactor, N, remained in operation. It has a closed primary cooling loop and releases only minor quantities of radioactivity to the river. Thus, the 1971 Hanford Surveillance Program shows the impact of other Hanford operations on the environment. These operations included the Purex chemical reprocessing plant, fuel fabrication for N Reactor, plutonium processing and scrap recovery, and laboratory operations.

Data presented in BNWL-1683, the 1971 Hanford Surveillance Program, shows conclusively that since shutdown of the once-through cooled production reactors, radioactivity released to the environs at Hanford has been reduced to negligible levels.[33] No unusual releases occurred in 1971 causing Concentration Guides, as given in AEC Manual Chapter 0524, Appendix, Table II, to be exceeded. All measurements of radioactivity were less than 15% of the applicable Concentration Guides. Radiation dose estimates for population groups in the plant evirons for 1971 were all less than 1% of applicable standards for plant operations. Offsite measurements of other air and water quality parameters were also well within applicable criteria and showed no significant evidence of plant operations.

Highlights of the observations included:

- No measureable effect on Columbia River quality was detectable from wastes released to ground disposal sites within the Hanford plant boundaries.

- Generally, the average airborne radioactive concentrations at the Hanford boundary were the same as the more distant sampling locations, indicating that Hanford operations were not contributing significantly to offsite airborne radioactivity.

- Average I-131 concentrations in milk locally available were less than 0.5% of the Concentration Guides for water. Increases of I-131 noted in milk for the latter part of 1971 are attributed to atmospheric nuclear weapons testing.

- Cs-137 and Sr-90 were detectable in milk locally available, but concentrations were less than samples obtained from the Puget Sound area - an area of high rainfall; since Richland has a desert climate, the activity is attributed to fall-out.

- Zn-65 activity (250 days half-life) was higher in local farm food-stuffs than commercial foodstuffs and can be attributed to residual activity in irrigation waters resulting from previous reactor operation; however, fallout Sr-90, Cs-137, Ce Pr-144, Zr Nb-95 and Ru-106 activities were higher in commercial foodstuffs than in local farm foodstuffs.

- Plutonium concentrations in soil and vegetation were typical of general regional levels for the arid western states.

The data on I-131 concentrations in milk in 1971 are confirmed in earlier years' reports. The environmental surveys for 1962 and 1963 contain analyses for locally produced milk.[34] The I-131 content was generally below 3 pCi/1, although fall-out from weapons testing and some period of above normals I-131 release from the reprocessing plants caused high readings for short periods. During the 1962-1963 period, the annual average I-131 release ranged from 5 curies/week at the beginning of the period to 3 curies/week at the end of the period.

(c) NFS - The Environmental Protection Agency has recently published an analysis of environmental radiation exposures and population doses from the NFS effluents.[35] The significant radionuclides were Kr-85, tritium, Sr-90, Cs-134, and Cs-137. In 1971, NFS began operating a new low-level waste treatment system to reduce the amount of strontium and cesium in its

liquid effluents. EPA concluded that the impact of this facility on humans in 1971 was well below all applicable radiation protection guides. A hypothetical individual maximally exposed locally would receive a whole body dose of 5.8 mrem/year. The plant processed 69 MT of fuel irradiated to 11000 MWD/MT in 1971. Estimating the total exposure in a 50 mile radius gave a total whole body exposure of 12 man-rem. The greatest exposure comes from tritium estimated to be present in Lake Erie, and the ingestion of deer meat. Natural background for the 0-50 mile radius is estimated at 275,000 man rem. The whole body exposure from the plant operating at 300 MT fuel/year at 33,000 MWD/MT is estimated to be 82 man-rem.

4. Description of the Irradiated Fuel Reprocessing Model

The mechanisms for discharge of effluents from the three fuel reprocessing plants differ somewhat. For this reason, and because it is likely during the remainder of this decade that these facilities will comprise the entire fuel reprocessing industry in the U.S., the collective operation of the three plants is chosen as the basis for the fuel reprocessing model.

The model plant is defined to have a capacity of 900 MTU/yr and the environmental releases and other related considerations are taken to be one-third of the aggregate for the entire industry. This capacity is equivalent to the annual fuel requirements of approximately 26 model LWR's. The model plant occupies a 2,000 acre site and operates for at least 20 years.

5. Environmental Considerations

a. Use of Natural Resources

(1) Land

Nearly all of the 2,000 acre site is only temporarily committed. Of this, approximately 100 acres are disturbed by plant construction and 1,900 acres remain an undisturbed exclusion area.[36]

At the end of its useful life, if necessary, the facilities can be dismantled and much of the area reclaimed. The area occupied by the plant itself and waste disposal areas probably could not be restored to its original condition. A conservative estimate is that an area of approximately 15 acres would be permanently committed.

(2) Water

Operations at the model plant will require water at the rate of approximately 600 gpm. This is equivalent to 10 million gallons of water per model LWR annual fuel requirement. Of this, about 6 million gallons is returned to the surface water and about 4 million gallons is released to air via evaporation and drift from the cooling tower.[37]

(3) Other

The power required to operate the model reprocessing plant is approximately 1.3 MWe. The energy required to produce the annual fuel requirement for the model LWR is 450 MW-hr, which corresponds to the consumption of 160 MT of coal at a fossil fuel fired plant producing this energy.[38]

b. Effluents

(1) Chemical

(i) Gaseous

The chemical off-gas effluents from irradiated fuel reprocessing are oxides of nitrogen, fluoride (associated with UF_6production), and combustion products from the plant's steam generators. The quantity of NO_x released from the model reprocessing plant is approximately 185 MT annually.

Extensive analyses have been made of the expected concentrations of airborne chemical effluents at the site boundary for the individual fuel reprocessing plants. The calculated site boundary NO_x concentrations are in the range of 0.1 - 1.0 $\mu g/m^3$. These concentrations are orders of magnitude lower than the EPA standard, an arithmetic mean concentration of 100 $\mu g/m^3$.[39]

Fluoride in reprocessing plant off-gases originates almost entirely from uranium hexafluoride production. The quantity of fluoride released from the model plant is estimated to be approximately 0.1 MT annually. The calculated fluoride concentrations at the site boundaries

are below the most stringent state standard for fluoride release, an arithmetic mean concentration of 0.5 $\mu g/m^3$ (State of Washington).[40]

(ii) Liquid

Only one of the three plants releases significant quantities of chemicals in liquid effluents. Table F-5 gives the most significant of these effluents. The estimated release rates are normalized to the capacity of the model reprocessing plant. This table also gives the maximum incremental increase in concentrations in off-site receiving waters. The incremental concentration increases are negligible.[41]

TABLE F-5

IRRADIATED FUEL REPROCESSING PLANTS
CHEMICALS IN LIQUID EFFLUENTS

Species	Annual Release* MT/yr	Incremental Increase in Concentration in Receiving Water Δppm
Sodium	137	1.3
Chloride	6.3	0.06
Sulfate	11.3	0.1
Nitrate (as Nitrogen)	4.8	0.04

*Normalized to the annual 900 MTU/yr capacity of the model plant.

(2) Radiological

(i) Gaseous

An irradiated fuel reprocessing plant releases airborne effluents containing krypton-85, tritium and minute quantities of radioactive iodine, other fission products and transuranic particulates which might pass through the off-gas treatment and filter systems. Table F-6 quantifies the estimated activity

released annually by the model plant, and it relates this activity to the potential maximum exposure to individuals at boundaries of the plants' exclusion areas. These exposure estimates are a) uncorrected for shielding that would be provided by clothing and buildings, b) uncorrected for occupancy time in the area.[42]

On these bases, the annual exposure could be 2.5 mrem to the whole-body, 4.17 mrem to bone, 2.58 mrem to the thyroid, and 9.2 mrem to the outer layer of skin. Thus, the whole-body exposure is less than 1% of that from natural background radiation.[43] The exposures projected for skin, thyroid and bone represent approximately 0.5%, 1.0%, and 0.05%, respectively, of the guideline limits recommended by the International Commission on Radiological Protection, Report No. 9.

(ii) Liquids

Of the three facilities comprising the irradiated fuel reprocessing industry, only the NFS plant release radionuclides in liquid effluents. This results in an equivalent annual release from the model reprocessing plant of approximately 65,000 curies of tritium, 4 curies of Ru-106, 2 curies of cesium-137, and 100 millicuries of Sr-90. Using a stream flow of 358 cu ft/sec at the NFS site boundary,[44] the calculated annual average concentration of tritium is about 5% of 10 CFR 20 limits for a 1 MT/day throughput; other isotopes released at the above rates would be about 0.5% of 10 CFR 20 limits. Estimated man-rem exposure from tritium in drinking water within a 50 mile radius is 50 man-rem.

TABLE F-6

IRRADIATED FUEL REPROCESSING PLANTS

GASEOUS RADIOACTIVE EFFLUENTS[44]

Exposure Mode Isotope	Annual Release Ci/yr	Exposure, Mrem/yr[(a)] Whole Body	Thyroid	Bone	Exposed Skin	Lungs
Submersion						
H-3	430,000	.76	.76	.76	.76	.76
Kr-85	9,000,000	.16	.16	.16	6.75	.32
Inhalation[(b)]				.61		.19
Dietary[(c)]						
H-3	430,000	1.44	1.44	1.44	1.44	1.44
Sr-90	.18			.94		
Ru-106	3.0	.02		.12	.18	.03
I-129	.06		1.26			
I-131[(d)]	.6		1.66			
Cs-134	1.2	.09		.07	.09	.02
Cs-137	0.6	.03		.06	.03	.01
		2.50	5.28	4.17	9.25	2.74

(a) Exposure normalized to 900 MT/yr; dose commitment in 50th year exposure at plant boundary.

(b) Dose from isotopes listed plus 25 Ci fission products (calculated as insoluble CE-144) and 0.25 Ci of transuranium isotopes.

(c) 30% of diet from local sources.

(d) 1 ℓ/day milk intake by child.

(iii) Solid

The volume of solid wastes, other than high level wastes, from a model LWR annual fuel requirement is summarized in Table F-7. The undissolved fuel element hulls, containing trace quantities of uranium plutonium, and fission products, and other fuel element parts will be stored or buried on-site in recoverable form and may eventually be shipped to a Federal repository. Discarded equipment will be decontaminated prior to disposal. Laboratory wastes, small tools, gloves, and clothing may be buried on-site or at a commercial burial ground.

TABLE F-7

IRRADIATED FUEL PROCESSING PLANT
SOLID WASTES OTHER THAN HIGH LEVEL
LAND BURIAL PER ANNUAL FUEL REQUIREMENT[45]

	Volume, cu. ft.
Undissolved fuel element hulls	350-700
Other fuel element parts and discarded equipment	140-230
Laboratory waste, small tools, gloves and clothing	190-1000

The solid wastes stored at NFS are stored in an essentially impermeable clay strata. At MFRP all solid wastes stored on site are stored in underground vaults equipped to detect, monitor and control water intrusion or leakage. At BNFP, solids will be kept in retrievable, sealed concrete drums stored underground.

(3) Thermal

The rate of heat dissipation from the model plant will be about 185 million Btu/hr. This is equivalent to 61 x 10^9 Btu per annual fuel requirement. The heat will be discharged to the atmosphere via the off-gas stack, a cooling tower and a cooling pond. All liquids released offsite will be cooled to ambient temperature prior to release.[46,47]

(4) High Level Wastes

High level liquid wastes containing more than 99.9% of the nonvolatile fission products are concentrated for storage on site in specially built, contained and monitored tanks for a maximum of 5 years. This is followed by conversion to inert solid and, after a maximum on-site storage time of ten years, eventual transfer to a Federally designated disposal site. At 150 days after discharge from the reactor, the activity of the irradiated fuel has decreased by radioactive decay to about 4 megacuries of fission products per MTU or 150 million curies per annual fuel requirement. In addition to the fission product content, there will be approximately 3.5 kilograms of plutonium and 350 kilograms of uranium in the wastes from an annual fuel requirement. The total quantity of high-level waste from an annual fuel requirement can be converted to a solid weighing approximately 1.4 to 2.3 MT.[48]

The MFRP plans on immediate solidification of high level wastes with no intermediate storage as liquid. The off-gases and particulate arising from this operation have been considered in the review of the MFRP.

(5) Man-rem Exposure from the Plants

Although tritium is released from two out of three of the plants comprising the model as a vapor, it can exchange with moisture, or condense and cause exposure when it is ingested as moisture or other tritiated compounds.

Using data in the Detailed Environmental Statements for MFRP and AGNS, and the EPA survey for NFS, the model fuel cycle facility is estimated to expose the population within a 50-mile radius to 167 man-rem most of which is from tritium ingestion.[49] This exposure is equivalent to 6 man-rem/year per annual fuel requirement.

(c) Accident Considerations[50]

At fuel reprocessing plants, operations having a potential for the occurrence of equipment failures or accidents which could disperse significant amounts of radioactive contaminants are performed within shielded process cells. These cells are designed to maintain adequate confinement capability in the event of accidents or natural phenomena much more severe than has been experienced historically for such plants or in the

locality of the plant. It is expected that during the life of the plant, some equipment failures will occur. Accordingly, monitors are provided in the system to detect process or equipment failures and to provide corrective action automatically, or signal a need for corrective action. Moreover, the plant is designed to cope with such failures or accidents, and the cells and equipment are designed so that they can be decontaminated for the repair or replacement of equipment. A ventilation system provides assurance that the contaminated air from within the cells, or from any inadvertent releases within the plant, will be routed through high efficiency filters that remove airborne radioactive particulate before the ventilation air is discharged to the stack. In summary, a fuel reprocessing plant is designed to (a) assure adequate margins of safety to prevent accidents, (b) cope with potential accidents, and (c) mitigate the consequences of accidents if they should occur as a result of multiple failures of systems or procedures that are intended to prevent accidents.

These plants are analyzed with respect to a wide spectrum of credible accidents and the consequence that might result if an accident should occur. While major equipment failures, or spills of radioactive materials within the plant, might disrupt operations and cause the plant to shutdown for cleanup and repair, it is not expected that such occurrences would result in the release of significant amounts of radioactivity so as to contaminate the offsite environs. That is, radioactive contamination would be confined within the process cell, or within the process building, and little if any might escape to contaminate the area in the vicinity of the plant, within the plant's exclusion area. Only a few accidents involving radioactive materials have occurred in existing plants, and none resulted in significant contamination beyond the immediate vicinity of the plant. The experience gained from these few accidents has resulted in improved safety procedures and features so that the probability of similar occurrences in the future is extremely low. Some examples of the types of accidents that might occur in fuel reprocessing plants, which would have little, if any, discernible impact on the offsite environs, are listed below. This is followed by a brief summary of the more significant potential accidents, irrespective of their low probability of occurrence, and an assessment of the possible consequences if they should occur as a result of multiple failures of systems or procedures that are intended to prevent their occurrence.

The following are examples of types of accidents that are postulated with respect to the analysis of irradiated fuel reprocessing operations. Those listed below are not expected to result in discernible contamination of the environs offsite, nor discernible exposure to the public.

