A Survey of LWR Environmental Control Technology Performance and Cost

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March 1980

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the Environmental Control Technology Division,
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1.0 INTRODUCTION

The generation of electrical energy from nuclear reactors releases radioactive and nonradioactive substances to the air, to streams, and to underground aquifers. Those releases believed to have a deleterious effect on man and the environment are subject to federal and state regulations that limit effluent releases. Before being licensed for construction and operation, operators of each plant in the nuclear fuel cycle must file an environmental report that describes the releases to the environment anticipated to result from the plant's operation, and the control technology planned to limit releases.

To assure that the environmental control technology remains adequate to meet the demands of increasing nuclear power generation, DOE's Environmental Control Division has sponsored a program at the Pacific Northwest Laboratory to identify areas in present and potential nuclear fuel cycles where control technology may be inadequate or where improved environmental controls can be justified on a cost/benefit basis. This portion of that program deals with the LWR fuel cycle.

To accomplish this overview of the LWR fuel cycle, a one-hundred-year projection of U.S. nuclear energy generation was made and known significant releases to the environment, both radioactive and nonradioactive, were calculated for each year during the one-hundred-year base period. Only normal operation releases were considered. Accidental releases were excluded. All facilities in the LWR fuel cycle were included, from uranium mining to fuel reprocessing plants.

Existing emission standards are directed toward controlling the release from specific plants, or are related to the amount of energy generated. For example, 90 CFR 140⁽¹⁾ specifies isotope limits in terms of curies released per GWe-yr. This study attempts to establish a ranking for species that are routinely released to the environment for a projected nuclear power growth scenario. Unlike comparisons made to existing standards, which are subject to frequent revision, the ranking of releases can be used to form a more logical basis for identifying the areas where further development of control technology could be required. This report describes projections of releases for

several fuel cycle scenarios, identifies areas where alternative control technologies may be implemented, and discusses the available alternative control technologies.

The available information on each plant in the nuclear fuel cycle was collected, with emphasis on the current methods of controlling releases at each generic plant type. These descriptions are published in Descriptions of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles, PNL-2286.⁽²⁾ Quantitative release factors for each radioactive and nonradioactive species released at each facility were generated.

In the present study, the release factors were used in a computer code system called ENFORM,⁽³⁾ which calculates the annual release of any species from any part of the LWR nuclear fuel cycle given a projection of installed nuclear generation capacity. This survey of fuel cycle releases was performed for three reprocessing scenarios (stowaway, reprocessing without recycle of Pu and reprocessing with full recycle of U and Pu) for a hundred-year period beginning in 1977. The radioactivity releases were ranked on the basis of a relative ranking factor. The relative ranking factor is based on the 100-year summation of the 50-year population dose commitment from an annual release of radioactive effluents. The nonradioactive releases were ranked on the basis of dilution factor. The dilution factor is that amount of air or water required to dilute the quantity released so that an acceptable concentration is reached.

The twenty highest ranking radioactive releases were identified and each of these was analyzed in terms of the basis for calculating the release and a description of the currently employed control method. Alternative control technology is then discussed, along with the available capital and operating cost figures for alternative control methods.

Twenty nonradioactive materials with the largest air dilution factors were also identified. The basis for the release calculation and the selection of the concentration value used in calculating the dilution factor are discussed. The current control technology is described. Control alternatives are then discussed, including available estimates of capital and operating costs.

The comprehensive list of radioactive effluents is contained in Appendix A. This list gives the relative ranking factors for each effluent associated with each of the three fuel cycle scenarios. The ranking factors for the whole body, thyroid, gastrointestinal tract, and lung are listed. Gross release of radioactivity in curies is given for the hundred-year period and for the year 2000.

Appendix B lists the year 2000 and the hundred-year total for each of the three scenarios for nonradioactive releases from each plant in the nuclear fuel cycle. Tables of the amount released and of the dilution factors are included.

Appendix C contains a list of the accumulated dose to the population from unit annual releases of each of the highest ranking radioactive effluents. A 40-year plant life with 30 years of additional dose accumulation at the mid-western reference site is assumed. Radiation exposure pathway summaries and combined pathway totals are given for air and water releases. These doses are used to calculate the total man-rem savings for each control technology. The cost-benefit ratios (in units of \$/man-rem) are based on these man-rem savings numbers, and are included in the discussion of each effluent control alternative addressed.

SECTION 1: REFERENCES

1. Code of Federal Regulations. Title 90, Part 140, as revised to January 13, 1977.
2. K. J. Schneider, T. J. Kabele, Descriptions of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles. PNL-2286, Pacific Northwest Laboratory, Richland, WA, September 1979.
3. C. M. Heeb, M. A. Lewallen, W. L. Purcell, B. M. Cole, ENFORM-II: A Calculational System for Light Water Reactor Logistics and Effluent Analysis. PNL-2429, Pacific Northwest Laboratory, Richland, WA, September 1979.

2.0 SUMMARY AND CONCLUSIONS

Projections of effluents from the nuclear fuel cycle, including some 250 nonradioactive materials and 175 radionuclides, were made for the 100-year period beginning in 1977. Fuel cycle facilities from the uranium mine to the reprocessing plant were considered.

The projections were based on an installed LWR energy capacity of 380 GWe in year 2000. Three reprocessing scenarios were considered: no reprocessing (stowaway cycle), reprocessing but no recycle, and reprocessing followed by recycle of plutonium and uranium.

Annual releases for each of these scenarios for each of the radioactive and nonradioactive species were computed. The releases were summed over the 100-year period. These sums are listed in the appendices. Ranking factors were developed by which to judge the significance of these releases.

The twenty radioactive species with the highest ranking factors and the twenty nonradioactive materials with the highest air dilution factors were selected from each of the three scenarios. These are shown in Tables 4.1 through 4.7 and 4.12 through 4.14. The basis for the release calculation is discussed in detail in Sections 4.1.2 and 4.2.2. Alternative control techniques are discussed for each of the twenty most significant species. The effective reductions that can be achieved and the cost of installation and operation (when available) are included. Data describing the most promising single alternative technology for each effluent are summarized in Tables 2.1 through 2.6.

2.1 RADIOACTIVE RELEASES

A cost-benefit ratio of \$1,000 per man-rem of exposure reduction is specified in 10 CFR 50 as an interim criterion at which installing control systems designed to reduce routine radioactive emissions from LWRs will be cost effective. In the twenty highest-ranked radionuclide emissions, three instances were found where installation of an alternative control system should be required, assuming that the \$1,000 per man-rem is applied to other facilities in the nuclear fuel cycle besides the reactors themselves. These are ^{14}C , ^{90}Sr and ^{232}U , all from the reprocessing plant.

TABLE 2.1. Twenty Highest Ranking Nuclides - Stowaway Cycle

Rank	Nuclide	Plant	Relative Ranking Factor for Total Body	Alternative Technology Reduction Factor	Incremental Cost of Alternative Control ^(b)		Description of Alternative Technology
					Mills/kWh	\$/man-rem	
1	¹³⁸ Xe	BWR	4.97E+5	0.23	--	--	Double holdup time from 30 min. to 60 min.
2	⁸⁸ Kr	BWR	1.07E+5	10 ⁻² -10 ⁻³	NA	NA	Low temperature charcoal absorption of steam ejector pump off gas.
3	³ H	PWR	6.29E+4	0.71	.002	16,000	Use tritium "getter" alloys in fuel rods. Alloys commercially available.
4	¹³⁵ Xe	BWR	6.03E+4	10 ⁻² -10 ⁻³	NA	NA	Low temperature charcoal absorption of steam ejector pump off gas.
5	⁸⁷ Kr	BWR	5.73E+4	10 ⁻² -10 ⁻³	NA	NA	Low temperature charcoal absorption of steam ejector pump off gas.
6	¹³⁴ Cs	PWR	4.27E+4	0.9-0.01	NA	NA	Recycle more material in liquid radioactive treatment system, more sent off plant in waste drums.
7	^{135M} Xe	BWR	2.89E+4	0.26	--	--	Double holdup time from 30 min. to 60 min.
8	¹³³ Xe	PWR	2.74E+4	--	NA	NA	Extend holdup time.
9	¹⁴ C	PWR	2.68E+4	0.20	.06	21,000	Caustic scrubbing of radwaste off-gas stream.
10	¹³⁷ Cs	PWR	1.75E+4	<0.10	--	--	Recycle more of clean radwaste treatment ¹³⁷ Cs goes off-site in solid waste drums.
11	¹⁴ C	BWR	1.63E+4	.008	.03	6,480	Caustic scrubbing of turbine condenser steam ejector pump off gas.
12	¹³³ Xe	BWR	1.33E+4	10 ² -10 ⁻³	NA	NA	Low temperature charcoal absorption of steam ejector pump off gas.
13	³ H	BWR	8.01E+3	0.50	.003	98,600	Use tritium "getter" alloys in fuel rods. Alloys are commercially available.
14	¹³¹ I	BWR	5.48E+3	0.59	.05	4,800 ^(a)	Additional HEPA filter on reactor building ventilation system.
15	⁸⁸ Kr	PWR	4.58E+3	--	NA	NA	Extend holdup time.
16	⁶⁰ Co	BWR	4.25E+3	0.22	.05	1 x 10 ⁶ ^(a)	Additional HEPA filter on reactor building ventilation system.
17	^{85M} Kr	BWR	2.41E+3	10 ⁻² -10 ⁻³	NA	NA	Low temperature charcoal absorption of steam ejector pump off gas.
18	²²² Rn	U.G. Mine	2.38E+3	--	NA	NA	Reduce mine wall surface area by coating, bulkheading and mine drying.
19	¹³⁶ Cs	PWR	2.19E+3	0.9-.01	NA	NA	Recycle more material in liquid radwaste treatment system.
20	¹³⁷ Cs	BWR	1.94E+3	0.11	.05	1.5 x 10 ⁶	Additional HEPA filter on reactor building ventilation system.

(a) Combined with other particulates.

(b) Includes accumulated population dose reduction for most critical organ.

TABLE 2.2. Twenty Highest Ranking Nuclides - Reprocessing Without Recycle

Rank	Nuclide	Plant	Relative Ranking Factor for Total Body	Alternative Technology Reduction Factor	Incremental Cost of Alternative Control (b)		Description of Alternative Technology
					Mills/kWh	\$/man-rem	
1	^3H	FRP	1.97E+6	10^{-2}	0.02	2,660	Voloxidation process.
2	^{138}Xe	BWR	4.97E+5	0.23	--	--	Double holdup time from 30 min. to 60 min.
3	^{85}Kr	FRP	1.92E+5	0.10	.009	11,400	Cryogenic separation of off gas after iodine scrubbing.
4	^{14}C	FRP	1.40E+5	10^{-2}	.003	369	Molecular sieve absorption after iodine scrubbing and absorption.
5	^{88}Kr	BWR	1.07E+5	$10^{-2}-10^{-3}$	NA	NA	Low temperature charcoal absorption of steam ejector pump off gas.
6	^3H	PWR	6.29E+4	0.71	.002	16,000	Use tritium "getter" alloys in fuel rods. Alloys commercially available.
7	^{135}Xe	BWR	6.03E+4	$10^{-2}-10^{-3}$	NA	NA	Low temperature charcoal absorption of steam ejector pump off gas.
8	^{87}Kr	BWR	5.73E+4	$10^{-2}-10^{-3}$	NA	NA	Low temperature charcoal absorption of steam ejector pump off gas.
9	^{90}Sr	FRP	4.35E+4	10^{-3}	.0009	938	Additional HEPA filter in dissolver off gas treatment system.
10	^{134}Cs	PWR	4.27E+4	0.9-0.01	NA	NA	Recycle more material in liquid radioactive waste treatment system, more send off plant in waste drums.
11	$^{135\text{M}}\text{Xe}$	BWR	2.89E+4	0.26	--	--	Double holdup time from 30 min. to 60 min.
12	^{133}Xe	PWR	2.74E+4	--	NA	NA	Extend holdup time.
13	^{14}C	PWR	2.68E+4	0.20	.06	21,600	Caustic scrubbing of radwaste, off gas stream.
14	^{137}Cs	PWR	1.75E+4	<0.10	--	--	Recycle more of clean radwaste treatment, goes off site in solid waste drums.
15	^{14}C	BWR	1.63E+4	.008	.03	6,480	Caustic scrubbing of turbine condenser steam ejector pump off gas.
16	^{133}Xe	BWR	1.33E+4	$10^{-2}-10^{-3}$	NA	NA	Low temperature charcoal absorption of steam ejector pump off gas.
17	^3H	BWR	8.01E+3	0.5	.003	98,600	Use tritium "getter" alloys in fuel rods. Alloys are commercially available.
18	^{131}I	BWR	5.48E+3	0.59	.05	4,800 ^(a)	Additional HEPA filter on reactor building ventilating system.
19	^{88}Kr	PWR	4.58E+3	--	NA	NA	Extend holdup time.
20	^{60}Co	BWR	4.25E+3	0.22	.05	1×10^6 ^(a)	Additional HEPA filter on reactor building ventilation.

(a) Combined with other particulates.

(b) Includes dose reduction for most critical organ.

TABLE 2.3. Twenty Highest Ranking Nuclides - Full Recycle

Rank	Nuclide	Plant	Relative Ranking Factor for Total Body	Alternative Technology Reduction Factor	Incremental Cost of Alternative Control Mills/kWh \$/man-rem (a)		Description of Alternative Technology
1	^3H	FRP	2.07E+6	10^{-2}	0.02	2,660	Voloxidation process.
2	^{138}Xe	BWR	5.01E+5	0.23	--	--	Double holdup time from 30 min. to 60 min.
3	^{85}Kr	FRP	1.73E+5	0.10	.009	11,400	Cryogenic separation of off gas after iodine scrubbing.
4	^{14}C	FRP	1.18E+5	10^{-2}	.003	369	Molecular sieve absorption after iodine scrubbing and absorption.
5	^{88}Kr	BWR	1.02E+5	10^{-2} - 10^{-3}	NA	NA	Low temperature charcoal absorption of steam ejector pump off gas.
6	^{135}Xe	BWR	7.93E+4	10^{-2} - 10^{-3}	NA	NA	Low temperature charcoal absorption of steam ejector pump off gas.
7	^3H	PWR	6.59E+4	0.71	.002	16,000	Use tritium "getter" alloys in fuel rods. Alloys commercially available.
8	^{87}Kr	BWR	5.42E+4	10^{-2} - 10^{-3}	NA	NA	Low temperature absorption of charcoal of steam ejector pump off gas.
9	^{134}Cs	PWR	4.25E+4	0.9-0.01	NA	NA	Recycle more materials in liquid radioactive waste treatment system.
10	^{90}Sr	FRP	3.90E+4	10^{-3}	.0009	938	Additional HEPA filter in dissolver off gas treatment system.
11	$^{135}\text{M}_{\text{Xe}}$	BWR	2.89E+4	0.26	--	--	Double holdup time from 30 min. to 60 min.
12	^{133}Xe	PWR	2.74E+4	--	NA	NA	Extend holdup time.
13	^{244}Cm	FRP	2.60E+4	10^{-3}	--	352,000	Same additional HEPA filters as for ^{90}Sr FRP.
14	^{14}C	PWR	2.28E+4	0.20	.06	21,000	Caustic scrubbing of radwaste, off gas stream.
15	^{137}Cs	PWR	1.76E+4	<0.10	--	--	Recycle more of clean radwaste treatment, goes off site in solid waste drums.
16	^{232}U	FRP	1.41E+4	10^{-3}	.00006	1.3	Add HEPA filter to main stack, only with extensive uranium recycle.
17	^{14}C	BWR	1.35E+4	.008	.03	6,480	Caustic scrubbing of turbine condenser steam ejector pump off gas.
18	^{133}Xe	BWR	1.33E+4	--	NA	NA	Extend holdup time.
19	^3H	BWR	8.45E+3	0.5	.003	98,600	Use tritium "getter" alloys in fuel rods. Alloys are commercially available.
20	^{238}Pu	FRP	6.21E+3	0.25	--	11,700	Add HEPA filter to dissolved and vessel off gas.

(a) Includes dose reduction for most critical organ.

TABLE 2.4. Nonradioactive Materials with the Twenty Highest Dilution Factors - Stowaway Fuel Cycle

Rank	Chemical	Plant	100 year Dilution ₃ Factor (m ³)	Alternative Technology Reduction Factor	Incremental Cost (mills/kWh)	Description of Alternative
1	Ammonia	Uranium Fuel Fabrication	4.406E+15	<0.5		Additional stage of scrubbing
2	Sulfur Oxides	Enrichment Cascade	3.308E+15	.6 to .2	.002	Double-alkali FGD system
3	Uranium	Acid Leach Mill	2.553E+15	.3 to .1	.0008	Venturi scrubber
4	Rock Dust	Surface Mine	2.371E+15	.3 to .2	.13	Cover waste rock and revegetate, spray with water after blasting
5	Nitrogen Oxides	Enrichment Cascade	1.985E+15	.15 to .05	.006	Selective catalytic reduction
6	Rock Dust	Underground Mine	1.499E+15	.3 to .2	.065	Cover waste rock and revegetate
7	Sulfur Oxides	BWR	1.257E+15			
8	Aldehydes	Surface Mine	9.484E+14	.5		Catalytic converters on diesel equipment
9	Nitrogen Oxides	Aqueous Conversion	7.543E+14	.90 .40	.0001	Combustion modification Nitric acid scrub/recycle
10	Nitrogen Oxides	Acid Leach Mill	6.127E+14	.40		Flue gas recirculation or water injection
11	Nitrogen Oxides	BWR	5.029E+14			
12	Aldehydes	Acid Leach Mill	4.902E+14	.20		Use natural gas
13	Nitrogen Oxides	Surface Mine	4.742E+14	.4		Water induction
14	Hexane	Aqueous Conversion	4.061E+14	~.01		Refrigeration of distillation overhead vapor
15	Nitric Acid	Uranium Fuel Fabrication	3.981E+14	~.1		Mist deentrainment
16	Aldehydes	Underground Mine	3.598E+14	~.4		More efficient catalytic converters
17	Hydrogen Fluoride	Aqueous Conversion	3.474E+14	~.4		Two-stage HF scrubber
18	Sulfur Oxides	Aqueous Conversion	3.165E+14	.1		Double alkali FGD
19	Sulfur Oxides	Surface Mine	2.634E+14			
20	Particulates	Surface Mine	2.634E+14			Turbocharged engines or water scrubbers

TABLE 2.5. Nonradioactive Materials with the Twenty Highest Dilution Factors - Reprocessing with No Recycle

Rank	Chemical	Plant	100 year Dilution ₃ Factor (m ³)	Alternative Technology Reduction Factor	Incremental Cost (mills/kWh)	Description of Alternative
1	Ammonia	Uranium Fuel Fabrication	4.406E+15	<0.5		Additional stage of scrubbing
2	Sulfur Oxides	Enrichment	3.308E+15	.6 to .2	.002	Double-alkali FGD
3	Uranium	Acid Leach Mill	2.553E+15	.3 to .1	.0008	Venturi scrubber
4	Nitrogenoxides	Reprocessing	2.533E+15	.5 .7 .2		Nitric acid scrub/recycle Combustion modifications Both
5	Rock Dust	Surface Mine	2.371E+15	.3 to .2	.13	Cover waste rock and revegetate
6	Nitrogen Oxides	Enrichment	1.985E+15	.15 to .05	.006	Selective catalytic reduction
7	Rock Dust	Underground Mine	1.499E+15	.3 to .2	.065	Cover waste rock and revegetate
8	Sulfur Oxides	BWR	1.257E+15			
9	Aldehydes	Surface Mine	9.484E+14	.5		Catalytic converters
10	Sulfur Oxides	Reprocessing	8.442E+14	.2	.0015	Lime scrubbing FGD
11	Nitrogen Oxides	Aqueous Conversion	7.543E+14	.8 .39	.001	Flue gas recirculation Nitric acid scrub/recycle
12	Nitrogen Oxides	Acid Leach Mill	6.127E+14	.4		Flue gas recirculation or water injection
13	Nitrogen Oxides	BWR	5.029E+14			
14	Aldehydes	Acid Leach Mill	4.902E+14	.2		Use natural gas
15	Nitrogen Oxides	Surface Mine	4.742E+14	.4		Water induction
16	Hexane	Aqueous Conversion	4.061E+14	~.01		Refrigeration of hexane overhead vapor
17	Nitric Acid	Uranium Fuel Fabrication	3.981E+14	~.1		Mist deentrainment
18	Aldehydes	Underground Mine	3.598E+14	~.4		More efficient catalytic converters
19	Hydrogen Fluoride	Aqueous Conversion	3.474E+14	~.4		Two-stage HF scrubber
20	Sulfur Oxides	Aqueous Conversion	3.185E+14	.1		Double alkali FGD

TABLE 2.6. Nonradioactive Materials with the Twenty Highest Dilution Factors - Reprocessing with Full Recycle

Rank	Chemical	Plant	Dilution Factor (m ³)	Alternative Technology Reduction Factor	Incremental Cost (mills/kWh)	Description of Alternative
1	Ammonia	Uranium Fuel Fabrication	3.268E+15	<0.5		Additional stage of scrubbing
2	Sulfur Oxides	Enrichment	3.266E+15	.6 to .2	.002	Double alkali FGD
3	Nitrogen Oxides	Reprocessing	2.533E+15	.3 to .1		Venturi scrubber
4	Nitrogen Oxides	Enrichment	1.960E+15	.5 .7 .2	.006	Nitric acid scrub/recycle Combustion modifications Both
5	Uranium	Acid Leach Mill	1.609E+15	.3 to .1	.0008	Venturi scrubber
6	Sulfur Oxides	BWR	1.257E+15			
7	Rock Dust	Surface Mine	1.139E+15	.3 to .2	.10	Cover waste rock and revegetate
8	Rock Dust	Underground Mine	1.103E+15	.3 to .2	.05	Cover waste rock and revegetate
9	Sulfur Oxides	Reprocessing	8.442E+14	.2	.0015	Lime scrubbing FGD
10	Nitrogen Oxides	Aqueous Conversion	6.179E+14	.8 .4 .2	.0001	Flue gas recirculation Nitric acid scrub/recycle Both
11	Nitrogen Oxides	BWR	5.029E+14			
12	Aldehydes	Surface Mine	4.559E+14	.5		Catalytic converters
13	Nitrogen Oxides	Acid Leach Mill	3.862E+14	.4		Flue gas recirculation or water injection
14	Hexane	Aqueous Conversion	3.282E+14	~.01		Refrigeration of hexane still overhead vapor
15	Aldehydes	Acid Leach Mill	3.090E+14	.2		Use natural gas
16	Nitric Acid	Uranium Fuel Fabrication	2.953E+14	~.1		Mist deentrainment
17	Hydrogen Fluoride	Aqueous Conversion	2.809E+14	~.4		Two stage HF scrubber
18	Aldehydes	Underground Mine	2.648E+14	~.4		More efficient catalytic converter
19	Sulfur Oxides	Aqueous Conversion	2.575E+14	.1		Double alkali FGD
20	Nitrogen Oxides	Surface Mine	2.217E+14	.4		Water induction

The control of ^{14}C through the use of molecular sieve absorption after iodine scrubbing has a computed cost-benefit ratio of \$369 per man-rem using the accumulated population dose method. The system was designed as part of the Environmental Impact Statement on Management of Commercially Generated Radioactive Waste⁽¹⁾ and has not yet been implemented. Its development and use as part of the reprocessing plant control technology are strongly indicated.

Emission of ^{90}Sr from the reprocessing plant could be reduced by installing additional HEPA filter stages on the dissolver off-gas stream. The cost of this reduction would be \$938 per man-rem. This is close enough to the 10 CFR 50 criterion to warrant more detailed evaluation and/or installation.

The control of ^{232}U will be required at the FRP UF_6 facility if appreciable amounts of multi-recycled uranium are reprocessed. A small cost-benefit ratio of \$1.30 per man-rem underscores this conclusion.

Four of the twenty highest ranked nuclides are noble gases from BWRs. Reduction of these releases can be accomplished by using a low-temperature charcoal absorption process. Unfortunately, no cost information was available on this process and no cost-benefit ratio could be computed. However, the process is being installed on some BWRs under construction and is apparently a feasible and acceptable process, in terms of cost and benefit as perceived by reactor purchasers.

Tables 2.1, 2.2 and 2.3 show that the remaining radionuclides originate at the reactor, except for ^{222}Rn emissions from the underground mine in the stowaway scenario. In the two scenarios with reprocessing, the ^{222}Rn effluent is displaced from the stowaway fuel cycle list (Table 4.1) by higher-ranking reprocessing plant emissions.

The reactor emission cost-benefit factors were substantially above the \$1,000 per man-rem value for all of the reactor emissions for which cost information on an alternative control technology could be found.

2.2 NONRADIOACTIVE RELEASES

The nonradioactive effluents released to the air break down into three classes:

- process materials
- internal combustion engine exhaust products
- steam boiler combustion products.

The most serious process material effluent is ammonia from the fuel fabrication plant. Existing water scrubbers remove between 75 and 90 percent of the ammonia. Further reduction in NH_3 emissions could be attained by adding an additional scrubber stage in series, a water absorption tower, or an absorption-reaction tower.

Other process material effluents include mine rock dust, conversion plant hydrogen fluoride and hexane, and uranium mill uranium dust. Reasonably adequate augmented or new control technologies exist for these effluents.

The control of emissions from combustion has received considerable technical emphasis in the past, and processes to limit exhaust gas emissions in other industries apply to nuclear fuel cycle facilities. Present commercial processes are the basis for the selection of alternative control processes. The distinction between mobile engines and stationary power plants determines the applicable process. The diesel engines in mining applications are mobile; stand-by power for reactors is provided by large stationary diesel engines.

The water induction process for NO_x reduction and catalytic converters for aldehydes generated by mobile combustion engines can reduce these mine effluents by 50 to 60%. Catalytic reduction for the stationary backup diesels is capable of a ten to twentyfold decrease in NO_x at a cost of 0.006 mills/kWh.

Combustion processes in boilers produce NO_x and SO_x emissions that may be reduced by three alternative control processes: modification of the combustion conditions, flue gas recirculation and water injection, and double alkali flue gas desulfurization.

2.3 RECOMMENDATIONS

Using the \$1,000/man-rem criteria (as discussed in Section 2.1), recommendations regarding ^{14}C , ^{90}Sr , and ^{232}U are offered in this section. Based on the non-radioactive release criteria, as described in Section 2.2, ammonia releases are also discussed in this section. Specific recommendations are described in the following sections.

2.3.1 ^{14}C From Reprocessing Plants

In this study, the alternative technology for ^{14}C control is the molecular sieve (zeolite) absorption process. This process has been used to remove both moisture and CO_2 from chemical plant gas streams. No application has been made to the gas composition that would be characteristic of a FRP dissolver off-gas stream. The process requires that water and nitrogen oxides be removed (a DF of 10^6 and 10^3 , respectively) from the zeolite feed stream. The ability to do this on concentrations that would be typical of a DOG iodine recovery stream has not been demonstrated.

Accordingly, if the decision is made to demonstrate and commercialize the liquid metal fast breeder reactor (LMFBR) and develop the associated fuel reprocessing or if recycle of LWR fuel is initiated, it is recommended that the molecular sieve absorption process be demonstrated.

2.3.2 ^{90}Sr From Reprocessing Plants

The recommended method of reducing the ^{90}Sr emissions from reprocessing plants is to install additional HEPA filter capacity in the main stack air-flow stream. This is an alteration to the plant design utilizing existing technology. No technical development is required to implement this control system.

2.3.3 ^{232}U From Reprocessing Plants

The release of ^{232}U is a problem only if the reprocessing plant processes recycled uranium. The design of the reprocessing plant should allow for the eventual installation of additional HEPA filter capacity in the UF_6 facility air stack. The level of ^{232}U should be monitored during operation on non-recycled fuel. If reprocessing of recycled uranium is

planned, the installation of additional HEPA filters might be required, depending on the normal level of ^{232}U release and the anticipated increase in ^{232}U contained in the recycled fuel to be processed.

None of these measures would involve the development of new environmental control technology.

2.3.4 Ammonia From Fuel Fabrication Plants

The removal of ammonia from an airstream is a classical chemical engineering exercise. The control technology options for this non-radioactive effluent are additional water scrubber stages, a water absorption tower or an absorption reactor tower. No new technical development is required. Plant operators can be expected to make the additional investment in each case as a particular plant nears the limit on released ammonia. The dilution factor is based on an assumed limit of $30 \mu\text{g}/\text{m}^3$.

SECTION 2: REFERENCES

1. Draft Environmental Impact Statement: Management of Commercially Generated Waste. DOE/EIS-0046-D, U.S. Department of Energy, Washington, D.C., April 1979.

3.0 TECHNICAL APPROACH

To evaluate the environmental control technologies for the nuclear fuel cycle, reference fuel cycles and facilities are first characterized. The radioactive and nonradioactive effluents from each facility in each fuel cycle are then identified and release factors are assigned to each effluent based on the best available information. Only releases from the normal operation of the facilities are included. An assumed nuclear generation schedule of 380 GWe by year 2000 is used in the ENFORM computer code system to calculate the mass flows of materials through the fuel cycle facilities. These mass flows and the release factors are used to calculate the time-dependent amount of each effluent from each facility in the fuel cycle. The effluents are ranked based on relative ranking factors for radionuclides and dilution factors for chemical effluents.

From the ranked effluents, the 20 most important radioactive and nonradioactive effluents are selected for detailed control methodology examination. The cost for new control methods are reported where literature information is available. These costs are compared with the anticipated reduction in the effluent material released.

3.1 FUEL CYCLE FACILITY DESCRIPTION

The reference fuel cycle and facilities used in this study reflect current conditions in the nuclear industry, as well as conditions that may be typical in the near future. Processes and technology that have not advanced at least through pilot plant scale are not considered. Actual facilities were selected wherever possible; in some cases, these real facilities are conceptually modified to accommodate the fuel cycle concept. Where no actual or planned facilities exist, conceptual facilities are developed. In some cases, more than one facility is studied.

In this study, mainline processing includes all bulk effluent controls and recycle systems integral to the mainline process; effluent control processing entails final effluent treatment steps that prepare the effluent stream

for release to the environment. Wastes are materials that are intended to be isolated from the environment. Ultimate disposition of the wastes is beyond the scope of this study.

The characterization of each fuel cycle facility involves several activities:

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

These activities are described in Sections 3.1.1 through 3.1.10.