Abnormal Event	Potential Consequence
• Drop fuel cask into cask unloading pool	Possible rupture of fuel pins and release of fission gas to atmosphere; contamination of storage pool water.
• Fuel element hung up in air during transfer to shear	Possible overheating and rupture of fuel pins; release of fission gas to atmosphere.
• Ignition of zirconium fires	Small fire of short duration - little, if any, damage.
• Rapid chemical reaction in dissolver	Vessel pressurized, seals blown, fission gases released to atmosphere; cell contaminated.
• Leak in recovered acid line	Contamination of cell or pipe trench in area of leak.
• Leak of any vessel or line confining radioactive material	Contamination of cell or pipe trench; transfer material to spare tank space, decontaminate cell and equipment, repair failure or replace equipment.
• Excessive entrainment radioactivity in evaporator overheads	Contamination of recovered acid or effluents, which must be recycled.
• Failure of an iodine scrubber	Reduced iodine removal efficiency of backup systems; shutdown plant until adequate efficiency restored.
• Filter failure	Detectable increase of radioactivity in stack effluent; shutdown plant and replace filter.
• Loss of ventilation zone control differential-pressure	Possible migration of radioactivity from controlled area to limited control area; correct deficiency and decontaminate building area.

• Solvent fire	May plug filter, contaminate cell and ventilation exhaust ducts; could require extensive cleanup of cell and ducts, and replacement of filter, while plant shutdown for repairs.
• Plutonium or waste concentrator explosion	Blowback of air, contamination of cell and possibly adjacent limited control area near cell; could require extensive cleanup of cell and adjacent building area, while plant shutdown for repairs; possible airborne particulate resulting in offsite exposures of less than 1 mrem.
• HF tank leak	Air concentration of toxic HF could be lethal to unprotected persons in vicinity of tank; not discernible offsite.

Table F-8 summarizes the possible consequences of the more significant potential accidents, if such accidents could occur, and is followed by a brief discussion of each accident. Even such major accidents, if they should occur, are not expected to result in radiological exposures that would have any discernible effect on the environment.

TABLE F-8

ESTIMATED RADIATION EXPOSURE AT SITE PERIMETER RESULTING FROM POSTULATED ACCIDENTS[51]

Accident	Organ of Greatest Exposure	Organ Dose (rem)
Criticality incident	Thyroid	0.04
Ion exchange resin fire	Lung	0.001
UF_6 loadout system leak	Bone	0.01
Storage pool cooler leak	Bone	0.01
Fuel assembly rupture	Thyroid	0.002

A criticality incident in a reprocessing plant is an unlikely event because the design of equipment and process limitations prevent such incidents. Safe spacing is ensured in storage basins by physically spacing the fuel elements in safe geometry even when dropped. Process systems and controls are designed to prevent assembly of an unsafe array. Nevertheless, a criticality accident is postulated, in which a burst of 10^{18} fissions is assumed. This yield is approximately an order of magnitude greater than that which has been experienced, on the average, in past accidents. It is further assumed that all noble gases and halogens (or halides) are discharged from the plant stack without taking credit for filters, and that the airborne fission products arrive at the site boundary 15 minutes after the burst. It is estimated that the whole body exposure from gamma radiation to an individual is approximately 3 mrem, and that the dose to the thyroid from radioiodine is 40 mrem.

Similarly, the design of equipment and process limitations prevent the occurrence and limit the consequences of a postulated ion exchange resin fire. However, in postulating a hypothetical ion exchange resin fire, it is assumed that 128 liters of resin, containing 30 gm of plutonium per liter, are contained in the column section that ruptures and burns. On the basis of known filter efficiencies and the results of burning experiments with metallic plutonium, it is estimated that approximately 10^{-5} of the plutonium, as insoluble plutonium oxide, passes the filter and is expelled through the stack. The resultant dose to the lung of an individual at the site boundary is estimated to be 1 mrem.

In a postulated UF_6 loadout system leak, 350 kg of UF_6 is assumed to escape as a result of a cylinder valve break at the loading temperature. The specific alpha activity of uranium in fuel irradiated to 33,000 MWd/T is approximately 1.4 Ci/kg. If it is assumed that the UF_6 bypasses the filter and is expelled as UO_2F_2 via the stack, the resultant dose to the bone of an individual at the site boundary is estimated to be approximately 12 mrem.

A leak in the storage pool cooler was postulated. The pool water activity is assumed to be approximately 5×10^{-3} μCi/ml. On the basis of Savannah River contaminant composition observations, Ce-144 is chosen to represent the potential hazard of the mixture of contaminants. It is assumed that 1.5 gal/min

of cooling water is vaporized during the course of one week. Inspection programs assure detection within one week, and a higher rate of leakage would be detectable earlier. Assuming release outside the containment at ground level in the building wake, the estimated dose to the bone of an individual at the site boundary is approximately 10 mrem.

A fuel assembly rupture is postulated, in which all of the fuel pins in one element rupture under 20 feet of water in the fuel storage pool. One element contains about 0.45 MT of irradiated uranium. The rupture of all of the fuel pins in the element would release approximately one-third of the Kr-85 inventory and 3% of the iodine inventory, i.e., that which had diffused from the fuel into the void space in the fuel element. The gases in the void space would escape and bubble to the surface of the fuel storage pool. However, most of the iodine would be absorbed in the fuel storage pool water. On the basis that one-third of the Kr-85 and 0.1% of the iodine escape to the surface of the fuel storage pool and are exhausted to the atmosphere, the estimated exposure (primarily to the thyroid) of an individual at the site boundary is approximately 2 mrem.

The storage of high-level radioactive liquid wastes in stainless steel tanks within stainless steel lined vaults, with redundant cooling systems, multiple sources of cooling water supply, spare tanks, and elaborate monitoring and alarm systems is deemed to represent a degree of containment as being essentially accident proof.[52] Moreover, these confinement systems are designed and constructed with a high degree of quality assurance to ensure their capability to withstand accidents, earthquake and tornado effects.[53] For these reasons, the probability of an accidental release of radioactivity is considered to be extremely low and thus there would not be any significant release to the environs.

(d) Contributions to the General Exposure

The reprocessing plants described in this chapter release all of the noble gases (predominantly Kr-85) and all of the available tritium present in the uranium dioxide fuel 150 days after shut down. A small fraction of the iodine isotopes, and small amounts of mixed fission products and actinides are also released. In the case of NFS, some part of the release is in a low level waste stream.

(i) Kr-85

The general exposure from Kr-85 may be assumed to come only from the isotope produced in reactor operation and released at the reprocessing plant. Using estimates for installed nuclear generating capacity, U.S. EPA estimates whole body annual exposure from Kr-85 in 1980 will be 0.003 mrem/person, compared to about 100 mrem/person from natural background.[54]

(ii) Tritium

Tritium is produced naturally by cosmic ray bombardment of oxygen and nitrogen and arrives directly from outer space. The natural inventory of tritium is estimated at from 25-80 x 10^6 Ci. Weapons have produced another 1-2 x 10^9 Ci. The dose from tritium depends on the H-3 content of food and water. The U.S. EPA has estimated that the total tritium dose from all sources of tritium - weapons, natural, and reactors - will be 0.03 mrem/year per person in 1980. Reactor produced tritium will contribute about 2% of the total.[55]

Tritium emitted from the reprocessing plant can cause exposure in man by direct inhalation, drinking water, and the dietary food chain.

(iii) Iodine

The iodine isotopes are artificial; there is the well established pathway for human exposure of atmospheric discharge → deposition on grass → cattle → milk → man. Other pathways from deposition are possible, as well as the pathway from aqueous release → man. I-131 has an 8.05 day half-life so that accumulations in nature will not occur.

I-129 has a very long half-life, 17 million years; iodine is reported not to concentrate to any appreciable extent in its transfer from soil to plants and to have a possible reaction with soil organic matter to become largely unavailable. Garner therefore concludes that "It appears doubtful, therefore, that a reservoir of I-129 in the soil would pose a long-term problem."[56]

(iv) Other fission products

Isotopes of ruthenium, strongtium, cesion, cerium, and other fission products may be released from reprocessing plants in small amounts.

Data show that strontium uptake by man is decreasing at about 14%/yr, reflecting the removal effects of leaching, fixation, and removal by plants.[57]

Cesium is known to be firmly bound by clay materials in many soils, and in sandy soils fixation may be complete in about three years after contamination. The general conclusion is that Cs-137 in plant materials has arisen from direct contamination or entrapment of solid particles, although Cs-137 may be taken up from plants grown in organic soils.[58]

Other fission products released in small amounts include Zr/Nb, Ru, and Ce isotopes. Of these, Ru is reported to be slightly excluded (concentration ratio in plant/soil = 0.01-1) and Zr/Nb and Ce are strongly excluded (concentration ratio <0.01).[59]

Radioisotopes such as strontium, cesium, and ruthenium can, however, reach man by dietary processes to cause exposure. (See Table F-6)

(v) Actinides

Plutonium and other actinides may be released in small amounts from the reprocessing plants. Experiments show that after deposition of particulate and initial stabilization, little or no resuspension of plutonium occurred except from heavy gusts of winds or mechanical disturbance. Other studies show considerable vertical migration over a 10 year period.[60] Plutonium is strongly excluded by plants (concentration factor <0.01).[61]

The Final Environmental Statement published by the U.S. AEC for the Midwest Fuel Recovery Plant considers the chronic deposition of I-129 and actinides for the time frame of the plant life in a more quantitative manner than is given above. The conclusion is that the radiological impact of deposited plutonium (used to characterize the actinides) is not expected to exceed that of radioactivity naturally present

in the soil. The iodine-129 pool in the soil is expected to require 50 years build up before the dietary supply from this source would be comparable to the pasture-milk route. The MFRP Final Environmental Statement also concludes that the dose from deposited radionuclides in the soil is almost completely due to tritium. The tritium yields a mean average dose of 0.6 mrem over much of the area within a 50-mile radius of the plant.[62]

The annual exposure to the population within a 50-mile radius of the model reprocessing plant is estimated to be 167 man-rem, corresponding to 6 man-rem/annual fuel requirement. The average annual dose/person within the 50-mile radius is about 0.055 mrem/person.[63]

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G. RADIOACTIVE WASTE MANAGEMENT

1. Summary

(a) General

The radioactive wastes resulting from the nuclear fuel cycle can be categorized as high-level and other than high-level. High-level wastes, generated at fuel reprocessing plants, contain fission products separated from fissile material recovered from irradiated fuel. Other than high-level wastes result from operations involving production of UF_6, fuel fabrication, and fuel reprocessing. These include all wastes, regardless of concentration or specific activity, which are not designated as high-level.

Appendix F of AEC regulation 10 CFR 50 requires that the inventory of high-level liquid waste at the fuel reprocessing plant be limited to that produced in the prior 5 years and that it be converted to solid form and be transferred to a Federal repository within 10 years of its separation from the irradiated fuel. The establishment of a means for long-term storage or disposal of high-level wastes is under consideration. Starting about 1980 and until a long-term repository can be established, the Federal government plans to provide the Retrievable Surface Storage Facility (RSSF) as the interim repository for high-level wastes. This interim facility will be designed with capability for storage of wastes for a 100-year period. The Federal government will have responsibility for care and maintenance over the interim facility. Control must be maintained as long as any waste is stored in a facility.

Radioactive wastes other than high-level are buried in near-surface shallow trenches, usually in the containers in which they are shipped. There is no intent to recover the wastes once they are buried. There are 6 commercial land burial sites in the United States authorized to receive and bury other than high-level wastes.

Land used for commercial land burial is owned or controlled by the States. In the event of default or abandonment of the site by the commercial operator, the State is obligated to provide care and maintenance of the site to assure its dedication to radioactive waste burial and to assure it is not used for other purposes.[1]

(b) Environmental Considerations

(1) Resource Use

The waste generated as a result of fuel cycle operations will require the commitment of less than 0.2 acre for the storage of both high-level and other than high-level wastes resulting from the model LWR annual fuel requirement.

(2) Effluents

No effluents to the off-site environment are expected to result from burial of waste classified as "other than high level." Analyses of surrounding streams, test wells and vegetation are used to detect any migration which might lead to offsite contaminations. If any buildup is found, measures will be taken to determine the source and eliminate it.

Under normal conditions, there will be no radioactive or chemical effluents from the Retrievable Surface Storage Facility. Releases of radioactivity to air will be minimal, and are estimated to be of the order .005 curies/year.

(3) Accidents

Possible accident effects at commercial land burial facilities would normally be confined to low level contamination of the immediate area of the accident and would not result in release of significant amounts of radioactive material to the environment. However, if there were a release to areas outside the facility, the contaminated areas would be surveyed for radioactivity and decontaminated.

There are two types of accidents involving high level wastes which may be postulated at the RSSF. Catastrophic failure of the proposed water cooling system could result in the eventual meltdown of waste. It is estimated that more than one week would have to elapse without any corrective actions before any meltdown would occur. The safety features, and the number of sequential failures that would have to occur for total loss of cooling and the time period available for corrective action make this accident incredible.

A waste canister handling accident at the RSSF can be postulated which may result in discharge of radioactivity to the air. First year bone dose at the site perimeter is estimated at 0.1 rem.

(4) Contributions to the General Exposure

The low level burial grounds and high level RSSF are not expected to increase significantly the exposure of the general public.

2. Description of the Radioactive Waste Management Industry

Radioactive waste generated during fuel cycle operations is divided into two categories, high-level and other than high-level. High-level waste is defined in Appendix F, 10 CFR 50, as the aqueous wastes resulting from the operation of the first cycle solvent extraction system, or equivalent and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuels. All other solid waste, regardless of its source, falls into the other than high-level category and may be sent to a commercial land burial facility for disposal.

(a) Disposal of Other Than High-Level Wastes

At the present time, there are six commercial land burial facilities which are authorized to receive and bury other than high-level wastes. Five of the sites are on land owned by States and the other site is on land owned by the Federal government and leased to the State. Commercial land burial facilities must be located on land which is owned by either a State or Federal government.[3] The purpose of this requirement is to assure long-term control of the site in the event of default or abandonment of the site by the commercial operator. It is intended that, after radioactive wastes are buried at the site, the land not be used for any other purpose. The States have the obligation for perpetual care and maintenance of land burial sites to assure their dedication to waste burial and to assure that they are not used for other purposes. Authorization to operate a commercial land burial facility is based on an analysis of nature and location of potentially affected facilities and of the site topographic, geographic, meteorological, and

hydrological characteristics, and usage of ground and surface waters in the general area, which demonstrate that buried radioactive waste will not migrate from the site.[4]

Monitoring wells are maintained at most burial sites and are sampled periodically to determine if there has been any migration of radioactivity. In addition, air, water and vegetation samples are taken around the site and analyzed for radioactivity. Should any sample reveal an increase in the concentration of radioactive material in an aquifer above that measured prior to commencement of burial operations and it is determined that the radioactivity originated in the burial ground, its significance must be analyzed, corrective actions developed, as appropriate, and the entire matter reported. Corrective actions are subject to approval by the Atomic Energy Commission or an Agreement State and additional corrective measures may be required as a regulatory agency deems appropriate. An analysis by the U.S. Department of Interior Geological Survey of Sheffield, Illinois burial site predicts migration times through the undisturbed glacial sediment at the site of about 125-150 years, with an increased migration time for ionic material.[5]

To date, there have been no substantiated reports of migration of radioactivity from commercial burial sites. In the unlikely event that there would be such a finding, several courses of action could be taken. These include: (1) a halt to burial operations, (2) removal of the radioactive material from the burial area in which the radioactivity originated, (3) grouting of the site from which the radioactivity originated, or (4) other such procedures which might be necessary, depending on the extent of migration of radioactivity from the site.