3.1.1 Surface Mine

A reference surface mining facility representative of current technology in commercial scale uranium mining was defined for this study, primarily based on the Anaconda Company's Jackpile mine located at Paguate, New Mexico.

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

Operations at the reference surface mine consist of drilling, blasting, and hauling the overburden. The underlying ore zones are graded according to uranium content, ripped using a ripper attached to a tractor, and loaded into dump trucks. The ore is stockpiled according to grades. The ore is blended, crushed, scanned, and loaded into train cars for transport to the reference milling facility. The processes of blasting the overburden, loading, and crushing the ore release most of the mass of airborne effluent contaminants as particulates. The radioactive decay products of uranium make up a portion of the airborne effluents released by these processes.

The main liquid effluent is produced by gravity flow of ground water into the pit retention ponds where water seeps into the ground or evaporates.

Liquid Effluent Processing

The main liquid effluent stream leaving the mine is the mine water, with a pH of 8.0 to 8.5.⁽¹⁾ This water flows by gravity to a holding pond in the mine pit where it is allowed to evaporate and to seep into the ground. Mine-water is also used to wet down haul roads for dust control; water used in this manner evaporates.

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

Airborne Effluent Processing

The airborne effluents are made up of dust, combustion gases (including blasting gas and equipment exhaust gas), radon gas, and radon daughters. All airborne effluents are released directly to the atmosphere without treatment. The airborne effluents are given off during blasting, loading, blending, and crushing.

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

3.1.2 Underground Mine

A reference underground mining facility representative of current technology for commercial scale uranium underground mining was defined based on an existing group of seven mines owned by Kerr-McGee Corporation at Ambrosia Lake in McKinley County, New Mexico. Underground mining at the Ambrosia Lake complex of mines is performed using a modified room-and-pillar mining method.

The reference underground mining facility produces uranium at the rate of 4234 MT of ore/day. This ore is shipped to a uranium milling facility for further processing.

The reference mining facility operations consist of drilling and blasting ore-bearing rock. This rock is collected and transported to the surface of the mine. The rock is loaded into dump trucks, scanned for ore grade and stock-piled according to the grade of the ore. The processes of blasting, loading,

and blending the ore release most of the mass of airborne effluent contaminants as particulates. The radioactive decay products of uranium make up a portion of the airborne effluents released by these processes.

The main liquid effluent is produced by pumping water out of mine excavation areas to retention ponds on the surface, where water seeps into the ground or evaporates.

Liquid Effluent Processing

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

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

Airborne Effluent Processing

The airborne effluents are made up of dust, combustion gases, radon gas, and radon daughters. These airborne effluents are given off during blasting, loading, and blending. (Radon gas emanates from New Mexico sandstone at $\geq 5 \times 10^{-14}$ Ci/cm²/sec).⁽²⁾ Dust is also released to the atmosphere by winds that entrain dust from dried out ore stockpiles. Various methods of airborne effluent treatment or control used in the reference mine are discussed in the following paragraphs.

Dilution is used to control the concentration of contaminants in the air. Airborne effluents are mixed with enough fresh air to reduce the concentration

of contaminants to acceptable levels. Dilution is accomplished using ventilation fans and mine openings that provide air passage. This method is used to control the concentrations of effluents such as dust, carbon monoxide, nitrogen oxides, hydrogen sulfide, sulfur dioxide, aldehydes, radon, and radon and its daughters. For this study it is assumed that fresh air is drawn into and through the mine and pumped out at the surface.

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

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

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

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

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

3.1.3 Uranium Milling

A reference uranium milling facility representative of the predominant current technology for commercial scale plants was defined for this study.

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

The reference uranium milling facility utilizes the acid leaching process for uranium recovery.

As the mill receives ore from the mine it is blended, crushed, ground, and leached with acid. The uranium is solvent extracted from the acid leach and subsequently stripped from the organic solvent. The yellowcake (ammonium diuranate) is formed by precipitation of the uranium in solution using ammonia. The yellowcake is washed, dried, pulverized and loaded into drums for shipment to the reference conversion facility.

About 6.5% of the uranium in the ore received from the mine is assumed to end up in either effluents or wastes.

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

Liquid Effluent Processing

The liquid effluents consist of seepage from the tailings pond. The material transported to the tailings pond contains about 85% of the radioactivity of the ore because the radioactive daughters of uranium are not extracted with the uranium. The seepage from the tailings pond contains some of these uranium daughters and some of the process chemicals used in the mill. The tailings pond and tailings dam are constructed to minimize the seepage rate. This is done by lining the bottom and sides of the tailings pond with clay or other earthen materials having low permeability to liquids.

Airborne Effluent Processing

Dust from the crushing and fine ore storage areas is collected by separate but similar wet-collection systems. These wet collection systems are estimated to be 95% efficient for the dusts encountered.⁽³⁾ The slurries discharged from

these collection systems are processed in a single small thickener tank and the thickened stream is recycled to the rod mill, while the clear water is recycled to the wet collection systems.

Dusts from the yellowcake dryer and drum loading operation are collected by a wet collection system that is estimated to be 99.3% efficient for the dusts encountered. (3, p. 31) The slurry discharged from this system is recycled to the first precipitation thickener.

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

3.1.4 Uranium Purification and Conversion

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

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

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

About 0.15% of the uranium received by the reference facility ends up in either effluents or wastes. The contaminated liquid and solid wastes either remain in retention ponds or are buried onsite.

The waste materials generated in the reference uranium conversion facility are radioactive liquid wastes and radioactive and nonradioactive solid wastes. The radioactive liquid wastes are of greatest concern in this step of the uranium fuel cycle.

The radioactive liquid waste stream from the solvent extraction system, known as raffinate, is primarily composed of ammonium nitrate, nitric acid, metallic salt impurities from the yellowcake feed, minute quantities of uranium, and radioactive daughter products of normal uranium decay. The raffinate is combined with spent sodium hydroxide from the solvent purification system and the miscellaneous digester off-gas scrubber and with excess recovered weak acid from the nitric acid absorber.^(3, p. 4) This combined raffinate stream is neutralized with ammonia; the ammonia also precipitates most of the contained radioactive elements and other heavy metal impurities. The resulting slurry is confined in storage ponds having sealed bottoms.^(a) The evaporating liquid becomes an airborne effluent.

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

Liquid Effluent Processing

The fluoride-containing liquid effluent stream (considered as an effluent rather than a waste) consists of several streams that are combined prior to treatment. The fluoride stream is primarily weak hydrofluoric acid from the off-gas scrubber system serving the hydrofluorination processes^(3, p. 5) and fluorination processes, and from the emergency vent off-gas system from process vessels and storage tanks. Added to this weak hydrofluoric acid stream are laboratory wastes, fluorine cell rework sludges (sodium carbonate solutions) and liquids^(3, p. 5) from the anhydrous hydrogen fluoride vaporizer sump. When combined these form the fluoride effluent stream, which is treated with slaked lime (calcium hydroxide) to neutralize the acid and raise the pH to 12. This resultant slurry flows to a fluoride sludge pond where most of the excess lime and

(a)W. J. Shelley, Kerr-McGee Nuclear Corporation, Oklahoma City, Oklahoma, letter to Harold L. Price, U.S. AEC, Washington, D.C., dated June 5, 1975.

calcium fluoride precipitate settles out. The overflow from the sludge pond is neutralized to a pH of about 7 by adding sulfuric acid. The resulting solution is fed to a clarifying pond where most of the remaining suspended calcium fluoride and calcium sulfate settle out. All ponds have sealed bottoms.

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

Airborne Effluent Processing

The treatment of airborne effluents from the facility consists mainly of filtration and scrubbing by various systems.

The miscellaneous digester off gas is scrubbed with sodium hydroxide, and the scrub solution is discharged to the liquid waste treatment system. The remaining off gas from the caustic scrubber is joined by the off gas from the primary digester before entering the nitric acid absorption column. The single effect uranium evaporator off gases pass through a condenser, are joined by off gases from the second stage uranium concentrator tanks and denitrators, and together these off gases are scrubbed with 40% nitric acid and cooled prior to entering the nitric acid absorption column. The off gas from absorption is assumed to be bag filtered before release to the main plant stack.

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

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

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

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

3.1.5 Gaseous Diffusion Enrichment

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

The reference gaseous diffusion uranium enrichment facility is designed for a nominal plant capacity of 8.75 million kg SWU/yr. It is designed to receive 13,333 MT of 0.711% ^{235}U feed material annually, produce 2,083 MT of 3.2% ^{235}U product and 11,250 MT of 0.25% ^{235}U tails.

Product material is shipped as UF_6 to uranium fuel fabrication plants where the UF_6 is converted to uranium oxide and used in the manufacture of fuel elements for LWRs. The 0.25% ^{235}U tails material is either stored onsite or shipped offsite.

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

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

During routine operations nearly all radioactive materials in the effluents result from maintenance of the main process equipment, and from the decontamination fluids used. Uranium, its radioactive decay daughters and chemical compounds are recovered from the decontamination fluids so that very little radioactivity is released to the environment from this plant.

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

Liquid Effluent Processing

About 28.1 million ℓ /day of liquid effluents are discharged from the plant. These effluents contain about 120 kg/day of chemical contaminants (mostly salts of calcium nitrate, ammonia, and fluoride ions) and about 0.37 kg/day of uranium (about 0.0074% of plant product output).

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

Before it is discharged to the holding pond, the cooling tower blowdown is treated with sulfuric acid and a reducing agent such as ferrous sulfate, sodium sulfite, or sulfur dioxide to reduce hexavalent chromium to the trivalent form. Next the blowdown is transferred to a neutralization tank where sodium

hydroxide or lime is added to raise the pH to approximately eight. Zinc and trivalent chromium precipitate under these conditions and are discharged to the primary holding pond with the remaining blowdown liquid.

Extremely low contamination plant laundry effluents and sanitary sewage are discharged to the sanitary sewage treatment facility; this is a conventional municipal type of sewage treatment plant with primary and secondary treatment. Eventually the effluents are discharged to the natural waterways.

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

Airborne Effluent Processing

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

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

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

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

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

The flame tower effluent passes through a sintered metal filter, a magnesium fluoride trap, a cold trap and a sodium fluoride trap before it is released to the atmosphere. The sintered metal filter collects particulates in the flame tower effluent and the magnesium fluoride trap absorbs volatile impurities. Both the cold trap and the sodium fluoride trap remove uranium hexafluoride from the effluent. Materials in these traps are replaced regularly. Some of the filter materials are initially subjected to heat to drive off UF_6 for direct recovery. The used absorbent materials are then subjected to appropriate solvents to release uranium compounds into solutions that become feedstock for the uranium recovery facility. Some of the filter materials are recyclable. The nonrecyclable portions are disposed of as solid waste, either onsite or offsite as appropriate.

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

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

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

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

3.1.6 Uranium Fuel Fabrication

A reference UO_2 fuel fabrication facility representative of current technology for commercial scale plants was defined for this study. It is based primarily on the Westinghouse Nuclear Fuel Plant - Columbia Site (W NFCS), designed to fabricate low-enriched UO_2 (U with ≤ 5.0 wt% ^{235}U) fuel assemblies.^(4,5)

The reference UO_2 fuel fabrication facility produces and ships fuel assemblies for large, modern PWRs and BWRs at the rate of 4.38 MTM/day (1600 MTM/yr). A PWR assembly contains 0.46 MTM in the Zircaloy-clad UO_2 or $\text{UO}_2\text{-PuO}_2$ fuel rods and a BWR assembly contains 0.19 MTM in the UO_2 or UO_2 plus $\text{UO}_2\text{-PuO}_2$ fuel rods.^(6, p. 2.32) The facility also receives prefabricated and hermetically sealed $\text{UO}_2\text{-PuO}_2$ fuel rods, and completes the assembly of these fuel elements.

The reference facility, when processing UO_2 fuel, receives uranium as UF_6 and first converts the uranium to UO_2 using the aqueous ammonium diuranate (ADU) process. The UO_2 is calcined, formed into pellets and loaded into prefabricated Zircaloy tubing. The fuel-containing rods are sealed and fabricated into fuel assemblies using mostly prefabricated external hardware. Clean uranium scrap is recycled to appropriate points in the process, while dirty uranium scrap (i.e., contaminated with extraneous materials) is purified by ADU precipitation before being recycled to the product stream.

About 0.73 million ℓ /day of liquid effluents are discharged from the plant. These effluents contain about 4000 kg/day of chemical contaminants which are mostly salts of calcium nitrate, ammonia, and fluoride ions, and about 0.0005 kg/day of uranium (the latter is about 0.00001% of plant throughput). The airborne effluents contain about 100 kg/day of chemical contaminants (mostly ammonia, nitrogen oxides, and some fluorides), and about 0.005 kg/day of uranium (mostly from the sintering furnace exhaust). The amount of uranium in airborne effluents is about 10 times that in the liquid effluents. The ADU conversion process is responsible for most of the chemical effluents from the plant.

Uranium-contaminated waste consists mostly of CaF_2 sludge. About 50,000 ℓ /day of CaF_2 sludge are held in lagoons. Other contaminated wastes, shipped offsite, amount to slightly over 1000 ℓ /day. Total contaminated wastes contain about 0.2% of the uranium fed to the plant. Nonuranium-contaminated waste is partly composed of scrap fuel assembly materials, which are returned to suppliers as scrap or released for scavenging. Most of the nonuranium-contaminated waste is deposited in an approved local landfill. (4, pp. 3.3-20 and 7.2-18)

Liquid Effluent Processing

The primary aqueous process effluent comes from the ADU conversion process. The effluent is cleaned ADU solids in the mainline process by two stages of centrifugation; it is then treated in the effluent treatment system by ion exchange to remove additional uranium and other cationic impurities. The supernatant liquid is then processed through cartridge filters before being routed to tanks where lime is added to precipitate the fluoride as CaF_2 . This slurry is sent to a distillation column to remove about 75% of the ammonia for reuse in the plant's ADU process. The liquid effluents from scrap recovery operations and contaminated sump solutions are also routed to the ammonia still. The remaining unrecovered ammonia is assumed to be vented to the atmosphere.

The ammonia still bottoms, which contain concentrated salts and solids, are routed to the first holding lagoon (lined pond) to allow the solids to settle. This lagoon also receives liquid effluents from most process scrubbers, which use water as the scrub solution. The supernatant liquid from the first lagoon is routed to a second lagoon for additional solids settling. The supernatant liquid from the second lagoon is pumped to the nearby river in combination with the sanitary effluent, which also includes water deionizer regeneration solutions and flushes, steam boiler blowdown, and chemicals for developing x-ray film in the laboratory. The water bleed stream from the closed-loop cooling tower is pumped to the sanitary effluent lagoon. A significant amount of the water in these liquid effluents evaporates into the atmosphere.

Airborne Effluent Processing

In cases where potential for radioactive materials or significant chemicals exist, air streams are treated with water scrubbers and/or HEPA filtration.

All process gases from the aqueous processing and scrap recovery systems are water scrubbed and pass through one stage of HEPA filtration. Fifteen scrubbers are used, including 10 for the mainline calciners (one for each calciner). The water scrub solutions from the mainline scrubbers (which remove much of the fluoride as hydrofluoric acid) are recycled to the first stage centrifuge of the mainline ADU process. The scrub water from the other scrubbers is routed to a quarantine (hold-up) tank before transfer to the first holding lagoon. The off gases from dissolution of scrap uranium are condensed to return much of the nitrogen oxides and condensible vapors to the dissolver before the noncondensable gases are routed to the scrubbers.

Many of the solids handling processes are dusty operations and filtration of the off gas is required before atmospheric release. The pellet drying operations are HEPA filtered at the air exhaust point of their respective hoods. (Although some of the other process steps may not have filtration in their immediate exhaust, such filtration is assumed at this time.) Ventilation exhausts from process building rooms that could contain uranium (i.e., process steps through fuel rod loading and sealing) are also routed through a bank of HEPA filters. Filtered air from the solids handling process steps is assumed to be routed to this latter bank of HEPA filters.

The off gases from the waste incinerator are water scrubbed before HEPA filtration. The scrub water is filtered and then routed to the contaminated sump for final effluent treatment.

Ventilation from other in-plant activities or areas is exhausted directly to the atmosphere without treatment. These exhausts result from:

- steam boiler combustion gases
- chemical and health physics laboratory ventilation
- calciner combustion gases
- plating and rinse hoods exhaust gases
- pre-etch exhaust gases

- pickling exhaust gases
- grid plating room ventilation
- air compressor ventilation
- chemical storage ventilation
- nonradioactive personnel area ventilation.

3.1.7 Mixed Oxide Fuel Fabrication

The reference $\text{UO}_2\text{-PuO}_2$ fuel fabrication facility selected for this study is representative of current technology and is primarily modeled on the Westinghouse Recycle Fuels Plant (RFP), a proposed large-scale plant with a capacity of producing 0.55 to 1.1 MT of $(\text{UO}_2\text{-PuO}_2)$ /day or 200 to 400 MT of $(\text{UO}_2\text{-PuO}_2)$ /year plant. This facility is designed to produce and ship mixed oxide Zircaloy-clad fuel rods for PWRs and BWRs to the reference UO_2 fuel fabrication facility for assembly.

The reference facility is designed to receive uranium oxide powder (from the reference UO_2 fabrication facility) and plutonium oxide powder. The powders are mechanically blended along with recycled $\text{UO}_2\text{-PuO}_2$ powder from other process steps in the facility. The blended powder is cold-pressed and sintered to yield $\text{UO}_2\text{-PuO}_2$ pellets that are loaded into Zircaloy tubes to produce the $\text{UO}_2\text{-PuO}_2$ fuel rods.

A total of about 1.3×10^9 l/day of air is released to the environment, which contains about 1200 kg/day of chemical effluents (sulfur oxides and nitrogen oxides, excluding nitrogen and water vapor), 1.4×10^{-8} kg U/day and 6.4×10^{-10} kg Pu/day. The liquid effluent discharge totals about 78,000 l/day and includes about 5 kg/day of chemical constituents and about 1.5×10^{-7} kg U/day and 6.9×10^{-9} kg Pu/day.

The contaminated solid wastes contain about 7 kg U/day and about 0.33 kg Pu/day. The contaminated solid wastes are to be either stored onsite (i.e., as dirty scrap) or disposed of offsite to an authorized waste repository.

Liquid Effluent Processing

All potentially contaminated liquid effluents are collected in one of the two sump tanks located in the basement. The smaller tank of (800 l provides

retention capacity while the contents of the larger 2300 ℓ tank are mixed, sampled, and analyzed for radioactivity and pH. If the alpha radioactivity is within the permissible discharge limit and the liquid has a near-neutral pH, it is pumped through a filter into one of the two 3800 ℓ quarantine tanks (3800 ℓ) for discharge to the sanitary treatment system and eventual discharge to the river.

If the alpha radioactivity exceeds the maximum permissible discharge limit, the liquid is transferred from the larger sump tank to a treatment tank (2300 ℓ) where it is neutralized with caustic, if necessary. The treated liquid is mixed and then pumped through filters into a deactivation feed tank (3800 ℓ) for deactivation treatment. The filters are mounted inside an alpha enclosure to collect particulates that may be present. Spent filter cartridges are transferred to the miscellaneous waste treatment system.

Airborne Effluent Processing

To minimize and restrict radioactive contamination within the reference facility three zones of confinement are provided. The outer zone has the lowest potential for contamination and is the normal work area for personnel. Outside air is drawn in, filtered, humidified, heated or cooled for human comfort, and distributed to the work area. The second zone is a limited access area used only for sampling and maintenance access to the third zone. The third zone is a restricted access area; it includes glove box interiors, decontamination and repair cell interiors, process lines and powder fabrication equipment. The third zone poses the highest potential for contamination because of its direct exposure to plutonium and uranium. Air from the normal access areas is drawn into the limited access areas for ventilation purposes, and air from the limited access areas is drawn into the restricted access areas to remove process heat and humidity. Most of the air in each area is recirculated after filtration to lower the quantity of gaseous effluent released to the environs. Recirculation of air in the normal access area amounts to about 1.1×10^9 ℓ/day (27,000 cfm), in the limited access area about 2.4×10^8 ℓ/day (6,000 cfm), and in the restricted access area, about 2.9×10^8 ℓ/day (7,000 cfm).

The interior normal access area is at a negative pressure relative to the outside. The limited access area is controlled at a more negative pressure, and the restricted access area has the lowest pressure. Thus, the air flows from a zone of lower contamination to one of higher contamination and the ventilation flow is directed toward the zones with the more extensive treatment systems.

Exhaust ventilation consists of two parallel systems, each containing two HEPA filters in series. The two systems operate at 50% of rated capacity, so if one fails, the other can handle the exhaust from the entire facility.

The caustic gas scrubber scrubs out contaminants in the airborne releases from two fume hoods, various glovebox vents, oven and furnace off-gases from the miscellaneous waste treatment roasting glovebox, and an acid tank vent.

3.1.8 Pressurized Water Reactor

A reference pressurized water reactor (PWR) facility representative of current technology for commercial scale facilities was chosen for this study. The reference PWR is based primarily on Portland General Electric Company's Trojan Nuclear Plant.⁽⁷⁾ This facility is located 7.2 km (4.5 miles) upstream from Rainier, Oregon on the Columbia River.

The reference pressurized water reactor facility produces 1178 MW (gross) and 1130 MW (net) of electricity at a nominal full reactor core power of 3411 MWt.

The reactor core is composed of 193 fuel assemblies that contain 264 UO_2 rods per assembly. A total of 101,033 kg (222,739 lb) of slightly enriched UO_2 is in the core in the form of ceramic pellets housed in slightly cold-worked Zircaloy-4 tubes from the reference uranium fuel fabrication plant.

The reactor core is the ultimate source of radioactive effluents and wastes that are discharged from the facility. A total of about 47.5×10^6 l/day of liquid effluents are discharged from the plant. These effluents contain maximum amounts of about 7300 kg/day of chemical contaminants and also about 3.5 Ci/day of radionuclides including tritium. The airborne effluents total about 47 billion l/day and represent the principal release mechanism for radioactive noble gases. These noble gases constitute about 94% of the airborne

radioactivity in curies, and exit the plant at the average rate of about 17 Ci/day. In addition, 1.0 Ci/day of ^3H (tritium) and ^{14}C combined is released in the airborne effluents. The total liquid and gaseous radionuclide releases contain only a small portion (<1%) of the total curie content of radionuclides that are produced in the core. The major amounts of radionuclides remain with the spent fuel, which is shipped offsite.

Contaminated solid wastes, shipped offsite for burial, amount to slightly over 270 kg/day .

Nonradioactive airborne effluents in the form of evaporated water and drift are ejected from the cooling tower to the atmosphere at a heat rejection rate of $2.3 \times 10^6 \text{ kWh/hr}$.

Liquid Effluent Processing

Liquid effluents in the reference PWR are divided into three categories: clean, dirty, and chemical. Clean effluents (such as reactor coolant, spent-fuel pool water, equipment drains, or resin transfer sluice water) are those that may have important concentrations of radioactivity or chemicals but are generally low in particulates. Dirty effluents (such as those from floor drains) are those that have a high particulate content but a low concentration of chemicals and radioactivity. The dirty effluent treatment system can receive overflows and relief valve discharges from the clean effluent treatment system. Chemical effluents are nonradioactive effluents (such as from the circulating water system) that may contain harmful quantities of nonradioactive chemicals.

Liquids containing radioactive materials that are releasable to the environment are piped to the discharge and dilution structure before discharge to the river.

Airborne Effluent Processing

The principal sources of gas received by the radioactive airborne effluent system are cover gas displaced from the chemical volume control system (CVCS) holdup tanks during normal operation, and air displaced from 1) the radioactive liquid effluent tanks as they are filled with liquid and 2) degasification of the primary system for refueling. Since the cover gas must be replaced

when the CVCS tanks are emptied, facilities are provided to recycle the gas that was collected and stored to minimize releases. The gases from tanks using nitrogen as a cover and from those containing liquids with hydrogen are kept separate from tanks and equipment that contain air or aerated liquids.

3.1.9 Boiling Water Reactor

A reference boiling water reactor (BWR) plant representative of current technology for commercial scale plants was chosen for this study, based primarily on the Washington Public Power Supply System (WPPSS) Nuclear Project No. 2 (WNP-2) located on DOE's Hanford Reservation approximately 12 miles north of Richland, Washington.^(8,9) The WNP-2 is a single unit nuclear electric generating plant having a nominal net electric power output of 1100 MWe. The plant consists of a boiling water reactor, turbine-generator, evaporative cooling tower system, a pumphouse that takes makeup water from the Columbia River, a 500-kV transmission line, and other facilities required to generate electric power and handle nuclear wastes.

About 14.1 million ℓ /day of liquid effluents are discharged from the plant. Contained in these daily effluents are approximately 3500 kg of chemical additives (primarily water treatment chemicals) and about 0.04 Ci of radionuclides including tritium. The airborne effluents total 18.1 trillion ℓ /day and contain about 23 Ci of radioactive noble gases, 0.007 Ci of radioactive iodine, 0.2 Ci of tritium, and 0.03 Ci of ^{14}C . Solid wastes shipped offsite average about 960 ℓ /day of high-radioactivity wastes and 180 ℓ /day of low-radioactivity wastes.

Nonradioactive airborne effluents in the form of evaporated water and drift are emitted from the cooling towers at the rate of 70.2 million ℓ /day and carry into the atmosphere 2.2 million kW-days of heat daily.

Operating the reference BWR requires control of radionuclide emissions to the environment to limit the effluents to acceptable amounts. The reactor core is the source of all radioactive effluents and wastes discharged from the plant. Small amounts of radioactive materials are transferred to the coolant through leaks in the fuel assemblies or from irradiated tramp uranium remaining on the outside of the fuel rods from the fuel fabrication process. System

corrosion products and coolant additives also become radioactive by irradiation from the core, thus increasing the radioactivity potentially available for release to the environs. Chemicals and heat are ejected from the water coolant by the heat dissipation system.

Liquid Effluent Processing

The liquid effluent management system is composed of a group of subsystems designed to collect, treat, and recycle different categories of effluent water. These subsystems are designated as the equipment drain, floor drain and chemical effluent systems. The radionuclide distribution of the liquid entering the radioactive effluent system influents is assumed to be the same as in the reactor coolant.

All radioactive liquid effluent process streams terminate in one of the sample or distillate tanks. Since the liquid management system operates on a batch basis, each treated batch is sampled and analyzed. If the sample indicates that the processed liquid is substandard in purity, equipment is provided to either recycle the batch through the same treatment or through a subsystem providing a higher degree of treatment. If the sample indicates that the radioactivity level is within acceptable discharge limits and the processed liquid is in excess of inventory capacity, the processed liquid is discharged to the river.

Airborne Effluent Processing

The airborne effluent system is divided into three systems: condenser off-gas treatment system, building ventilation, and heat dissipation system.

The off-gas treatment system removes off gas from the main condenser steam-jet air ejector. This stream undergoes catalytic recombination, cooling, water removal, holdup, filtration and is ultimately released to the atmosphere. Holdup times are sufficient so that the short-lived xenon and krypton isotopes decay and are removed from the effluent system.

The reactor, radioactive waste, and turbine buildings have separate ventilation and air conditioning systems. Each system has various filters, water coils, heaters and fans to circulate and purify the air.

The reference BWR uses circular mechanical draft cooling towers to dissipate the effluent heat. The cooling tower system is part of the closed-cycle cooling water system. The heat from the turbine exhaust steam is transferred to the closed cycle cooling water in the main condenser. The heated water passes to the cooling towers where the heat is transferred to the atmosphere by partial evaporation. This water, plus make-up water, is returned to the condenser.

3.1.10 Fuel Reprocessing

The purpose of a fuel reprocessing facility is to separate, purify, and prepare for recycle the uranium and plutonium present in the irradiated fuel elements discharged from nuclear reactors. The reference LWR fuel reprocessing facility selected for this study is representative of current technology and is modeled after an essentially completed commercial scale AGNS Barnwell Nuclear Fuels Plant.⁽¹⁰⁾

The reference fuel reprocessing facility is designed to receive and store spent LWR uranium and mixed oxide fuels. The uranium and plutonium from five metric tons of fuel can be recovered each 24-hr operating day.

The fuel is mechanically declad, dissolved in nitric acid, and the fission product and transplutonic element contaminants are separated from the fuel materials by a liquid-liquid solvent extraction process. Plutonium and uranium are separated from each other and purified as nitrate solutions. The plutonium is then converted to the solid oxide form, utilizing an oxalate precipitation process followed by calcination. The plutonium is then shipped offsite, in this study, where it is available for fabrication into mixed oxide fuel elements. The uranium is converted successively to the oxide, to the fluoride, and then "burned" to the hexafluoride in a fluorine reactor. The UF_6 is then ready for recycle to a re-enrichment facility before reuse in a nuclear power system.

Liquid Effluent Processing

Since all of the liquid streams leaving either the plutonium product facility or the UF_6 facility are piped back to the main separations facility for liquid treatment, all liquid effluents from these facilities receive

additional treatment. The main separations facility does not routinely release radioactive liquid effluents. It releases liquids such as blowdown from the cooling towers and boilers, demineralizer regeneration wastes, and single-pass cooling water discharges. These are all nonradioactive discharges under normal operations and are discharged to a retention pond. The liquids are retained in the pond up to 17 days before their discharge to the nearby river. Comprehensive sampling and analysis is done to assure that no radioactive liquid effluents are released to the environment via these discharges.

Airborne Effluent Processing

The airborne effluent treatment system for the main separations facility consists of various prefiltration, HEPA filtration, and scrubbing steps. The main process off-gas system starts with the dissolver off gases, which pass through a condenser and a knockout (de-entrainment) pot. The gases are joined by various other process off gases and then pass through a scrubber to remove radioiodine using a HNO_3 - $\text{Hg}(\text{NO}_3)_2$ scrub, and a water absorber to recover NO_x as nitric acid for reuse.

The remaining process gases are added to this stream of gases. These gases pass through another condenser, another knockout pot, another HNO_3 - $\text{Hg}(\text{NO}_3)_2$ iodine scrubber, a heater, and seven parallel banks of filter units. Each unit has a prefilter, a silver zeolite iodine adsorber, and two final stages of HEPA filters in series.

The treated gases are discharged to the main 100 m stack. The building ventilation system provides two stages of roughing-plus-HEPA bank filtration for exhausted air. The off gases from the concentrated plutonium process areas are first filtered by a roughing filter and two stages of HEPA filters before joining the building ventilation air where they are again filtered by a roughing-plus-HEPA filter bank.