Existing commercial land burial facilities are located in the States of Washington, Nevada, Illinois, Kentucky, South Carolina, and New York. The Illinois facility is licensed by the AEC; the remaining sites are licensed by the states. Currently, about 1,000,000 cubic feet of packaged radioactive waste materials are buried per year.[6] It has been estimated that the annual volume will increase to about 2,000,000 cubic feet by 1975 and 4,000,000 cubic feet by 1980.[7]

An average burial trench at a commercial burial site is about 300 feet long, 30 feet wide, and 20 feet deep and has a

volume of 180,000 cubic feet.[8] The volume is not completely utilized since there are voids between packages and between packages and earth fill. Assuming 100,000 cubic feet of waste can be stored in a trench, approximately 10 trenches are needed per year to accommodate the current rate of burial of radioactive wastes. The total land area of the six burial sites is about 600 acres.[9] Assuming 50% usage of available land for trenches, this land area would accommodate over 1400 average burial trenches and would provide for burial of 140,000,000 cubic feet of packaged waste.

The commercial land burial sites are located in rural, sparsely settled areas or in virtually uninhabited areas such as the Armagosa Desert in Nevada.[10] The sites themselves are generally isolated so that public access to them is limited. The areas in which wastes are buried are enclosed by fences and access to the sites is carefully controlled by the site operator.

The prime operations at a commercial land burial facility are the receipt, temporary storage, and burial in trenches of packaged radioactive wastes. The packages that are shipped to the burial facilities must meet the requirements of the Department of Transportation (DOT) and the Atomic Energy Commission (AEC) for transportation of radioactive material.[11]

The packages are normally buried as received with no reprocessing or repackaging of package contents. However, in some cases, the primary package containing the waste is shipped in a reusable overpack or secondary container which may be required by DOT regulations for shipment of the particular materials involved. In those instances, the primary package is removed from the reusable overpack before burial of the primary package.

The suitability of a site for burial of radioactive wastes depends on the geological and hydrological characteristics of a site and its ability to retain the radioactive material so that there will be no migration of the radioactive material from the burial site. No credit is taken for containment provided by the packages once they are buried. The purpose of the packages is to provide ease of handling and minimization of personnel exposure and to prevent loss of the radioactive material to the surroundings prior to burial.

The volume of packaged radioactive waste consigned to a commercial land burial facility by the various steps in the fuel cycle is relatively small. There is no waste buried at commercial facilities from operations in the mining, milling, and enrichment steps. During production of UF_6, waste consisting of such things as rags, sweepings, boxes, piping, etc. contaminated with uranium is generated. The average concentration of the waste is low (a few thousandths of a microcurie per gram) and the volume of packaged waste sent to a commercial land burial facility for disposal amounts to a few thousand cubic feet for the model LWR annual fuel requirement.[12] Fuel fabrication operations generate wastes similar to those generated by UF_6 production facilities.

Fuel reprocessing operations generate wastes consisting of general laboratory waste, small tools, gloves, clothing, etc. contaminated with fission products and/or fissile materials.

The volume of waste generated as a result of reprocessing the spent fuel from a model LWR annual fuel requirement ranges from 200 to 1000 cubic feet, depending on the compaction or other volume reduction methods utilized at the fuel reprocessing facility.[13]

(b) High-Level Waste Disposal

Appendix F, 10 CFR 50, requires that the inventory of high-level liquid waste at a fuel reprocessing plant must be limited to that generated in the prior five years. The liquid waste must be converted to dry solids and transferred to a Federal repository no later than ten years following separation of fission products from irradiated fuels. The solids will contain a variety of fission products and will ultimately be in a non-reactive form.

The spent fuel from a model LWR processed annually in a fuel reprocessing plant produces approximately 10,000 gallons of radioactive liquid waste which, when converted to a solid, weighs approximately 1.4 - 2.3 MT.[14] Assuming that this waste is in the form of calcined solids diluted with twice its volume of inert material, it would occupy a volume of approximately 70 cubic feet.

It was planned to construct a Federal repository in a salt mine for long-term geological storage of solid high-level

wastes by the mid 1970's. However, subsequent events have deferred the site selection and construction of such a facility.

The present alternative plan is to design and construct a Retrievable Surface Storage Facility capable of safely storing high-level radioactive waste containers for 100 years or until such time as a permanent Federal repository can be established.[15] The Federal government will have responsibility for the care and maintenance for the RSSF which will be used for storage of high-level waste and the future repository for permanent storage of such waste. The intended life of the RSSF is 100 years; however, the Federal government will have the obligation for care and maintenance as long as any waste is stored in the facility.[16] Although a repository for long-term geologic storage of high-level waste is intended to isolate the waste from man and the biosphere, the Federal government will have the obligation to maintain control over the site in perpetuity.

3. Description of Model Waste Handling Facilities

(a) Land Burial Facility[17]

A model land burial facility for other than high-level wastes consists of 100 acres of land located in a rural, sparsely settled area. The site location is near a highway so that there is reasonable access to the site. The site characteristics are such that the ground water is well below the bottom of the deepest trench. The precipitation in the site area is on the order of a few inches per year up to 35-45 inches per year. In a trench in which rainwater could collect arrangements for pumping such water out of the trench are made. The soil provides good ion exchange characteristics to minimize percolation of radioactivity which may be leached from the solid waste to the groundwater. There is no nearby use of groundwater or well water downstream from the site. The site and its vicinity have the characteristically slow water movement through the soil in a direction in which there is little or no land use.

Buildings on the site provide space for offices, a laboratory, temporary storage of packaged radioactive wastes, and other waste handling as may be necessary, such as solidification of

low concentration liquids. The storage space is also used for storage of vehicles, earth moving equipment, fork lifts, etc., which are necessary for preparation of trenches and handling of packages containing radioactive wastes.

The portion of the site in actual use is fenced so that access to trenches and buildings is prevented. The fence also serves to minimize entry by area wildlife.

The operator of a site has a program for environmental monitoring. This program includes sampling of air, water, and vegetation to determine migration, if any, of radioactive material from the actual location of burial. Records are maintained of the monitoring results.

Trenches which are completed are cared for to minimize erosion and are marked to specify the contents. Packages in partially filled trenches are covered over with earth frequently to minimize access to the waste, provide shielding during placement of packages in the trench, and to minimize entry of water into the trench.

The model facility keeps temporary storage of packages to a minimum. Packages are placed in a trench and covered with earth as soon after receipt as possible.

(b) High-Level Waste Storage Facility[18]

In recognition of the need to take timely technical and budgetary steps to assure that facilities are available to accept the commercial high-level waste to be initially delivered in early eighties, the Commission, in the early spring of 1972, announced that it was proceeding on a program to design, construct and operate a surface (or near-surface) facility in which the solidified commercial high-level waste in sealed canisters will be stored. The facility and the canisters will be continuously monitored and maintained, and the canisters may be easily retrieved at any time if future technological development offers equally safe alternate acceptable options having clear advantage over monitored maintained surface storage.

Since that time, engineering work on: (1) selection of the specific engineering procedures for receiving and

handling sealed waste canisters; (2) heat removal, shielding, monitoring and maintenance of canisters and facilities; (3) conceptual design of facilities; (4) selection of site(s) for the facilities; (5) preliminary cost estimates; (6) preliminary analysis of safety under normal and abnormal conditions; and (7) operating and maintenance procedures, has proceeded with the objective that, while actual construction need not be initiated until 1979, all information needed to request Congressional authorization and initial funding for the first module of the repository will be available in time to allow the Commission, should it so desire, to include at least the initial phases of the project in its FY 1976 budget submission.

General Considerations

Any facility used to manage safely the high-level radioactive waste generated by the nuclear power industry must provide that the waste be contained in a way to assure that the radioactive material will not migrate to the environment and that penetrating radiation generated by the waste will not impact on man.

Provision for containment and radiation shielding for the relatively small volumes mentioned earlier would be easily achievable by simple containment were it not for the fact that radioactive decay releases significant quantities of heat for significant time periods (for example, each one foot in diameter by 10 feet long canister may generate as much as 5KW of heat at the time it is received at the RSSF). Should adequate provisions not be made to remove this heat and transfer it to the natural heat sink of the atmosphere, the waste and the canister would melt. Thus, the major factor in the design of the RSSF for high-level waste is the technique used to remove the heat from the waste.

The Commission has carried out extensive evaluations of safety, reliability, operability, maintainability and economics of various methods for removing heat, and has essentially narrowed the area for further study to techniques using either water or air as the heat transfer medium. Water has been selected as the medium used in the reference design, but continuing study and evaluation is being made for the use of air as the coolant.

Reference Design

In the reference design concept, the incoming shipping casks, each containing a number of sealed canisters of waste, are removed from the rail car or truck on which they were transported from the reprocessor, and transferred into the shielded receiving area.

In this area, the shipping cask is opened and the waste canisters are removed for inspection and any necessary decontamination, repair, recanning or precooling.

Following any necessary pretreatment, the individually sealed waste canister is placed in a water filled transfer cask and transported through a transfer corridor to a water cooled storage basin.

Figure G-1 shows the plan layout of the receiving cell and its relationship to the cask receiving area and transfer corridor. Figure G-2 shows the elevation layout of the receiving cell.

When the transfer cask arrives at the Storage cell, it is removed from its rail transporter and lowered with its contained canister into the water basin. The canister is removed, under water, from the cask and moved into its position in the water cooled storage cell. See Figures G-3 and G-4.

The storage portion of the facility consists of a series of basin modules, each designed to hold five hundred one foot in diameter by ten feet long waste canisters. Each basin has its own cooling system where water is circulated by a pump through a heat exchanger immediately adjacent to the basin. External cooling water is circulated through this heat exchanger where it picks up the heat and is then sent to a cooling tower where the heat is transferred to the outside air.

The total facility will be constructed in segments on a time schedule to meet deliveries from the reprocessors. The estimated number of annual shipments (assuming 12 waste cans per shipment) is as follows:

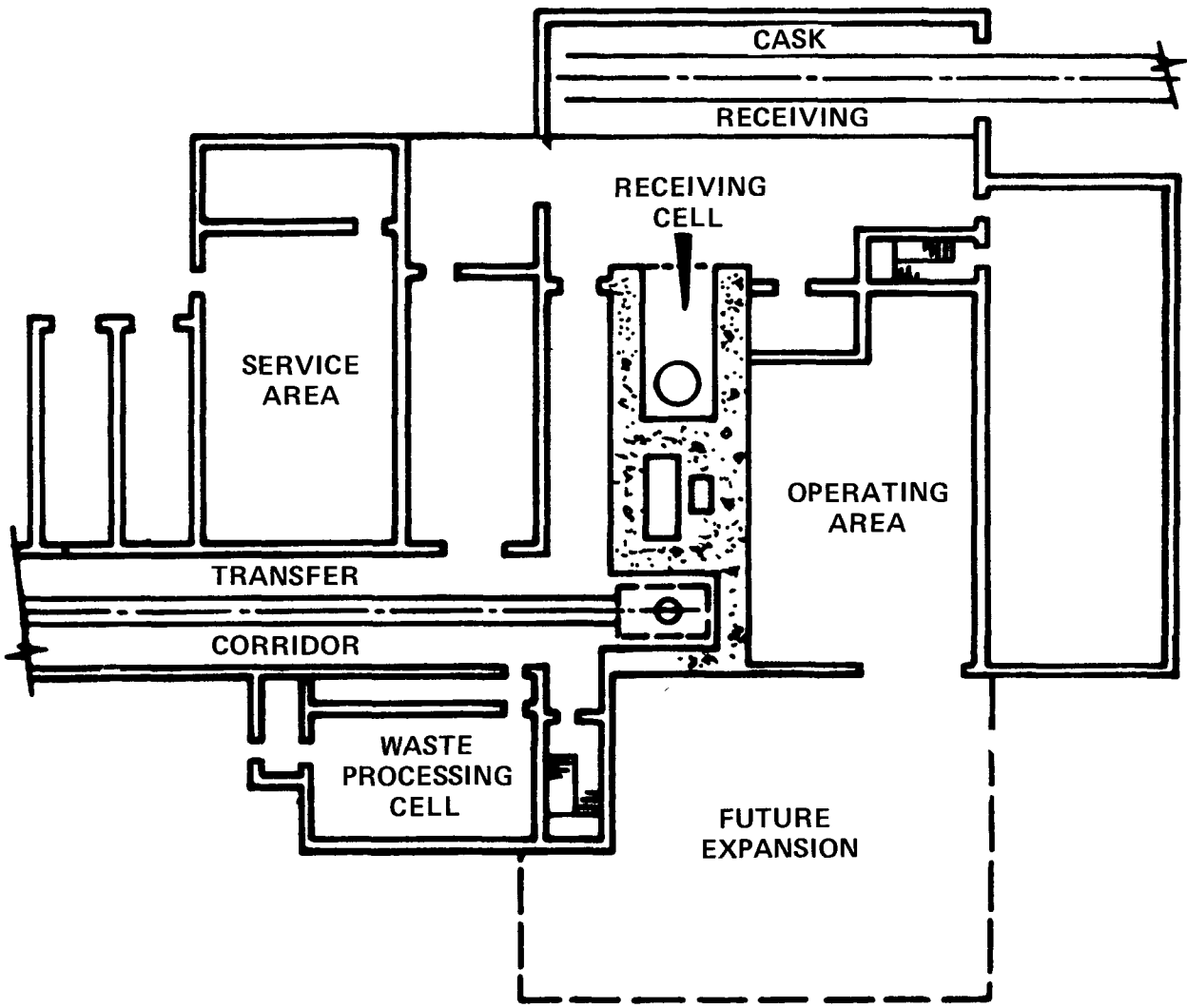

Figure G-1
REFERENCE DESIGN
RETRIEVABLE SURFACE STORAGE FACILITY
CANISTER RECEIVING AREA

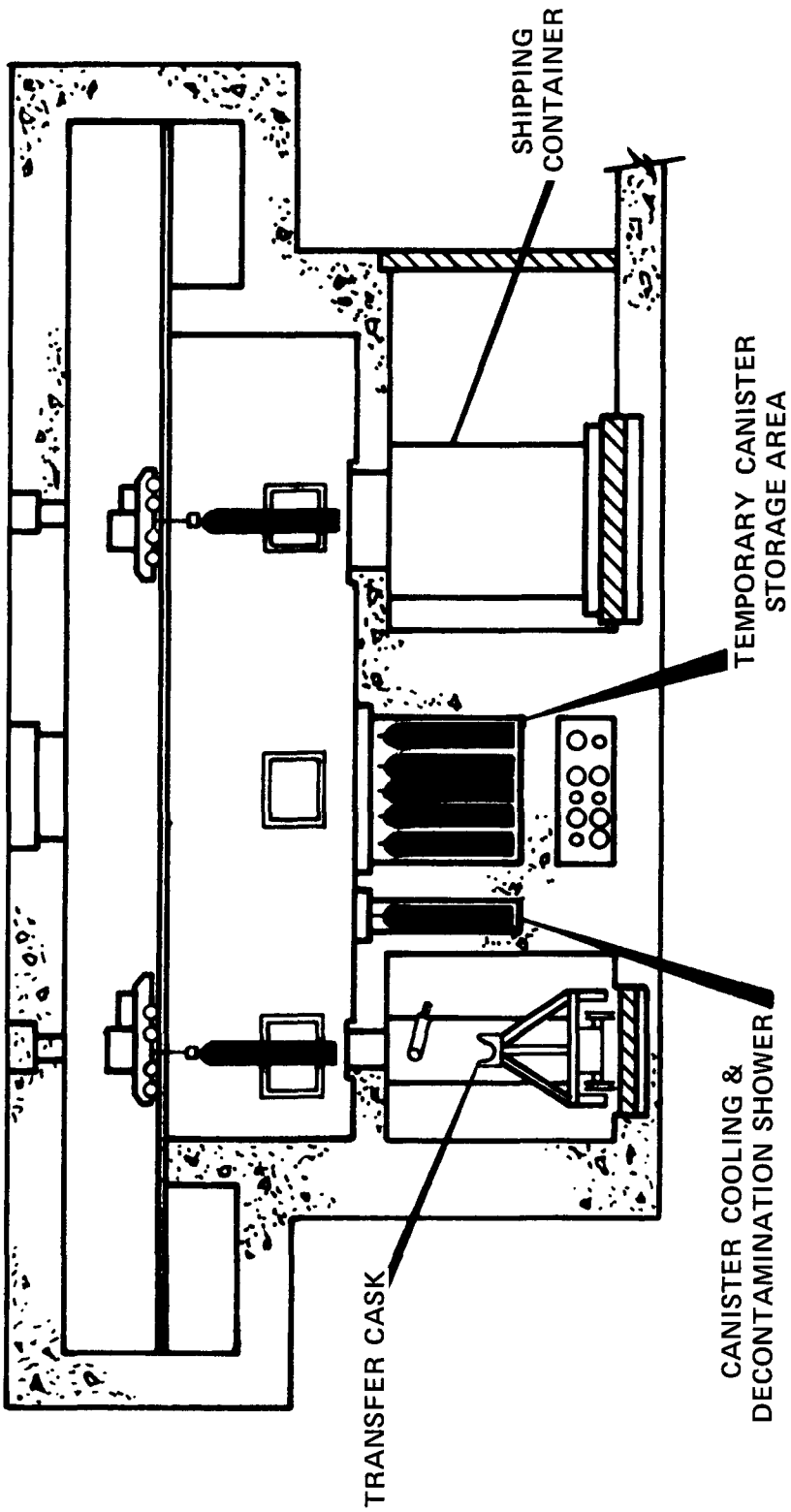

Figure G-2
REFERENCE DESIGN
RETRIEVABLE SURFACE STORAGE FACILITY
CANISTER RECEIVING CELL

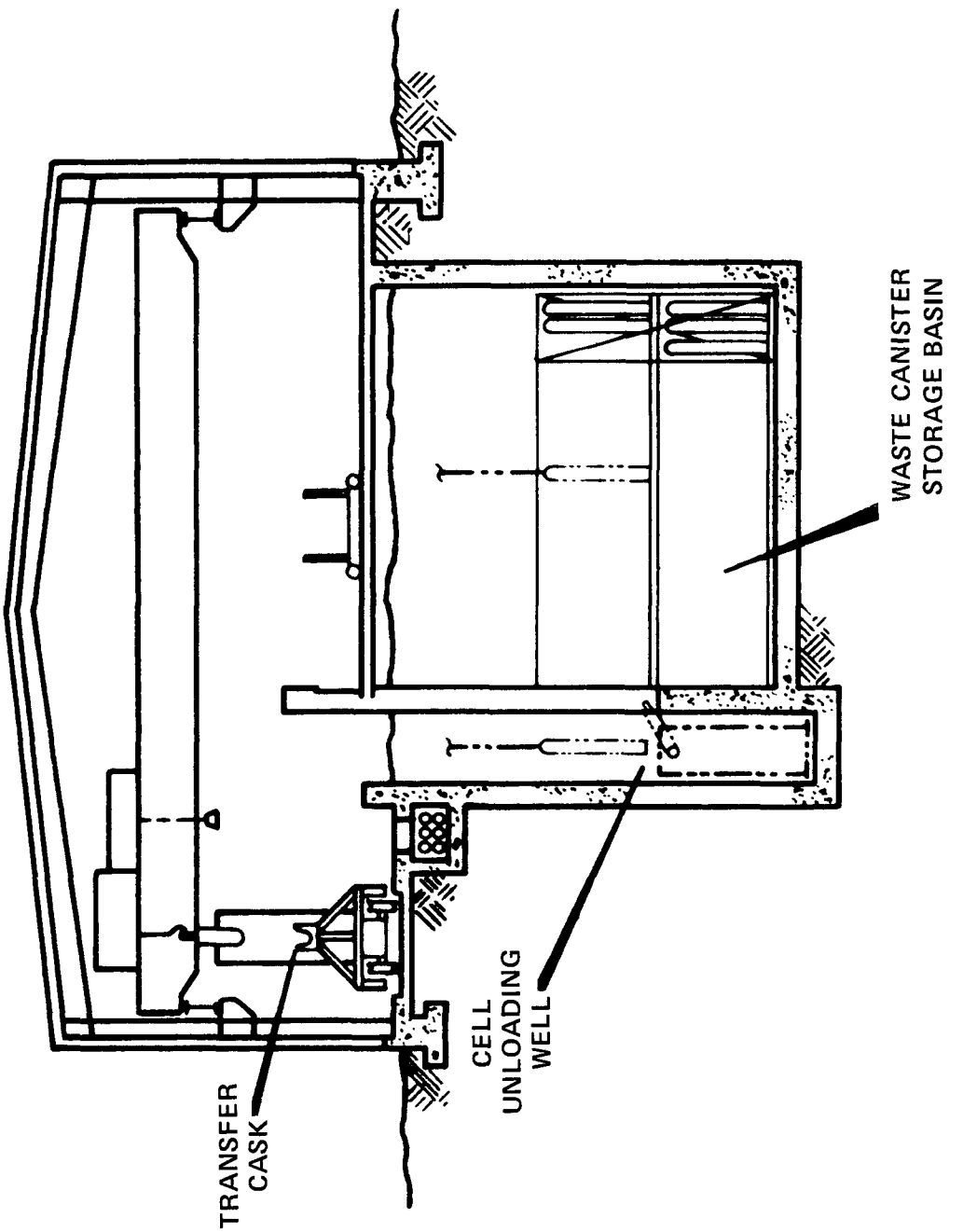

Figure G-3
REFERENCE DESIGN
RETRIEVABLE SURFACE STORAGE FACILITY
CANISTER STORAGE BASIN

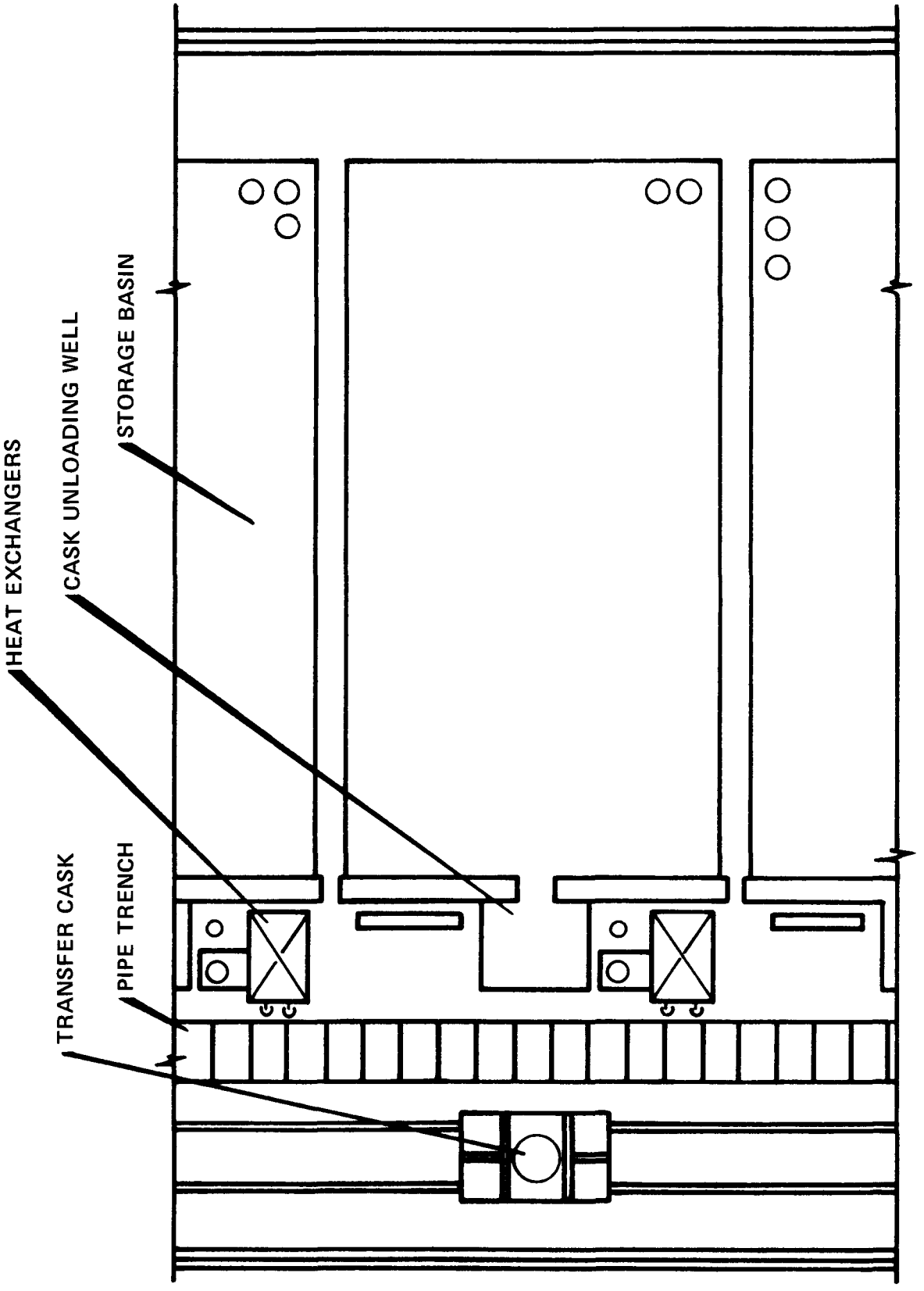

Figure G-4
REFERENCE DESIGN
RETRIEVABLE SURFACE STORAGE FACILITY
CANISTER STORAGE BASIN PLAN

Year	No. of Shipments Received at Repository
1985	20
1990	70

4. Environmental Considerations

(a) Use of Natural Resources

(1) Land Use

The volume of other than high-level packaged radioactive waste which is generated during fuel cycle operations is variable and difficult to estimate. However, the total quantity of radioactive material contained in such wastes is small and amounts to only a few curies. It is estimated that the nuclear fuel cycle activities required to produce the annual fuel requirement for a model LWR will generate about 10 curies of radioactive material in other than high-level wastes. This activity will be contained in wastes sent to commercial land burial facilities for disposal. Assuming an average concentration of radioactivity in the waste of 0.025 microcurie per gram and a waste density of 1 g/cc, the total waste volume will be approximately 14,000 cubic feet. Assuming no further compaction of the waste, the final volume of packages containing the waste could approximate 20,000 cubic feet per annual model LWR fuel requirement.

If the waste is packaged in 55-gallon drums, about 3,000 drums would be needed. If the drums are placed in rows 5 deep and 10 wide in an average 30 foot wide burial trench, 60 rows will be required. Since the drums are 2 feet in diameter, a total area of 3600 square feet of land surface will be required. This is less than 0.1 acre.

For the solid high-level waste which would be stored in a Retrievable Surface Storage Facility, it is estimated that the waste from the annual fuel requirement of a model LWR would be about 70 cubic feet and would be stored in 10 containers. It is estimated that about 4000 waste containers would be stored in the initial

module of the engineered structure storage facility. About 0.1 acre of land is required for the interim storage of the annual high-level wastes from the model LWR fuel requirement. Based on the above estimates, the land area required for disposal of all radioactive wastes from manufacture and reprocessing of a model LWR annual fuel requirement is less than 0.2 acre.

(2) Water and Other Resources Use

There is very little use of water or other natural resources involved in normal operations involving the burial or storage of solid packaged wastes classified as other than high level generated as a result of fuel cycle operations.

Table G-1 summarizes the water and electrical energy use for the Federal High Level Waste Repository.

(b) Effluents

(1) Chemical and Radiological

The normal operations involved in the burial of "other than high level" radioactive wastes in solid form are not expected to result in any effluent releases to the offsite environment.

Under normal operating conditions of the high-level waste repository, air releases will be minimal and produce air concentrations both on and off the site that are well below the recommended acceptable concentrations. The sources for occasional releases to the cell air would be material from: (1) receipt of contaminated casks; (2) decontamination of contaminated canisters; (3) repair or over packaging of failed canisters; and (4) miscellaneous clean-up operations around the storage basins. Since all exhaust air will be filtered through three HEPA filters in series, these events are calculated to result in releases of radionuclides to the atmosphere in the range of 0.005 Ci/yr which is near the lower limit of detection. The maximum concentration of transuranics leaving the stack is estimated to be 1.0×10^{-12} μCi/cc while that of the fission products is 1.7×10^{-10} μCi/cc. For the public at the outer exclusion fence, dispersion, diffusion

Table G-1

SUMMARY OF RESOURCES USE FOR HIGH-LEVEL WASTE MANAGEMENT

	Full Facility	Normalized to an Annual Fuel Requirement of the Model 1000 MWe Reactor
Land Use (acres)		
Temporarily Committed	∿1000	∿0.1
Permanently Committed	∿100	∿0.01
Water Use (millions of gallons) (1)		
Evaporated	∿1000	∿0.13
Cooling Tower Blowdown	∿1000	∿0.13
Electrical Energy (MWH/yr) (2)	$\sim 61 \times 10^3$	∿7.7
Solid Waste (Cu. Ft.)		
Nonradioactive	∿200/day	∿9
Radioactive	Max. 50/day	Max. 2

NOTES:

(1) Based on evaporation to remove heat plus an equal amount for blowdown.

(2) For pumping water.

and dilution would reduce the estimated exposure to a very small fraction of the ICRP recommended maximum exposure.

No contaminated water will leave the facility. However, there may be occasional releases of small amounts of radioactive materials from leaking canisters in underwater storage to cell water. Such an event would be immediately detected by the continuous monitoring of the water in the storage basin. When such canister failure is detected by the basin monitor, procedures are put into effect to isolate the failed canister and remove it for repair or recanning. In the meantime, the basin water is circulated through an ion exchange decontamination system. The contaminated resin is then managed in accordance with its level of radioactivity.

(2) Thermal

Due to the very low concentrations of radioactive materials in the other than high-level wastes that result from nuclear fuel cycle operations, there is essentially no heat release to the environment from these wastes.