3.2 LWR SCENARIOS

Three fuel cycle scenarios were chosen to generate the fuel cycle effluents. They are:

- stowaway (spent fuel sent to a repository)

- reprocessing without recycle (Pu is stored)
- reprocessing with complete recycle of U and Pu.

An installed nuclear generation of 380 GWe by the year 2000 was used as a current and optimistic installation schedule; the incremental capacities are shown in Figure 3.1. Each of the three fuel cycle scenarios uses the same installed capacity schedule. The generation schedule is a conservative choice from the viewpoint of projecting effluent releases.

Table 3.1 summarizes the resource requirements for the three scenarios including U_3O_8 usage, enrichment requirements, fabrication, spent fuel and radwaste burden. Table 3.2 gives the resource requirements in year 2000, while Table 3.3 gives the requirements in year 2025.

FIGURE 3.1. LWR Energy Capacity

TABLE 3.1. Production at LWR Facilities, 100-Year Total^(a)

	U ₃ O ₈ (10 ⁶ ST)	Enrichment (10 ⁹ SWU)	Fabrication		Reactor Discharge (10 ³ MT)	Reprocessing ^(b)		
			UO ₂ (10 ³ MT)	MO _x (10 ³ MT)		Recovered U (10 ³ MT)	Recovered Pu (10 ³ MT)	Radwaste (10 ³ MT)
Stowaway	4.978	2.410	660.9	--	649.8	--	--	--
Reprocessing w/o Recycle	4.978	2.410	660.9	--	649.8	605.1	5.130	22.89
Reprocessing and Recycle	3.138	2.297	490.1	170.7	649.8	600.0	9.557	23.62

(a) The period 1977 through 2076

(b) In the reprocessing scenarios spent fuel is stored a minimum of 1.5 years prior to reprocessing.

TABLE 3.2. Production at LWR Facilities, Year 2000

	U ₃ O ₈ (10 ³ ST)	Enrichment (10 ⁶ SWU)	Fabrication		Reactor Discharge (10 ³ MT)	Reprocessing ^(a)		
			UO ₂ (10 ³ MT)	MO _x (10 ³ MT)		Recovered U (10 ³ MT)	Recovered Pu (10 ³ MT)	Radwaste (10 ³ MT)
Stowaway	74.2	35.7	9.96	--	8.28	--	--	--
Reprocessing w/o Recycle	74.2	35.7	9.96	--	8.28	6.536	0.0556	0.242
Reprocessing and Recycle	53.4	33.7	8.18	1.78	8.28	6.504	0.0833	0.246

(a) In the reprocessing scenarios spent fuel is stored a minimum of 1.5 years prior to reprocessing.

3.2.1 Stowaway

The stowaway scenario facilities include uranium mining and milling through spent fuel discharge at LWR facilities. Spent fuel is assumed to be disposed of by isolation in geologic repositories. Waste disposal is not within the scope of this analysis. Thus, for this scenario, system mass flows are only used through reactor discharge.

Since the stowaway scenario treats residual uranium and plutonium in reactor spent fuel as waste, the use of feed uranium is higher for stowaway and reprocessing without recycle than for the recycle scenario.

3.2.2 Reprocessing without Recycle

This scenario is similar to the stowaway cycle except that spent reactor fuel is reprocessed (starting in 1985) and the recovered uranium and plutonium are stored for future use, such as for the LMFBFR. Since recycle in LWRs is not used, the front end fuel cycle mass flows and associated impacts are the same as in the stowaway cycle. Because of the fuel reprocessing plant (FRP), emissions from the reprocessing without recycle scenario are greater than emissions from the stowaway cycle.

3.2.3 Reprocessing and Recycle

In this scenario spent reactor fuel is reprocessed starting in 1985. As plutonium and uranium are recovered, they are reintroduced into the system and undergo exposure and power production in the reactor. The recycle step is simulated three times for both uranium and plutonium. As shown in Tables 3.1 through 3.3, U_3O_8 demand and separative work requirements are decreased as plutonium and uranium are recycled. Use of U_3O_8 decreases 37% over the 100 year scenario. Separative work decreases about 5%. From the viewpoint of fuel cycle emissions, the introduction of recycle in the third scenario reduces the "front end" effluents by reducing the amount processed, while it adds reprocessing plant wastes to the total fuel cycle emissions.

TABLE 3.3. Production at LWR Facilities, Year 2025

	U ₃ O ₈ (10 ³ ST)	Enrichment (10 ⁶ SWU)	Fabrication		Reactor Discharge (10 ³ MT)	Reprocessing ^(a)		
			UO ₂ (10 ³ MT)	MO _x (10 ³ MT)		Recovered U (10 ³ MT)	Recovered Pu (10 ³ MT)	Radwaste (10 ³ MT)
Stowaway	59.2	29.55	8.06	--	9.70	--	--	--
Reprocessing w/o Recycle	59.2	29.55	8.06	--	9.70	9.55	0.0815	0.368
Reprocessing and Recycle	28.7	28.50	5.01	3.053	9.70	9.45	0.165	0.381

(a) In the reprocessing scenarios spent fuel is stored a minimum of 1.5 years prior to reprocessing.

3.3 RADIOACTIVE RELEASE CALCULATION

The ENGEN module in the ENFORM-II system takes as input the installed LWR generation schedule and one of the recycle scenarios and computes the time-dependent uranium and plutonium mass flows through all facilities in the fuel cycle. It then writes a data base that contains all of the time dependent isotopic information for 175 isotopes in the reactors through the reprocessing plant. Options are available that can closely control the recycle of uranium and plutonium.

Energy generation can be controlled exactly by manipulating the installed capacity schedule plus the input schedule of plant factors. Alternatively, the installed capacity can be combined with a schedule of reactor plant factors as a function of the age of the reactor, and the energy generation is then computed by ENGEN.

Releases of radioactive material to the environment are calculated using an ENGEN-generated data base for each of the three nuclear generation scenarios. The data base contains the number of gram atoms of each nuclide as a function of time for each step in the fuel cycle from the reactor through reprocessing. The annual release is calculated by the following equation:

$$GATS(N,I,T) * RELFAC(N,I) = REL(N,I,T)$$

where GATS(N,I,T) is the number of gram atoms on the data base for isotope N, plant type I at time period T. RELFAC(N,I) is the release factor and REL(N,I,T) is the number of gram atoms released.

From the number of gram atoms released, the radioactivity of the release is obtained by multiplying the release by the decay constant and then by the conversion constant for the decay rate in gram atoms per second to curies (1.6283×10^{13}). The dose to the environment is calculated by multiplying the curies released by the dose coefficient in units of person-rem per curie. Dilution factors are calculated by dividing the curies released by the relevant air or water emission standard. This gives the effective volume of air or water that must be available to dilute the given release so that it meets the standard.

From the uranium mine through to the fabrication step, releases are calculated on the basis of annual throughput. The release factor is in units of kilograms released per kilogram of uranium plus plutonium processed during that year. The curies released are calculated by converting the kilograms released to gram atoms released, multiplying by the decay constant and then converting the gram atom decay rate to curies. The dose is calculated by multiplying the number of curies released by the dose coefficient.

3.3.1 Release Factor Calculation

The release factors for the mine, mill, conversion, enrichment and fabrication are in units of kilograms released per kilograms of uranium plus plutonium processed during the year. From the reactors through reprocessing, the units are in gram atoms of the isotope released per gram atoms of the isotope contained in the throughput. The reason for the difference in definition between the "head end" release factor and the "back end" factor is that until the reactor burnup occurs, the mixture of radioactive species is fairly simple: ^{222}Rn , ^{226}Ra and U and Pu isotopes. When the burnup stage is reached, however, the number of actinide, fission product and activation species is large and the mixture composition is sensitive to exposure, initial fissile content and power density. These parameters of irradiation depend on the installed nuclear generation scenario. To reflect these scenario-dependent changes, it was necessary to define a new release factor that would give the correct release for differing isotopic compositions.

The release factors were evaluated from a review of the literature. The details of the evaluations are contained in Appendixes A and B of PNL-2286, Description of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles.⁽¹¹⁾ In most instances, the release factor evaluation involved an exercise of judgment to provide numerical values. An index of release factor reliability was devised as a crude means of establishing the credibility of a particular release calculation. The reliability criteria, in order of increasing reliability, are: 1) engineering estimate, 2) laboratory measurement, and 3) plant experience.

The release factors for isotopes from the reactors and reprocessing are calculated from reference sources. The release factor is defined as the amount released divided by the amount processed. The amount of a given nuclide being processed at the time of the reference release is not known in general. It was assumed that the composition of the material processed at the time of the release was that of the equilibrium PWR or BWR batch. ORIGEN⁽¹²⁾ compositions for these materials were then used to determine the actual amount processed and a release factor was calculated by dividing that amount into the reference release. Since different reference sources can be used for different isotopes of the same element, different release factor values can result for isotopes of the same element. If the exact process material composition was known at the time of the release, then the release factor for all isotopes of a given element should be the same, since the release is controlled by chemical and physical processes that act on each isotope of a given element in the same way.

3.3.2 Relative Radionuclide Ranking Factors

Relative ranking factors for each radioactive effluent are calculated to help determine effluent control priorities for radionuclides in the effluents from the three fuel cycle scenarios considered in this study. These ranking factors are based on the 100-year summation of the 50-year population dose commitment from one-year exposures. All radionuclides in the annual effluents from each fuel facility are considered. The resulting ranking factors, which are based on the dose from annual effluents, do not account for the buildup of radioactivity in the environment during a plant lifetime. Thus, they may underestimate the total population dose associated with operating a given fuel

cycle facility. For this reason, these doses are called relative ranking factors, and they are only used to order the effluents. They are not used to determine the expected population doses.

Relative ranking factors are calculated for two assumed environmental locations. The uranium mine and mill are assumed to be located on a site typical of the arid western United States. All other facilities are assumed to be located at a typical midwestern location.

The mine-mill site is characterized by:

- A fenced boundary, which includes 13 km^2 in a rectangular form 4 km by 3.25 km.
- An average population density of 3 persons per km^2 out to an 80 km radius.
- A total population of 5.6×10^4 people within an 80 km radius.
- The nearest dwelling is a small farm located 0.46 km from the fence. A milk cow and a garden are kept.
- No streams are located near the site. There are no liquid effluents from the site.
- The site receives 30 cm (12 in.) precipitation every year.
- The wind blows 16% of the time, with an average speed of 5.7 m/s (11 mph). Air releases are from a 10 m stack.
- The average dispersion factors for the population are $2.1 \times 10^{-9} (\text{s/m}^3)$ for inhalation and $1.4 \times 10^{-8} (\text{s/m}^3)$ for food production.

Pathway specific parameters for the population residing within 80 km of the arid western site are listed in Table 3.4.

The midwestern site, where the remaining fuel cycle facilities are assumed to be located, is characterized by:

- A fenced boundary, including 4.7 km^2 in a rectangular form 2.35 km by 2.0 km. A moderately large river runs through one corner of the site.
- An average population density out to an 80 km radius of 174 persons per square kilometer.

- A total population of 3.5×10^6 people within an 80 km radius.
- The nearest dwelling is a farm house located 1.3 km from the site. A milk cow eats from the pasture for seven months of the year and the garden is irrigated by water from the river.
- Drinking water and boating and swimming are the main uses of the river. Fish taken from the river are consumed at an average rate of 6.9 kg/yr.
- The site receives 61 cm (24 in.) of precipitation every year.
- The average annual wind speed is 14.8 km/hr (9.2 mph). Air releases are from a 10 m stack.
- The average dispersion parameters for the population are 2.2×10^{-9} (s/m³) for inhalation and 2.5×10^{-8} (s/m³) for food production.
- The river average annual flow rate is 1420 m³/s (50,000 cfs).

TABLE 3.4. Exposure Pathway Parameters for the Population at the Arid Western Site

Food Types	Holdup (days) ^(a)	Air Release Consumption (kg/yr or l/yr)	Yield (kg/m ²)	Growing Period (days)
Leafy Vegetables	14	3.0	1.5	90
Other Above-ground Vegetables	14	2.3	0.7	60
Potatoes	14	6.5	4.0	90
Other Root Vegetables	14	1.1	5.0	90
Berries	14	0.39	2.7	60
Melons	14	0.52	0.8	90
Orchard Fruit	14	3.3	1.7	90
Wheat	14	4.7	0.72	90
Other Grain	14	1.2	1.4	90
Eggs	4	21.0	0.84	90
Milk	4	30.0	1.3	30
Beef	20	28.0	0.84	90
Pork	20	28.0	0.84	90
Poultry	20	14.0	0.84	90

(a) Average time between harvest and consumption.

Pathway-specific parameters for the population residing within 80 km of the midwestern site are listed in Table 3.5. Exposure pathways from airborne releases include: external from air submersion or contaminated ground, and internal from inhalation and ingestion of farm products. Exposure pathways from liquid releases include: external from shoreline activities, swimming, or boating, and internal from ingestion of aquatic foods, ingestion of drinking water, and ingestion of irrigated farm products.

TABLE 3.5. Exposure Pathway Parameters for the Population at the Midwestern Site

<u>Food Types</u>	<u>Holdup (days)(a)</u>	<u>Air Release Consumption (kg/yr or l/yr)</u>	<u>Liquid Release Consumption (kg/yr or l/yr)</u>	<u>Yield (kg/m²)</u>	<u>Growing Period (days)</u>
Leafy Vegetables	14	30	5.0	1.5	90
Other Above-Ground Vegetables	14	23	3.8	0.7	60
Potatoes	14	65	11	4.0	90
Other Root Vegetables	14	11	1.8	5.0	90
Berries	14	3.9	0.65	2.7	60
Melons	14	5.2	0.87	0.8	90
Orchard Fruit	14	33	5.5	1.7	90
Wheat	14	47	7.8	0.72	90
Other Grain	14	12	2.0	1.4	90
Eggs	4	30	5.0	0.84	90
Milk	4	100	17	1.3	30
Beef	20	40	6.7	0.84	90
Pork	20	40	6.7	0.84	90
Poultry	20	20	3.3	0.84	90
Fish	24	--(b)	1.0	--	--
Drinking Water	48	--	88	--	--
Shoreline	24	--	4.0(c)	--	--
Swimming	24	--	2.0(c)	--	--
Boating	24	--	4.0(c)	--	--

(a) Average time between harvest and consumption.

(b) Two dashes indicate no data required for liquid pathway analysis.

(c) Hours per year exposure for the average member of the population.

3.3.3 Accumulated Radiation Dose Methodology

Accumulated radiation doses are calculated for the critical radionuclides identified in the ranking procedure. These doses are used to calculate the cost-effectiveness (in units of \$/man-rem of dose reduction) and total man-rem saved by using various effluent control technologies. The methodology used to calculate the accumulated radiation dose to the population is the same as defined for the Environmental Impact Statement for the Management of Commercially Generated Radioactive Waste.⁽¹³⁾ The exposure pathways and parameters discussed in Section 3.3.2 are used to calculate the accumulated radiation doses (ADFs) to the population. These ADFs are calculated for the midwestern site only, using a plant life of 40 years with 30 years of additional dose commitment and exposure to residual radionuclides in the environment.

3.4 NONRADIOACTIVE RELEASES

The generation of electrical energy from a nuclear source, in addition to the radioactive species released to the environment, also involves the release of nonradioactive substances that can be similar in quantity and kind to those from conventional industrial plants. To calculate these releases the annual throughput of the plant in kilograms of uranium and plutonium is multiplied by a release factor in units of kilograms of a given type of material released per kilograms of heavy metal processed by the plant each year. The annual throughputs for each plant in the fuel cycle are generated by ENGEN for a given nuclear generation scenario and stored on the data base. The releases are calculated by the ENMAT code which produces reports after interrogating the data base. Output reports list air and water effluent releases separately.

Dilution factors are used as a means of comparing the amount of the release with the toxic properties of the chemical substance being released. The dilution factor is defined as the amount of air or water that would be required to dilute the amount released so the resulting concentration would be the value specified by the standard.

3.4.1 Release Factor Calculation

Release factors are a ratio of kilograms of effluent to the throughput of the plant. Release factors for mining, milling, purification and conversion, and fuel fabrication are kilograms effluent per kilogram uranium input. For diffusion enrichment, the factor is computed as kilograms effluent per kilogram product. For BWR, PWR and reprocessing, the release factor is kilograms effluent per kilogram uranium charged to the reactor.

Each release factor is rated with a reliability on a scale of three: 1) engineering estimate, 2) laboratory measurement, and 3) plant experience.

The calculation of individual release factors is contained in Description of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles, PNL-2286.⁽¹¹⁾ These factors are based on information gleaned from plant descriptions and the literature.

3.4.2 Standards and Dilution Factors

Existing environmental standards for both gaseous and liquid effluents are used to assess the present and future needs for control of the nonradioactive effluents from the nuclear fuel cycle.

Three types of standards for gaseous effluents are used: 1) emission standards, 2) ambient air quality standards, and 3) toxicological standards. Federal standards are used where they exist. Emission standards have been set for four hazardous pollutants, and ambient air quality standards have been set for six other categories (SO_x , particulates, CO, oxidants, NO_x , and hydrocarbons). Toxicological standards are estimated where official guidelines do not exist.

Threshold limit values (TLVs), the official federal standards for industrial air, have been used to estimate acceptable ambient limits. The estimated standards are usually more stringent than the actual regulations. A pseudo-standard is calculated by the formula:

$$X_p = 1.65 \times 10^{-3} * \text{TLV}$$

where X_p is the permissible ambient concentration, and
TLV is the threshold limit value.

More detailed explanation of standards calculations for both air and water may be found in Appendixes B, C and D of BNWL-2219, Environmental Assessment Methodology for the Nuclear Fuel Cycle.⁽¹⁴⁾

Three types of standards are used for liquid chemical effluents: 1) federal guidelines and standards, 2) water quality criteria, and 3) toxicity data. Federal effluent guidelines have been developed for mining, milling and steam electric power generation. Water quality criteria are published by the EPA. Each effluent is rated by "most critical use," the most stringent standard for the seven categories of water uses. When water quality criteria are not available, they are estimated using toxicology standards. These standards consist of oral lethal dose concentrations (LD_{50}) for rats, and TL_m , the limit where an effect is first noted.

Dilution Factors

The magnitude of the dilution factor is a basis for comparing the chemicals, facilities, yearly variations, and total effluent discharged. A typical dilution factor for an airborne effluent from similar facilities is $1.0 \times 10^{11} \text{ m}^3/\text{yr}$. As a comparison, the volume of the atmosphere of the earth (at sea level density) is $4.3 \times 10^{18} \text{ m}^3$.

3.4.3 ENMAT

Nonradioactive effluent releases reports are generated with the ENFORM subsystem module ENMAT. ENMAT uses the mass flows from the data base file generated by ENGEN. These mass flows are converted to and reported as quantities of materials released from air or water for each plant in the fuel cycle. These releases may also be presented as a dilution factor in cubic meters of air or liters of water.

An important feature of ENMAT is its capability to rank the output. This is used to determine which materials are the worst offenders and in which plant and through what medium they occur. The subprogram RANK restructures the output generated by ENMAT in a user-defined hierarchy and re-reports all of the materials in the system or only those of concern. Certain inputs may also be ranked: release factors, dilution standards, effluent rates, and control efficiencies.

3.5 COST METHODOLOGY

To establish the economic impact of alternative means of controlling emissions from the nuclear fuel cycle, the base case cost of power is determined for each of the scenarios: stowaway, reprocessing without recycle, and full recycle. The contribution of each processing step to the total power cost is determined. This method relates the capital costs due to improvements in emission controls at a given process step in the fuel cycle to the total power cost involving all fuel cycle steps.

3.5.1 Unit Cost Methodology

The levelized unit costs are developed for each reference facility with its expected throughput. Unit cost is the sum of present value cash flows divided by the sum of present value throughputs. The cash flows are the required annual revenues that recover all expenses plus the return on equity required by the facility operator. Computer code UNICOST determines these required cash flows from estimates of facility capital cost and annual operating costs, then performs the levelized unit cost calculations.

Table 3.6 exhibits the financial parameters used in UNICOST for the three different types of facility ownerships: federal, electric utility, and private industry. Government ownership of repository, plutonium storage, and enrichment facilities is assumed, with electric utility ownership of reactors. Large private industries are the assumed owners of other facilities.

TABLE 3.6. UNICOST Assumed Financial Parameters

<u>Type of Ownership</u>	<u>Federal Government</u>	<u>Electric Utility</u>	<u>Private Industry</u>
Cost of Equity Capital	0	11%	12%
Cost of Debt	7%	7.5%	8%
Debt/Equity Ratio	0/100	50/50	25/75
Weighted Average Cost of Capital (after tax)	7%	7%	10%
Federal Tax Rate	0	48%	48%
State Tax	0	6.5%	6.5%
Investment Tax Credit		7%	7%

Facility costs were obtained from two studies recently completed at Pacific Northwest Laboratory. The facility costs for front-end processes were obtained from Fuel Cycle Cost Projections⁽¹⁵⁾ prepared for the U.S. Nuclear Regulatory Commission. The facility costs for reactor and back-end facilities were obtained from the Technology for Commercial Radioactive Waste Management⁽¹⁶⁾ prepared for U.S. Department of Energy. For the latter study capital cost estimates for new facilities were developed by Bechtel, Incorporated.⁽¹⁷⁾ The costs from those two studies are escalated to mid-1978 using "Producer Price Index - Industrial Commodities" from the U.S. Bureau of Labor Statistics.

The facility costs and resultant levelized unit costs are summarized in Table 3.7. Most of the entries in Table 3.7 represent a fully loaded facility and do not need additional comment. Three entries, however, are more complex and are commented on below.

Uranium mining and milling costs are divided by the industry into "Reserve," "Probable," "Possible," and "Speculative" categories. These divisions are further divided in three forward cost categories, \$10/lb, \$15/lb and \$30/lb. Capital cost for "Probables" is higher than for known reserves because of increased exploration costs. Costs for the "Possibles" and "Speculative" resources are assumed to increase due to even higher exploration costs. The estimated amount of uranium available in each category is exhibited in Table 3.8.⁽¹⁸⁾

A resource depletion algorithm is utilized to estimate the price of U_3O_8 . It is assumed that the price is set by the recovery cost of the highest category mined in any year, with the condition that no more than 1/15 of the uranium in any category will be mined in any year.

The cost for spent fuel storage and shipping is treated as a service which combines multiple facilities. It is assumed that 75% of spent fuel is stored in reactor basins, while 25% will be stored in independent spent fuel storage basins. The average shipping distance from a reactor to a storage basin, to a packaging plant, or to a reprocessing plant is assumed to be 1000 miles. The federal repository is assumed to begin operation in 1985.

TABLE 3.7. Unit Cost Parameters for Fuel Cycle Facilities or Services (mid-1978 dollars)

	Reference Plant Capacity or Throughput 2000 Ton/day	Capital Cost \$ Million	Annual Operation Cost \$ Million	Reference	Ownership	Unit Cost	Units
Uranium Mine/Mill							
Reserves							
\$10 Forward Cost		220.1	18.6	1	Private	28.05	\$/lb U ₃ O ₈
\$15 Forward Cost		124.5	13.2	1	Private	36.70	\$/lb U ₃ O ₈
\$30 Forward Cost		104.3	11.5	1	Private	55.00	\$/lb U ₃ O ₈
Probable Resources							
\$10 Forward Cost		378.4	18.6	1	Private	49.30	\$/lb U ₃ O ₈
\$15 Forward Cost		160.7	13.2	1	Private	47.70	\$/lb U ₃ O ₈
\$30 Forward Cost		128.0	11.5	1	Private	70.20	\$/lb U ₃ O ₈
UF ₆ Conversion	10,000 MTU/yr	80.3	22.6	1	Private	5.46	\$/kg U
Enrichment	8.75 million SWU/yr	4200	199.4	1	Government	100	\$/SWU
UO ₂ Fabrication	1500 MTU/yr	66.3	88.5	1	Private	93.90	\$/kg U
MOX Fabrication	400 MTHM/yr				Private		
Process		185	52	2		260.70	\$/kg HM
Waste Management		23.2	.8	2		17.02	\$/kg HM
Reactor	1200 MWe	960	26	2	Utility	23.16	mills/kWh
Spent Fuel Storage and Shipping							
Independent Spent Fuel Storage Basin	1000 MT/yr	172	3.5	2	Private		
Stowaway Scenario						51.70	\$/kg Discharge
Reprocessing Scenarios						30.00	\$/kg Discharge
Fuel Reprocessing	2000 MTHM/yr				Private		
Process		698	52	2		105.50	\$/kg HM
Waste Management		406	25.2	2		66.90	\$/kg HM
Transuranic Waste Shipping and Disposal							
Stowaway Scenario				2	Government	65.32	\$/kg Discharge
Reprocessing Scenarios				2	Government	45.40	\$/kg Discharge
Plutonium Oxide Shipping and Storage	200 MT	242	4.4	2	Government	2500	\$/kg Pu Recovered

TABLE 3.8. U.S. Uranium Resources - January 1, 1977
Thousands of Tons U_3O_8

<u>Cost Category</u>	<u>Reserves</u>	<u>Resources</u>		
		<u>Probable</u>	<u>Possible</u>	<u>Speculative</u>
\$10	250	275	115	100
\$15	160	310	375	90
\$30	270	505	1120	480

Similarly, the waste shipping and disposal is treated as a service combining multiple facilities. This cost includes spent fuel packaging (stowaway scenario only), transportation, and disposal. The average shipping distance from a reprocessing plant or packaging plant to a repository is assumed to be 1500 miles.

The reference waste management system for the reprocessing plant includes:

- high level waste vitrification
- packaging of fuel residue without treatment
- incineration of combustibles
- cement immobilization of liquid wastes
- recovery of iodine, ^{14}C , and krypton from dissolver off gas.

The reference waste management system for the MOX fabrication plant includes:

- incineration of combustibles
- cement immobilization of liquid wastes.

3.5.2 Power Cost Calculations

The unit costs, discussed in the preceding section, and the fuel cycle throughputs are used to determine a levelized power cost. The levelized power cost is the sum of the present value annual costs divided by the sum of the present value energy production. The annual costs are the unit costs multiplied by the throughputs, summed over all of the facilities and services exhibited in Table 3.7. Computer code ENCOST, an internal part of ENGEN, is used to calculate the power costs for the three scenarios considered in this study: stowaway, reprocessing without recycle, and reprocessing with full uranium and plutonium recycle.

The results of the power cost calculation are shown in Table 3.9. For the three scenarios, reactor costs account for 76 to 80 percent of the total power cost; fuel cycle costs account for the balance. Of the fuel cycle cost, U_3O_8 purchases range from 49 percent for the recycle scenario up to 63 percent for the stowaway scenario. Uranium purchase accounts for 10 to 15 percent of total power cost. In the reprocessing without recycle scenario, no credit was given for the sale of plutonium. The percentages of total power cost that can be attributed to each process in the nuclear fuel cycle are presented in Table 3.10.

TABLE 3.9. Power Cost Assigned to Process
(mills/kWh) (mid-1978 Dollars)

	<u>Stowaway</u>	<u>Reprocessing Without Recycle</u>	<u>Full Recycle</u>
U_3O_8	4.59	4.59	3.14
UF_6 Conversion	.15	.15	.13
Enrichment	1.72	1.72	1.60
UO_2 Fabrication	.44	.44	.37
MOX Fabrication			
Processing			.20
Waste Management			.01
Reactor	23.16	23.16	23.16
Spent Fuel Storage and Shipping	.19	.11	.11
Fuel Reprocessing			
Processing		.33	.33
Waste Management		.21	.21
Transuranic Waste Shipping and Disposal	.24	.16	.16
Plutonium Oxide Shipping and Storage		.06	
Total Nonreactor Power Cost	7.33	7.77	6.26
Total Power Cost	30.49	30.93	29.42

The sensitivity of total power cost to changes in unit cost for various processes is presented in Table 3.11. This table shows the change in power cost (mills/kWh) per dollar change in unit cost for any process. For example, if the price of U_3O_8 increases \$1, the power cost increases 0.074 mills/kWh in the no recycle scenario.

TABLE 3.10. Percentage of Power Cost Attributable to each Facility or Service

	<u>Stowaway</u>	<u>Reprocessing Without Recycle</u>	<u>Full Recycle</u>
U ₃ O ₈	15.1	14.8	10.7
UF ₆ Conversion	.5	.5	.4
Enrichment	5.6	5.6	5.4
UO ₂ Fabrication	1.4	1.4	1.3
MOX Fabrication			
Processing Without Waste Management			.7
Waste Management			<u>.03</u>
Total MOX Fabrication			.73
Reactor	76.0	74.9	78.7
Spent Fuel Storage and Shipping	.6	.4	.4
Fuel Reprocessing			
Processing Without Waste Management		1.1	1.1
Waste Management		<u>.7</u>	<u>.7</u>
Total Reprocessing		1.8	1.8
Transuranic Waste Shipping and Disposal	.8	.5	.5
Plutonium Oxide Shipping and Storage		.2	
Total Non-Reactor	24.0	25.1	21.3
Total ^(a)	100.0	100.0	100.0

(a) columns may not add to 100.0 due to rounding off.

TABLE 3.11. Change in Power Cost per Dollar Unit Cost (mills per kWh/Unit Cost)

	<u>Denominator Units</u>	<u>Stowaway</u>	<u>Reprocessing Without Recycle</u>	<u>Full Recycle</u>
U ₃ O ₈	\$/lb	.074	.074	.056
UF ₆ Conversion	\$/lb	.027	.027	.024
Enrichment	\$/SWU	.017	.017	.016
UO ₂ Fabrication	\$/kg U	.005	.005	.004
MOX Fabrication	\$/kg HM			.001
Reactor	Mills/kWh	1.0	1.0	1.0
Spent Fuel Storage and Shipping	\$/kg Discharged	.004	.004	.004
Fuel Reprocessing	\$/kg		.003	.003
Transuranic Waste Ship- ping and Disposal	\$/kg Discharged	.004	.004	.004
Plutonium Oxide Shipping and Storage	\$/kg PU Recovered		negligible	

A slightly different sensitivity of total power cost to changes in various unit costs can be obtained from Table 3.10. This table provides the percentage change in total power costs per percentage change in each process's unit cost. For example, uranium purchase represents 15.1% of power cost in the stowaway scenario, so an increase of 10% in uranium purchase price increases power cost by 1.51%. Some caution is required in the use of this percentage sensitivity. Compounding changes in process unit costs affects the denominator and thus the percentage calculation. Table 3.11 can be used for compounding changes, however.