Canisters containing solid high-level wastes at the RSSF will generate a small amount of heat. The wastes in each canister (about 7 cubic feet) will generate about 2-5 kw of heat, depending on the elapsed time since the material was first created in the reactor. This heat will be dissipated to the atmosphere. During transfer and storage of canisters in the RSSF, some heat transfer medium will be used to dissipate the heat from the sealed canisters.

(c) Accident Effects

There have been no accidents at burial grounds under Federal or State jurisdictions that resulted in offsite environmental effects. Some minor accidents have occurred involving materials not utilized in any fuel cycle.

Accidental opening of an other than high-level waste package prior to burial and release of the package contents could occur,

however, at a commercial land burial facility. Normally, the scattered waste materials would be confined to the fenced facility and the impact on the environment would be negligible. However, even if it is assumed that as much as 1/3 of the waste contained in a 55-gallon drum is released to the unrestricted area, the effect on the environment would be insignificant. The volume of a 55-gallon drum is approximately 2×10^5 cubic centimeters. Using the assumption made previously of a waste concentration of 0.025 microcurie per gram and density of 1 g/cc, the total amount of radioactivity involved is about 1.7 millicuries. If the waste were uniformly dispersed over an area of one acre, the concentration of the radioactive material would be about 0.04 microcurie per square foot or 4×10^{-5} microcurie per square centimeter. Dispersion over a greater area would result in a proportionally lower concentration. Much of the dispersed material would be in the vicinity of the site which is normally uninhabited and unused. Recovery of the bulk of the scattered waste could easily be accomplished. Radiation surveys could be made and the area decontaminated.

For the high level waste repository, detailed safety analyses must be based on the specifics of design and of actual site location which are not now available.

Preliminary safety analyses have been made, based on conceptual design and on the assumption that standards for protection against the forces of man and nature used for other nuclear facilities such as reprocessing plants, etc., will apply.

A situation of considerable concern would be loss of ability to remove heat from the stored cans. This would result in melting of the canisters and waste and loss of some fraction of the isolation of the radioactive material from the environment.

The probability of this situation occurring is prevented by a combination of engineered features including, (i) redundancy of power supply and other essential cooling systems; (ii) structural strength to withstand credible forces of nature - earthquake, tornado, etc.; (iii) combination of structural strength, plant security, etc., to withstand credible overt forces of man; (iv) modular basin cell construction which

limits the number of canisters subject to a single castastrophic event.

Thus, before a meltdown could occur, it would be necessary to have a series of failures of systems which will be engineered, constructed, and operated for maximum reliability under rigorous quality assurance programs before a situation could occur where sufficient water could not be added to and maintained in the cell to keep it from leaking or boiling dry. The timing for such a series of failures to result in uncorrectable situations is important. The individual failure of power systems for circulating the coolant would not result in pool water boiling for at least 16 hours. Various corrective actions may be taken any time within a week which would prevent cell water from boiling away. After the complete loss of water, an additional day would be required before the waste would begin to melt. The number of sequential failures required of highly reliable systems, combined with the long time periods available for repair and recovery from each, result in the judgment that this is an incredible incident.

The maximum credible accident that can be conservatively postulated is assumed to take place during one of the various transfers of a single waste canister in air in the receiving cell. It is assumed that the canister is inadvertently dropped to the receiving cell floor. While the canisters are designed to be high integrity vessels and would probably not rupture it is postulated for this analysis that it will rupture, and that its entire contents will be suspended in the air of the receiving cell. The cell air, containing this full load of waste material, then passes through two sets of HEPA filters. The effluent air from the filters is then assumed to contain 0.02 milligrams of waste per cubic meter of air discharged.[19] It is assumed that the waste is contained in one complete air change or 400 cubic meters. Using the values of 0.02 mg/m^3 and 400 m^3, a release to the environs of 0.008 grams of waste is postulated to have taken place. Dispersion calculations were made using a stack height of 28 meters, under stable conditions and a wind speed of 1 m/sec. The resultant exposure calculations are summarized below:

	At inner exclusion Area fence, 0.2 mile (operator)	At outer exclusion Fence 0.7 mile (public)
Estimated first year bone dose	0.15 rem	0.1 rem

These estimated exposures for operators and the general public are 30% and 20% of the ICRP recommended maximum dose.

(d) Contributions to the General Exposure

Naturally occurring members of the U-235 and U-238 decay chains and small amounts (<10 Ci/AFR) of fission products and actinide elements may be buried as low level waste as a result of fuel cycle operations. Migration of radioactivity from the burial grounds is not anticipated.

The RSSF will contain fission products and actinides of various ages. Release of these mixed fission products and actinides to the environment is expected to be of the order of 5 millicurie/yr.

The low level burial grounds and high level waste disposal above ground facility are not expected to increase significantly the exposure of the general public -- the increase is estimated at about 0.01% of background.

The presence of long-lived radiotoxic actinides in the high-level wastes has been the subject of extensive technical and non-technical articles.

The actinides present in high level wastes are diluted with inert material and with radioactive material of substantially shorter half-lives than, say, Pu 239. Weinberg has estimated that the concentration of Pu 239 in the high level waste is about 39 parts per million. After decay of most of the other radioactivity in the high level wastes, the hazard from the waste is comparable to that of pitchblende ore.[20]

REFERENCES

1. See for example letter from State of Nevada Department of Conservation and Natural Resources to USAEC, "Lease Agreement State of Nevada - Nuclear Engineering, Co.," USAEC Docket 27-10 (Feb. 15, 1962).

2. United States Atomic Energy Commission, Management of Commercial High Level Wastes, SECY-2371 (March 17, 1972) p. 20.

3. 10 CFR Part 20, Section 20.302.

4. Ibid.

5. U.S. Geological Survey, "Report of Geologic and Hydrologic Conditions at a Proposed Site for Burial of Solid Radioactive Waste, Southwest of Sheffield, Bureau County, Illinois," July 1967, p. 19.

6. United States Atomic Energy Commission, The Nuclear Industry-1971, WASH-1174-71 (1971) p. 154.

7. Ibid.

8. United States Atomic Energy Commission, Land Burial of Solid Radioactive Wastes: Study of Commercial Operations and Facilities, WASH-1143 (1968) Table 2, p. 33.

9. Ibid.

10. Ibid.

11. 10 CFR Part 71, 49 CFR Parts 173 and 177.

12. Allied Chemical Corp., "Application for Source Material License, Amendment," USAEC Docket 40-3392, Feb. 17, 1971.

13. Allied-Gulf Nuclear Services, "Barnwell Nuclear Fuel Plant Applicant's Environmental Report," USAEC Docket No. 50-332 (Nov. 5, 1971) Table 3.6-3, p. 76.

14. Management of Commercial High-Level Radioactive Wastes, p. 6.

15. Ibid., pp. 13, 16-17.

16. 10 CFR Part 50, Appendix F.

17. The model presented in this section is based on information in Land Burial of Solid Radioactive Wastes. Table 2, p. 33.

18. The model presented in this section is based on information in the statement of Dr. Frank K. Puttman, Director, Waste Management and Transportation, USAEC at the Hearings on the Uranium Fuel Cycle, February 1, 1973, Washington, D.C.

19. ORNL-4451, Siting of Fuel Reprocessing Plants and Waste Management Facilities, ORNL ed., (July 1970).

20. Weinberg, A. M., "Social Institutions and Nuclear Energy," Science, 177 (July 7, 1972), p. 33.

H. TRANSPORTATION

1. Summary

(a) General

Seven steps in the transportation of materials to and from facilities involved in the nuclear fuel cycle are considered in this environmental survey as follows. Three steps - shipment of ore from mine to mill, shipment of uranium concentrate from mill to uranium hexafluoride (UF_6) production plant, and shipment of natural UF_6 to the enrichment plant - involve the transport of non-fissile, low specific activity material. Two steps - shipment of enriched UF_6 to the uranium dioxide (UO_2) plant and shipment of UO_2 to the fabrication plant - involve the transport of fissile, low specific activity material. (The latter transportation step is not present for fabrication plants which incorporate the UF_6 to UO_2 conversion process.) One step - the shipment of wastes from UF_6 plants, fuel fabrication plants and fuel reprocessing plants to commercial land burial sites - involves the transport of low level solid wastes. One step - the shipment of waste storage from the reprocessing plant to a Federal waste storage facility - involves the transport of non-fissile, solid, high level waste material. In addition, the three steps (shipment of fuel to, irradiated fuel from, and waste from reactors) covering the transportation of materials to and from nuclear power plants are considered in the Detailed Environmental Statement by the Directorate of Licensing, U. S. Atomic Energy Commission, for each individual licensing action on specific nuclear power plants.

Packaging and transport of these radioactive materials are regulated at the Federal level by the Atomic Energy Commission and the Department of Transportation (DOT). Certain aspects, such as limitations on gross weight of trucks, are regulated by the States. The regulations are designed to protect employees, transport workers, and the public from external radiation and exposure to radiation and radioactive materials as a result of normal and accident conditions of transport. The requirement for low specific activity material is such that it is most unlikely that a person could ingest (inhale) a sufficient mass of material, under any circumstances arising in transport, to give rise to a significant radiation hazard.[1] Fissile materials are so limited and the packaging so designed as to

assure nuclear criticality safety under both normal and accident conditions of transport. Containers of solid radioactive high level wastes must be of Type B, designed to withstand severe accidents.

Table H-1 gives the number of shipments and total travel miles for each transportation step in the nuclear fuel cycle, normalized to the annual fuel requirement of the model 1000 MWe LWR. It is noteworthy that the transportation from mine to mill constitutes 97% of the total shipments and about 1/5 of the total travel miles. The milling plant is generally located in close proximity to the model open pit mine, the distance involved per shipment averages 5 miles and public highways are usually not involved.

(b) Environmental Considerations

The adverse environmental effects of the shipment of materials in the nuclear fuel cycle are those which are characteristic of the trucking industry in general. The increase in density of truck traffic from fuel cycle shipments will be small compared with total truck traffic. The fuel cycle transportation requirements consume about 20,000 gallons of diesel fuel per LWR annual fuel requirement or about 8×10^{-7} of the diesel fuel used by the trucking industry.

The combustion of 20,000 gallons of diesel fuel in a typical truck releases from 1.8 to 3.4 metric ton of oxides of nitrogen which is about 0.4% of the NO_x from the fuel cycle normalized to an annual fuel requirement. Only the shipment of solid high level waste material will involve the release of a measurable quantity of heat, 30 kW, to the atmosphere.

The transportation of ore from the model open pit mine to the mill is generally over a distance of about 5 miles, usually not on public highways, in relatively low population density areas (11.5 people per square mile) and involves ore that is about 0.2% uranium. None of the considerations normal to this operation nor resulting from any postulated accident would be expected to have environmental effects of any consequence.

Table H-1

Summary of Environmental Considerations for the Transportation Steps of the Nuclear Fuel Cycle

(Normalized to Model LWR Annual Fuel Requirement)

Step - Material Transported	Assumed Mode	Shipments	Travel Miles
1. Mine to Mill - Ore	Truck-Mostly Private land	3,350	16,800
2. Mill to UF_6 Production - U_3O_8	Truck-Public H'way and Rail	12	12,000
3. UF_6 Production to Enrichment - Natural UF_6	Truck-Public H'way and Rail	22	11,000
4. Enrichment to UO_2 Plant - Enriched UF_6	Truck-Public H'way and Rail	5	3,750
5. UO_2 Plant to Fabrication - Enriched UO_2	Truck-Public H'way	9	6,750
6. Low level wastes to Commercial Land Burial Sites	Truck-Public H'way	58	29,000
7. Solid Wastes to Federal Storage - Fission Products	Rail	1	2,000
Totals - Public highway truck shipments		106	62,000
Totals - Truck shipments		3,450	80,000

Under normal conditions, shipments of material required for the annual fuel requirement of the model LWR expose the general population to a small radiation dose, amounting to approximately 0.33 man-rem for onlookers, people along the route and transportation workers. The design of shipping containers for other than Type A quantities and low specific activity materials prevents release to the environment in all but the most severe accidents. Accidental criticality, which is only possible during transport with enriched uranium and which could lead to significant adverse environmental effects, is prevented by means of strict controls on container designs and on amounts of fissile material which may be shipped.

(c) Accident Considerations

The probability of an accident occuring in transportation is small, about 10^{-6} per vehicle mile and decreases with increased severity of the accident to an extremely small probability of about 10^{-13} per vehicle mile for extremely severe accidents. A serious accident resulting in an accidental criticality event with concomitant radiation exposure such as might be related to the transport of enriched uranium materials is judged not to be credible. The packaging is designed to prevent criticality under normal and severe accident conditions. An accident which could lead to accidental criticality with UF_6 would require breach of an inner container, which is unlikely to happen other than in an extremely severe accident. In addition, the contents would have to be moderated, for example, water introduced into the package. (Any small holes in a UF_6 package would probably be plugged by the products produced by the reaction of UF_6 with water.) All other packages of enriched uranium are subcritical even in the event they are accidentally moderated by water.

The other type of accidents which could result in high radiation exposure in the vicinity of the accident relates to an event which might breach the shielding container for high-level solid waste. High-level solid wastes are not likely to be shipped before the 1980's. Nonetheless, based on a 2000 mile shipment to a Federal storage facility, and an accident rate of 0.8 accidents per million rail-car-miles, it is estimated that 0.048 accidents of any type, and 0.5×10^{-6} severe accidents might occur relevant to the shipment of high-level waste per model LWR lifetime. High-level waste containers and transport vehicles are designed and constructed to withstand accidents likely to be encountered in transport.

Considering the low probability of a uranium fuel cycle component being involved in a serious accident, the nature and form of the low specific activity materials, and the requirements for package design for UF_6, fissile, and high-level activity material, it is concluded that the risk to the environment from transportation of materials that form the uranium fuel cycle is small.

Within the United States over the past 25 years, there have been only about 300 reportable accidents in transportation involving packages of radioactive material. Only about 30 involved any release of contents or increased radiation levels and none resulted in serious injuries from radiation. Millions of packages, including more than 3600 packages of irradiated fuel, have been transported during that period by all modes of transport.

The consequences of an accident involving radioactive material are mitigated by the procedures which carriers are required to follow. These procedures include: segregation of persons from packages and materials; immediate notification of the shipper and DOT in case of an accident, fire, or leaking package; and a requirement that vehicles, cars, building areas, and equipment not be placed in service again until surveyed and, where necessary, decontaminated.

Trained personnel equipped to monitor the accident area and competent to act as advisers are available through an inter-Governmental radiological assistance program. The radiological assistance teams are dispatched in response to calls for emergency assistance. This assistance has been made available in the few transportation accidents involving radioactive materials shipments which have occurred in recent years. Should a major release occur, this type of assistance would help reduce the impact on the environment.

(d) Contributions to the General Exposure

The transportation of materials in the uranium fuel cycle does not contribute to the distribution of radionuclides to the environment, except possibly during ore transportation. Any small amounts of ore falling from a truck are transported from their original location to the environment.

Transportation does contribute to the external exposure of the general public and transportation workers as described above.

2. Description of Transportation Steps and Transportation Model

(a) Mining to Milling - Ore

Ore is usually sand or limestone rock and is shipped from the mine to the milling plant. Ore is classified as low specific activity material. It is transported in bulk by truck or rail.* Approximately 27.2 MT of ore are transported per vehicle. Since the milling plant is generally located in close proximity to the model open pit mine, the distances involved are about 5 miles and in general do not involve public highways. Where ore shipments are trucked from remote mine locations, haulage could involve transport over public highways. The average shipment takes approximately 1/2 hour. Table H-2 gives the transportation data for shipments of ore from mine to mill.

(b) Milling to UF_6 Production

The mill product is a powder and ranges in consistency from granular to powder. This powder, commonly called "yellowcake," is shipped from uranium milling plants in the Western United States to two sites in the United States as well as abroad for conversion to UF_6.

Under the regulations of the DOT, the mill product is classified as low specific activity material.[2]

Typically, the concentrate is packaged in 55-gallon steel drums which have a capacity of about 0.38 MT U_3O_8 depending upon the moisture content of the concentrate. For truck shipments, approximately 40 drums are loaded per vehicle. This results in a net weight of about 15.2 MT of U_3O_8. For rail shipments, approximately 100 drums are loaded on one car, or a net weight of about 38 MT of U_3O_8. In some cases, as many as 160 to 180 drums are loaded in one car by using deck boards on top of the first layer of drums and putting a second layer on top. All shipments are likely to be made under exclusive use--full load--arrangements. Such shipments are transported an average distance of 1,000 miles.[3]

* Each of the transportation models, except the transport of solid wastes from the reprocessing plant, assumes shipment by truck.

Table H-2

Transportation Data for

Shipments of Ore from Mine to Mill

Minimum Shipment Distance (miles)	0
Maximum Shipment Distance (miles)	40
Model Shipment Distance (miles)	5
Model Ore Shipment (MT)	27.2

	Model 1000 MWe Annual Fuel Requirement
Ore Weight (MT)	91,000
Metric-Ton Miles	455,000
No. of Shipments	3,350
Travel (miles)	16,800

The average transit time is 5 to 6 days by truck and 7 to 10 days by rail. Shipments may also be made by truck and rail, i.e., by truck to a rail head and then by rail to the conversion plant. Table H-3 gives the transportation data for shipments of U_3O_8 to the UF_6 production plant.

(c) UF_6 Production to Isotopic Enrichment Plant - Natural UF_6

UF_6 is a white solid at room temperature. At higher pressures and temperatures, it melts to form a clear, colorless, high density liquid. Natural UF_6 is shipped as a solid from the UF_6 production plant to a gaseous diffusion plant for isotopic enrichment.

Under the regulations of the DOT, UF_6 is classified as low specific activity material.[4]

Typically, UF_6 is packaged in either a 10-ton cylinder, 49-1/2 inches in diameter by 118-1/2 inches long, with a capacity of 10 MT UF_6 and a nominal gross weight of 11.6 MT; or a 14-ton cylinder, 49-1/2 inches in diameter by 149-3/4 inches long, with a capacity of 12.7 MT UF_6 and a nominal gross weight of 15 MT. Almost all shipments of UF_6 are made by truck. Normally, one 14-ton cylinder is loaded per vehicle or two 10-ton cylinders per vehicle. All shipments are likely to be made under exclusive use--full load--arrangements. Such shipments are transported an average distance of 500 miles.[5]

Shipments of slightly enriched and depleted UF_6 may also be made among the three gaseous diffusion plants on an exclusive use basis and UF_6 may be shipped from the fuel reprocessing to the enrichment plants.

Time in transit varies from eight hours to two days, with an average of 11 hours. The transportation data for shipment of UF_6 to the enrichment plant are given in Table H-4.

(d) Enrichment Plant to UO_2 Plant - Enriched UF_6

Enriched UF_6 is a fissionable material and does not differ in appearance from the natural UF_6. It is shipped as a solid from the gaseous diffusion plant to the fuel fabrication plant (or the UO_2 production plant).

Under the regulations of the AEC and DOT, enriched UF_6 is shipped as Type A, fissile material.[6]

Table H-3

Transportation Data for Shipments

of U_3O_8 Concentrate to UF_6 Production Plant

Minimum Shipment Distance (miles)	275
Maximum Shipment Distance (miles)	2200
Model Shipment Distance (miles)	1000
Model U_3O_8 Shipment (MT)	15.2

	Model 1000 MWe Annual Fuel Requirement
U_3O_8 Weight (MT)	182
Metric-Ton Miles	182,000
No. of Shipments	12
Travel (miles)	12,000

Table H-4

Transportation Data for Shipments

of UF_6 to the Enrichment Plant

Minimum Shipment Distance (miles)	20
Maximum Shipment Distance (miles)	900
Model Shipment Distance (miles)	500
Model UF_6 Shipment (MT)	12.7 (1 14-T cylinder)

	Model 1000 MWe Annual Fuel Requirement
UF_6 Weight (MT)	270
Metric-Ton Miles	135,000
No. of Shipments	22
Travel (miles)	11,000

Typically, enriched UF_6 is packaged in 2-1/2 ton cylinders, 30 inches in diameter by 81 inches long, with a capacity of 2.2 MT of UF_6, packaged within a protective outer packaging. The nominal weight of the cylinder, contents and outer packaging is 2.9 MT. Normally, shipments are made by truck. Truck shipments will likely be made under exclusive use--full load--arrangements. Such shipments will be transported an average distance of 750 miles.[7] Five (5) cylinders constitute a full load.

Time in transit varies from six hours to seven days, with the average shipment taking 1-1/2 days. The transport data for shipment of enriched UF_6 to the UO_2 plant are given in Table H-5.

(e) UO_2 Plant to Fuel Fabrication - Enriched UO_2

UO_2 is produced from UF_6 as a powder. It is compacted to form pellets for loading into fuel tubes. Fuel fabrication plants may receive the UF_6, and convert it to UO_2 prior to other processing, in which case there will be no transport of UO_2. In other cases, a fuel fabricator may receive UO_2 either as powder or pellets from a conversion facility.

Under the regulations of the AEC and DOT, UO_2 is shipped as Type A, fissile material.[8]

Typically, UO_2 is packaged in steel pails, within an inner gasketed steel cylinder which is supported in a double high 55-gallon steel drum. Approximately 0.11 MT of UO_2 is packaged per drum.

Almost all shipments of UO_2 are made by truck. Normally, 40 drums are loaded per vehicle, with a net weight of 4.5 MT of UO_2 per shipment. Shipments will likely be made under exclusive use--full load--arrangements. Such shipments will be transported an average distance of 750 miles.[9]

The time in transit varies from a few hours to 10 days, the average shipment being 3 days. Table H-6 gives the transportation data for shipments of UO_2 to the fuel fabrication plant.

(f) Transportation of Low Level Waste

Low level wastes are generated at the UF_6 production plants, fuel fabrication plants, and fuel reprocessing plants which may be shipped offsite for disposal.

Table H-5

Transportation Data for Shipment of

Enriched UF_6 to the UO_2 Plant

Minimum Shipment Distance (miles)	150
Maximum Shipment Distance (miles)	3000
Model Shipment Distance (miles)	750
Model Enriched UF Shipment (MT)	11 (5 2-1/2-T cylinders)

	Model 1000 MWe Annual Fuel Requirement
Enr. UF_6 Weight (MT)	52
Metric-Ton Miles	39,000
No. of Shipments	5
Travel (miles)	3,750

In the case of UF_6 production plants, this waste, with a volume of about 8,000 ft^3, consists of hydrofluor ash, paper, rags, gloves, tools, etc. contaminated with uranium. It is normally packaged in sealed 55-gallon steel drums and shipped by common carrier to commercial land burial facilities as low specific activity radioactive material. This is equivalent to 1100 to 1600 drums or 20 to 30 trailer loads per model LWR annual fuel requirement.

In the case of fuel fabrication plants, approximately 5,000 ft^3 of waste, consisting of paper, rags, gloves, tools, etc. is shipped in sealed 55-gallon steel drums by common carrier to commercial land burial facilities. This is equivalent to 700 to 1000 drums or 15 to 20 trailer loads per model LWR annual fuel requirement.

In the case of the fuel reprocessing plants, approximately 1000 ft^3 of waste, consisting of laboratory waste, small tools, gloves, clothing, resins, etc. is shipped in sealed 55-gallon steel drums by common carrier to commercial land burial facilities. This is equivalent to 150 to 400 drums or 3 to 8 trailer loads per model LWR annual fuel requirement.

Low level wastes from UF_6 production, fuel fabrication, and fuel reprocessing are shipped under the regulations of the Department of Transportation. Time in transit varies from 8 hours to 2 days, with an average of 11 hours. The transport data for shipments of low level wastes are given in Table H-7.

(g) Fuel Reprocessing Plant to Federal Storage Facility - High Level Wastes

The solidified fission product waste from fuel reprocessing plants must be shipped for long-term storage in the Retrievable Surface Storage Facility (RSSF). The ultimate site for high-level waste storage to the RSSF no later than 10 years following separation of the fission products from the irradiated fuel.[10] At that time, the decay heat of the fission products will be less than 5% of the level present when the spent fuel was originally received from the reactor.[11]

For the near term, it is assumed that solid wastes will be retained at the reprocessing plant site for essentially the full ten year period. Following this period they will be shipped by rail to the RSSF until a long term Federal repository is established.

Table H-6

Transportation Data for Shipment of

UO_2 to the Fuel Fabrication Plant

Minimum Shipment Distance (miles)	0
Maximum Shipment Distance (miles)	1600
Model Shipment Distance (miles)	750
Model UO_2 Shipment (MT)	4.5 (40 drums)

	Model 1000 MWe Annual Fuel Requirement
UO_2 Weight (MT)	40
Metric-Ton Miles	30,000
No. of Shipments	9
Travel (miles)	6,750

TABLE H-7

Transportation Data for Shipment of Low Level Waste from UF_6 Production Plants, Fuel Fabrication Plants, and Fuel Reprocessing Plants to a Commercial Disposal Facility

Minimum Shipment Distance (miles)	20
Maximum Shipment Distance (miles)	900
Model Shipment Distance (miles)	500
Model Low Level Waste Shipment (ft^3)	240

	Model 1000 MWe Annual Fuel Requirements
Solid Waste Volume (ft^3)	14,000
No. of Shipments	58
Travel (miles)	500

Shipping containers will resemble the casks utilized in shipments of spent fuel from the reactor to the reprocessing plant. A shipment is assumed to consist of approximately 10-12 waste containers. The shipment will contain roughly ten megacuries of radioactivity in about 100 ft^3 of solid waste from a fuel requirement of a model LWR, and generate approximately 100,000 Btu/hr. of heat.[12] Such shipments will be transported an average distance of 2000 miles and will take, on the average, approximately 8 days. Table H-8 gives the transportation data for shipments of solid waste to the RSSF.

3. Environmental Considerations

(a) Traffic Aspects

There will be 106 truck shipments on public highways for the annual fuel requirement of the model LWR. According to the Federal Highway Administration, the average number of trucks per day on any specific section of the U.S. highway generally varies from about 100 to 10,000. The gross weight of the materials considered is such that a truck can stay within the weight restrictions of the State (usually about 23 MT). There should be no need for overweight permits and, therefore, no excessive loads on bridges or major routes.

While ore shipments for the model mine-mill complex will involve only truck travel on privately owned land, in certain cases ore is hauled over relatively long distances using public highways. Since most of the uranium mines and mills are located in rather sparsely populated areas of the country and are served by lightly traveled public roads, the overall impact of even the longer mileage haulages will have an insignificant effect on the population or environment. Approximately 3400 total ore shipments are required for the annual fuel requirement of the model LWR.

(b) Natural Resources

Truck transportation representing a total of 80,000 miles, is too small to have a measurable effect on the environment due to the contaminants contributed by the fuel consumed. According to the American Trucking Association, an intercity truck

Table H-8

Transportation Data for Shipment of Solidified Radioactive Waste from the Fuel Reprocessing Plant to the Retrievable Surface Storage Facility

Minimum Shipment Distance (miles)	1000
Maximum Shipment Distance (miles)	3000
Model Shipment Distance (miles)	2000
Model High Level Waste Shipment (ft^3)	120 (max of 12 waste containers)

	Model 1000 MWe Annual Fuel Requirement
Solid Waste Volume (ft^3)	117
No. of Shipments	1
Travel (miles)	2000

averages 4.9 miles per gallon diesel fuel and, during 1970, trucks consumed more than 25 billion gallons of diesel fuel. The combustion of 20,000 gallons of diesel fuel would release from 1.8 to 3.4 metric tons of oxides of nitrogen which is about 0.2% of the NO_x from the fuel cycle related to the annual fuel requirements.[13]

(c) Thermal Effluents

Only the transport of solid high level waste from the reprocessing plant releases a detectable amount of heat to the environment. The waste releases approximately 30 kW or about 100,000 Btu/hr. This can be compared to the rate at which heat is released from a 100 horsepower truck diesel engine which is about 50 kW or 180,000 Btu/hr.

(d) Radiation Exposures

It is estimated that radiation dose rates in the vicinity of a fully loaded truck of unirradiated materials are approximately 1 mrem/hr at the outside surface of the truck, 0.4 mrem/hr at 3 ft from the surface, and 0.05 mrem/hr 15 ft from the surface. For the rail car containing high level wastes, it is estimated that the dose rate at the surface of the car is 55 mrem/hr, 25 mrem/hr at 3 ft from the surface, and 3 mrem/hr 15 ft from the surface.

Radiation exposures for the general public from the annual fuel requirement of 106 truck shipments of fuel cycle materials and low-level wastes for an average distance of 600 miles, 3350 ore shipments, and one 2000 mile rail shipment of solid high level waste have been estimated as follows:

(1) Onlookers. Members of the general public are normally excluded from loading and unloading operations, but exposures might occur at enroute truck stops for fuel and eating. Trucks are placarded on both sides and the front and rear as "Radioactive." Members of the general public are unlikely to remain near a truck more than a few minutes. If a person spends 3 minutes at an average distance of 3 feet from the truck, the dose would be about 0.02 mrem. If 10 persons on the average were so exposed, the total annual dose to such onlookers would be about 0.02 man-rem for the 106 shipments.

(2) People along the Shipping Route.[14] The radiation level at 6 feet from a truck load of unirradiated materials will be approximately 0.1 mrem/hr. The assumptions used in calculating annual dose to the public are: the vehicle travels 200 miles per day, the mean population density along the route is 330 persons per square mile, the trip is 600 miles one way, and 106 trips are required per year. The resultant cumulative annual dose to approximately 200,000 persons in an area along that route between 100 feet and 1/2 mile on either side of the vehicle would be about 0.011 man-rem. For the single rail shipment of 2000 miles and a radiation level of 10 mrem/hr at 6 feet from the rail car, it is estimated that the cumulative dose to approximately 600,000 persons in an area along the route between 100 feet and 1/2 mile on each side of the freight car would be approximately 0.036 man-rem.

(3) Transportation Workers - Truck Drivers. Two truck drivers during a 600 mile trip would probably spend no more than 20 hours in the cab and about one hour outside the truck at an average distance of 3 feet from the cargo areas for the average shipment of unirradiated materials. With an average radiation level of 0.02 mrem/hr above background in the cab of the truck, each driver would receive about 0.8 mrem/shipment or a total about 0.0016 man-rem/shipment The cumulative annual dose to sixteen drivers to complete the 106 shipments would be about 0.17 man-rem.