The power cost partitioning (Tables 3.9 and 3.10) and the power cost sensitivity (Table 3.11) will be used in subsequent sections of this report to analyze effects of effluent control alternatives on power cost.

3.5.3 UNICST and ENCOST

UNICST (Levelized Unit Cost Generator) calculates the levelized unit cost of production from a single plant or facility. The levelized costs from a set of plants of the same type can be grouped together and averaged to create a system cost over a function of time.

Plant building schedules can also be simulated if required. Given a production demand schedule and a plant technology sequence (predictions as to size and availability of plants) UNICST can calculate when a plant should be built and specify the plant size as a function of time. A division that represents a single vendor's share of the market can also be imposed as a control on the building schedule.

In addition to the levelized unit cost of production and plant building schedules, certain annual monitoring flows are calculated:

- depreciation (straight line, sum of years digits, and double declining balance)
- bond interest
- property taxes and insurance costs
- state revenue taxes
- income and income taxes
- overall cash flow.

ENCOST calculates the overall levelized power costs from annual throughputs generated in ENGEN and the unit costs from UNICST. It contains a uranium cost model that establishes an annual U_3O_8 cost based upon the cumulative uranium demand and the cost structure of the uranium reserves. The price is determined by the highest cost category being mined, assuming that no more than a pre-set fraction of a given ore category can be depleted in a given year.

The levelized power costs are reported for each of the following fuel cycle steps:

- Mine (Underground and surface)
- Mill (Acid Leach, Alkali Leach)
- U_3O_8
- UF_6 Conversion
- Enrichment
- Fabrication (UO_2 and MOX)
- Reactor (PWR and BWR)
- Storage
- Spent Fuel Transportation
- Reprocessing
- Waste Disposal
- Pu Sales.

The impact on power cost from higher investments in improved emission control processes can be computed using the sensitivities in Table 3.11.

SECTION 3: REFERENCES

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4.0 RESULTS OF ANALYSIS

Projections of the effluents from the LWR fuel cycle were made using the ENFORM computer code for each of three fuel cycles for the 100-year operating period from 1977 to 2076. Rankings of the effluents are made in the following sections in an attempt to identify the twenty most important radioactive and nonradioactive effluents from the three fuel cycles.

For radioactive effluents, two possible ranking schemes are compared in Section 4.1. These ranking schemes are based on relative ranking factors calculated for each radionuclide. For nonradioactive effluents, a ranking scheme is discussed in Section 4.2. This ranking is based on calculated dilution factors designed to be an index of the general toxicity of each effluent species. Complete listings of the projected effluents, listed by effluent species, are given in Tables A.1 through A.3 for radioactive effluents, and Tables B.1 through B.3 for nonradioactive effluents. The effluents are listed in these tables for each type of facility operating in each fuel cycle, with annual release factors for air and water. The total release over the 100 year study period and the annual release in the year 2000 are also listed for each effluent species. Listings of the ranking factors calculated for the 100 year total effluents are given in Tables A.4 through A.6 for radioactive effluents and Tables B.4 through B.9 for nonradioactive effluents.

A discussion of the available effluent control methods which may reduce the impact of selected effluent species is also given in Section 4.1 for radioactive effluents and Section 4.2 for nonradioactive effluents. These discussions include cost and effectiveness information from the literature for the various effluent control systems considered.

For radionuclides, the man-rem savings expected from each effluent control technology are calculated based on unit accumulated population dose factors (APD) listed in Appendix C. These 70-year APDs are calculated for the radionuclides of concern identified by the ranking procedure. Tables C.1 through C.3, C.5 and C.6 contain pathway-specific listings of the APDs for air and liquid exposure pathways. The combined air pathway APDs are listed in Table A.4, and the combined liquid pathway APDs are listed in Table A.7.

Since effluent concentration limits are specified for radionuclides⁽¹⁾ in terms of concentration, in units of $\mu\text{Ci}/\text{mL}$, it is possible to compute dilution factors for radionuclides. It is not proper to make direct comparisons of radioactive and nonradioactive dilution factors for several reasons. A further discussion of this topic is found in Section 4.3.

4.1 PRINCIPAL RADIOACTIVE EFFLUENTS

Relative ranking factors are calculated for each radionuclide released to air or water to help rank the effluents from the three fuel cycle scenarios considered in this study. These ranking factors are calculated by the radiation dose methodology discussed in Section 3.3.2. While these ranking factors are based on the summation of the fifty year committed dose equivalents to the population from annual releases, they are not intended to be used as indicators of total population dose. This is because doses from annual releases over a facility lifetime do not account for the dose from radionuclides that accumulate in the environment from the previous years of plant operation. At the end of the plant life, the accumulated population dose for certain radionuclides, organs of reference, and exposure pathways may far exceed the population dose calculated using only the annual releases. However, it is felt that the relative ranking factors calculated in this study and listed in Tables A.4 through A.6, are useful in determining the top twenty radionuclides of concern for each fuel cycle.

Using the relative ranking factors for the radionuclides listed in Appendix A, two ranking schemes are next considered. In the first ranking scheme, the top twenty radionuclide effluents are determined in order of decreasing total body ranking factor. The top twenty radionuclides ranked by total body ranking factor for the three fuel cycle scenarios considered are listed in Tables 4.1 through A.3. In the second ranking scheme, the top twenty radionuclide effluents are determined by considering all 5 of the critical organs. The top twenty radionuclides for the three fuel cycles considered are listed in Tables 4.4 through 4.6 in order of decreasing ranking factor considering the 5 critical organs.

TABLE 4.1. Twenty Highest Total Body Relative Ranking Factors for the Stowaway Fuel Cycle

<u>Order</u>	<u>Nuclide</u>	<u>Plant</u>	<u>Relative Ranking Factor for Total Body^(a)</u>
1	^{138}Xe	BWR	4.97E+5
2	^{88}Kr	BWR	1.07E+5
3	^3H	PWR	6.29E+4
4	^{135}Xe	BWR	6.03E+4
5	^{87}Kr	BWR	5.73E+4
6	^{134}Cs	PWR	4.27E+4
7	$^{135\text{m}}\text{Xe}$	BWR	2.89E+4
8	^{133}Xe	PWR	2.74E+4
9	^{14}C	PWR	2.68E+4
10	^{137}Cs	PWR	1.75E+4
11	^{14}C	BWR	1.63E+4
12	^{133}Xe	BWR	1.33E+4
13	^3H	BWR	8.01E+3
14	^{131}I	BWR	5.48E+3
15	^{88}Kr	PWR	4.58E+3
16	^{60}Co	BWR	4.25E+3
17	$^{85\text{m}}\text{Kr}$	BWR	2.41E+3
18	^{222}Rn	U.G. MINE	2.38E+3
19	^{136}Cs	PWR	2.19E+3
20	^{137}Cs	BWR	1.94E+3

(a) These factors are shown for all radionuclide effluents from the stowaway fuel cycle in Table A.4 in Appendix A.

TABLE 4.2. Twenty Highest Total Body Relative Ranking Factors for the Reprocessing without Recycle Fuel Cycle

Order	Nuclide	Plant	Relative Ranking Factor for Total Body ^(a)
1	^3H	FRP	1.97E+6
2	^{138}Xe	BWR	4.97E+5
3	^{85}Kr	FRP	1.92E+5
4	^{14}C	FRP	1.40E+5
5	^{88}Kr	BWR	1.07E+5
6	^3H	PWR	6.29E+4
7	^{135}Xe	BWR	6.03E+4
8	^{87}Kr	BWR	5.73E+4
9	^{90}Sr	FRP	4.35E+4
10	^{134}Cs	PWR	4.27E+4
11	$^{135\text{m}}\text{Xe}$	BWR	2.89E+4
12	^{133}Xe	PWR	2.74E+4
13	^{14}C	PWR	2.68E+4
14	^{137}Cs	PWR	1.75E+4
15	^{14}C	BWR	1.63E+4
16	^{133}Xe	BWR	1.33E+4
17	^3H	BWR	8.01E+3
18	^{131}I	BWR	5.48E+3
19	^{88}Kr	PWR	4.58E+3
20	^{60}Co	BWR	4.25E+3

(a) These factors are shown for all radionuclide effluents from the reprocessing without recycle fuel cycle in Table A.5 in Appendix A.

TABLE 4.3. Twenty Highest Total Body Relative Ranking Factors for the Full U and Pu Recycle Fuel Cycle

<u>Order</u>	<u>Nuclide</u>	<u>Plant</u>	<u>Relative Ranking Factor for Total Body^(a)</u>
1	^3H	FRP	2.07E+6
2	^{138}Xe	BWR	5.01E+5
3	^{85}Kr	FRP	1.73E+5
4	^{14}C	FRP	1.18E+5
5	^{88}Kr	BWR	1.02E+5
6	^{135}Xe	BWR	7.93E+4
7	^3H	PWR	6.59E+4
8	^{87}Kr	BWR	5.42E+4
9	^{134}Cs	PWR	4.25E+4
10	^{90}Sr	FRP	3.90E+4
11	$^{135\text{m}}\text{Xe}$	BWR	2.89E+4
12	^{133}Xe	PWR	2.74E+4
13	^{244}Cm	FRP	2.60E+4
14	^{14}C	PWR	2.28E+4
15	^{137}Cs	PWR	1.76E+4
16	^{232}U	FRP	1.41E+4
17	^{14}C	BWR	1.35E+4
18	^{133}Xe	BWR	1.33E+4
19	^3H	BWR	8.45E+3
20	^{238}Pu	FRP	6.21E+3

(a) These factors are shown for all radionuclide effluents from the full U and Pu recycle fuel cycle in Table A.6 in Appendix A.

TABLE 4.4. Twenty Highest Relative Ranking Factors for All
Organs for the Stowaway Fuel Cycle

<u>Order</u>	<u>Nuclide</u>	<u>Plant</u>	<u>Relative Ranking Factor(a)</u>	<u>Critical Organ</u>
1	^{131}I	BWR	2.10E+6	Thyroid
2	^{138}Xe	BWR	5.04E+5	Lung
3	^{131}I	PWR	4.01E+5	Thyroid
4	^{14}C	PWR	1.34E+5	Bone
5	^{88}Kr	BWR	1.09E+5	Lung
6	^{133}I	BWR	9.24E+4	Thyroid
7	^{14}C	BWR	8.15E+4	Bone
8	^3H	PWR	6.29E+4	Total Body
9	^{135}Xe	BWR	6.14E+4	Lung
10	^{87}Kr	BWR	5.80E+4	Lung
11	^{134}Cs	PWR	4.27E+4	Total Body
12	$^{135\text{m}}\text{Xe}$	BWR	2.92E+4	Lung
13	^{133}Xe	PWR	2.88E+4	Lung
14	^{234}U	Aqueous Conversion	2.09E+4	Bone
15	^{137}Cs	PWR	1.94E+4	Bone
16	^{238}U	Aqueous Conversion	1.89E+4	Bone
17	^{230}Th	Acid Leach Mill	1.87E+4	Bone
18	^{133}Xe	BWR	1.40E+4	Lung
19	^{133}I	PWR	1.97E+4	Thyroid
20	^3H	BWR	8.01E+3	Total Body

(a) These factors are shown for all radionuclide effluents from the
stowaway fuel cycle in Table A.4 in Appendix A.

TABLE 4.5. Twenty Highest Relative Ranking Factors for All Organs for the Reprocessing without Recycle Fuel Cycle

Order	Nuclide	Plant	Relative Ranking Factor ^(a)	Critical Organ
1	^{129}I	FRP	6.28E+6	Thyroid
2	^{131}I	BWR	2.10E+6	Thyroid
3	^3H	FRP	1.97E+6	Total Body
4	^{14}C	FRP	7.01E+5	Bone
5	^{138}Xe	BWR	5.04E+5	Lung
6	^{131}I	PWR	4.01E+5	Thyroid
7	^{85}Kr	FRP	3.67E+5	Lung
8	^{90}Sr	FRP	1.91E+5	Bone
9	^{14}C	PWR	1.34E+5	Bone
10	^{88}Kr	BWR	1.09E+5	Lung
11	^{133}I	BWR	9.24E+4	Thyroid
12	^{14}C	BWR	8.15E+4	Bone
13	^{241}Pu	FRP	6.97E+4	Bone
14	^{238}Pu	FRP	6.45E+4	Bone
15	^3H	PWR	6.29E+4	Total Body
16	^{135}Xe	BWR	6.14E+4	Lung
17	^{87}Kr	BWR	5.80E+4	Lung
18	^{244}Cm	FRP	4.63E+4	Bone
19	^{134}Cs	PWR	4.27E+4	Total Body
20	$^{135\text{m}}\text{Xe}$	BWR	2.92E+4	Lung

(a) These factors are shown for all radionuclide effluents from the reprocessing without recycle fuel cycle in Table A.5 in Appendix A.

TABLE 4.6. Twenty Highest Relative Ranking Factors for all
Organs for the Full U and Pu Recycle Fuel Cycle

<u>Order</u>	<u>Nuclide</u>	<u>Plant</u>	<u>Relative Ranking Factor^(a)</u>	<u>Critical Organ</u>
1	^{129}I	FRP	6.72E+6	Thyroid
2	^{133}I	BWR	2.13E+6	Thyroid
3	^3H	FRP	2.07E+6	Total Body
4	^{232}U	FRP	6.95E+5	Lung
5	^{14}C	FRP	5.90E+5	Bone
6	^{138}Xe	BWR	5.08E+5	Lung
7	^{244}Cm	FRP	4.36E+5	Bone
8	^{131}I	PWR	4.06E+5	Thyroid
9	^{85}Kr	FRP	3.32E+5	Lung
10	^{238}Pu	FRP	2.47E+5	Bone
11	^{90}Sr	FRP	1.71E+5	Bone
12	^{241}Pu	FRP	1.58E+5	Bone
13	^{14}C	PWR	1.14E+5	Bone
14	^{88}Kr	BWR	1.03E+5	Lung
15	^{133}I	BWR	9.26E+4	Thyroid
16	$^{135\text{m}}\text{Xe}$	BWR	8.07E+4	Lung
17	^{14}C	BWR	6.73E+4	Bone
18	^3H	PWR	6.59E+4	Total Body
19	^{87}Kr	BWR	5.48E+4	Lung
20	^{134}Cs	PWR	4.24E+4	Total Body

(a) These factors are shown for all radionuclide effluents from the full U and Pu recycle fuel cycle in Table A.6 in Appendix A.

Summaries of the important radionuclides using these two ranking schemes are shown in Tables 4.7 and 4.8. While there are other possible ranking schemes using the relative ranking factors listed in Appendix A, no further effort is made in this study beyond a comparison of the two schemes selected.

Currently available effluent control technologies are discussed in the following sections. Cost-effectiveness factors (in units of \$/man-rem of dose reduction) and estimated man-rem savings for specific radionuclides with specific effluent control technologies are based on accumulated population dose factors (APDs) using the dose model discussed in Section 3.3.3. Listings of the APDs for unit annual releases to either air or water at the reference sites used in this study are found in Appendix C. For each effluent control technology, the Ci/year savings per plant is multiplied by the APD to arrive at the total man-rem savings over a 70 year period. The total cost of each technology is divided by the man-rem savings, giving units of \$/man-rem savings, for cost-effectiveness comparison.

The annual release generally follows the energy generation curve with some time lag due to inherent delays as material moves through the fuel cycle. However, the composition of irradiated material being processed can vary significantly with time. Therefore, a given effluent's maximum release may occur at a different time than that at which the maximum amount of material is being processed. An extreme example of this is illustrated in Figure 4.1, which shows the ^{232}U dose and the amount of fuel reprocessed each year. Peak reprocessing is reached in 2017, but the peak in the ^{232}U population dose commitment from annual releases does not come until 2037 -- twenty years later. This is because multi-recycled uranium contains ^{232}U in greater proportion than once-through uranium. As this ^{232}U material reaches reprocessing the ^{232}U dose increases even though the total amount reprocessed is declining.

The twenty effluents with the highest relative ranking factors are discussed in the following sections, beginning with releases from uranium mining and ending with releases from the reprocessing plant. Table 4.7 illustrates the reordering of releases for all three scenarios by the fuel cycle that emits them; isotopes of the same element are collected together. The discussions identify the sources of the release and suggest alternative control strategies that would reduce the amount of the effluent released.

TABLE 4.7. Summary of the Twenty Highest Relative Ranking Factors Based on Total Body

<u>Plant</u>	<u>Element Or Nuclide</u>	<u>Ranking Order^(a)</u>		
		<u>Stowaway</u>	<u>No Recycle</u>	<u>Full Recycle</u>
U.G. Mine	^{222}Rn	18	-- (b)	--
PWR	^3H	3	6	7
	Cs	6,10,19	10,14	9,15
	Xe	8	12	12
	Kr	15	19	--
	^{14}C	9	13	14
BWR	^3H	13	--	19
	^{60}Co	16	20	--
	Xe	1,4,7,12	2,7,11,16	2,6,11,18
	Kr	2,5,17	5,8	5,8
	^{131}I	14	--	--
	^{14}C	11	15	17
	^{137}Cs	20	--	--
FRP	^3H	--	1	1
	^{90}Sr	--	9	10
	Kr	--	3	3
	^{14}C	--	4	4
	^{244}Cm	--	--	13
	^{232}U	--	--	16
	^{238}Pu	--	--	20

(a) See Tables 4.1, 4.2 and 4.3 for the individual rankings within each fuel cycle.

(b) Two dashes indicate that the radionuclide listed is not in the top twenty for the fuel cycle shown.

TABLE 4.8. Summary of the Twenty Highest Relative Ranking Factors Based on all 5 Critical Organs

Plant	Element Or Nuclide	Ranking Order ^(a)		
		Stowaway	No Recycle	Full Recycle
Acid Leach Mill	²³⁰ Th	17	--(b)	--
	²³⁴ U	14	--	--
	²³⁸ U	16	--	--
Conversion	³ H	8	15	18
	¹⁴ C	4	9	13
	I	3,19	6	8
PWR	Cs	11,15	19	20
	Xe	13	--	--
	³ H	20	--	--
BWR	¹⁴ C	7	12	17
	Kr	5,10	10,17	14,19
	I	1,6	2,11	2,15
FRP	Xe	2,9,12,18	5,16,20	6,16
	³ H	--	3	3
	¹⁴ C	--	4	5
	Kr	--	7	9
	⁹⁰ Sr	--	8	11
	¹²⁹ I	--	1	1
	²³² U	--	--	4
	²³⁸ Pu	--	14	10
	²⁴¹ Pu	--	13	12
	²⁴⁴ Cm	--	18	7

(a) See Tables 4.4, 4.5, and 4.6 for the individual rankings within each fuel cycle.

(b) Two dashes indicate that the radionuclide listed is not in the top twenty for the fuel cycle shown.

FIGURE 4.1. Population 50-year Dose Commitments from Annual Releases of ^{232}U from the FRP and from the Entire Full Recycle Scenario

4.1.1 Radon-222 Released from the Underground Mine

The only radionuclide to appear on the list of the twenty highest relative ranking factors ordered by decreasing total body factor that is not produced by irradiation in a reactor is ^{222}Rn released from underground mines. The release factor used in calculating the release is based upon a generic release of 15.9 Ci/ton U_3O_8 from mine vents and 0.8 Ci/ton U_3O_8 from above-ground sources.⁽²⁾ Reference 2 lists the factors that influence the amount of ^{222}Rn in vent air; the principal factors are the amount of mine wall exposed and the amount of water in the mine which comes from areas of high ^{226}Ra content.

Operating practices that can reduce the ^{222}Rn emission are:

- bulkheading to stagnate areas
- backfilling with barren sand (sand free of ^{226}Ra)
- coating walls with gas impermeable materials
- minimizing release of mine water by better pumping and draining.

Most of these operating practices will vary greatly in applicability to specific mines. The releases calculated assume a generic mine with above-ground waste rock and ore piles at the sizes they would have halfway through the life of the mine. Doses are calculated on the basis of a single yearly release during mining activity. No provision is made for the potential continued production and release of ^{222}Rn after the mine ceases operations. This is a cause of current concern about uranium mine and mill radioactive emissions.

4.1.2 Tritium Released from the PWR

There are three main sources of tritium in a PWR:⁽³⁾

1. Ternary fission in the fuel rods (58%)
2. Dissolved boron in the coolant (21%)
3. Dissolved lithium in the coolant (21%).

Another often neglected source is lithium impurity in the fuel pellet. Levels of 1 to 2 ppm of natural lithium in the pellet can produce ^3H from the n, α reaction, which is equivalent to ternary fission sources.

The release factor used for tritium is based on a generic PWR release of 1300 Ci/yr. Approximately 300 Ci/yr are in the form of an airborne release and 1000 Ci/yr are released as liquid effluent. The present practice is to release ^3H from the plant to minimize occupational exposure to plant personnel and yet stay within effluent concentration limits.

Several methods of reducing tritium emission have been proposed. The first of these involves the use of lithium with a high percentage of the ^7Li isotope. This would lower the production of tritium from the n, α reaction on ^6Li , which is the source of about 21% of the total tritium produced.⁽³⁾ The elimination of this source could reduce the 1300 Ci/yr effluent on the generic PWR by 270 Ci/yr at a cost of \$31,000/yr.⁽⁴⁾ This assumes a cost of \$3,400/kg for enriched lithium at an annual usage of 9 kilograms. The cost effectiveness of this method would therefore be in the \$115/Ci range.

Another proposed change that would eliminate the largest source of tritium would be to use tritium getters in the fuel rods.⁽⁵⁾ The tritium in the fuel rods is formed by ternary fission of the fuel nuclides and from lithium impurity. Tritium from inside the fuel rod diffuses through the clad and escapes directly from leaking fuel rods into the primary coolant. Tritium getters are proprietary zirconium-base alloys that have been tested in BWRs. Assuming that 58% of the annual release rate of 1300 Ci is from the fuel rods and assuming that the tritium getters are 50% efficient, 380 Ci/yr could be eliminated. This would cost approximately \$15,200/yr, or \$40/Ci.⁽⁶⁾

The use of tritium getters in the fuel rod would merely move the site of possible release from the reactor to the spent fuel storage facility or to the FRP. The ultimate advantage, however, is that when the tritium is retained within the fuel rod it would be easier to concentrate for special treatment such as the voloxidation process at the FRP.

Many PWRs use B_4C as control rod material. Use of a silver-indium-cadmium alloy would reduce tritium releases by 144 Ci/yr at an annual cost of \$10,000/yr⁽⁶⁾ for a cost effectiveness of \$70/Ci.

The last type of removal would be to continuously remove tritium from the primary coolant by water electrolysis, solvent extraction or laser

photo-chemistry.^(7,8) Cost estimates range from \$0.34 to \$3.40/gal of tritiated water processed.^(a) This would cost approximately \$36.30 to \$363.00/Ci, assuming 2.5 $\mu\text{Ci}/\text{cm}^3$.

Table 4.9 summarizes the estimates of cost effectiveness for alternative control measures and the maximum percentage reduction in ^3H releases that could be attained.

TABLE 4.9. Comparative Cost Effectiveness of Tritium Reduction Methods

Method	Mills/kWh	Cost per Curie Reduced (\$/Ci)	Cost per man-rem Total Body (\$/man-rem)	Maximum Reduction (%)
Enriched Lithium	0.04	115	48,300	21
Tritium Getters in the Fuel Rod	0.002	40	16,800	29
Primary Coolant Scrubbing	0.001 - 0.012	36-363	15,100 - 151,000	21
Use of Ag-In-Cd in Place of B_4C Control Rods	0.001	70	29,400	11

4.1.3 Cesium Released from the PWR

Cesium is released from PWRs in both gaseous and liquid effluents. Three cesium isotopes are included in this release: ^{134}Cs , ^{136}Cs , and ^{137}Cs . The air release factors used in computing the total release are: 0.0016 Ci/yr for ^{134}Cs , 0.00295 Ci/yr for ^{136}Cs and 0.00167 Ci/yr for ^{137}Cs , or 0.00624 Ci/yr for all three isotopes.⁽⁹⁾ Liquid release factors are based on the following assumed liquid releases for three isotopes: 0.13 Ci/yr for ^{134}Cs , 0.062 Ci/yr for ^{136}Cs and 0.10 Ci/yr for ^{137}Cs for a total of 0.292 Ci/yr.⁽⁹⁾

The cesium isotopes originate as fission products in the fuel rods. Their appearance as effluents depends on the number of fuel rods in the core and in spent fuel storage having defective clad, and in the number of steam generator tube leaks that cause primary coolant to leak into the secondary coolant system. The amount of cesium released as a liquid effluent is fifty times as much as the amount released as a gas.

(a)L. L. Burger, Pacific Northwest Laboratory, Richland, WA, personal communication, June 1976.

Gaseous Effluent Control

The gaseous release points are listed in Table 4.10. Releases could be reduced by augmentation of the filter systems. Additional filters will be most cost effective when applied to the subsystems that are the largest contributors to the overall release versus the flow rate of the subsystem, since capital and operating costs of filters are proportional to the flow rate. An additional HEPA filter of sufficient capacity to filter the gas collection header system, the vent collection header system, and the containment purge exhaust would reduce releases from the primary coolant system by processing at 49,125 cfm. An additional HEPA filter on the air ejector vent exhaust to handle carry-over of activity into the secondary coolant system from steam generator tube leaks would have to process an additional 59 cfm. These increases in filtration would process a total of 49,184 cfm. Assuming a capital cost of \$18 per cfm and annual operating cost of \$1.30/cfm, UNICOST computes a levelized unit cost of 0.03 mills/kWh for the additional HEPA filters on PWRs. This expense over the assumed 40-year life of the plant would be $\$8.22 \times 10^6$. The exposure reduction over the plant life would be 4.03 man-rem. The cost benefit ratio is $\$2 \times 10^6$ man-rem. The process is not feasible economically in terms of the benefit derived.

TABLE 4.10. Release of Cesium Gas from PWRs⁽⁶⁾

<u>System</u>	<u>Present Treatment</u>	<u>Flow Rate m³/day(cfm)</u>	<u>Plant Exit Point</u>
Gas collection header	HEPA filter	1.0E3 (2.5E1)	Containment building exhaust
Vent. collection header	HEPA filter	4.1E3 (1.0E2)	Containment building exhaust
Fuel and auxiliary building vent. exhaust	Prefilter plus HEPA filter	4.3E6 (1.1E5)	Containment building exhaust
Containment purge exhaust	Prefilter and HEPA filter	2.0E6 (4.9E4)	Containment building exhaust
Turbine building vent. exhaust	None	4.1E7 (1.0E6)	Turbine building vent. exhaust
Air ejector vent. exhaust	Prefilter, HEPA filter, deep bed charcoal filter, final HEPA filter	2.4E3 (5.9E1)	Turbine building vent.
Steam packing exhaust	None	5.0E4 (1.2E3)	Turbine building vent.
		Total Flow Rate	
		4.7E7 (1.2E6)	

Liquid Effluent Control

The primary source of radioactive cesium liquid effluents is expected to be the clean radioactive effluent treatment system. This system terminates in the treated effluent monitor tanks. The contents of these tanks can either be recycled or discharged. If recycling is chosen because the effluent liquid is too radioactive, the liquid is ultimately evaporated, packaged and shipped offsite.

This system presents a good deal of flexibility. If the cesium activities at a PWR site were to become too high, then more evaporated liquid effluent could be sent offsite in waste drums at some increased cost. It is unlikely that an additional investment in a new treatment system would be more cost effective than recycling more clean radwaste in the present system.

4.1.4. Xenon and Krypton Released from the PWR

The ultimate source of noble gas (primarily ^{133}Xe and ^{88}Kr) released from PWRs is leaking or failed fuel rods. When the fuel cladding is breached, the fission product noble gases can leak into the primary coolant system. Steam generator tube leaks provide a pathway into the secondary coolant system, where the bulk of the release is from the turbine condenser air ejector exhaust.

The major sources of ^{88}Kr and ^{133}Xe are shown in Table 4.11.⁽⁹⁾ The release factors are based on an assumed annual release of 7.81 Ci for ^{88}Kr and 3,660 Ci for ^{133}Xe .⁽⁹⁾ These releases assume that 0.2% of the fuel rods are

TABLE 4.11. Sources of ^{88}Kr and ^{133}Xe

Source	Total Release (%)	
	^{88}Kr	^{133}Xe
Gas Collection Header System	0	33
Coolant Purge Exhaust	5.6	49.1
Turbine Condenser Air Ejector Exhaust	35.5	6.7
Fuel Auxiliary Vent. Exhaust	58.9	11.2

leaking. Periodic operational cladding failures of up to 1% are assumed in calculating emissions from the chemical volume control system in the primary loop. A nominal three-day retention period in the holdup tanks is also assumed.

The isotopes ^{88}Kr and ^{133}Xe have half-lives of 2.8 hours and 5.27 days respectively. These half-lives are short enough so that extending the retention time in the holdup tanks would be an adequate means of reducing the emission of these particular isotopes.

4.1.5. Carbon-14 Released from the PWR

The primary sources of ^{14}C in 1000 MWe PWRs are the fuel and the coolant. The sources of ^{14}C are shown below.

<u>Source</u>	<u>Production Rate Ci/yr</u>
Fuel $^{17}\text{O}(\text{n},\text{d})^{14}\text{C}(0.037\%)$	4.1
Fuel $^{14}\text{N}(\text{n},\text{p})^{14}\text{C}(20 \text{ ppm})$	17.3
Coolant ⁽¹¹⁾ $^{17}\text{O}(\text{n},\text{d})^{14}\text{C}$	8.0
Coolant $^{14}\text{N}(\text{n},\text{p})^{14}\text{C}^7$	<u>0.09</u>
	29.49

The release of ^{14}C occurs in gaseous streams; the release factor for stack releases was based on a 8.8 Ci/yr release from the generic plant. Amounts released from several sources are listed below:

<u>Pathway</u>	<u>Annual ^{14}C Release Ci/year</u>
Gaseous radwaste treatment system	7.0
Condenser steam-jet air ejector off gas vent	0.11
Steam generator blowdown tank vent	4.5×10^{-4}
Turbine gland seal condenser exhaust	9.2×10^{-7}
Fuel handling building ventilation	0.69
Containment building purge exhaust	1.0
Auxiliary building ventilation	8.0×10^{-4}
Turbine building ventilation	<u>1.8×10^{-3}</u>
Total annual ^{14}C release	8.80

The EPA study by Bray et al.⁽¹¹⁾ identified caustic scrubbing as the most promising technique for removing CO₂, which carries most of the ¹⁴C, from the sources listed above. Various other techniques were considered including fixed bed absorption with molecular sieves, solvent extraction in a fluorocarbon solvent, ethanolamine scrubbing, wet scrubbing, lime bed absorption, and cryogenic distillation.

The proposed caustic scrubbing system, which consists of three different design options, is capable of 90%, 99.0% or 99.9% removal of ¹⁴C. The system scrubs the radwaste off gas, which is the source of 80% of the ¹⁴C effluent. For the 99.9% removal design the overall plant reduction of ¹⁴C release would be on the order of $.999 \times .80 = .799$, or nearly 80%, assuming that all other sources in the plant are untreated.

The capital costs associated with this system are \$140,000 for the caustic scrubber itself plus a \$800,000 recombiner unit required to oxidize all gaseous carbon compounds to CO₂ prior to the caustic scrubbing step. Total capital costs are, therefore, \$940,000. Annual operating costs are estimated at \$116,000. These costs are in 1976 dollars and include no contingency factor. Assuming 35% for contingency and 14% for escalation, the capital cost is \$1,450,000 and the annual operating cost is \$179,000 in 1978 dollars.

The incremental power cost for adding ¹⁴C scrubbers to PWRs is 0.06 mills/kWh. The total cost over 100 years is \$6.2 billion. The most critical dose for ¹⁴C is the bone dose. The scrubber would result in a saving of 784 man-rem over the 70-year period covered by the APD factor. The capital and operating cost over this period would be \$16.4 million. The cost benefit ratio is \$20,969/man-rem and the total body dose reduction would cost \$104,850/man-rem.

4.1.6 Tritium Released from the BWR

The four principal sources of tritium in BWRs are:

1. Ternary fission in fuel rods
2. Boron in the control blades
3. Deuterium activation of coolant water
4. ⁶Li (n,α) ³H from lithium impurities in the fuel pellet.

The release factors used were taken from the FSAR for the reference BWR.⁽¹²⁾ The releases calculated using the GALE code from draft Regulatory Guide 1.10 were 12 Ci/yr to liquid and 68 Ci/yr to air. Table 4.12 displays the amounts of tritium released in liquid from BWRs from 1969 to 1972. Though the actual history shows considerable variation in the liquid release from year to year and from plant to plant, the calculated value of 12 Ci/yr is in the range of actual liquid releases. It is generally agreed⁽¹³⁾ that releases of tritium in liquid effluent are larger than releases in gas; however, the calculated value of 68 Ci/yr for gaseous releases was chosen for conservatism even though it exceeds the assumed liquid release rate of 12 Ci/yr.

TABLE 4.12. BWR Tritium Release History
(Liquid Effluent)

<u>Plant</u>	<u>Power</u>	<u>1969</u>	<u>1970</u>	<u>1971</u>	<u>1972</u>
Oyster Creek	640	5	22	22	62
Nine Mile Pt.	640	<1	20	12	28
Millstone - 1	685			13	20
Dresden - 1	200	6	5	9	43
Dresden 2 & 3	800(ea)		31	9	26
La Crosse ^(a)	50	25	20	91	121
Monticello	545			<1	<1
Big Rock Point	70	28	53	10	10
Humboldt Bay	65	5	7	<7	5
Pilgrim	669				4
Vermont Yankee	540				0

(a) Fuel rods at La Crosse are stainless steel clad; fuel rods at other plants are clad with zirconium.

Liquid releases of tritium come from the liquid radwaste treatment system. This system includes filters and demineralizers that remove dissolved fission and activation products, but do not remove tritium.

Tritium is released in air from the turbine condenser air ejector partly in the form of HT, which is not affected by the off-gas treatment system unless

a recombination step for radiolytic hydrogen and oxygen is included. If this step is included, then the HT is converted to HTO, which is condensed. Most of the air release, however, is in the form of uncondensed HTO humidity. This humidity is released through ventilation of spaces within the plant that are subject to process steam and water leakage.

Reduction in emissions of tritium may be accomplished using hydrogen-deuterium-tritium absorbing alloys, called tritium getters. These zirconium-based alloys have been tested in reactors, and are available in sheet or chip form. With a reduction of 50% in the tritium formed through ternary fission in the fuel rods, a saving of at most 40 Ci/yr could be achieved at a cost of ~ \$27,000/yr.^{(a)(6)} This would cost \$690/Ci or \$98,600/man-rem. Other forms of reducing tritium emissions such as primary coolant scrubbing of tritium are even more expensive.^(7,8) It does not appear warranted to apply specific tritium control techniques to BWRs, especially because tritium formation rates are lower for BWRs than for PWRs. However, an increase in the number of leaking fuel rods and B₄C control blades can drastically increase the amount of tritium formed, so that close monitoring of tritium effluents should be maintained.

4.1.7 Particulate Releases of ⁶⁰Co, ¹³¹I, ¹³⁷Cs from the BWR

Particulate releases from BWRs are primarily composed of ⁶⁰Co, ¹³¹I and ¹³⁷Cs. Although the particulates are released to air, some liquid releases contain these isotopes. The calculated releases are based on the following assumed releases rates from the generic plant:⁽¹²⁾

	<u>Release Rates (Ci/yr)</u>	
	<u>Air</u>	<u>Liquid</u>
⁶⁰ Co	0.013	0.000063
¹³¹ I	0.46	0.00073
¹³⁷ Cs	0.0063	0.002

(a) Iacovino assumes cost of gettering material is proportional to the weight of fuel in the core.

The sources of the particulate releases within the plant are listed in Table 4.13. The largest source is the reactor building. The present filter system in the reactor building consists of a prefilter, a HEPA filter and a charcoal absorber. The most cost effective way to reduce particulate emissions might be to install an additional HEPA filter, with a capacity of 95,000 cfm, in the reactor building ventilation system. This would reduce ^{60}Co emission by 78%, ^{131}I emission by 41% and ^{137}Cs emission by 89%. On the basis of capital cost at \$18/cfm and annual operating and maintenance of \$1.30/cfm this filter would require a capital expenditure of \$1.7 million and annual operating cost of \$120,000. UNICOST calculated a unit cost of 0.05 mills/kWh for the additional filter system. A reduction in total body dose of 27.3 man-rem is achieved at a cost of \$13.7 million. This is \$500,000/man-rem for total body; however, the highest critical organ dose is to the thyroid from ^{131}I . The cost effectiveness of the system is \$4843.0/man-rem in terms of the critical organ dose.

TABLE 4.13. BWR Particulate Release Points⁽¹³⁾

	Flow rate, l/min (cfm)	Percent of Total Release		
		^{60}Co	^{131}I	^{137}Cs
Reactor Building	2,690,000 (95,000)	77.7	40.9	88.8
Radwaste Building	2,320,000 (82,000)	6.9	0.1	1.6
Turbine Building	7,530,000 (266,000)	15.4	41.6	9.6

4.1.8 Xenon and Krypton Released from the BWR

The main source of noble gases released from the BWR plant is failed or leaking fuel rods in the core. Fission product noble gases escape through defects and holes in the cladding and travel out of the core following the steam flow paths. Since 99.9% of the reactor steam flow passes through the turbine, the irradiated noble gases end up in the steam jet air ejector system, which maintains the condenser vacuum. The basic noble gas treatment system is a simple 30-minute holdup on the air ejector off gas. This allows the short-lived isotopes to decay before release through the stack.

The releases used for the ranking calculation are shown in Table 4.14. These releases are based on the assumed 30-minute holdup time. This holdup time reduces the zero time radioactivity by a factor of approximately 25.⁽¹⁴⁾

TABLE 4.14. Annual Noble Gas Release Rates from the BWR

<u>Isotope</u>	<u>Annual Release Rate Ci/yr</u>	<u>Half Life</u>
^{138}Xe	1,400	14.2 min.
^{88}Kr	240	2.84 hr.
^{135}Xe	1,100	9.1 hr.
^{87}Kr	200	76.0 min.
^{135m}Xe	740	15.3 min.
^{133}Xe	270	5.25 days

Four processes to reduce noble gas emissions have been considered:⁽¹⁵⁾

1. Ambient temperature absorption on activated charcoal. The advantages of this system are that it is relatively simple to operate and large scale experience has been gained at the Gundremmingen BWR.⁽¹⁴⁾ Disadvantages include the explosion and fire hazard and the large volume beds required (10 MT of charcoal).
2. Low temperature charcoal absorption. In this process the large volume of charcoal absorption beds required for the ambient temperature absorption process is greatly reduced; however, high refrigeration costs are incurred. This system is commercially available.⁽¹²⁾ Holdup times on the order of days to weeks are available depending upon the operating flow rates. These times are more than sufficient to reduce all of the short-lived isotopes in the top twenty list to an acceptable level. Dilution factors in the range of 100 to 10,000 are quoted⁽¹⁴⁾ for design basis mixes of Xe and Kr isotopes treated in these systems.
3. Cryogenic distillation. This process has a high technological level of development because it is used in the liquid air industry. Pilot installations based on this technology have operated successfully.⁽¹⁶⁾ The

system is more successful for long-lived isotopes such as ^{85}Kr than for the short-lived isotopes on the list of twenty most important nuclides. Advantages to the process are its low, well-defined capital costs and high reliability. Disadvantages are the potential zone explosion hazard and the high efficiency gas cleanup required.

4. Fluorocarbon adsorption. Although up to 1974 this process had not been tested at a nuclear facility, fluorocarbon absorption offers low refrigeration costs, low solvent costs, a very low explosion hazard and reduced process gas pre-treatment. Disadvantages include high system pressures (300 to 400 psig) with high leak potential, low product purity and some corrosion hazard.

Since most of the systems discussed above have sufficient holdup time to remove the short-lived noble gas isotopes that appear on the list of twenty most important radioactive effluents, selection of one of these processes must be based on its ability to control other radionuclides. The low-temperature activated charcoal system is designed to reduce the release of the longer-lived noble gas isotopes such as ^{85}Kr ; it appears to be the most commercially acceptable alternative to the 30-minute hold-up system used as the basis for the release calculation. Installation of augmented control systems will likely remove the short-lived noble gas isotopes from the list of most significant effluents.

4.1.9 Carbon-14 Released from the BWR

The primary sources of ^{14}C in 1000 MWe are the same as those listed for the PWR.⁽¹¹⁾ Sources and production rates are:

<u>Source</u>	<u>Production Rate Ci/yr</u>
Fuel $^{17}\text{O}(\text{n},\text{d})^{14}\text{C}(0.037\%)$	4.1
Fuel $^{14}\text{N}(\text{n},\text{p})^{14}\text{C}(20 \text{ ppm})$	17.3
Coolant $^{17}\text{O}(\text{n},\text{d})^{14}\text{C}$	9.2
Coolant $^{14}\text{N}(\text{n},\text{p})^{14}\text{C}(1 \text{ ppm})$	<u>0.26</u>
	30.86

Carbon-14 is primarily a gaseous effluent; the release factor for stack releases was based on a 9.064 Ci/yr release from the generic plant. Curies of ^{14}C released and the percent of curies from each source⁽¹⁷⁾ are shown below:

Pathway	Annual ^{14}C Release Ci/yr	% of Total
Condenser steam-jet air ejector off gas	9.0	99.3
Turbine gland seal condenser exhaust	0.015	0.2
Reactor building purge exhaust	0.011	0.1
Turbine building ventilation	0.038	0.4
Radwaste building ventilation	6.04×10^{-6}	0.0
Total annual release of ^{14}C (Ci/yr)	9.064	100.0

The EPA study by Bray et al.,⁽¹¹⁾ identified caustic scrubbing as the most promising technique for removing CO_2 from the sources listed above. Various other techniques were considered including fixed bed absorption with molecular sieves, solvent extraction in a fluorocarbon solvent, ethanolamine scrubbing, wet scrubbing, lime bed absorption and cryogenic distillation.

The proposed caustic scrubbing system, which consists of three different design options, is capable of 90%, 99% or 99.9% removal of ^{14}C respectively. If the system were installed on the condenser steam-jet air ejector off gas, which is responsible for 99.3% of the BWR release, then an overall plant ^{14}C release reduction of $.993 \times .999 = .992$, or about 99%, could be achieved.

The capital costs for caustic scrubbing are estimated to be \$140,000. Operating costs are put at \$109,000/yr. These costs are in 1976 dollars and include no contingency factor. Assuming 35% contingency and escalation factor of 14%, the capital cost is \$216,000 and annual operating cost is \$168,000 in 1978 dollars.

The incremental power cost for adding ^{14}C scrubbers to BWRs is 0.03 mills/kWh. At this incremental cost, the forty-year cost of the system would be \$8.22 million. The critical dose is to the bone. The system would save 1,220 man-rem in forty years of operation, for a cost benefit of \$6,480/man-rem. The total body benefit is 250 man-rem for a ratio of \$32,900/man-rem.

4.1.10 Tritium Released From Fuel Reprocessing Plant

Tritium released from the fuel reprocessing plant tops the list of the twenty most important nuclides released from both of the reprocessing scenarios. About seventy percent of the tritium contained in the spent fuel is released out the main stack.⁽¹⁷⁾ This release factor is derived from the following values:

- 1.8×10^{-2} Ci/sec released⁽¹⁸⁾
- 4.52×10^{-2} g tritium/MTU (ORIGEN code, chain 10)
- 5 MT/day plant throughput.

About 60% of the 100-year whole body dose from the entire fuel cycle is from the tritium released.

A tritium removal system was designed for this study by Bechtel Inc.⁽¹⁹⁾ Tritium is removed from spent fuel at the head end of reprocessing by the voloxidation process developed at the Oak Ridge National Laboratory. The tritium gas is evolved at the voloxidation furnace and later recovered as tritiated water. This method will provide a dilution factor of 100 for tritium.⁽²⁰⁾

The capital cost of voloxidation is estimated at \$42 million in 1976 dollars, which escalates to \$48 million in 1978 dollars. The annual operating cost was estimated at \$265,000 in 1973 dollars,⁽²⁰⁾ which corresponded to a much lower capital cost estimate of \$2.7 million. Assuming an annual maintenance cost of 4% of capital, and then escalating the operating estimate (net of maintenance) to 1978 and adding back the maintenance cost (4% of \$48 million), an annual operating and maintenance cost of \$21 million is estimated.

As calculated by UNICOST, (described in section 3.5.1), the addition of the voloxidation process results in an incremental reprocessing cost of \$6.60 per kg reprocessed, or an incremental power cost of 0.020 mills/kWh. The dose saving over the 40 years of plant operation is 1.5×10^5 man-rem to the total body. The cost for the same period is \$396 million. The total body dose reduction costs \$2,658/man-rem.

4.1.11 Krypton-85 Released From Fuel Reprocessing Plant

Krypton-85 released from the fuel reprocessing plant is third on the list of the twenty nuclides ranked highest in terms of whole body factor in both of the reprocessing scenarios (refer to Tables 4.2 and 4.3). In the reference reprocessing plant, essentially all of the ^{85}Kr contained in the spent fuel enters the dissolver off-gas stream and is released out the main stack.⁽¹⁸⁾ The reference release rate is 0.43 Ci/sec.

A krypton recovery system was designed by PNL as part of the Draft Environmental Impact Statement - Management of Commercially Generated Radioactive Waste.⁽²¹⁾ This system uses cryogenic separation of the noble gases from the off-gas stream after iodine scrubbing and adsorption. This system is designed to recover 90% of the krypton in pressurized gas cylinders. Ten percent of the krypton will still be released out the main stack.

The capital cost for the krypton recovery system was estimated at \$22 million $\pm$ 30% in 1976 dollars. The operating cost was estimated at \$1.08 million per year. These costs escalate to \$25.2 million capital and \$1.24 million per year in 1978 dollars. The incremental levelized unit cost computed by UNICOST is \$2.85 per kg reprocessed, or an incremental power cost of 0.009 mills/kWh. The accumulated population dose reduction for the reference plant is 14,990 man-rem. The cost of this reduction is \$171 million for a cost-benefit ratio of \$11,400/man-rem.

4.1.12 Carbon-14 from the Fuel Reprocessing Plant

Carbon-14 released from the fuel reprocessing plant is fourth on the list of nuclides ranked highest in terms of whole body factor in the reprocessing scenarios (see Tables 4.2 and 4.3). In the reference reprocessing plant, all of the ^{14}C contained in the spent fuel is released out the main stack.⁽¹⁷⁾

A ^{14}C removal system was designed by PNL as part of the Draft Environmental Impact Statement - Management of Commercially Generated Radioactive Waste.⁽²¹⁾ This system utilizes a molecular sieve (zeolite) to recover CO_2 from the off-gas stream after iodine scrubbing and adsorption. The ^{14}C is recovered as calcium carbonate. This method will provide a dilution factor of 100 for ^{14}C .⁽²¹⁾

The capital cost for the ^{14}C removal system was estimated at \$7 million in 1976 dollars. The annual operating cost was estimated at \$0.11 million in 1976 dollars.⁽²¹⁾ These costs escalate to \$8 million and \$0.125 million in 1978 dollars, respectively. The incremental levelized unit cost computed by UNICOST is \$0.96 per kg reprocessed, or an incremental power cost of 0.003 mills/kWh. The cost over the 40 years of plant operation would be \$57.6 million. The 40 year reduction in the critical bone dose would be 1.56×10^5 man-rem. This is \$369/man-rem. The corresponding cost benefit ratio for the total body dose is \$1,846/man-rem.

4.1.13 Strontium-90 Released from Fuel Reprocessing Plant

Strontium-90 released from the fuel reprocessing plant ranks ninth and tenth on the list of significant nuclides for the reprocessing scenarios (shown in Tables 4.2 and 4.3). The fraction of ^{90}Sr released is 2.3×10^{-9} .^(17, Appendix A) The ^{90}Sr release is predominantly in the dissolver off gas (DOG) and the vessel off gas (VOG). It is released out the main stack as a particulate. The release factor was computed from a release of 8.8×10^{-9} Ci/s.⁽²²⁾

Containment of ^{90}Sr in the reference fuel reprocessing plant^(17, pp. 12-1 to 12-70) consists of a prefilter and two series of HEPA filters. Another series of HEPA filters would result in a decontamination factor of 1000.⁽²³⁾ The air flow through the main stack is approximately 110,000 standard cubic feet per minute.⁽²²⁾ Capital cost for HEPA filter installations were estimated at \$18/cfm and annual operating and maintenance costs at \$1.30/cfm.⁽²⁴⁾ The total annual cost would be \$143,000. The capital cost would be about \$2,000,000. The incremental levelized unit cost computed by UNICOST is \$0.31 per kg reprocessed, or an incremental power cost of 0.0009 mills/kWh. The total cost of the additional filters over the 40 year period of the dose calculation would be \$18.6 million. A reduction of 19,800 man-rem in the accumulated population dose to the most critical organ (bone) would be realized. This is \$938/man-rem. The corresponding figure for the total body-dose reduction would be \$3,550/man-rem.

4.1.14 Curium-244 Released from Fuel Reprocessing Plant

Curium-244 released from the fuel reprocessing plant ranks thirteenth on the list of nuclides that provide the highest relative ranking factors for the whole body for the recycle scenario (shown in Table 4.3). The fraction of ^{244}Cm released is 6.3×10^{-9} ,^(17, Appendix A) based on a release rate of 3.9×10^{-12} Ci/s.⁽²²⁾ The ^{244}Cm released is predominantly in the dissolver off gas (DOG) and the vessel off gas (VOG). It is released out the main stack as a particulate.

Containment of ^{244}Cm in the reference plant is accomplished by a prefilter and two series of HEPA filters.^(17, pp. 12-1 to 12-70) The same additional series of HEPA filters discussed for ^{90}Sr release in Section 4.1.13 also yields a decontamination factor of 1000 for ^{244}Cm . The reduced ^{244}Cm release results in a 52.8 man-rem reduction in the lung dose, which is the most critical organ. The cost for the system is the same as calculated for ^{90}Sr -- \$18.6 million. The cost benefit ratio is \$352,000/man-rem. The total body dose reduction is \$16.9 million per man-rem. Installation of the system would be justified primarily on the reduction in the ^{90}Sr bone dose.

4.1.15 Uranium-232 Released from Fuel Reprocessing Plant

Uranium-232 is listed as one of the twenty most important nuclides only for the recycle scenario. It occurs due to the buildup of ^{236}U in repeatedly recycled uranium.

Uranium-232 is released from the UF_6 facility.⁽²⁵⁾ The dominant effluent sources and reference treatment are presented in Table 4.15.

The first four sources in Table 4.15 release effluents out the main UF_6 facility stack with a flow rate of 6,854 cubic feet per minute. Adding a series of HEPA filters would yield a decontamination factor of 1,000 for the particulate ^{232}U release.⁽²³⁾ Using a capital cost of \$18/cfm and annual operating cost of \$1.30/cfm,⁽²⁴⁾ the incremental levelized unit cost computed by UNICOST is \$0.02 per kg reprocessed, or an incremental power cost of 0.00006 mills/kWh. During the year 2041 the amount of ^{236}U undergoing irradiation from repeatedly recycled uranium reaches a maximum on the full recycle scenario. This is a 4 Ci/year release rate from all reprocessing plants, which reprocess 7,333 MT of spent fuel in that year. At a levelized cost of \$.02/kg the cost of the system over the hypothetical 40 years of release would be \$5.9 million.

TABLE 4.15. Source and Treatment of Major ^{232}U Releases in Reference Fuel Reprocessing Plant

Sources	Present Treatment	Treatment Efficiency	Percent of Release	Air Flow scfm
UO_3 Dust Collectors	2 bag filters	99.9%	55	5,044
UF_4 Dust Collector	2 bag filters	99.9%	10	1,500
Oxide Vacuum Cleaner	Centrifugal separator and 2 bag filters	99.9%	3	275
Reductor off gas	2 porous metal filters	99.9%	2	35
Roof vents	Untreated	0.0	31	160,350

The HEPA filter installation would result in a saving of 4.55×10^6 man-rem accumulated population dose to the lungs, the most critical organs during the same 40 year period. This reduction would cost \$1.30/man-rem. The cost-benefit ratio for the total body dose is \$1,038/man-rem. This indicates that the addition of HEPA filters to the UF_6 facility stack should be done before appreciable amounts of recycled uranium are reprocessed.

4.1.16 Plutonium-238 Released from the Fuel Reprocessing Plant

Plutonium-238 released from the fuel reprocessing plant ranks twentieth on the list of nuclides that provide the highest relative factors for the whole body for the recycle scenario (shown in Table 4.3). The fraction of ^{238}Pu released is 1.4×10^{-9} , (17, Appendix A) based on 1.3×10^{-10} Ci/s released out the main stack and $4. \times 10^{-11}$ Ci/s released out the plant service concentrator stack.⁽²²⁾ The main stack release is predominantly from the dissolver off gas and the vessel off-gas streams. The ^{238}Pu is released as a particulate.

Containment of ^{238}Pu in the main separations plant is accomplished by a prefilter and two series of HEPA filters.^(17, pp. 12-1 to 12-70) The same additional series of HEPA filters discussed for ^{90}Sr release in section 4.1.13 also yields a decontamination factor of 1000 for the ^{238}Pu released from the main stack. Only about 75% of the ^{238}Pu release is out the main stack, so the net decontamination factor is about 4. The reduced ^{238}Pu release reduces the

lung dose (critical organ) by 1,584 man-rem. The cost of \$18.6 million for the system yields a cost benefit ratio of \$11,700/man-rem. The ratio for the whole body dose is \$268,000/man-rem. However installation of the system is better justified by the \$938/man-rem for the reduction in the ⁹⁰Sr bone dose.

4.2 PRINCIPAL NONRADIOACTIVE EFFLUENTS

The nonradioactive effluents identified in the survey of the nuclear fuel cycle were ranked by the 100-year dilution factor. This ranking established a tentative list of the most important effluents for each plant in the fuel cycle. The twenty nonradioactive effluents with the highest dilution factors are shown in Tables 4.16, 4.17 and 4.18 for the stowaway, reprocessing but no recycle and the full recycle scenarios, respectively. As for the radioactive effluents, the 100-year dilution factors were used as a basis for the ranking because they summarize the time dependent behavior of the releases.

The list of nonradioactive effluents includes only air releases. No water releases from the mine or mill were assumed to occur, based on descriptions of the reference facilities. In general, water pollution is a more localized problem than air pollution, and severity and treatment options for liquid effluents are highly site-dependent. Therefore attention was focused on effluents released to the air.

Hypothetical water releases were calculated, however, and are included in Appendix B. Concentrations of effluents downstream of each plant were calculated based on release to a river with an average flow rate of 50,000 cfs ($8.5E+7$ l/min).

The comparison of nonradioactive releases was based on the dilution factor. In the dilution factor, quantity released and the hazard of the release are incorporated into a single number. The dilution factor is defined as the volume of air or water required to dilute the quantity released so that the resulting concentration satisfies the concentration of the standard or estimated standard. Ambient air quality standards and estimates based on the official federal standards for industrial air, have been used to estimate acceptable ambient limits.⁽²⁶⁾ The estimated standard is calculated by the formula:

TABLE 4.16. Ranking of Dilution Factors for Nonradioactive Airborne Effluents - Stowaway Cycle

<u>Rank</u>	<u>Dilution₃ Factor (m³)</u>	<u>Chemical Name</u>	<u>Plant</u>
1	4.406E+15	Ammonia	Uranium Fuel Fabrication
2	3.308E+15	Sulfur Oxides	Enrichment Cascade
3	2.553E+15	Uranium	Acid Leach Mill
4	2.371E+15	Rock Dust	Surface Mine
5	1.985E+15	Nitrogen Oxides	Enrichment Cascade
6	1.490E+15	Rock Dust	Underground Mine
7	1.257E+15	Sulfur Oxides	BWR
8	9.484E+14	Aldehydes	Surface Mine
9	7.643E+14	Nitrogen Oxides	Aqueous Conversion
10	6.127E+14	Nitrogen Oxides	Acid Leach Mill
11	5.029E+14	Nitrogen Oxides	BWR
12	4.902E+14	Aldehydes	Acid Leach Mill
13	4.742E+14	Nitrogen Oxides	Surface Mine
14	4.061E+14	Hexane	Aqueous Conversion
15	3.981E+14	Nitric Acid	Uranium Fuel Fabrication
16	3.598E+14	Aldehydes	Underground Mine
17	3.474E+14	Hydrogen Fluoride	Aqueous Conversion
18	3.165E+14	Sulfur Oxides	Aqueous Conversion
19	2.634E+14	Sulfur Oxides	Surface Mine
20	2.634E+14	Nonrad. Particulates	Surface Mine

TABLE 4.17. Ranking of Dilution Factors for Nonradioactive Airborne Effluents - Reprocessing, No Recycle

<u>Rank</u>	<u>Dilution₃ Factor (m³)</u>	<u>Chemical Name</u>	<u>Plant</u>
1	4.406E+15	Ammonia	Uranium Fuel Fabrication
2	3.308E+15	Sulfur Oxides	Enrichment Cascade
3	2.553E+15	Uranium	Acid Leach Mill
4	2.553E+15	Nitrogen Oxides	Reprocessing
5	2.371E+15	Rock Dust	Surface Mine
6	2.371E+15	Rock Dust	Surface Mine
7	1.985E+15	Nitrogen Oxides	Enrichment Cascade
8	1.257E+15	Sulfur Oxides	BWR
9	9,484E+14	Aldehydes	Surface Mine
10	8.442E+14	Sulfur Oxides	Reprocessing
11	7.643E+14	Nitrogen Oxides	Aqueous Conversion
12	6.127E+14	Nitrogen Oxides	Acid Leach Mill
13	5.029E+14	Nitrogen Oxides	BWR
14	4.902E+14	Aldehydes	Acid Leach Mill
15	4.742E+14	Nitrogen Oxides	Surface Mine
16	4.061E+14	Hexane	Aqueous Conversion
17	3.981E+14	Nitric Acid	Uranium Fuel Fabrication
18	3.598E+14	Aldehydes	Underground Mine
19	3.474E+14	Hydrogen Fluoride	Aqueous Conversion
20	4.185E+14	Sulfur Oxides	Aqueous Conversion

TABLE 4.18. Ranking of Dilution Factors for Nonradioactive Airborne Effluents - Full U and Pu Recycle

<u>Rank</u>	<u>Dilution₃ Factor (m³)</u>	<u>Chemical Name</u>	<u>Plant</u>
1	3.268E+15	Ammonia	Uranium Fuel Fabrication
2	3.266E+15	Sulfur Oxides	Enrichment Cascade
3	2.533E+15	Nitrogen Oxides	Reprocessing
4	1.950E+15	Nitrogen Oxides	Enrichment Cascade
5	1.609E+15	Uranium	Acid Leach Mill
6	1.257E+15	Sulfur Oxides	BWR
7	1.139E+15	Rock Dust	Surface Mine
8	1.193E+15	Rock Dust	Underground Mine
9	8.442E+14	Sulfur Oxides	Reprocessing
10	6.179E+14	Nitrogen Oxides	Aqueous Conversion
11	5.029E+14	Nitrogen Oxides	BWR
12	4.555E+14	Aldehydes	Surface Mine
13	3.862E+14	Nitrogen Oxides	Acid Leach Mill
14	3.282E+14	Hexane	Aqueous Conversion
15	3.080E+14	Aldehydes	Acid Leach Mill
16	2.953E+14	Nitric Acid	Uranium Fuel Fabrication
17	2.809E+14	Hydrogen Fluoride	Aqueous Conversion
18	2.648E+14	Aldehydes	Underground Mine
19	2.875E+14	Sulfur Oxides	Aqueous Conversion
20	2.277E+14	Nitrogen Oxides	Surface Mine

$$X_p = 1.65 \times 10^{-3} * TLV$$

where

X_p is the permissible ambient concentration

TLV is the threshold limit value.

Release factors that form the basis of this ranking are taken directly or calculated from the applicable plant documentation or measurement. The 20 nonradioactive effluents with the highest releases may change as a result of further study of the release factors. The list of the twenty highest dilution factors is flexible and is intended as a priority list for more detailed analysis.

The twenty nonradioactive effluents with the highest dilution factors are described in the following sections. Each description identifies the source of the effluent and suggests alternative control technologies that could reduce the amount of effluent released. The effluents are described in the order of the source facility in the fuel cycle; Table 4.19 illustrates the re-ordering of effluents by source for the three scenarios.