It is estimated that 1,600 driving hours would be required to complete the 3,350 ore shipments. Based on a radiation level in the cab of 0.02 mrem/hr the dose to all drivers would be 0.032 man-rem. This dose would be distributed to 10 drivers.

Brakemen. For rail shipment of the high-level waste shipment, train brakemen would be expected to spend 1 minute to 10 minutes each in the vicinity of the rail car during the 2000 mile trip for an average exposure of 0.5 mrem for the shipment. With 10 different brakemen involved along the route, the cumulative dose for the shipment would be 0.005 man-rem.

Freight Handlers. For shipments which are transported as "full-loads," exposure to carriers' freight handlers would

be zero, since the packages are loaded at the point of origin and unloaded at the point of discharge and are not handled enroute. High level waste, low level wastes, and ore shipments are transported as full loads.

For shipments that are less than full load, e.g., partial shipment of UO_2, the packages may spend an average of 12 hours on the loading docks and 24 hours in storage. While in storage, the exposure to handlers is essentially zero.

Handling requires mechanical equipment because of the weight of the packages. Assuming 1 to 3 handlers are exposed a total of 10 minutes to an hour each, from a distance of 3 to 15 feet, the exposures would then range from 1 mrem to 0.02 mrem per handler. The average exposure would probably be in the range of 0.2 mrem per handler for 3 handlers, or about 0.030 man-rem per year for 48 shipments.

During actual transfer of a shipment, 3 handlers (not necessarily the same 3 handlers previously mentioned) would be unlikely to be exposed for more than 30 minutes each, at an average distance of 3 feet, each receiving about 0.20 mrem. This would be a total annual exposure of about 0.030 man-rem for 48 shipments.

A summary of the estimated population doses from the transportation steps considered is given in Table H-9.

(e) Accident Considerations

A truckload of low specific activity nuclear fuel cycle shipments may be involved in an accident. In 1969, the accident rate for hazardous materials' shipments was 1.69 per million vehicle miles.[15] Based on this rate and the average public highway truck shipment distance of 600 miles, a shipment of non-enriched material or low level wastes might be involved in an accident once in 1000 shipments. Considering that over 3000 shipments are required during the 30 year lifetime of the model LWR, about 2.8 accidents could be postulated during this period for each model LWR. In the event that a package of low specific activity material were in an accident, the low specific activity and the radiation levels associated with the materials limit the radiological impact from accidents involving these materials to negligible levels.[16]

Table H-9

Estimated Population Doses Under Normal Conditions for Transportation Steps in Nuclear Fuel Cycle

Model 1000 MWe LWR Annual Fuel Requirement

Group	Man-Rem	Population Exposed
Onlookers	0.02	1060
People along the route		
Truck Shipments	0.011	200,000
Rail Shipment (waste)	0.036	600,000
Transportation Workers		
Unirradiated Materials	0.23	28
Ore	0.032	10
High Level Waste (rail)	0.005	10

Ore shipments, most of which are made over private roads, might have a higher accident rate than predicted from data on hazardous materials' shipments. The nature of ore (relatively large solids) and the location of these shipment routes makes the potential radiological impact of these accidents small.

A truckload of fissile material could be involved in a public highway accident on the same frequency basis as noted above for low specific activity materials. Thus an accident might occur once in 800 shipments or about 0.5 accidents during the life of a model LWR. The packaging for fissionable materials, i.e., enriched UF_6 and UO_2, is designed to prevent release or criticality under normal and severe accident conditions.[17] An accident which could lead to accidental criticality would require a practically incredible sequence of events including (1) release of the contents from the package or breach of the cylinder in the case of the UF_6 cylinders, which is unlikely to happen other than in an extremely severe accident: (2) submergence in water or other low atomic number material to provide neutron moderation (accidental criticality in air for the low enrichments in the LWR fuel cycle is not possible) and (3) collection of the material in a geometrically favorable array. The probability of such an accident is so small as to be considered incredible.

It is not anticipated that high level wastes will be transported in the near future. However, for the 2,000 mile shipment considered and an accident rate of 0.8 accidents per million rail car miles,[18] a shipment of high level wastes might be involved in an accident once in 625 shipments. Considering that about 30 shipments of high level waste casks will be required during the estimated lifetime of a model LWR, then approximately 4.8×10^{-2} accidents could occur during this period. The containers for high-level wastes must be designed and constructed to withstand accidents likely to be encountered in transport.[19] Even though a cask were involved in an accident, it is extremely unlikely that the cask would be breached. The high-level wastes are stable material, sealed in packages. In the event of

an accident causing loss of cooling, the packages would get hot but not to the extent that they would fail. The breach of shielding or containment could result in high radiation exposure in the vicinity of the accident. Should any of the solid waste spill from a container, it could be removed by remote handling techniques, and the area decontaminated without permanent contamination of the environment.

There are some records of minor transport accidents involving radioactive materials. A truck transporting uranium ore concentrates went into a river to avoid a rock slide. Calculations of the resulting concentration of uranium in the river indicated that AEC limits (10 CFR 20) for water in unrestricted areas[20] were not exceeded.

In a recent accident, four cushioned freight cars were derailed, each containing approximately 50 to 60 tons of slightly depleted uranium oxide sealed in 55-gallon drums. Inspection by an AEC Radiological Assistance Team revealed that seals on the cars were unbroken and no radioactive material had escaped to the environment.[21]

In several thousands of shipments of UF_6 made by the AEC and its contractors, there have been transport accidents, but there are no records of a container being damaged to the extent that UF_6 was released or the container integrity being breached.[22]

In the shipment of packages containing radioactive wastes to a burial ground, the truck collided with a passenger car. Despite the fact that the driver of the truck was injured, no packages containing radioactivity were ruptured.[23]

There has been no extensive experience in shipping high activity wastes. An accident has occurred involving similar type shipping casks handling an irradiated fuel element. In this shipment, the truck was forced off the road and down an embankment. Despite the fact that the truck driver was killed, and the shipping cask tumbled from the truck and embedded itself in the ground, no activity was released. Even though this accident is atypical of

those that might occur in the fuel cycle in shipping high activity wastes since they will be shipped by rail, it is cited to demonstrate that shipping casks have survived severe accidents and maintained their integrity.[24]

The consequences of an accident involving radioactive material are mitigated by the procedures which carriers are required to follow.[25] These procedures include: segregation of persons from packages and materials; immediate notification of the shipper and DOT in case of an accident, fire, or leaking package; and a requirement that vehicles, cars, building areas, and equipment not be placed in service again until surveyed and, where necessary, decontaminated.

Trained personnel equipped to monitor the area and competent to act as advisers are available through an inter-Governmental radiological assistance program. The radiological assistance teams are dispatched in response to calls for emergency assistance. This assistance has been made available in the few transportation accidents involving radioactive materials shipments which have occurred in recent years. Should a major release occur, this type of assistance would help reduce the impact on the environment.

(f) Contributions to the General Exposure

The transportation of materials in the uranium fuel cycle does not contribute to the distribution of radionuclides to the environment, except possibly during ore transportation. Any small amounts of ore falling from a truck are transported from their original location to the environment.

Transportation does contribute to the external exposure of the general public and transportation workers. The levels are very low. Approximately 50 people may be exposed to dosages ranging from 0.5% to 10% of natural background; other members of the public may be exposed to additional exposure amounting to 0.02% of natural background.

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2. 49 CFR Part 173, Sections 173.389(c) and 173.392.

3. Nuclear Assurance Corporation, Transportation of Nuclear Fuel Material in the United States. (Nuclear Assurance Corporation, Atlanta, Georgia, 1970), pp. 48, 50, 51, 54.

4. 49 CFR 173.389(c) and 173.392.

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6. 49 CFR 173.389(1).
   49 CFR 173.396(b).
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10. 10 CFR 50, Appendix F.

11. Siting of Fuel Reprocessing Plants and Waste Management Facilities, compiled and edited by ORNL, ORNL-4451 (July 1970) Table 3.11, Table 3.23.

12. Ibid., Table 3.11.

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15. Ibid., Table 3, pp. A-5 and A-6.

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19. 49 CFR 173.389.

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22. Allied-Gulf Nuclear Services, "UF_6 Plant Environmental Report," USAEC Docket 70-1327, Appendix III, pp. 35, 36, 37.

23. G. Wayne Kerr, USAEC, private comm.

24. John M. Chandler, The Peach Bottom Spent Fuel Element Shipping Cask Accident December 8, 1971, ORNL-TM-3844 (July 1972).

25. 49 CFR 171.15, 174.566, and 177.861.

OVERVIEW OF TOTAL NUCLEAR FUEL CYCLE

The preceding portions of this survey deal with the aspects of the uranium fuel cycle as related to an individual model LWR. To provide additional perspective on the environmental effects of the uranium fuel cycle, an overview of the combined effects from the total uranium fuel cycle industry has been estimated and is included in this section. Since the size and nature of the industry is dependent to a great extent upon the time frame of the evaluation, two time periods have been selected for this overview. The time frames utilized are as follows:

A. The date the survey was prepared (mid 1972); and

B. The end of this decade (1979-1980).

In order to evaluate the environmental effects of the uranium fuel cycle, it is first necessary to establish the size of the industry that it serves. In 1972, about 10-12,000 MWe of nuclear electric generation capability was estimated to be operational in the United States. The existing nuclear fuel cycle industry has capabilities that in general are in excess of the requirements for this size power generation capacity. Table O-1 summarizes the capabilities of the present day nuclear fuel cycle industry and relates these capabilities to the needs of today's power generation capacity.

Although other fuel cycle schemes are competing with the LWR concept, it appears that the prevalent method for generation of electrical power by nuclear energy will continue to be light water cooled and moderated uranium fueled reactors through the end of this decade. Several commercial size high temperature gas-cooled reactors (HTGR) have been committed and are planned to be operational by the end of this decade or the early part of the next. It is estimated that this component of the nuclear power generation capability will be less than 5% (2-3%) of the nation's capacity by 1980. It is known that some utilities have plans to utilize bred plutonium in the form of mixed oxide LWR reload fuel in the latter part of the 1970's. Production facilities for this type of fuel are being planned and may be in operation during the latter half of the decades small amounts of this fuel could be available in the period 1976-1978. Production quantities of fuel could be expected to be manufactured by the end of the decade and as much as 5% of the total fuel in use by 1980 may be of the mixed oxide (Pu-U) variety. An additional concept for future application is the liquid metal fast breeder reactor (LMFBR). However, it is not expected that any significant application of this concept will be in commercial use by 1980. A

TABLE O-1

NUCLEAR FUEL CYCLE INDUSTRY

1972

Type of Plant	Plant Average Annual Capacity Thousands of MT	Total Industry Annual Capacity Thousands of MT	Approx. Annual Demand from Nuclear Power Generation Thousands of MT	No. of Plants Available	Approximate No. of Plants Rqd to Meet Power Needs
Uranium Mines - Ore	250-750	8200	4500	220	10
Uranium Mills - U_3O_8	0.5-1.1	19	9	20	12
UF_6 Production - U	5-15	19	8	2	1+
Isotopic Enrichment - SWU	6	10	5	3	1
Fuel Fabrication - U	0.3-0.5	3	1.2	10	3+
Fuel Reprocessing - U	0.3	0.15*	0.2	2	1

*One plant in operation for about 6 months

commercial scale LMFBR demonstration unit is planned to be in operation early in the next decade. In summary, it appears that the nuclear generation of electric power for the remainder of this decade will be predominantly by the use of LWR's fueled with uranium dioxide and that this concept will constitute 90-95% of the industry throughout this period.

Numerous estimates of the size of the nuclear electric generation industry have been made and have required frequent revisions as a result of changing conditions and schedules. A consensus of these estimates indicate that approximately 140-150,000 MWe may be installed and on line by the year 1980. Based upon this projection, the requirements of the nuclear fuel cycle to service the power generation industry have been estimated and are shown in Table 0-2.

Uranium Mining

1972

In 1972, domestic uranium mines produced about 6.3 million MT of ore per year having an average assay of about 0.2% U_3O_8. These mines have a total rate capacity of about 8.2 million MT per year. About 70% of the ore is mined in New Mexico and Wyoming with an additional 17% mined in Colorado and Utah. Only about 70% of the ore produced is required to meet the demands of today's nuclear power industry.

Over 98% of the uranium is produced by open pit and underground mining. About one-half of the total ore is produced in 29 open pit mines with individual capacities up to 700,000 MT per year and 193 underground mines with individual capacities up to 230,000 MT per year produce most of the remainder. The environmental considerations for an open pit mine producing 480,000 MT per year are listed in Table 0-3.

1980

By the end of the decade, the nuclear electric generation industry will require the mining of about 17 million MT of uranium ore annually. The bulk of the known uranium reserves are in New Mexico, Wyoming, Texas, Colorado, and Utah. It is expected that mining methods will be similar to those used today except that a larger percentage of the ore may be mined using underground mining techniques since a large percentage of the known reserves occur at depths greater than 400 feet. The environmental effect of the uranium mining industry at the end of the decade may be represented by 30-40 mines similar to that shown in Table 0-3. However, the average amount of land use per mine is expected to decrease as the percentage of ore mined by underground methods increases.

TABLE O-2

PROJECTED

NUCLEAR FUEL CYCLE INDUSTRY

1980

Type of Plant	Plant Size Thousands of MT	Annual Requirement Thousands of MT	No. of Average Plants Required to Meet Power Demands
Uranium Mines - Ore	250-750	17,000	30-40
Uranium Mills - U	0.5-1.1	34	40-50
UF_6 Production - U	5-15	34*	3 Low Enriched Plants & 3-4 Natural Plants
Isotopic Enrichment - SWU	7.5	20	3
Fuel Fabrication - U	0.3-1.8	5.3	8-10
Fuel Reprocessing - U	0.3-1.5	3	3-4

*Including recycle of recovered U from reprocessing operations
Nuclear Power Generation Basis: 140-150,000 MWe

TABLE O-3

SUMMARY OF ENVIRONMENTAL CONSIDERATIONS

FOR OPEN PIT URANIUM MINE - 480,000 MT/YR

Natural Resource Use	
Land (acres)	
Temporarily committed	290
Permanently committed	10
Overburden moved (millions of MT)	14
Water (millions of gallons)	
Discharged to ground	650
Fossil Fuel	
Electrical Energy (thousands of MW-hr)	1.3
Equivalent coal (thousands of MT)	0.5
Effluents	
Chemical (MT)	
Gases	
SO_x	45
NO_x	27
Hydrocarbons	1.6
CO	0.1

Uranium Milling

1972

In 1972, there were approximately 20 mills operational in the United States with a combined capacity of about 17,000 MT of U_3O_8 annually. Of these plants, 70% are within the output range of 500-1100 MT/yr. of U_3O_8. From Table 0-1 it is indicated that 1972 nuclear power industry requires only 9,000 MT per year. Thus, it is apparent that approximately one-half of the 20 operational uranium mills would be adequate for that size power generation industry. These mills are located in sparsely populated areas in close proximity to mining operations principally in the States of New Mexico, Wyoming, Colorado, and Utah. The environmental considerations from a 1000 MT/yr. U_3O_8 uranium milling industry may be characterized by 20 mills each having environmental effects similar to those noted in Table 0-4.