4.2.1 Rock Dust from Surface Mine

Rock dust from the surface mine was ranked as the fourth, fifth and seventh largest effluent in the stowaway, no recycle and full recycle scenarios, respectively. The amount of dust released is assumed to be 598 kg/day for the mine producing 4234 MT ore per day. Mining accounts for 19% of the dust, primary crushing 5%, and the waste rock pile accounts for 76% of the calculated values.

The amount of dust released from the waste rock pile is assumed to be an average for the lifetime of the mine, and assumes a constant wind speed of 4.4 m/s. The calculations reflect assumptions about the surface layer of dust particles that are available for suspension. (27, p. 28) The release factors are conservative; dry deposition may result in an order of magnitude difference in the source. (27, pp. 28,29) Since the waste rock storage area appears to dominate the dust releases over the life of the mine, dust reduction techniques should be used on the waste rock pile. Methods for dust reduction include sprinkling with water and stabilizing with chemicals.

TABLE 4.19. Twenty Nonradioactive Airborne Effluents with Highest Dilution Factors, Ranked by Plant Type

Plant	Chemical	Ranking Order		
		Stowaway	NR	FR
Surface Mine	1. Rock Dust	4	5	7
	2. Aldehydes	8	9	12
	3. Nitrogen Oxides	13	15	20
	4. Sulfur Oxides	19	--	--
	5. Nonradioactive Particulates	20	--	--
Underground Mine	6. Rock Dust	6	7	8
	7. Aldehydes	16	18	18
Acid Leach Mill	8. Uranium	3	3	5
	9. Nitrogen Oxides	10	12	13
	10. Aldehydes	12	14	15
Conversion	11. Nitrogen Oxides	9	11	10
	12. Hexane	14	16	14
	13. Hydrogen Fluoride	17	19	17
	14. Sulfur Oxides	18	20	19
Enrichment Cascade	15. Sulfur Oxides	2	2	2
	16. Nitrogen Oxides	5	6	4
U Fuel Fabrication	17. Ammonia	1	1	1
	18. Nitric Acid	15	17	16
BWR	19. Sulfur Oxides	7	8	6
	20. Nitrogen Oxides	11	13	11
FRP	21. Nitrogen Oxides	--	4	3
	22. Sulfur Oxides	--	10	9

In calculating the release, it is assumed that all waste rock is hauled to a dump site adjacent to the pit. Dumping the waste rock into a mined-out area of the pit when possible could reduce the windblown dust.

When a dump is complete at the mine used as a reference facility, slopes are reduced to 3:1, covered with topsoil and mulch, seeded, and fertilized.^(28, p. 66) Applying this treatment to the waste rock pile during the production life of other mines could reduce the windblown dust to a very low level. If the mine had only 5% of its lifetime of waste rock exposed, the dust emissions could be cut by 69%.

A continuous covering and revegetation program would add \$1.80/lb to the price of yellowcake.⁽²⁹⁾ This includes a 15 cm layer of clay and a 45 cm layer of soil, then revegetation. Using Table 3.11, the increased cost of yellowcake would increase the power cost by 0.13 mills/kWh in the no reprocessing scenario and by 0.10 mills/kWh in the reprocessing scenario. The total system cost for 100 years would be \$20 billion and \$15 billion respectively.

The next largest dust emission is from mining; 95% of the mining dust is caused by blasting and 5% results from haulage.⁽²⁷⁾ The emission may be reduced by spraying with a mist of water after blasting as is done with underground mining. Reducing the dust from blasting by half would decrease the release factor by about 9%. Dust from crusher operations may also be reduced by wetting the ore.

4.2.2 Aldehydes from Surface Mine

Aldehydes from surface mining are the eighth, ninth and twelfth largest effluents from the stowaway, no recycle, and full recycle scenarios, respectively. The release is based on the use of 6500 gallons of diesel fuel per day for a 4233 MT/day mine. Emission factors set by the EPA⁽³⁰⁾ were used to calculate the quantity of aldehydes produced. It was assumed that the equipment produced 6.5 lb of aldehydes per thousand gallons of diesel fuel consumed.

Catalytic reactors on the exhaust streams of the diesel powered equipment can be used to reduce aldehyde emissions. Catalysts should be able to reduce the aldehyde emissions by 50 percent or more.^(31, p. 8)

4.2.3 Nitrogen Oxides from the Surface Mine

Nitrogen oxide emissions from surface mining are ranked as thirteenth and fifteenth for the no recycle and stowaway cases and as twentieth for the full recycle scenario. The nitrogen oxide emission rate is based on the use of 6500 gallons of diesel fuel per day at the reference surface mine and EPA emission factors.^(30, p. 3.2.7) The release rate is about 0.37 lb NO_x per gallon of fuel used; this amounts to about 1093 kg per day for a mine producing 4233 MT of ore per day.

Water induction and exhaust gas recirculation can be used to reduce NO_x emissions. Water induction will have the least penalty for engine performance;⁽³²⁾ although the disadvantages of this method include possible corrosion and wear in the induction system, extra storage tanks required for carrying water and the possibility of freezing, the advantage of induction over exhaust gas recirculation is that penalties in performance and smoke levels are greatly reduced. NO_x emissions can be reduced by 60 to 70% with the induction of 6% total water intake by mass.

4.2.4 Sulfur Oxides from Surface Mining

Sulfur oxides from surface mining were ranked seventeenth in the stowaway fuel cycle scenario. The release of sulfur oxides results from the use of diesel-powered mining equipment. It is assumed that 6500 gallons of 0.22% sulfur diesel oil are used per day at the 4233 MT/day reference facility. Sulfur oxide emissions are 31.2 lb per thousand gallons of diesel fuel,⁽³⁰⁾ or about 92 kg/day. Emissions are directly proportional to the sulfur content of the fuel.

The quantity of SO_x released at each mine is quite small. It appears as a highly ranked effluent because there are many surface mines. The concentration of SO_x at each site is well below the standard. The removal of sulfur oxides from the exhaust gases of diesel mining equipment does not appear to be an economic option.

4.2.5 Nonradioactive Particulates from Surface Mining

Nonradioactive particulates from surface mining are ranked twentieth in the stowaway fuel cycle. Particulates are released from diesel-powered mining and hauling equipment. The amounts released are calculated based on the use of 6500 gallons of diesel fuel per day and an emission rate of 0.025 lb of particulates per gallon of fuel.⁽³⁰⁾

Carbon particulates (smoke) are caused by the decomposition of fuel with insufficient oxygen.^(33, p. 26) This condition may result from insufficient air fed to the engine and incomplete mixing of air and fuel.

It is possible to reduce particulate emissions by using turbocharged engines, and limiting maximum power withdrawn from the engine.^(34, p. 57) Proper maintenance of diesel engines, particularly maintenance of fuel injection equipment, is also important. Turbocharging, however, may cause more smoke under acceleration. With improved air-to-fuel ratio control devices and fuel injection, there appears to be no inherent problem in developing turbocharged engines under transient conditions.^(33, p. 38)

Water scrubbers may also be used to remove fine particles from exhaust gases.^(35, p. 96)

4.2.6 Rock Dust from Underground Mine

The release of rock dust from the underground mine was rated as the sixth, seventh and eighth most significant effluent for the stowaway, no recycle, and full recycle scenarios, respectively.

The calculated release is based on an underground mining complex that produces 4234 MT/day. The assumed release is 265 kg/day; 2.3% of this amount results from hauling, 11.3% from crushing, and 86.4% from the waste rock pile. The amount of dust generated by hauling and crushing is assumed to be the same as for the surface mine; the amount of waste rock and thus the amount of dust produced from waste rock is assumed to be half as great. It is assumed that waste rock is distributed near the mine entrance.

With these assumptions, the major source of dust appears to be the waste rock piles. The emissions can be reduced by wetting, covering with earth, and revegetating. By having no more than 5% of the waste rock exposed, the release of dust could be reduced by 78%.

Assuming that the underground mine creates only half as much waste rock as the surface mine, continuous covering and revegetation of the waste rock pile will increase the price of yellowcake \$0.90/lb. This cost is based on a report to EPA by Pedco Environmental Inc.^(28, p. 10) This is an increased power cost of 0.065 mills/kWh for the no recycle scenarios and 0.050 mills/kWh for the recycle scenario. The total 100-year system cost increase would be \$10 billion and \$7.5 billion respectively.

The next largest release of rock dust results from ore crushing. This release may be reduced by wetting.

4.2.7 Aldehydes from Underground Mine

Aldehydes from underground mining are ranked eighteenth for the reprocessing fuel cycles and sixteenth for the stowaway cycle.

The release factor is based on the use of 3250 gallons of diesel fuel per day; this is half the quantity of diesel fuel used in the surface mine for producing equal tonnage. EPA emission factors are used⁽³⁰⁾ and it was assumed that catalytic exhaust purifiers remove half the aldehydes from the exhaust.

The release factor is based on exhausting about 0.2 g aldehydes per hp-hr. In experimental setup, one catalyst reduced emissions from .22 g per hp-hr to 0.04 g,^(31, p.3) over an 80% reduction. Such reductions may be possible in actual mine experience.

The use of an exhaust purifier capable of removing 80% of the aldehydes in the exhaust would reduce emissions by 40%.

4.2.8 Uranium from Acid Leach Mill

Uranium from the acid leach mill is ranked as the third largest release for the stowaway and reprocessing but no recycle scenarios. It ranks fifth

for the recycle scenario. The uranium effluent comes from the crusher, fine ore bin, leach, sample room and yellowcake dryer.^(36, p. 5-11) About 99% of the uranium released comes from the yellowcake dryer.

Dust collection and ventilation systems in the crushing area, screen area and fine ore bin use negative pressure and wet scrubbers. The sample preparation room uses dust hoods and water spray chamber cleaning.^(37, p. 4-1) The ventilation system in the yellowcake area includes two wet scrubbers that collect gases and dust from the yellowcake dryer, centrifuge area, and packaging facilities. The overall design efficiency of this system is greater than 99%.

The baffled wet orifice scrubber and another wet scrubber are operated in series. Modifications to the system include separating the two scrubbers. No increase in dust emissions is expected.^(37, p. 4-3.4)

To meet the new EPA standard for offsite radiation, 10 CFR 190, the mill will need a collection efficiency of 99.5 to 99.9% for yellowcake particles.

Some alternative uranium particulate control options are listed in Table 4.20. The cost estimates are accurate to within 25%.^(36,38) An additional alternative option, electrostatic precipitation, for the 4000 CFM may cost \$84,000 with an annual operating cost of about \$8,000.

TABLE 4.20. Dust Abatement Equipment

<u>Equipment</u>	<u>Efficiency (%)</u>	<u>Capital Cost (1000 \$)</u>	<u>Annual Operating Cost (1000 \$)</u>	<u>Mills/kWh</u>
Wet Scrubber	97.9	38.5	4.7	
Venturi Scrubber	99.5	47.4	9.0	0.0004
Venturi Scrubber	99.7	56.5	13.6	0.0006
Venturi Scrubber	99.9	61.0	20.3	0.0008
Venturi Scrubber Above Add. HEPA Filter	100%	92.5	25.1	0.0011

4.2.9 Nitrogen Oxides from Acid Leach Mill

Nitrogen oxides from acid leach mills were ranked as the tenth, twelfth and thirteenth most significant nonradioactive effluents for the stowaway, no recycle, and full recycle scenarios, respectively.

The release calculation is based on an assumed 35,000 lb of NO_x per year^(39, p. 41) from a 20×10^6 Btu/hr natural gas-fired boiler. This is approximately 210 lb NO_x per 10^6 cf of natural gas, which is in the expected range of 120 to 230 per 10^6 cf of natural gas.

A 60% reduction of the amount of NO_x released can be achieved using flue gas recirculation or steam or water injection.^(40, p. 35) The release rate of about 96 kg/day would then be reduced to 38 kg/day.

4.2.10 Aldehydes from the Acid Leach Mill

Aldehydes from the acid leach mill are the twelfth, fourteenth and fifteenth most significant effluents released from the stowaway, no recycle, and full recycle scenarios, respectively.

The dilution factor calculations are based on an effluent rate of 1752 lb of aldehydes per year^(39, p.41) from a 2000 ton per day milling facility. The source of the emissions is the 20×10^6 Btu/hr natural gas-fired steam boiler. Diesel or LPG is used as backup fuel.

The EPA emission factors for aldehydes from natural gas combustion indicate an aldehyde production of only 350 lb/yr. Fuel oil combustion produces 2340 lb/yr of aldehydes.⁽³⁰⁾ Therefore, the release rate of aldehydes can be minimized by using natural gas for steam generation whenever possible.

The concentration of aldehydes one quarter mile from the source is well below the estimated standard of 5 micrograms per cubic meter. Further control of aldehydes does not appear to be economically feasible.

4.2.11 Nitrogen Oxides from Aqueous Conversion

Nitrogen oxides from the aqueous conversion process are ranked as the ninth, tenth and eleventh most significant effluents for the stowaway, non-reprocessing and reprocessing fuel cycle scenarios, respectively. About one

third of the NO_x , or 5.8 MT/mo, results from the combustion of natural gas.^(41, p. III-8; 43, p. 24) Two thirds, or 12.1 MT/mo, comes from the absorber tail gas.^(42, p. 24)

Presently, combustion off gas from the steam boilers is released directly to the main plant stack. The process off-gas system associated with the major source of NO_x is shown in Figure 4.2. Gases from the single effect uranium evaporator, boildown tanks, and denitrators are scrubbed with acid and cooled before entering the nitric acid absorption column. Miscellaneous digester off gas is scrubbed with sodium hydroxide and mixed with the primary digester off gas before entering the absorption column. The tail gas from the nitric acid adsorption column is filtered before release to the main plant stack.

The concentration of NO_x in the untreated stack release is probably about 2,000 to 3,000 ppm, which is comparable with that of nitric acid plants.^(43, p. 103) The release rate of NO_x from the nitric acid absorber tail gas can be lowered by reducing NO_x to nitrogen, or by oxidation of NO_x and recovery as nitric acid.

For new nitric acid plants with effluent treatment systems, the maximum NO_x permitted in the effluent is 3 lb of NO_2 per ton of acid produced.^(29, p. B-3) This is equivalent to an NO_x concentration of 209 ppm in stack releases from a typical plant operation.^(44, p. 73)

The emissions of NO_x from combustion of natural gas may be reduced by using combustion modifications or treating the acid plant tail gas. Combustion modifications include low excess air and staged combustion. Low excess air can reduce NO_x emissions by about 20% and can increase boiler efficiency.⁽⁴⁵⁾ Staged combustion may decrease the NO_x emissions by 30 to 70%.⁽³¹⁾

Flue gas recirculation is the most effective method for reducing NO_x emissions from natural gas combustion. Reductions in NO_x emissions of 60%⁽⁴⁰⁾ can be achieved with unimpaired boiler efficiency.⁽⁴⁵⁾

The most widely used process for cleaning acid plant tail gas is non-selective catalytic reduction of NO_x to N_2 and O_2 using natural gas. High capital and operating costs, and the requirement of clean fuel make this process unattractive for future use. Other methods used for cleaning tail gas are selective catalytic reduction and continuous catalytic absorption.

FIGURE 4.2. Process Off-Gas System

Selective catalytic reduction (SCR) using ammonia has been used for both flue gas and acid plant tail gas cleanup. NO_x removal efficiencies are better than 90%. The total cost of SCR is about 50 to 60% of the cost of nonselective reduction. (43, p. 105)

Recovery of NO_x as nitric acid can be accomplished by using the CDL/Vitok process of continuous catalytic adsorption. (46) A schematic of this process is shown in Figure 4.3. The process flow is similar to conventional adsorption-stripping systems. In the CDL/Vitok process, a column is added following the main absorber. Mixed phase catalytic reaction with scrubbing provides internal recycle and reduces NO_x leakage. The release of NO_x from the absorber is reduced by over 90%. In addition, the acid recycle should reduce the purchased acid requirements by about 15 MT/mo or between 3 and 4%.

FIGURE 4.3. Catalytic Absorption of Nitrogen Oxides

The current CDL/Vitok process appears to be the most economical NO_x abatement system for nitric acid plants.⁽⁴⁰⁾ This process involves nitric acid scrubbing and recycle. The technique has low capital and operating costs, and uses only 25% of the energy needed for catalytic reduction.⁽⁴⁰⁾ Its high liquid-to-gas ratio may reduce the tower capacity.

The capital investment for the CDL/Vitok process, scaled down to the equivalent plant size, is about \$120,000. The annual cost is estimated at about \$34,000, including taxes, depreciation, and return on investment.⁽⁴⁰⁾

The reference facility converts 9057 MT U/yr. The CDL/Vitok process would increase the conversion cost by \$0.002/lb of uranium. Using Table 3.11, the incremental power cost is 1×10^{-4} mills/kWh. This represents an increase in the 100-year total system cost of \$17 million. This will result in a 61% reduction in the NO_x released from the conversion plant.

4.2.12 Hexane from Aqueous Conversion

Hexane from the aqueous conversion process is ranked fourteenth in the stowaway cycle and fifteenth and sixteenth in the full recycle and no recycle scenarios, respectively. Release of hexane occurs primarily through release of uncondensed hexane vapor vented from the solvent extraction step of purification. The loss of hexane to evaporation from a 9072 MTU/yr plant is estimated at 6.7 gallons of hexane per MTU or 207 kg per day.

Hexane vapor is discharged primarily from the hexane still and the solvent rework circuit vent system in the solvent extraction building.^(41, p. V-14) Condensers have been added to the hexane still to reduce the emission of hexane.

Refrigeration equipment could be used to reduce the hexane release further. A one-to-two ton refrigeration unit would be capable of condensing virtually all the hexane in the overhead vapor from the hexane still. However, size of a refrigeration unit for a facility would depend on the composition and total mass flow rate of the overhead stream. Reduction of hexane release would be closely tied to the size of the unit.

4.2.13 Hydrogen Fluoride from Aqueous Conversion

The release of hydrogen fluoride is ranked seventeenth for the stowaway and full recycle scenarios and nineteenth for the reprocessing without recycle scenario. The amount of HF released is 0.195 MT/mo or about 6.4 kg per day.^(42, p. 24) The sources of HF include the HF scrubber, fluorine emergency vent, and the fluorine cell hood rework exhaust. The HF scrubber treats most of the fluoride-containing streams. The scrub water is neutralized with lime and calcium fluoride is precipitated. Presently, the gases from the fluorine emergency vent and the fluorine cell rework area are released directly to the atmosphere. Releases of HF occur during fluorine cell dismantling, about 30 min every 3 days.⁽⁴¹⁾

The source of most of the HF released is the off gas from the HF scrubber; about 4 kg/day of HF are emitted. A two-stage scrubbing system, such as the one used at the Paducah Gaseous Diffusion Plant, could reduce the HF losses.^(47, 5-2) The first stage serves as recovery system with HF concentration maintained at 15%. The second stage serves as a total removal system with the HF concentration maintained at less than 2%. Overall efficiency of greater than 99% is anticipated.

The intermittent releases of HF from cell rework and the emergency vent contribute about 37% of the total HF release. Treatment of releases through the scrubber system may be infeasible. However, the ground-level concentration can be reduced by discharging these streams through a higher stack or vent.

It is estimated that the overall release rate of HF would decrease from 6.4 kg/day to about 2.3 kg/day with the use of a two-stage HF scrubber. The HF in effluent from scrubbed stream would be reduced to 5% of its original value.

4.2.14 Sulfur Oxides from Aqueous Conversion

Sulfur oxides from aqueous conversion are the eighteenth, twentieth and nineteenth most significant releases from the stowaway, reprocessing without recycle and reprocessing scenarios, respectively. The major source of SO_x is reduction off gas, which produces 4.1 MT SO_x per month.⁽⁴²⁾ This stream contains about 500 ppm SO_x .

Presently, this gas stream is filtered and run through a waste gas burner. A non-regenerative flue gas desulfurization process could be added to reduce SO_x released in the gas stream. An alternative process of double-alkali scrubbing has achieved a 90% SO_2 removal rate under inlet concentrations similar to those of the reduction off-gas stream at the aqueous conversion facility.⁽⁴⁸⁾

4.2.15 Sulfur Oxides from the Enrichment Cascade

Sulfur oxide from the diffusion enrichment cascade has the second highest dilution factor in all scenarios. The source of the SO_x is the coal-fired steam plant, which consists of four 100,000 lb/hr boilers. The average steam production rate is 130×10^6 Btu/hr.

The release factor used is based on a release of 1797 kg/day.^(49, p. 313-10) This release rate is equivalent to 1.9 g per million calories ($1.06/10^6$ Btu gross); this value is within the New Source Performance Standards.^(30, p. B-2)

The coal composition assumed includes 2.5% sulfur, 8% ash; the heat content is 12,000 Btu/lb. This is similar to midwestern coal with level 3 beneficiation. About half the coal in the U.S. is beneficiated.⁽⁵⁰⁾ The release rate associated with the current control method is equivalent to burning coal with a sulfur content of 0.625% with no scrubbing system.

The current method for reducing SO_x emissions at the generic plant is wet lime scrubbing. Scrubbing is assumed to transfer 75% of the sulfur from the flue gas to a slurry, which is discharged to settling ponds. A schematic diagram of the system is shown in Figure 4.4. Alternatives to wet lime scrubbing include double alkali scrubbing and regenerative scrubbing processes. Modifications to the combustion process may also reduce SO_x releases.

The present lime scrubbing method for SO_2 is a sludge-producing flue gas desulfurization (FGD) process. Use of the double alkali process would further reduce SO_2 release. Scrubbing is done with a sodium hydroxide solution which is regenerated by lime. This results in a sludge similar to the lime scrubbing process,⁽⁴⁹⁾ but with higher SO_2 removal efficiencies and better reliability. Eight-five to ninety-five percent removal of SO_2 may be achieved.⁽⁵¹⁾

FIGURE 4.4. Flow Diagram - Airborne Effluent Treatment

The capital investment for a conventional nonregenerative desulfurization system is about 6.2 million dollars (1978). The annual operating cost is 265 thousand dollars per year (1978). The incremental levelized unit cost calculated by UNICOST is \$0.13/SWU. This is 0.002 mills/kWh, or \$0.3 billion over 100 years.

A new FGD system, assuming 90 to 95% efficiency could be attained, would decrease the effluent SO_2 by 40 to 80%.

Potential savings in cost and materials may be realized by using a regenerative process. In a regenerative process, a material used to react with SO_2 can be regenerated for recycling. During the regeneration step, absorbed SO_x is liberated and treated to make sulfuric acid or elemental sulfur. The two most highly developed processes are the magnesium oxide process (Chemico) and the Wellman-Lord process (Davy Powergas). The problem of sludge residues is of much smaller magnitude than for the non-regenerative FGD processes. The development of regenerative FGD systems, however is in an early stage; the process is most attractive for large utility boilers.

The capital cost of a regenerative process is about \$7.9 million in 1978 dollars. Operating cost is about \$165,000 \$/yr,⁽⁵²⁾ in 1978 dollars. The incremental levelized unit cost calculated by UNICOST is \$0.11/SWU; this is 0.002 mills/kWh or \$0.29 billion over 100 years.

Longer term reductions in SO_2 release may be achieved with advanced combustion alternatives such as fluidized bed combustion or use of solvent refined coal (SRC). In the fluidized bed combustion process, limestone is mixed with the coal, and SO_x is removed in the boiler. A number of test units are being installed in the U.S.⁽⁴⁰⁾ Advantages include lower NO_x emissions, smaller size, and lower capital costs than conventional boilers with FGD units.

In the solvent refined coal process, the coal product is low in sulfur and ash. Solvent refined coal is more expensive than untreated coal, but the plant would require no capital outlay for FGD equipment. Sulfur content of the coal is reduced to about 0.3%. The use of solvent refined coal is most appropriate for medium to small utility boilers with load factors less than 65%.⁽⁵²⁾

The capital cost of an SRC plant would be about \$2.4 million (1978 dollars) less than that of a conventional boiler, but the added operating cost would be about \$765,000/yr (1978 dollars).⁽⁵²⁾

4.2.16 Nitrogen Oxides from the Enrichment Cascade

Nitrogen oxides from diffusion enrichment are ranked fifth in the stowaway cycle and fourth and seventh in full recycle and reprocessing without recycle scenarios. The major source of NO_x is the coal-fired steam plant, which produces 98% of effluent NO_x . The quantity produced is 10 kg per metric ton of coal burned. This is 0.6 lb NO_x per 10^6 Btu, which meets the New Source Performance Standard.⁽⁴⁰⁾

The NO_x concentration produced by the generic plant is roughly 520 ppm. With current technology, industrial coal-fired boilers can achieve emission levels of 450 ppm NO_x . The 1980 EPA goal of 150 ppm can be achieved with developed and field-applied technology. The 1985 EPA goal is 100 ppm.⁽⁴⁰⁾ To achieve this, an 80% reduction from the present emission rate is required.

Changes in both operation and design of combustion systems may be used to control NO_x emissions. Such changes that can be applied to coal-fired boilers include staged combustion, low excess air firing, and reduced heat release rate. Treatment of stack off gases will also reduce the release of NO_x .

The use of low excess air firing is most attractive for initial 20% reduction in NO_x emissions.⁽⁴⁰⁾ With low excess air firing, particulate emissions do not increase as they do with most of the other combustion-modification NO_x reduction methods, and the boiler efficiency is maintained or improved.⁽⁴⁵⁾

Staged combustion attempts to reduce peak flame temperature and maintain low oxygen concentrations to prevent the formation of nitrogen oxides. This can reduce NO_x emissions by about 40%.

A 20% reduction could be achieved by using excess air firing, (420 ppm). Combustion staging could further reduce the concentration by 30%, (310 ppm). An EPA experimental pulverized coal burner emits 150 ppm NO_x . Further reduction in NO_x emissions will require fuel gas treatment.

Treatment of stack gases can be accomplished using dry or wet techniques. Dry techniques include selective catalytic reduction (SCR) and noncatalyzed reduction; these processes use ammonia, NO_x/SO_x removal with activated carbon, systems based on other adsorbents, and electron-beam radiation. Presently, SCR has the highest technological level of development⁽⁴⁰⁾. Wet processes are of four types: oxidation absorption, absorption oxidation, oxidation reduction, and reduction. Wet processes alone are generally not as effective as dry processes for removing NO_x . Wet processes may have advantages in simultaneous NO_x/SO_x removal.

SCR units have NO_x removal efficiencies of 85 to 95% one design consistently removes 98 to 99%. The capital cost for such a unit is about $\$1.6 \times 10^6$.⁽⁴⁰⁾ The annual operation cost is about \$2 million, in 1978 dollars. The incremental levelized unit cost computed by UNICOST is \$0.31/SWU. This yields an incremental power cost of 0.005 mills/kWh, or an 100 year system cost of \$0.77 billion. For the alternative process of staged combustion boilers with SCR flue gas treatment, the NO_x emissions would decrease by about 95%.

Noncatalytic reduction has removal efficiencies about 75% of SCR. Experiments have yielded 70% efficiency, and an actual unit has achieved 50% reduction of NO_x emissions.⁽⁵³⁾ The cost has been estimated at 7 to 15¢ per 10^6 Btu fired, or \$75-\$160 thousand per year. A drawback to both SCR and noncatalytic reduction is that they use ammonia as a reagent at the rate of 1.1 to 1.2 moles NH_3 /mole NO_x .

Electron beam radiation may achieve 80% removal of both NO_x and SO_x . This method uses electricity rather than reagents, but has the drawback of high capital cost. The power consumption is comparable to scrubbing techniques. (40)

4.2.17 Ammonia from Uranium Fuel Fabrication

Ammonia from uranium fuel fabrication was calculated to be most significant nonradioactive effluent from the three nuclear fuel cycle scenarios, as ranked by dilution factor.

Ammonia is generated by the calcining and drying operations:

The quantity of NH_3 assumed in calculating the release is about 720 kg/day from a 1600 MT/day plant. This is based on ammonia concentration of about 500 mg/m³ and a ventilation rate of 6×10^4 m³/hr. (54, p. 313-10)

The present method of control includes venturi type water scrubbers. The scrubbers are credited with 75% (53, p. 3.3-8) to about 90% (56, p. 16-5) removal efficiency. The ammonia-laden wastewater is treated with lime, distilled, absorbed and recovered. (56)

The scrubbed air stream is a dilute mixture of ammonia in air containing about 700 ppm or 0.07 mole % NH_3 . Additional emission control equipment options include an additional scrubber stage in series, a water absorption tower, or an absorption-reaction tower (54, p. 7.2-4). These options involve standard processing techniques and equipment. Absorbed ammonia would be transferred to liquids, and the burden on the liquid effluent system would increase.

4.2.18 Nitric Acid from Uranium Fuel Fabrication

Nitric acid from uranium fuel fabrication is ranked fifteenth for the stowaway scenario, seventeenth for reprocessing without recycle and sixteenth for the full recycle scenarios.

The acid originates in laboratory hoods; hood vents are exhausted directly to the atmosphere. The amount released from the generic facility is estimated at about 1 kg/hr, scaled from a smaller plant where the release is about

1 lb/hr. (57, p. 4-10) The release of nitric acid mist can be reduced by the use of simple de-entrainment devices. A fiber mist eliminator could remove about 99% of the acid mist from the ventilation air.

4.2.19 Sulfur Oxides from the BWR

Sulfur oxides are produced by the heating boiler and three standby diesel engines at the reference BWR. The units consume #2 fuel oil with a sulfur content of 0.4%.

The heating boiler is used an equivalent of 3 months per year, at 25% full load operation, and produces 13,650 lb SO_x . The 3 diesel engines operate one hour per month; they operate with a full load for 24 hours at least once every 18 months and produce 1400 lb SO_2/yr . (58)

The combustion at the BWR is a relatively small source of SO_x . It appears as the sixth through eighth ranked pollutant because there are many BWRs. The concentration of SO_x at each site is well below the standard. Since the combustion sources are small, dispersed and intermittent, it is not economic to install scrubbers for SO_x removal.

4.2.20 Nitrogen Oxides from the BWR

Nitrogen oxides are produced by the heating boiler and three standby diesel engines at the reference BWR. The heating boiler produces 9800 lb of NO_x per year, and the diesel generators produce a total of 980 lb annually. (25) Nitrogen oxides from the BWR appear as the eleventh or thirteenth ranked pollutant because there are many BWRs. Each source of NO_x is small and intermittent, and the concentration of NO_x at each site is well below the standard.

Low excess air firing may be used to reduce the NO_x emissions from the boiler by about 20%.

Because of the site dispersion and low intensity of the NO_x emitted from the BWR, control of the NO_x from these small combustion sources should be of low priority.

4.2.21 Nitrogen Oxides from Reprocessing

Nitrogen oxides from reprocessing have the third highest dilution factor for the full recycle and for the no recycle scenarios. There are two major sources of nitrogen oxides; sixty percent comes from process sources, and forty percent is from combustion. The release factor used assumes that the process evolves about 1200 kg NO_x per day and combustion produces about 800 kg/day. (25, 22)

NO_x releases from the main stack at the reprocessing facility are made up of process off gas (55.7%) and gases from the plutonium processing facility (2.1%). Other releases from the reprocessing facility include NO_x from process boilers (38.3%) and cold off gas (2.4%). Releases from the UF_6 facility (1.5%) include untreated combustion gases and acid tank sparging.

Currently, nitrogen oxides generated by the separations facility are treated by the off-gas system shown in Figure 4.5. Nitrogen oxide removal is achieved with a water absorber. NO_x is recovered as nitric acid for reuse.

FIGURE 4.5. Process Off-Gas System (18, p. 13)

Methods for removing nitrogen oxides from process gas streams include scrubbing, catalytic reduction, and absorption. The present treatment for NO_x removal is scrubbing with water, which removes most of the NO_2 . The remaining NO_x is largely NO .^(59, p. 13-5) Because NO does not combine with water or most other scrubbing solutions,^(47, p. 5-9) high efficiency absorption requires that NO be oxidized to NO_2 . Residual NO_x in the scrubber effluent can be passed through an oxidation chamber where NO is converted to NO_2 for subsequent absorption.

A commercial process uses an absorber with a catalytic packing and nitric acid as the absorption media.⁽⁴⁶⁾ The NO_x is converted to HNO_3 , recovered, and recycled. The process, which was shown schematically in Figure 4.3, could reduce the concentration of the effluent from the process from about 300 ppm to 200 ppm. The overall release rate of NO_x from the plant would be reduced by 52%.

Most of the NO_x from combustion is generated by burning fuel oil in the process steam boilers. Combustion gases are released to the atmosphere untreated. When natural gas is used, the production of NO_x from combustion is cut by 64%.^(18, p. 86)

Nitrogen oxide production from combustion gases (40% of the total NO_x) can be reduced by combustion modification techniques and by flue gas treatment. Combustion modification techniques include flue gas recirculation, low excess air firing, reduced combustion preheating, steam or water injection, reduced heat release rate, and staged combustion.

Using the EPA emission factors^(30, p. 1.4-2, 1.3-2) and the amount of fuel used,^(17, p. 12-67) the amount of NO_x produced by combustion should be about 220 kg/day. The 800 kg/day estimated in the environmental report^(25, p. 13) appears to be quite conservative.

A combination of combustion modifications should reduce the NO_x release rate from 33 kg/hr presently assumed^(25, p. 13) to 9 kg/hr. This would decrease the overall release factor by 21% from the present value.

4.2.22 Sulfur Oxides from Reprocessing

Sulfur oxides from reprocessing were ranked ninth for full recycle and tenth for the no recycle cases. The reprocessing facility releases about 390 kg/day of sulfur oxides, which are generated by the combustion of fuel oil. About 93% of the release is from process boilers, and 7% is from building heating.^(22, p. 3-5) The present combustion process using fuel oil produces about 0.38 lb SO₂ per 10⁶ Btu (0.68 kg/10⁶ kcal) produced. Combustion gases are released to the atmosphere with no treatment.

The concentration of SO₂ in the boiler stack gas is about 0.4 ppm for natural gas combustion and about 230 ppm for fuel oil combustion.^(18, p. 86, 87) This low concentration along with oxygen concentrations higher than utility combustion operations reduce the effectiveness of wet scrubbing systems.⁽⁶⁰⁾

The control technique used in the future will be determined by the selection of fuel. If natural gas is used, control equipment will not be required.

Flue gas desulfurization for a 38 MW oil-fired plant burning No. 2 fuel oil for process heat could reduce sulfur emissions by about 80%. The capital cost for flue gas desulfurization system sized for a 38 MW plant is about \$2.5 million⁽⁶¹⁾ with operating costs of about \$400,000 (in 1978 dollars) per year.⁽⁵²⁾ The incremental levelized unit cost computed by UNICOST is \$0.51/kg reprocessed. This is 0.0015 mills/kWh, or a 100 year cost of \$0.23 billion.

4.3 DISCUSSION OF RADIOACTIVE AND NONRADIOACTIVE EFFLUENT COMPARISONS

It is possible to calculate dilution factors for radioactive effluents in a manner similar to those calculated for chemicals in this study. These factors would be based on the maximum permissible concentration values for air and water listed in Reference 1. A comparison of the toxicity of radionuclides and toxic elements has been attempted in radioactive waste management studies by Haug⁽⁶²⁾ and Tonnessen.⁽⁶³⁾ Such a comparison, based on dilution factors, has the following limitations:

- First, chemical toxicity is usually expressed in terms of minimum lethal dose (MLD) or LD₅₀ (the amount of a substance that would kill 50% of the exposed subjects in a specified amount of time). Such toxicity indices do not take into account the effects of low-level chronic exposures to toxic elements or chemicals.
- Second, current EPA interim standards for drinking water consider only nine elements, with only two references to specific organic chemical groups.⁽⁶⁴⁾ Even if standards existed for all chemical elements, the question of low-level chronic exposure would still exist.
- Third, the standards for radionuclide concentrations in drinking water were formulated before the EPA standards for heavy metals, and account for both genetic and somatic radiation effects. Thus, they cannot be directly compared with the EPA's interim drinking water standards.
- Fourth, absolute dilution factors have no real physical meaning. The calculated dilution factors can be used as a relative index of toxicity but only when comparing substances with similarly based standards for acceptable exposure.

An accepted method of comparing the toxicity of radionuclides and elements or chemical compounds should be developed as an aid in the analysis of all industrial effluents. Since no method is currently endorsed by the EPA, no attempt is made in this study to compare radionuclide and chemical effluents.

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APPENDIX A

PROJECTED RADIOACTIVE EFFLUENTS

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PROJECTED RADIOACTIVE EFFLUENTS

The tables in Appendix A characterize the radioactive effluents projected by ENFORM computer program for the nuclear fuel cycles considered in this study. The material included in each table is shown below.

Table

- A.1. Combined Air and Water Releases - Stowaway Cycle
- A.2. Combined Air and Water Releases - Reprocessing without Recycle
- A.3. Combined Air and Water Releases - Full Recycle
- A.4. Relative Ranking Factors - Radionuclide Releases from the Stowaway Fuel Cycle
- A.5. Relative Ranking Factors - Radionuclide Releases from the Reprocessing without Recycle Fuel Cycle
- A.6. Relative Ranking Factors - Radionuclide Releases from the Full Recycle Fuel Cycle

TABLE A.1. Projected Radioactive Effluents - Stowaway Cycle, Combined Air and Water Release

Plant	Nuclide	Release Factor		Total Curies	Year 2000 Annual
		Air	Water		
Underground Mine	Rn-222	1.40E-10		4.85E+07	8.48E+05
	Ra-226	4.00E-12	9.00E-12	2.89E+01	5.07E-01
	U-234	6.21E-10	7.40E-09	1.12E+02	1.95E+00
	U-235	8.18E-08	9.74E-07	5.09E+00	8.91E-02
	U-238	1.14E-05	1.36E-04	1.10E+02	1.93E+00
Surface Mine	Rn-222	2.50E-11		6.08E+06	6.81E+04
	Ra-226	1.35E-11		2.11E+01	2.36E-01
	U-234	2.11E-09		2.96E+01	2.31E-01
	U-235	2.77E-07		9.39E-01	1.05E-02
	U-238	3.87E-05		2.04E+01	2.23E-01
Acid Leach Mill	Rn-222	1.30E-12		6.13E+05	9.13E+03
	Ra-226	5.40E-13	6.00E-11	1.83E+02	2.73E+00
	Th-230	3.00E-11	2.00E-07	1.22E+04	1.82E+02
	U-234	1.36E-08	1.64E-08	5.69E+02	8.47E+00
	U-235	1.76E-06	2.16E-06	2.57E+01	3.84E-01
	U-238	2.46E-04	3.02E-04	5.59E+02	8.33E+00
Aqueous Conversion	U-234	1.90E-10	5.78E-08	1.37E+03	2.05E+01
	U-235	2.50E-08	7.61E-06	6.26E+01	9.35E-01
	U-238	3.49E-06	1.06E-03	1.35E+03	2.02E+01
Enrichment	Th-234		1.00E-13	1.53E+03	2.31E+01
	U-234	1.52E-13	4.33E-09	1.77E+01	2.67E-01
	U-235	3.37E-07	5.15E-07	1.21E+00	1.82E-02
	U-238	9.22E-06	6.47E-05	1.63E+01	2.45E-01
Fabrication	U-234	1.79E-10	1.82E-11	8.06E-01	1.21E-02
	U-235	3.74E-08	3.81E-09	5.84E-02	8.80E-04
	U-238	1.13E-06	1.15E-07	2.74E-01	4.13E-03
PWR	H-3	2.00E-02	7.00E-02	1.63E+07	2.08E+05
	C-14	3.00E-01		3.32E+04	4.27E+02
	Cr-51	6.00E-08	1.00E-06	1.08E+02	1.44E+00
	Mn-54	2.00E-06	9.00E-06	3.54E+01	4.63E-01
	Fe-55	3.00E-07	6.00E-06	1.02E+02	1.32E+00
	Fe-59	2.00E-06	5.00E-05	6.78E+01	8.97E-01
	Co-58	1.00E-06	4.00E-05	9.42E+02	1.23E+01
	Co-60	4.00E-05	8.00E-04	2.00E+02	2.58E+00
	Br-83	1.00E-10	6.00E-10	1.70E+01	2.19E-01
	Br-84	3.00E-11	8.00E-12	2.31E+00	3.01E-02
	Br-85	3.00E-12	5.00E-15	2.02E-01	2.62E-03
	Kr-83M	5.00E-07		1.21E+04	1.57E+02
	Kr-85	2.00E-03		8.53E+06	1.08E+05
	Kr-85M	8.00E-07		6.04E+04	7.85E+02
	Kr-87	2.00E-07		2.92E+04	3.79E+02
	Kr-88	5.00E-07		1.06E+05	1.38E+03
	Kr-89	1.00E-08		2.63E+03	3.41E+01
	Rb-86	1.00E-09	3.00E-08	5.50E+00	7.10E-02
	Rb-88	2.00E-09	3.00E-11	4.32E+02	5.61E+00
	Sr-89	2.00E-12	8.00E-11	2.39E+01	3.11E-01
	Sr-90	2.00E-12	2.00E-11	6.43E-01	8.16E-03
	Sr-91	5.00E-12	3.00E-11	1.27E+01	1.66E-01
	Y-90	1.00E-12	3.00E-11	9.39E-01	1.19E-02
	Y-91	2.00E-11	4.00E-10	1.60E+02	2.09E+00
	Y-91M	5.00E-12	3.00E-11	2.50E+01	3.26E-01
	Y-93	7.00E-13	5.00E-13	5.42E-01	7.06E-03
	Zr-95	3.00E-13	3.00E-11	1.67E+01	2.18E-01
	Nb-95	3.00E-13	3.00E-11	1.69E+01	2.20E-01
	Mo-99	2.00E-09	4.00E-08	2.54E+04	3.33E+02
	Tc-99M	2.00E-09		1.05E+03	1.38E+01
	Ru-103	3.00E-13	8.00E-12	4.01E+00	5.27E-02
	Ru-106	1.00E-13	3.00E-12	6.56E-01	8.51E-03
	Ag-110M		2.00E-09	2.76E+00	3.56E-02
	Te-125M	6.00E-11	1.00E-09	1.27E+00	1.62E-02
	Te-127	8.00E-11	1.00E-09	3.01E+01	3.96E-01
	Te-127M	1.00E-10	3.00E-09	1.85E+01	2.43E-01
	Te-129M	2.00E-10	4.00E-09	9.39E+01	1.23E+00
	Te-131	1.00E-11	5.00E-11	1.79E+01	2.35E-01

TABLE A.1. (contd)

Plant	Nuclide	Release Factor		Total Curies	Year 2000 Annual
		Air	Water		
PWR	Te-131M	1.00E-10	2.00E-09	1.07E+02	1.40E+00
	Te-132	2.00E-10	3.00E-09	1.50E+03	1.97E+01
	I-130	1.00E-10	3.00E-09	3.82E+01	4.96E-01
	I-131	7.00E-10	4.00E-08	1.38E+04	1.82E+02
	I-132	2.00E-10	3.00E-09	1.55E+03	2.03E+01
	I-133	4.00E-10	2.00E-08	1.30E+04	1.70E+02
	I-134	5.00E-11	4.00E-11	6.50E+01	8.51E-01
	I-135	3.00E-10	3.00E-09	1.86E+03	2.43E+01
	Xe-131M	1.00E-03		2.73E+06	3.57E+04
	Xe-133	8.00E-05		5.09E+07	6.66E+05
	Xe-133M	2.00E-05		3.08E+05	4.03E+03
	Xe-135	1.00E-06		1.48E+05	1.88E-03
	Xe-135M	4.00E-08		6.82E+03	8.92E+01
	Xe-137	7.00E-09		4.32E+03	5.66E+01
	Xe-138	4.00E-08		2.38E+04	3.12E+02
	Cs-134	2.00E-10	2.00E-08	1.85E+03	2.36E+01
	Cs-136	2.00E-09	3.00E-08	7.39E+02	9.53E+00
	Cs-137	6.00E-10	3.00E-08	1.25E+03	1.60E+01
	Ba-140	1.00E-12	2.00E-11	1.21E+01	1.58E-01
	La-140	7.00E-13	2.00E-11	1.22E+02	1.60E-01
	Ce-141	4.00E-13	8.00E-12	4.65E+00	6.08E-02
	Ce-143	2.00E-13	3.00E-12	1.55E+00	2.03E-02
	Ce-144	2.00E-13	9.00E-11	3.93E+01	5.06E-01
	Pr-143	3.00E-13	7.00E-12	3.51E+00	4.58E-02
	Pr-144	2.00E-13	5.00E-12	2.28E+00	2.94E-02
	Np-239	5.00E-13	8.00E-12	6.11E+01	8.10E-01
BWR	H-3	7.00E-03	1.00E-03	7.05E+05	8.69E+03
	C-14	3.00E-01		2.02E+04	2.52E+02
	Na-24		5.00E-05	7.25E+00	9.51E-02
	P-32		2.00E-06	4.12E-01	5.41E-03
	Cr-51	3.00E-06	2.00E-07	1.65E+02	2.17E+00
	Mn-54	3.00E-05	7.00E-08	3.90E+01	5.01E-01
	Mn-56		2.00E-07	1.01E+01	1.33E-01
	Fe-55		2.00E-07	1.92E+00	2.42E-02
	Fe-59	2.00E-05	8.00E-08	1.18E+01	1.55E-01
	Co-58	1.00E-06	3.00E-08	9.60E+00	1.24E-01
	Co-60	1.00E-03	6.00E-06	9.85E+01	1.23E+00
	Ni-65		6.00E-08	4.45E-02	5.84E-04
	Cu-64		2.00E-06	2.10E+01	2.75E-01
	Zn-65	5.00E-03	7.00E-05	1.98E+01	2.47E-01
	Br-83		5.00E-11	4.77E-01	6.08E-03
	Br-84		2.00E-12	4.75E-02	6.10E-04
	Kr-83M	1.00E-06		9.54E+03	1.22E+02
	Kr-85	1.00E-03		2.07E+06	2.53E+04
	Kr-85M	3.00E-05		8.85E+05	1.13E+04
	Kr-87	4.00E-05		2.28E+06	2.92E+04
	Kr-88	3.00E-05		2.49E+06	3.19E+04
	Kr-89	1.00E-07		1.03E+04	1.32E+02
	Rb-89		2.00E-12	2.09E-01	2.68E-03
	Sr-89	6.00E-10	2.00E-12	6.79E+01	8.71E-01
	Sr-90	2.00E-11		2.89E-01	3.53E-03
	Sr-91		2.00E-11	2.84E+00	3.64E-02
	Sr-92		1.00E-11	1.42E+00	1.82E-02
	Y-91		6.00E-13	8.84E-02	1.13E-03
	Y-91M		2.00E-11	5.59E+00	7.16E-02
	Y-92		2.00E-11	3.19E+00	4.10E-02
	Y-93		2.00E-11	3.51E+00	4.52E-02
	Zr-95	2.00E-11		4.25E+00	5.46E-02
	Mo-99		1.00E-11	2.34E+00	3.03E-02
	Tc-99M		5.00E-11	1.02E+01	1.32E-01
	Tc-101		1.00E-13	2.16E-02	2.79E-04
	Ru-103		2.00E-13	3.71E-02	4.80E-04
	Ru-105		5.00E-12	7.07E-01	9.20E-03
	Rh-105		2.00E-12	2.25E-01	2.91E-03
	Sb-124	7.00E-08		4.76E+00	5.86E-02
	Te-129M		7.00E-12	6.01E-02	7.77E-04

TABLE A.1. (contd)

Plant	Nuclide	Release Factor		Total Curies	Year 2000 Annual
		Air	Water		
BWR	Te-131		2.00E-13	2.31E-02	2.99E-04
	Te-131M		6.00E-12	1.18E-01	1.52E-03
	Te-132		6.00E-14	1.09E-02	1.41E-04
	I-131	4.00E-08	6.00E-11	5.27E+03	6.82E+01
	I-132		2.00E-11	3.75E+00	4.85E-02
	I-133	7.00E-08	8.00E-11	1.73E+04	2.23E+02
	I-134		6.00E-12	1.68E+00	2.17E-02
	I-135		4.00E-11	8.73E+00	1.13E-01
	Xe-131M	5.00E-05		5.28E+04	6.80E+02
	Xe-133	1.00E-04		2.47E+07	3.18E+05
	Xe-133M	2.00E-06		1.19E+04	1.54E+02
	Xe-135	2.00E-04		1.35E+07	1.69E+05
	Xe-135M	1.00E-04		6.60E+06	8.51E+04
	Xe-137	4.00E-08		9.56E+03	1.23E+02
	Xe-138	6.00E-05		1.38E+07	1.78E+05
	Cs-134	1.00E-09	2.00E-10	4.10E+01	4.99E-01
	Cs-136	4.00E-10	6.00E-10	8.32E+00	1.04E-01
	Cs-137	3.00E-09	9.00E-10	7.90E+01	9.70E-01
	Cs-138		4.00E-11	9.30E+00	1.20E-01
	Ba-139		3.00E-12	6.99E-01	9.01E-03
	Ba-140	5.00E-10	3.00E-12	1.12E+02	1.45E+00
	La-140		6.00E-13	1.37E-01	1.77E-03
	La-141		1.00E-12	2.12E-01	2.73E-03
	La-142		2.00E-12	4.08E-01	5.26E-03
	Ce-141	4.00E-11	2.00E-13	8.53E+00	1.10E-01
	Ce-143		2.00E-13	3.76E-02	4.85E-04
	Pr-143		3.00E-13	5.61E-02	7.23E-04
	W-187		9.00E-09	3.27E-01	4.33E-03
	Np-239		3.00E-12	8.46E+00	1.11E-01

TABLE A.2. Projected Radioactive Effluents - Reprocessing Without Recycle Combined Air and Water Release

Plant	Nuclide	Release Factor		Total Curies	Year 2000 Annual
		Air	Water		
Underground Mine	Rn-222	1.40E-10		4.85E+07	8.48E+05
	Ra-226	4.00E-12	9.00E-12	2.89E+01	5.07E-01
	U-234	6.21E-10	7.40E-09	1.12E+02	1.95E+00
	U-235	8.18E-08	9.74E-07	5.09E+00	8.91E-02
	U-238	1.14E-05	1.36E-04	1.10E+02	1.93E+00
Surface Mine	Rn-222	2.50E-11		6.08E+06	6.81E+04
	Ra-226	1.35E-11		2.11E+01	2.36E-01
	U-234	2.11E-09		2.06E+01	2.31E-01
	U-235	2.77E-07		9.39E-01	1.05E-02
	U-238	3.87E-05		2.04E+01	2.28E-01
Acid Leach Mill	Rn-222	1.30E-12		6.13E+05	9.13E+03
	Ra-226	5.40E-13	6.00E-11	1.83E+02	2.73E+00
	Th-230	3.00E-11	2.00E-07	1.22E+04	1.82E+02
	U-234	1.36E-08	1.64E-08	5.69E+02	8.47E+00
	U-235	1.76E-06	2.16E-06	2.57E+01	3.84E-01
	U-238	2.46E-04	3.02E-04	5.59E+02	8.33E+00
Aqueous Conversion	U-234	1.90E-10	5.78E-08	1.37E+03	2.05E+01
	U-235	2.50E-08	7.61E-06	6.26E+01	9.35E-01
	U-238	3.49E-06	1.06E-03	1.35E+03	2.02E+01
Enrichment	Th-234		1.00E-13	1.53E+03	2.31E+01
	U-234	1.52E-13	4.33E-09	1.77E+01	2.67E-01
	U-235	3.37E-07	5.15E-07	1.21E+00	1.82E-02
	U-238	9.22E-06	6.47E-05	1.63E+01	2.45E-01
Fabrication	U-234	1.79E-10	1.82E-11	8.06E-01	1.21E-02
	U-235	3.74E-08	3.81E-09	5.84E-02	8.80E-04
	U-238	1.13E-06	1.15E-07	2.74E-01	4.13E-03
PWR	H-3	2.00E-02	7.00E-02	1.63E+07	2.08E+05
	C-14	3.00E-01		3.32E+04	4.27E+02
	Cr-51	6.00E-08	1.00E-06	1.08E+02	1.44E+00
	Mn-54	2.00E-06	9.00E-06	3.54E+01	4.63E-01
	Fe-55	3.00E-07	6.00E-06	1.02E+02	1.32E+00
	Fe-59	2.00E-06	5.00E-05	6.78E+01	8.97E-01
	Co-58	1.00E-06	4.00E-05	9.42E+02	1.23E+01
	Co-60	4.00E-05	8.00E-04	2.00E+02	2.58E+00
	Br-83	1.00E-10	6.00E-10	1.70E+01	2.19E-01
	Br-84	3.00E-11	8.00E-12	2.31E+00	3.01E-02
	Br-85	3.00E-12	5.00E-15	2.02E-01	2.62E-03
	Kr-83M	5.00E-07		1.21E+04	1.57E+02
	Kr-85	2.00E-03		8.53E+06	1.08E+05
	Kr-85M	8.00E-07		6.04E+04	7.85E+02
	Kr-87	2.00E-07		2.92E+04	3.79E+02
	Kr-88	5.00E-07		1.06E+05	1.38E+03
	Kr-89	1.00E-08		2.63E+03	3.41E+01
	Rb-86	1.00E-09	3.00E-08	5.50E+00	7.10E-02
	Rb-88	2.00E-09	3.00E-11	4.32E+02	5.61E+00
	Sr-89	2.00E-12	8.00E-11	2.39E+01	3.11E-01
	Sr-90	2.00E-12	2.00E-11	6.43E-01	8.16E-03
	Sr-91	5.00E-12	3.00E-11	1.27E+01	1.66E-01
	Y-90	1.00E-12	3.00E-11	9.39E-01	1.19E-02
	Y-91	2.00E-11	4.00E-10	1.60E+02	2.09E+00
	Y-91M	5.00E-12	3.00E-11	2.50E+01	3.26E-01
	Y-93	7.00E-13	5.00E-13	5.42E-01	7.06E-03
	Zr-95	3.00E-13	3.00E-11	1.67E+01	2.18E-01
	Nb-95	3.00E-13	3.00E-11	1.69E+01	2.20E-01
	Mo-99	2.00E-09	4.00E-08	2.54E+04	3.33E+02
	Tc-99M	2.00E-09		1.05E+03	1.38E+01
	Ru-103	3.00E-13	8.00E-12	4.01E+00	5.27E-02
	Ru-106	1.00E-13	3.00E-12	6.56E-01	8.51E-03
	Ag-110M		2.00E-09	2.76E+00	3.56E-02
	Te-125M	6.00E-11	1.00E-09	1.27E+00	1.62E-02
	Te-127	8.00E-11	1.00E-09	3.01E+01	3.96E-01
	Te-127M	1.00E-10	3.00E-09	1.85E+01	2.43E-01
	Te-129M	2.00E-10	4.00E-09	9.39E+01	1.23E+00
	Te-131	1.00E-11	5.00E-11	1.79E+01	2.35E-01

TABLE A.2. (contd)

Plant	Nuclide	Release Factor		Total Curies	Year 2000 Annual
		Air	Water		
PWR	Te-131M	1.00E-10	2.00E-09	1.07E+02	1.40E+00
	Te-132	2.00E-10	3.00E-09	1.50E+03	1.97E+01
	I-130	1.00E-10	3.00E-09	3.82E+01	4.96E-01
	I-131	7.00E-10	4.00E-08	1.38E+04	1.82E+02
	I-132	2.00E-10	3.00E-09	1.55E+03	2.03E+01
	I-133	4.00E-10	2.00E-08	1.30E+04	1.70E+02
	I-134	5.00E-11	4.00E-11	6.50E+01	8.51E-01
	I-135	3.00E-10	3.00E-09	1.86E+03	2.43E+01
	Xe-131M	1.00E-03		2.73E+06	3.57E+04
	Xe-133	8.00E-05		5.09E+07	6.66E+05
	Xe-133M	2.00E-05		3.08E+05	4.03E+03
	Xe-135	1.00E-06		1.48E+05	1.88E-03
	Xe-135M	4.00E-08		6.82E+03	8.92E+01
	Xe-137	7.00E-09		4.32E+03	5.66E+01
	Xe-138	4.00E-08		2.38E+04	3.12E+02
	Cs-134	2.00E-10	2.00E-08	1.85E+03	2.36E+01
	Cs-136	2.00E-09	3.00E-08	7.39E+02	9.53E+00
	Cs-137	6.00E-10	3.00E-08	1.25E+03	1.60E+01
	Ba-140	1.00E-12	2.00E-11	1.21E+01	1.58E-01
	La-140	7.00E-13	2.00E-11	1.22E+02	1.60E-01
	Ce-141	4.00E-13	8.00E-12	4.65E+00	6.08E-02
	Ce-143	2.00E-13	3.00E-12	1.55E+00	2.03E-02
	Ce-144	2.00E-13	9.00E-11	3.93E+01	5.06E-01
	Pr-143	3.00E-13	7.00E-12	3.51E+00	4.58E-02
	Pr-144	2.00E-13	5.00E-12	2.28E+00	2.94E-02
	Np-239	5.00E-13	8.00E-12	6.11E+01	8.10E-01
BWR	H-3	7.00E-03	1.00E-03	7.05E+05	8.69E+03
	C-14	3.00E-01		2.02E+04	2.52E+02
	Na-24		5.00E-05	7.25E+00	9.51E-02
	P-32		2.00E-06	4.12E-01	5.41E-03
	Cr-51	3.00E-06	2.00E-07	1.65E+02	2.17E+00
	Mn-54	3.00E-05	7.00E-08	3.90E+01	5.01E-01
	Mn-56		2.00E-07	1.01E+01	1.33E-01
	Fe-55		2.00E-07	1.92E+00	2.42E-02
	Fe-59	2.00E-05	8.00E-08	1.18E+01	1.55E-01
	Co-58	1.00E-06	3.00E-08	9.60E+00	1.24E-01
	Co-60	1.00E-03	6.00E-06	9.85E+01	1.23E+00
	Ni-65		6.00E-08	4.45E-02	5.84E-04
	Cu-64		2.00E-06	2.10E+01	2.75E-01
	Zn-65	5.00E-03	7.00E-05	1.98E+01	2.47E-01
	Br-83		5.00E-11	4.77E-01	6.08E-03
	Br-84		2.00E-12	4.75E-02	6.10E-04
	Kr-83M	1.00E-06		9.54E+03	1.22E+02
	Kr-85	1.00E-03		2.07E+06	2.53E+04
	Kr-85M	3.00E-05		8.85E+05	1.13E+04
	Kr-87	4.00E-05		2.28E+06	2.92E+04
	Kr-88	3.00E-05		2.49E+06	3.19E+04
	Kr-89	1.00E-07		1.03E+04	1.32E+02
	Rb-89		2.00E-12	2.09E-01	2.68E-03
	Sr-89	6.00E-10	2.00E-12	6.79E+01	8.71E-01
	Sr-90	2.00E-11		2.89E-01	3.53E-03
	Sr-91		2.00E-11	2.84E+00	3.64E-02
	Sr-92		1.00E-11	1.42E+00	1.82E-02
	Y-91		6.00E-13	8.84E-02	1.13E-03
	Y-91M		2.00E-11	5.59E+00	7.16E-02
	Y-92		2.00E-11	3.19E+00	4.10E-02
	Y-93		2.00E-11	3.51E+00	4.52E-02
	Zr-95	2.00E-11		4.25E+00	5.46E-02
	Mo-99		1.00E-11	2.34E+00	3.03E-02
	Tc-99M		5.00E-11	1.02E+01	1.32E-01
	Tc-101		1.00E-13	2.16E-02	2.79E-04
	Ru-103		2.00E-13	3.71E-02	4.80E-04
	Ru-105		5.00E-12	7.07E-01	9.20E-03
	Rh-105		2.00E-12	2.25E-01	2.91E-03
	Sb-124	7.00E-08		4.76E+00	5.86E-02
	Te-129M		7.00E-12	6.01E-02	7.77E-04

TABLE A.2. (contd)