1980

The nuclear electric generation industry by the end of this decade will require the operation of about 40-45 uranium mills. It is estimated that these facilities will employ technology very similar to that for 1972's plants with minor technological improvements which will tend to minimize some of the environmental considerations. Since the bulk of the known uranium reserves are centered in the far western States of New Mexico, Wyoming, Colorado, and Utah, it is expected that new milling facilities will be located in those areas near companion mining operations and in sparsely populated relatively arid regions. Thus, the uranium milling industry at the end of the present decade may be represented by 40-45 operating units, each having effects on the environment as listed in Table 0-4.

UF_6 Production

1972

The nuclear generation industry requires about 8,000 MT of uranium as uranium hexafluoride (UF_6). The two facilities in operation at the present time have capacity considerably in excess of this level. It is probable that either existing plant could meet this demand without difficulty. Thus, to meet present day requirements, essentially only one UF_6 production plant is required. The environmental considerations for a 5000 MTU/yr. UF_6 production plant are summarized in Table 0-5.

TABLE O-4

SUMMARY OF ENVIRONMENTAL CONSIDERATIONS

URANIUM MILL - 1000 MT/Yr. U_3O_8

Natural Resource Use	
Land (acres)	
Temporarily committed	50
Permanently committed (limited use)	250
Water (millions of gallons/yr.)	
Discharged to air	360
Fossil Fuel	
Electric Energy (thousands of MW-hr/yr.)	15
Equivalent Coal (thousands of MT/yr.)	5.4
Natural gas (millions of scf/yr.)	380
Effluents	
Chemical	
Gases (MT/yr.)	
SO	485
NO_x (40% from natural gas use for process heat)	485
Hydrocarbons	7
CO	1.7
Liquids (thousands of MT/yr.)	
Tailing Solutions	1300
Solids (thousands of MT/yr.)	
Tailings	500
Radiological (curies/yr.)	
Gases (including airborne particulates)	
Rn-222	410
Ra-226	0.1
Th-230	0.1
U-natural	0.2
Liquids	
U & daughters	11
Solids	
U & daughters	6700
Thermal (millions of Btu/yr.)	390

TABLE O-5

SUMMARY OF ENVIRONMENTAL CONSIDERATIONS

URANIUM HEXAFLUORIDE PRODUCTION PLANT - 5000 MTU/Yr.

Natural Resource Use	
Land (acres)	
Temporarily committed	1400
Permanently committed	10
Water (millions of gallons/yr.)	
Discharged to air	100
Discharged to water bodies	1100
Total	1200
Fossil Fuel	
Electrical Energy (thousands of MW-hr/yr.)	47
Equivalent Coal (thousands of MT/yr.)	17
Natural Gas (millions of scf/yr.)	550
Effluents	
Chemical (MT/yr.)	
Gases	
SO_x	800
NO_x (25% from natural gas for process heat)	280
Hydrocarbons	17.6
CO	5.5
F	3.0
Liquid	
$SO_4^=$	124
NO_3^-	3
F^-	243
Cl^-	6
$Na^+ + K^{++}$	93
$Nl+_3$	43
Fe	1.2
Solids	1000
Radiological (curies/yr.)	
Gases	
Uranium	0.004
Liquids	
Ra-226	0.0935

Th-230	0.04
Uranium	1.21
Solids (buried)	
Other high level	24.
Thermal (billions of Btu/yr.)	500

1980

Plans are under way at the present time to initiate the recycle of uranium recovered from the fuel reprocessing step. It appears that each of the fuel reprocessing facilities may have a UF_6 production capability for recycle of recovered uranium values before the end of the decade. The requirements for UF_6 by the end of this decade are estimated to be approximately 34,000 MTU as UF_6. It is estimated that this requirement could be made up from the combined capacities of the planned UF_6 production facilities at the reprocessing plants amounting to 2700 MTU and facilities for production of UF_6 from natural uranium. This expanded demand could be met by the expansion of existing plants to double or triple their present capacity and additional new plants could be added so that a total of 3-4 facilities for the production of natural UF_6 could be operational by the end of the decade. At this time, no significant technological advances can be projected that will affect environmental considerations from these plants. Accordingly, it is projected that UF_6 production plants in 1980 will resemble in most respects the plants of today's era but may be about double their size. Therefore, the industry can be represented by a combination of about 3-4 natural uranium hexafluoride plants, each twice the size of the unit summarized in Table 0-5 and three smaller plants handling recovered slightly enriched uranium.

Isotopic Enrichment

1972

The nuclear generation industry in 1972 required about 5,000 MT of SWU to satisfy its present enrichment requirements. The industry is supplied with enrichment services from the complex of the three AEC owned and contractor operated gaseous diffusion plants. Essentially any one of the existing plants operated independently would be adequate to meet this demand. However, since all three installations are operated in a combined fashion, it is difficult to isolate the environmental considerations of an individual plant. Accordingly, the environmental effects of the total three-unit complex as it is operating today are summarized in Table 0-6.

1980

It is planned to increase the capability of the existing three-plant complex from about 10,000 MT SWU to 22-27,000 MT SWU. This increased capability will be achieved without the construction of major new gaseous diffusion facilities and will be accomplished primarily by improving and

TABLE 0-6

SUMMARY OF ENVIRONMENTAL CONSIDERATIONS

FOR URANIUM ENRICHMENT COMPLEX

Natural Resource Use	1972 10,500 MT SWU	1980 18,000 MT SWU
Land (acres)		
Temporarily committed	1500	1500
Permanently committed	nil	nil
Water (millions of gallons/yr)		
Discharged to air	8100_6	12,000
Discharged to water bodies*	10^6	1.8×10^6***
Fossil Fuel		
Electrical Energy (thousands of MW-hr/yr)	28,500	41,000
Equivalent Coal (thousands of MT)	10,000	10,000***
Effluents		
Chemical (MT/yr.)		
Gases		
SO_x	400,000	400,000
NO_x	100,000	100,000
Hydrocarbons	1000	1000
CO	2500	2500
Particulates	100,000	100,000
F	45	45
Liquids		
Ca^+	490	880
Cl	740	1130
Na^+	740	1130
$SO_4^=$	490	880
Fe	36	65
NO_3	240	450
Radiological (curies/yr.)		
Gases		
Uranium	0.2	0.3
Liquids		
Uranium	1.8	3.1
Thermal (billions of Btu/yr)	290,000	420,000

*power plant cooling
**67% at power plants
***about 1/3 of electrical power from nuclear stations in 1980.

upgrading present units. The modifications will involve installation of improved equipment and increased utilization of electrical power. Thus, no new processing plants are required to meet the projected 1980 industry demands and accordingly the land requirement for this portion of the fuel cycle will remain essentially constant to the end of the decade. It should be noted that the utilities providing power to the gaseous diffusion complex have made commitments for the installation of significant amounts of additional power generation capacity. Included in these commitments are major nuclear generation stations amounting to 8-10,000 MWe of capacity. It is estimated that this switch over from essentially all coal burning power plants to some nuclear powered stations could effectively result in about one-third of the power requirements for the gaseous diffusion complex being provided by nuclear generation facilities. The industry demand in 1980 will require operation of the gaseous diffusion complex at a level of 20,000 MT SWU. Assuming that the plants will be modified to incorporate current improved technology, this level of operation will require approximately 7,400 MW of electrical power. On the basis that two-thirds of the power for this operation could be provided by coal burning power stations, the amount of power supplied by coal fired stations in 1980 will amount to 3,200 MW which is about constant with today's situation. Thus, despite the fact that the separative work capability of the complex will be increased by about 70% and its power rating will be upgraded by about 50%, the major gaseous chemical effluents, which come from the combustion of coal, attributable to the isotopic enrichment function may remain constant with today's levels. The use of natural resources such as water (assuming once through cooling at the power plants) and liquid chemical and all radiological effluents might be expected to increase at a rate essentially equivalent to the increased separative work capability. A summary of the environmental considerations of the enrichment complex in 1980 is listed in Table 0-6.

Fuel Fabrication

1972

The fuel requirements for the 1972 nuclear generation industry were approximately 1200 MTU. This capacity was met by 10 existing plants, a number of which have limited capacity and which conduct only a portion of the processes required to produce fuel assemblies for reactors. In fact, only two of the facilities that were in operation in 1972 are large scale production plants which have capacities similar to that considered for the model plant in this statement. The environmental considerations for a 900 MTU fuel fabrication plant are summarized in Table 0-7.

TABLE O-7

SUMMARY OF ENVIRONMENTAL CONSIDERATIONS
FOR 900 MTU/Yr. FUEL FABRICATION PLANT

Natural Resource Use	
Land (acres)	
Temporarily committed	100
Permanently committed	nil
Water (millions of gallons)	
Discharged to water	135
Fossil Fuel	
Electrical Energy (thousands of MW-hr.)	44
Equivalent Coal (thousands of MT)	16
Natural Gas (millions of scf)	94
Effluents	
Chemical (MT)	
Gases	
SO_x	600
NO_x	160
Hydrocarbons	1.6
CO	4
F	0.1
Liquids	
N as NH_3	220
N as NO_3	140
F	106
Solids	
CaF_2	680
Radiological (curies)	
Gases	
Uranium	0.005
Liquids	
Uranium	0.5
Th-234	0.3
Solids (buried)	
Uranium	6.0
Thermal (billions of Btu)	230

1980

Plans are under development for the expansion of the existing production facilities and for the design and construction of numerous new production type fuel fabrication facilities to replace some of the smaller units now in operation. It is estimated that by the end of the decade, 8-10 production facilities could be in operation to meet the annual requirements of over 5,000 MTU of fuel per year. In the case of fuel fabrication, technological advances have been under development for several years which could have a significant effect on environmental effects. The development of a dry process for conversion of UF_6 to UO_2 has been in progress for some time and it is anticipated that this technique will be used by the end of the decade, substantially reducing both gaseous and liquid chemical effluents that are associated with process operations. This process improvement will essentially eliminate the chemical effluents of ammonia and fluoride. Thus, this industry can be characterized in 1980 by 8-10 plants similar to the one summarized in Table 0-7 with the elimination of most of the process chemical effluents.

Fuel Reprocessing

1972

One plant for the reprocessing of commercial nuclear power reactor fuel has been in operation for about six years. This plant is currently shut down for extensive modifications and has operated for only a portion of 1972. A second plant is nearing the operational stage and is planned to be handling irradiated fuel during 1973. An additional plant is under construction for operation by the middle of the decade. As noted in Table 0-1 there is little demand for reprocessing services at the present time. Much of that demand has been met by the one plant operating for part of a year and storage of fuel at that plant planned to be operational in 1973. The environmental effects of the model 900 MTU/yr. reprocessing plant are shown in Table 0-8.

1980

It is estimated that three fuel reprocessing plants may be operational before the end of the decade with a combined capability of processing 2,700 MTU annually. A fourth plant is being planned for start-up late in this decade or early in the 1980's. It appears that these plants would be adequate to meet the power industry needs. Thus, the industry in 1980 can be characterized by 3-4 plants similar to the plant outlined in Table 0-8.

TABLE O-8

SUMMARY OF ENVIRONMENTAL CONSIDERATIONS
OF 900 MTU/YR FUEL REPROCESSING PLANT

Natural Resource Use	
Land (acres)	
Temporarily committed	2000
Permanently committed	100
Water (millions of gallons)	
Discharged to air	100
Discharged to water	150
Fossil Fuel	
Electrical Energy (thousands of MW-hr.)	12
Equivalent Coal (thousands of MT)	4
Effluents	
Chemical (MT)	
Gases	
SO_x	160
NO_x	185
Hydrocarbons	0.5
CO	1
F	14
Liquids	
Na^+	140
Cl^-	0.5
$SO_4^{=}$	14
NO_3 (as N)	5
Radiological (curies)	
Gases (including entrainment)	
Tritium (thousands)	430
Kr-85 (thousands)	9000
I-129	0.06
I-131	0.6
Fission products	26
Transuranics	0.10
Liquids	
Tritium (thousands)	65
Ru-106	4
Cs	2
Sr-90	0.100
Thermal (billions of Btu)	1600

Waste Management

1972

In 1972, there were six commercial land burial sites in operation in the United States with a total area of approximately 600 acres. Not all of this land is available for actual burial of wastes since some of the land area is needed for support facilities, pre-burial storage, etc. The land available for waste burial is adequate for the amount of radioactive waste generated by fuel cycle industries in 1972, about 1.0-1.5 acres annually. At the present time, there is no requirement for a Federal storage facility for long-term storage of solidified high-level wastes generated as a result of fuel reprocessing operations.

1980

By 1980, it is estimated that the nuclear electric generation capacity will increase to about 12 times present capacity. On this basis, about 12 to 18 acres will be needed for burial of radioactive waste generated by fuel cycle facilities. This would be well within the capacity of the currently existing commercial land burial sites and it does not appear that additional sites would be required. By 1980, it is anticipated that a Retrievable Surface Storage Facility (RSSF) will be under construction for storage of solidified high-level wastes. The high-level wastes, in a combination of liquid and solid forms, could be stored at the fuel reprocessing facilities without significant environmental effects until the RSSF is completed and available for storage of wastes during the next decade.

Transportation

1972

The nuclear power generation industry amounted to 10-12 annual operating units. The transportation needs of the supporting fuel cycle are shown in Table 0-9. The movement of low specific activity material constitutes almost all of these shipments. The heat and weight in any shipment and the relatively small number of shipments will essentially have no appreciable effect on the environment. The estimated population exposure for onlookers, people along the route and transportation workers is 4.2 man-rem.

TABLE O-9

SUMMARY OF ENVIRONMENTAL CONSIDERATIONS

FOR TOTAL NUMBER OF PACKAGES TRANSPORTED ANNUALLY

Step-Material Transported	1972 Total No. of Truck Shipments	1980 Total No. of Truck Shipments
1. Mine to Mill - Ore	40,000	500,000*
2. Mill to UF_6 Production -	140	1,800**
3. UF_6 Production to Enrichment - Natural UF_6	260	3,300**
4. Enrichment to UO_2 Plant - Enriched UF_6	60	750**
5. UO_2 Plant to Fabrication - Enriched UO_2	180	1,400**
6. Low level waste to Commercial Land Burial Sites	700	8,700
7. Solid Wastes to Federal Storage - Fission Products	12(Rail)***	150(Rail)***

*Almost all of these shipments are made on privately owned land.

**Number of shipments may be reduced by shipments from larger processes being switched from truck to larger rail shipments.

***These packages, one (1) per shipment, will be stored at the reprocessing site until after 1980 when the Federal storage and repository facilities are planned for use.

1980

By the end of the decade the size of individual plants may increase and certainly the number of plants will greatly increase. As production levels increase at a particular site, the transportation requirements may favor switching from truck to rail shipment. Typical of this change might be the shipment of natural UF_6 in cylinders from the UF_6 production plant to the gaseous diffusion plant.

Despite the fact that the mass handled in transportation should increase by a factor of about 12-15, the quantities involved will continue to be of little consequence with regard to the total transportation industry. A summary of the shipments is shown in Table 0-9. The estimated population exposure is 53 man-rem. It is assumed that this 53 man-rem exposure will be distributed among at least 600,000 people giving an average exposure of 0.09 mrem/person/year. The dose due to the average natural background radiation is about 100 mrem/person/year.

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