Plant	Nuclide	Release Factor		Total Curies	Year 2000 Annual
		Air	Water		
SWR	Te-131		2.00E-13	2.31E-02	2.99E-04
	Te-131M		6.00E-12	1.18E-01	1.52E-03
	Te-132		6.00E-14	1.09E-02	1.41E-04
	I-131	4.00E-08	6.00E-11	5.27E+03	6.82E+01
	I-132		2.00E-11	3.75E+00	4.85E-02
	I-133	7.00E-08	8.00E-11	1.73E+04	2.23E+02
	I-134		6.00E-12	1.68E+00	2.17E-02
	I-135		4.00E-11	8.73E+00	1.13E-01
	Xe-131M	5.00E-05		5.28E+04	6.80E+02
	Xe-133	1.00E-04		2.47E+07	3.18E+05
	Xe-133M	2.00E-06		1.19E+04	1.54E+02
	Xe-135	2.00E-04		1.35E+07	1.69E+05
	Xe-135M	1.00E-04		6.60E+06	8.51E+04
	Xe-137	4.00E-08		9.56E+03	1.23E+02
	Xe-138	6.00E-05		1.38E+07	1.78E+05
	Cs-134	1.00E-09	2.00E-10	4.10E+01	4.99E-01
	Cs-136	4.00E-10	6.00E-10	8.32E+00	1.04E-01
	Cs-137	3.00E-09	9.00E-10	7.90E+01	9.70E-01
	Cs-138		4.00E-11	9.30E+00	1.20E-01
	Ba-139		3.00E-12	6.99E-01	9.01E-03
	Ba-140	5.00E-10	3.00E-12	1.12E+02	1.45E+00
	La-140		6.00E-13	1.37E-01	1.77E-03
	La-141		1.00E-12	2.12E-01	2.73E-03
	La-142		2.00E-12	4.08E-01	5.26E-03
	Ce-141	4.00E-11	2.00E-13	8.53E+00	1.10E-01
	Ce-143		2.00E-13	3.76E-02	4.85E-04
	Pr-143		3.00E-13	5.61E-02	7.23E-04
	W-187		9.00E-09	3.27E-01	4.33E-03
	Np-239		3.00E-12	8.46E+00	1.11E-01
FRP	H-3	7.00E-01		1.54E+08	1.67E+06
	C-14	1.00E+00		1.73E+05	1.85E+03
	Kr-85	8.00E-01		4.04E+09	4.37E+07
	Sr-89	2.00E-09		8.98E-04	1.93E-05
	Sr-90	2.00E-09		7.88E+01	8.37E-01
	Y-90	2.00E-09		7.88E+01	8.37E-01
	Y-91	2.00E-09		5.32E-03	1.13E-04
	Zr-95	3.00E-09		3.46E-02	7.22E-04
	Nb-95	3.00E-09		7.50E-02	1.56E-03
	Ru-103	3.00E-09		4.03E-05	8.77E-07
	Ru-106	3.00E-09		1.90E+02	1.48E+00
	I-129	9.00E-04		1.87E+01	1.97E-01
	Cs-134	2.00E-09		8.69E+01	1.04E+00
	Cs-137	2.00E-09		1.11E+02	1.18E+00
	Ce-141	3.00E-09		1.16E-06	2.48E-08
	Ce-144	3.00E-09		1.22E+02	1.74E+00
	Pm-147	3.00E-09		8.67E+01	1.03E+00
	U-232	2.00E-05		1.62E-01	1.60E-03
	U-233	2.00E-05		9.20E-04	9.44E-06
	U-234	2.00E-05		1.23E+01	1.23E-01
	U-235	2.00E-05		2.20E-01	2.27E-03
	U-236	2.00E-05		2.83E+00	2.95E-02
	U-237	2.00E-05		3.04E+01	3.33E-01
	U-238	2.00E-05		4.00E+00	4.33E-02
	Pu-238	1.00E-09		1.31E+00	1.37E-02
	Pu-239	1.00E-09		1.84E-01	1.99E-03
	Pu-240	1.00E-09		2.83E-01	3.05E-03
	Pu-241	1.00E-09		6.06E+01	6.64E-01
	Pu-242	1.00E-09		9.96E-04	1.05E-05
	Am-241	2.00E-09		7.87E-01	7.49E-03
	Am-242	2.00E-09		1.33E-02	1.39E-04
	Cm-242	6.00E-09		1.40E+00	2.17E-02
	Cm-243	6.00E-09		1.40E-02	1.46E-04
	Cm-244	6.00E-09		4.37E+00	4.61E-02

TABLE A.3. Projected Radioactive Effluents - Full Plutonium and Uranium Recycle, Combined Air and Water Release

Plant	Nuclide	Release Factor		Total Curies	Year 2000 Annual
		Air	Water		
Underground Mine	Rn-222	1.40E-10		3.57E+07	6.26E+05
	Ra-226	4.00E-12	9.00E-12	2.13E+01	3.82E-01
	U-234	6.21E-10	7.40E-09	8.21E+01	1.44E+00
	U-235	8.18E-08	9.74E-07	3.75E+00	6.57E-02
	U-238	1.14E-05	1.36E-04	8.13E+01	1.43E+00
Surface Mine	Rn-222	2.50E-11		2.92E+06	4.62E+04
	Ra-226	1.35E-11		1.01E+01	1.60E-01
	U-234	2.11E-09		9.91E+00	1.57E-01
	U-235	2.77E-07		4.51E-01	7.13E-03
	U-238	3.87E-05		9.79E+00	1.55E-01
Acid Leach Mill	Rn-222	1.30E-12		3.86E+05	6.57E+03
	Ra-226	5.40E-13		1.16E+02	1.97E+00
	Th-230	3.00E-11	6.00E-11	7.69E+03	1.31E+02
	U-234	1.36E-08	1.64E-08	3.59E+02	6.10E+00
	U-235	1.76E-06	2.16E-06	1.62E+01	2.76E-01
	U-238	2.46E-04	3.02E-04	3.53E+02	6.00E+00
Aqueous Conversion	U-234	1.90E-10	5.78E-08	1.11E+03	1.75E+01
	U-235	2.50E-08	7.61E-06	5.06E+01	7.98E-01
	U-238	3.49E-06	1.06E-03	1.09E+03	1.73E+01
Enrichment	Th-234		1.00E-13	1.51E+03	2.29E+01
	U-234	1.52E-13	4.33E-09	1.75E+01	2.65E-01
	U-235	3.37E-07	5.15E-07	1.19E+00	1.80E-02
	U-238	9.22E-06	6.47E-05	1.61E+01	2.43E-01
Uranium Fabrication	U-234	1.79E-10	1.82E-11	5.98E-01	9.98E-03
	U-235	3.74E-08	3.81E-09	4.33E-02	7.23E-04
	U-238	1.13E-06	1.15E-07	2.03E-01	3.39E-03
MOX Fabrication	U-234	2.25E-15	2.40E-14	2.77E-05	2.89E-07
	U-235	4.70E-13	5.02E-12	2.01E-06	2.09E-08
	U-238	1.42E-11	1.52E-10	9.45E-06	9.84E-08
	Pu-238	1.74E-14	1.85E-13	5.84E-01	6.07E-03
	Pu-239	3.16E-13	3.37E-12	3.86E-02	4.01E-04
	Pu-240	1.87E-13	2.00E-12	8.23E-02	8.57E-04
	Pu-241	1.11E-13	1.18E-12	2.20E+01	8.19E-03
	Pu-242	6.25E-14	6.66E-13	4.85E-04	5.05E-06
PWR	H-3	2.00E-02	7.00E-02	1.71E+07	2.15E+05
	C-14	3.00E-01		2.83E+04	3.84E+02
	Cr-51	6.00E-08	1.00E-06	8.88E+01	1.26E+00
	Mn-54	2.00E-06	9.00E-06	3.46E+01	4.58E-01
	Fe-55	3.00E-07	6.00E-06	8.21E+01	1.14E+00
	Fe-59	2.00E-06	5.00E-05	5.97E+01	8.27E-01
	Co-58	1.00E-06	4.00E-05	9.81E+02	1.28E+01
	Co-60	4.00E-05	8.00E-04	1.67E+02	2.30E+00
	Br-83	1.00E-10	6.00E-10	1.54E+01	2.05E-01
	Br-84	3.00E-11	8.00E-12	2.22E+00	2.92E-02
	Br-85	3.00E-12	5.00E-15	1.92E-01	2.53E-03
	Kr-83M	5.00E-07		1.10E+04	1.46E+02
	Kr-85	2.00E-03		7.73E+06	1.01E+05
	Kr-85M	8.00E-07		5.75E+04	7.57E+02
	Kr-87	2.00E-07		2.76E+04	3.64E+02
	Kr-88	5.00E-07		1.01E+05	1.33E+03
	Kr-89	1.00E-08		2.48E+03	3.27E+01
	Rb-86	1.00E-09	3.00E-08	4.48E+00	6.18E-02
	Rb-88	2.00E-09	3.00E-11	4.10E+02	5.40E+00
	Sr-89	2.00E-12	8.00E-11	2.24E+01	2.97E+01
	Sr-90	2.00E-12	2.00E-11	5.78E-01	7.56E-03
Sr-91	5.00E-12	3.00E-11	1.21E+01	1.60E-01	
Y-90	1.00E-12	3.00E-11	8.41E-01	1.10E-02	
Y-91	2.00E-11	4.00E-10	1.52E+02	2.00E+00	
Y-91M	5.00E-12	3.00E-11	2.38E+01	3.14E-01	
Y-93	7.00E-13	5.00E-13	5.27E-01	6.93E-03	
Zr-95	3.00E-13	3.00E-11	1.64E+01	2.16E-01	
Nb-95	3.00E-13	3.00E-11	1.66E+01	2.18E-01	

TABLE A.3. (contd)

Plant	Nuclide	Release Factor		Total Curies	Year 2000 Annual
		Air	Water		
PWR	Mo-99	2.00E-09	4.00E-08	2.55E+04	3.33E+02
	Tc-99M	2.00E-09		1.05E+03	1.38E+01
	Ru-103	3.00E-13	8.00E-12	4.13E+00	5.38E-02
	Ru-106	1.00E-13	3.00E-12	7.57E-01	9.46E-03
	Ag-110M		2.00E-09	3.64E+00	4.41E-02
	Te-125M	6.00E-11	1.00E-09	1.48E+00	1.83E-02
	Te-127	8.00E-11	1.00E-09	3.16E+01	4.11E-01
	Te-127M	1.00E-10	3.00E-09	1.96E+01	2.53E-01
	Te-129M	2.00E-10	4.00E-09	9.66E+01	1.26E+00
	Te-131	1.00E-11	5.00E-11	1.81E+01	2.37E-01
	Te-131M	1.00E-10	2.00E-09	1.08E+02	1.41E+00
	Te-132	2.00E-10	3.00E-09	1.51E+03	1.98E+01
	I-130	1.00E-10	3.00E-09	3.65E+01	4.84E-01
	I-131	7.00E-10	4.00E-08	1.40E+04	1.83E+02
	I-132	2.00E-10	3.00E-09	1.57E+03	2.05E+01
	I-133	4.00E-10	2.00E-08	1.30E+04	1.70E+02
	I-134	5.00E-11	4.00E-11	6.48E+01	8.49E-01
	I-135	3.00E-10	3.00E-09	1.85E+03	2.42E+01
	Xe-131M	1.00E-03		2.76E+06	3.60E+04
	Xe-133	8.00E-05		5.09E+07	6.66E+05
	Xe-133M	2.00E-05		3.08E+05	4.03E+03
	Xe-135	1.00E-06		1.90E+05	2.25E+03
	Xe-135M	4.00E-08		6.79E+03	8.90E+01
	Xe-137	7.00E-09		4.33E+03	5.67E+01
	Xe-138	4.00E-08		2.39E+04	3.13E+02
	Cs-134	2.00E-10	2.00E-08	1.85E+03	2.37E+01
	Cs-136	2.00E-09	3.00E-08	8.73E+02	1.08E+01
	Cs-137	6.00E-10	3.00E-08	1.26E+03	1.61E+01
	Ba-140	1.00E-12	2.00E-11	1.20E+01	1.57E-01
	La-140	7.00E-13	2.00E-11	1.21E+01	1.59E-01
	Ce-141	4.00E-13	8.00E-12	4.59E+00	6.02E-02
	Ce-143	2.00E-13	3.00E-12	1.53E+00	2.01E-02
	Ce-144	2.00E-13	9.00E-11	3.79E+01	4.94E-01
	Pr-143	3.00E-13	7.00E-12	3.47E+00	4.55E-02
	Pr-144	2.00E-13	5.00E-12	2.20E+00	2.87E-02
	Np-239	5.00E-13	8.00E-12	6.04E+01	8.10E-01
BWR	H-3	7.00E-03	1.00E-03	7.44E+05	9.00E+03
	C-14	3.00E-01		1.67E+04	2.25E+02
	Na-24		5.00E-05	7.72E+00	9.58E-02
	P-32		2.00E-06	4.16E-01	5.51E-03
	Cr-51	3.00E-06	2.00E-07	1.31E+02	1.90E+00
	Mn-54	3.00E-05	7.00E-08	3.90E+01	5.07E-01
	Mn-56		2.00E-07	8.77E+00	1.23E-01
	Fe-55		2.00E-07	1.50E+00	2.09E-02
	Fe-59	2.00E-05	8.00E-08	1.02E+01	1.42E-01
	Co-58	1.00E-06	3.00E-08	1.02E+01	1.31E-01
	Co-60	1.00E-03	6.00E-06	8.23E+01	1.11E+00
	Ni-65		6.00E-08	3.52E-02	5.10E-04
	Cu-64		2.00E-06	1.82E+01	2.55E-01
	Zn-65	5.00E-03	7.00E-05	1.57E+01	2.16E-01
	Br-83		5.00E-11	4.33E-01	5.72E-03
	Br-84		2.00E-12	4.56E-02	5.95E-04
	Kr-83M	1.00E-06		8.66E+03	1.15E+02
	Kr-85	1.00E-03		1.86E+06	2.36E+04
	Kr-85M	3.00E-05		9.41E+05	1.10E+04
	Kr-87	4.00E-05		2.16E+06	2.82E+04
	Kr-88	3.00E-05		2.36E+06	3.09E+04
	Kr-89	1.00E-07		9.69E+03	1.27E+02
	Rb-89		2.00E-12	1.97E-01	2.58E-03
	Sr-89	6.00E-10	2.00E-12	6.37E+01	8.37E-01
	Sr-90	2.00E-11		2.57E-01	3.27E-03
	Sr-91		2.00E-11	2.70E+00	3.53E-02
	Sr-92		1.00E-11	1.37E+00	1.78E-02
	Y-91		6.00E-13	8.37E-02	1.10E-03
	Y-91M		2.00E-11	5.32E+00	6.95E-02
	Y-92		2.00E-11	3.08E+00	4.01E-02

TABLE A.3. (contd)

Plant	Nuclide	Release Factor		Total Curies	Year 2000 Annual
		Air	Water		
BWR	Y-93		2.00E-11	3.43E+00	4.45E-02
	Zr-95	2.00E-11		4.19E+00	5.42E-02
	Mo-99		1.00E-11	2.35E+00	3.03E-02
	Tc-99M		5.00E-11	1.02E+01	1.32E-01
	Tc-101		1.00E-13	2.18E-02	2.81E-04
	Ru-103		2.00E-13	3.84E-02	4.91E-04
	Ru-105		5.00E-12	7.55E-01	9.60E-03
	Rh-105		2.00E-12	2.42E-01	3.04E-03
	Sb-124	7.00E-08		5.57E+00	6.56E-02
	Te-129M		7.00E-12	6.19E-02	7.93E-04
	Te-131		2.00E-13	2.35E-02	3.02E-04
	Te-131M		6.00E-12	1.20E-01	1.54E-03
	Te-132		6.00E-14	1.10E-02	1.42E-04
	I-131	4.00E-08		5.36E+03	6.89E+01
	I-132		2.00E-11	3.80E+00	4.89E-02
	I-133	7.00E-08		8.00E-11	1.73E+04
	I-134		6.00E-12	1.68E+00	2.17E-02
	I-135		4.00E-11	8.73E+00	1.13E-01
	Xe-131M	5.00E-05		5.35E+04	6.87E+02
	Xe-133	1.00E-04		2.47E+07	3.19E+05
	Xe-133M	2.00E-06		1.19E+04	1.54E+02
	Xe-135	2.00E-04		1.78E+07	2.02E+05
	Xe-135M	1.00E-04		6.59E+06	8.51E+04
	Xe-137	4.00E-08		9.62E+03	1.24E+02
	Xe-138	6.00E-05		1.39E+07	1.79E+05
	Cs-134	1.00E-09	2.00E-10	4.17E+01	5.11E-01
	Cs-136	4.00E-10	6.00E-10	1.01E+01	1.19E-01
	Cs-137	3.00E-09	9.00E-10	7.96E+01	9.74E-01
	Cs-138		4.00E-11	9.37E+00	1.21E-01
	Ba-139		3.00E-12	6.96E-01	8.99E-03
	Ba-140	5.00E-10	3.00E-12	1.12E+02	1.45E+00
	La-140		6.00E-13	1.36E-01	1.76E-03
	La-141		1.00E-12	2.09E-01	2.71E-03
	La-142		2.00E-12	4.05E-01	5.24E-03
	Ce-141	4.00E-11	2.00E-13	8.44E+00	1.09E-01
	Ce-143		2.00E-13	3.72E-02	4.82E-04
	Pr-143		3.00E-13	5.56E-02	7.18E-04
	W-187		9.00E-09	3.26E-01	4.35E-03
	Np-239		3.00E-12	8.51E+00	1.13E-01
FRP	H-3	7.00E-01		1.62E+08	1.73E+06
	C-14	1.00E+00		1.46E+05	1.66E+03
	Kr-85	8.00E-01		3.65E+09	4.07E+07
	Sr-89	2.00E-09		8.47E-04	1.85E-05
	Sr-90	2.00E-09		7.06E+01	7.73E-01
	Y-90	2.00E-09		7.06E+01	7.73E-01
	Y-91	2.00E-09		5.06E-03	1.09E-04
	Zr-95	3.00E-09		3.41E-02	7.15E-04
	Nb-95	3.00E-09		7.40E-02	1.55E-03
	Ru-103	3.00E-09		4.13E-05	8.96E-07
	Ru-106	3.00E-09		1.26E+02	1.65E+00
	I-129	3.00E-02		6.66E+02	6.91E+00
	Cs-134	2.00E-09		8.72E+01	1.05E+00
	Cs-137	2.00E-09		1.12E+02	1.19E+00
	Ce-141	3.00E-09		1.15E-06	2.46E-08
	Ce-144	3.00E-09		1.18E+02	1.70E+00
	Pm-147	3.00E-09		8.56E+01	1.01E+00
	U-232	2.00E-05		1.74E+02	2.71E-03
	U-233	2.00E-05		9.79E-03	1.03E-05
	U-234	2.00E-05		1.58E+01	1.40E-01
	U-235	2.00E-05		2.08E-01	2.13E-03
	U-236	2.00E-05		4.04E+00	3.67E-02
	U-237	2.00E-05		6.88E+01	5.64E-01
	U-238	2.00E-05		3.96E+00	4.30E-02
	Pu-238	1.00E-09		5.01E+00	3.46E-02
	Pu-239	1.00E-09		2.66E-01	2.58E-03
	Pu-240	1.00E-09		6.04E-01	5.09E-03

TABLE A.3. (contd)

Plant	Nuclide	Release Factor		Total Curies	Year 2000 Annual
		Air	Water		
Reprocessing	Pu-241	1.00E-09		1.38E+02	1.13E+00
	Pu-242	1.00E-09		3.72E-03	2.38E-05
	Am-241	2.00E-09		1.98E+00	1.38E-02
	Am-242	2.00E-09		1.08E-01	6.32E-04
	Cm-242	6.00E-09		5.37E+00	5.72E-02
	Cm-243	6.00E-09		3.47E-02	2.82E-04
	Cm-244	6.00E-09		4.11E+01	2.55E-01

TABLE A.4. Relative Ranking Factors - Radionuclide Releases from the Stowaway Fuel Cycle

Plant	Nuclide	Release Factor		Relative Ranking Factors				
		Air	Water	Total Body	GI Tract	Thyroid	Bone	Lung
Underground Mine	Rn-222	1.40E-10		2.38E+03	2.38E+03	2.38E+03	2.38E+03	5.09E+03
	Ra-226	4.00E-12	9.00E-12	3.08E+02	1.59E+01	1.53E+01	4.17E-01	9.10E+01
	U-234	6.21E-10	7.40E-09	1.85E-01	4.61E-02	3.22E-03	2.92E+00	1.24E+01
	U-235	8.18E-08	9.74E-07	7.69E-03	2.35E-03	1.76E-06	1.27E-01	5.28E-01
	U-238	1.14E-05	1.36E-04	1.55E-01	3.58E-02	9.48E-06	2.63E+00	1.07E+01
Surface Mine	Rn-222	2.50E-11		2.99E+02	2.99E+02	2.99E+02	2.99E+02	6.38E+02
	Ra-226	1.35E-11		2.74E+02	1.42E+01	1.37E+01	3.71E+02	8.13E+01
	U-234	2.11E-09		4.42E-01	1.10E-01	7.70E-03	6.98E+00	2.95E+01
	U-235	2.77E-07		1.83E-02	5.58E-03	4.20E-06	3.01E-01	1.26E+00
	U-238	3.87E-05		3.71E-01	8.54E-02	2.26E-05	6.28E+00	2.55E+01
Acid Leach Mill	Rn-222	1.30E-12		3.02E+01	3.02E+01	3.02E+01	3.02E+01	6.44E+01
	Ra-226	5.40E-13	6.00E-11	2.13E+01	1.10E+00	1.06E+00	2.88E+01	6.30E+00
	Th-230	3.00E-11	2.00E-07	5.21E+02	1.48E+00	1.18E-01	1.87E+04	5.06E+03
	U-234	1.36E-08	1.64E-08	5.52E+00	1.37E+00	9.62E-02	8.72E+01	3.69E+02
	U-235	1.76E-06	2.16E-06	2.25E-01	6.88E-02	5.17E-05	3.71E+00	1.55E+01
	U-238	2.46E-04	3.02E-04	4.57E+00	1.05E+00	2.79E-04	7.73E+01	3.14E+02
Aqueous Conversion	U-234	1.90E-10	5.78E-08	1.29E+03	1.47E+03	4.32E-01	2.09E+04	4.22E+03
	U-235	2.50E-08	7.61E-06	5.51E+01	8.51E+01	6.43E-03	9.05E+02	1.80E+02
	U-238	3.49E-06	1.06E-03	1.11E+03	1.30E+03	3.46E-02	1.89E+04	3.66E+03
Enrichment	Th-234		1.00E-13	8.32E-02	2.21E+03	3.80E-02	1.61E+00	3.80E-02
	U-234	1.52E-13	4.33E-09	1.59E+01	1.88E+01	3.15E-03	2.57E+02	5.87E-01
	U-235	3.37E-07	5.15E-07	6.92E+00	3.18E+00	1.47E-03	1.14E+02	4.21E+02
	U-238	9.22E-06	6.47E-05	3.62E+01	2.01E+01	1.81E-03	6.14E+02	1.67E+03
Uranium Fabrication	U-234	1.79E-10	1.82E-11	1.05E+01	2.91E+00	3.11E-02	1.69E+02	6.87E+02
	U-235	3.74E-08	3.81E-09	7.04E-01	2.50E-01	1.56E-04	1.16E+01	4.66E+01
	U-238	1.13E-06	1.15E-07	3.08E+00	8.28E-01	1.82E-04	5.23E+01	2.05E+02
PWR	H-3	2.00E-02	7.00E-02	6.29E+04	6.29E+04	6.29E+04	0.0	6.29E+04
	C-14	3.00E-01		2.68E+04	2.68E+04	2.68E+04	1.34E+05	2.68E+04
	Cr-51	6.00E-08	1.00E-06	7.10E-02	1.09E+00	6.90E-02	6.60E-02	2.70E-01
	Mn-54	2.00E-06	9.00E-06	1.99E+01	4.34E+01	1.83E+01	1.83E+01	3.86E+01
	Fe-55	3.00E-07	6.00E-06	1.27E+00	3.07E+00	5.61E-06	7.86E+00	3.70E+00
	Fe-59	2.00E-06	5.00E-05	7.58E+00	5.36E+01	1.66E+00	8.24E+00	1.19E+01
	Co-58	1.00E-06	4.00E-05	4.97E+01	2.82E+02	2.13E+01	2.13E+01	6.91E+01
	Co-60	4.00E-05	8.00E-04	4.66E+02	6.30E+02	4.44E+02	4.44E+02	5.72E+02
	Br-83	1.00E-10	6.00E-10	1.94E-03	1.90E-03	6.06E-04	6.06E-04	6.06E-04
	Br-84	3.00E-11	8.00E-12	5.72E-02	5.59E-02	5.59E-02	5.59E-02	5.59E-02
	Br-85	3.00E-12	5.00E-15	7.39E-06	1.60E-06	1.60E-06	1.60E-06	1.60E-06
	Kr-83M	5.00E-07		2.98E-03	2.98E-03	2.98E-03	2.98E-03	1.61E-01
	Kr-85	2.00E-03		4.05E+02	4.05E+02	4.05E+02	4.05E+02	7.74E+02
	Kr-85M	8.00E-07		1.64E+02	1.64E+02	1.64E+02	1.64E+02	1.67E+02
	Kr-87	2.00E-07		7.33E+02	7.33E+02	7.33E+02	7.33E+02	7.42E+02
	Kr-88	5.00E-07		4.58E+03	4.58E+03	4.58E+03	4.58E+03	4.64E+03
	Kr-89	1.00E-08		1.56E+01	1.56E+01	1.56E+01	1.56E+01	1.66E+01
	Rb-86	1.00E-09	3.00E-08	9.50E+00	4.01E+00	4.15E-03	4.15E-03	4.15E-03
	Rb-88	2.00E-09	3.00E-11	3.42E+00	3.24E+00	3.24E+00	3.24E+00	3.24E+00
	Sr-89	2.00E-12	8.00E-11	3.61E+00	2.05E+01	8.92E-05	1.25E+02	1.83E+00
	Sr-90	2.00E-12	2.00E-11	1.04E+02	1.23E+01	4.02E-07	4.35E+02	1.26E+00
	Sr-91	5.00E-12	3.00E-11	4.50E-02	1.01E+00	4.34E-02	8.27E-02	1.92E-01
	Y-90	1.00E-12	3.00E-11	1.23E-05	5.69E-01	7.15E-06	2.00E-04	1.15E-02
	Y-91	2.00E-11	4.00E-11	2.41E-01	2.02E+02	1.85E-02	8.26E+00	2.92E+01
	Y-91M	5.00E-12	3.00E-11	3.08E-02	3.08E-02	3.08E-02	3.08E-02	4.61E-02
	Y-93	7.00E-13	5.00E-13	7.07E-04	3.13E-01	7.04E-04	7.71E-04	3.51E-02
	Zr-95	3.00E-13	3.00E-11	1.37E-01	7.02E+00	1.27E-01	1.73E-01	7.83E-01
	Nb-95	3.00E-13	3.00E-11	1.51E-01	8.49E+02	7.37E-02	3.29E-01	2.63E-01
	Mo-99	2.00E-09	4.00E-08	1.25E+02	1.99E+03	1.88E+01	1.88E+01	2.68E+02
	Tc-99M	2.00E-09		2.84E+00	1.27E+01	2.84E+00	2.84E+00	4.64E+00
	Ru-103	3.00E-13	8.00E-12	4.17E-02	1.20E+00	3.74E-02	4.75E-02	2.02E-01
	Ru-106	1.00E-13	3.00E-12	2.45E-02	2.03E+00	2.02E-02	5.39E-02	4.65E-01
	Ag-110M		2.00E-09	9.24E-02	6.70E+00	8.27E-02	1.00E-01	8.27E-02
	Te-125M	6.00E-11	1.00E-09	2.64E-02	7.88E-01	5.88E-02	1.96E-01	5.07E-02
	Te-127	8.00E-11	1.00E-09	3.92E-03	1.69E-00	1.32E-02	1.78E-02	3.28E-02
	Te-127M	1.00E-10	3.00E-09	1.03E+00	2.84E+01	2.16E+00	8.47E+00	1.29E+00
	Te-129M	2.00E-10	4.00E-09	8.75E+00	2.75E+02	1.88E+01	5.42E+01	1.19E+01
	Te-131	1.00E-11	5.00E-11	1.59E-02	1.60E-02	1.59E-02	1.59E-02	2.52E-02

TABLE A.4. (contd)

Plant	Nuclide	Release Factor		Relative Ranking Factors				
		Air	Water	Total Body	GI Tract	Thyroid	Bone	Lung
PWR	Te-131M	1.00E-10	2.00E-09	1.75E+00	1.86E+02	3.11E+00	3.94E+00	1.89E+00
	Te-132	2.00E-10	3.00E-09	6.85E+01	3.50E+03	8.03E+01	1.12E+02	6.19E+01
	I-130	1.00E-10	3.00E-09	2.37E-01	2.73E-01	8.96E+00	2.31E-01	1.96E-01
	I-131	7.00E-10	4.00E-08	7.88E+02	4.10E+02	4.01E+05	9.44E+02	8.84E+01
	I-132	2.00E-10	3.00E-09	6.59E+00	6.43E+00	3.12E+01	6.59E+00	6.34E+00
	I-133	4.00E-10	2.00E-08	3.90E+01	7.96E+01	1.07E+04	5.87E+01	1.67E+01
	I-134	5.00E-11	4.00E-11	1.70E+00	1.65E+00	4.08E+00	1.71E+00	1.65E+00
	I-135	3.00E-10	3.00E-09	1.51E+01	1.63E+01	2.03E+02	1.51E+01	1.40E+01
	Xe-131M	1.00E-03		1.65E+02	1.65E+02	1.65E+02	1.65E+02	2.34E+02
	Xe-133	8.00E-05		2.74E+04	2.74E+04	2.74E+04	2.74E+04	2.88E+04
	Xe-133M	2.00E-05		1.79E+02	1.79E+02	1.79E+02	1.79E+02	1.89E+02
	Xe-135	1.00E-06		6.59E+02	6.59E+02	6.59E+02	6.59E+02	6.71E+02
	Xe-135M	4.00E-08		2.99E+01	2.99E+01	2.99E+01	2.99E+01	3.01E+01
	Xe-137	7.00E-09		1.29E+00	1.29E+00	1.29E+00	1.29E+00	2.64E+00
	Xe-138	4.00E-08		8.56E+02	8.56E+02	8.56E+02	8.56E+02	8.68E+02
	Cs-134	2.00E-10	2.00E-08	4.27E+04	1.26E+03	3.57E+02	2.22E+04	5.91E+03
	Cs-136	2.00E-09	3.00E-08	2.19E+03	3.59E+02	1.73E+01	7.82E+02	2.48E+02
	Cs-137	6.00E-10	3.00E-08	1.75E+04	1.11E+03	6.11E+02	1.94E+04	3.53E+03
	Ba-140	1.00E-12	2.00E-11	1.75E-01	4.75E+00	2.98E-02	2.24E+00	1.67E+00
	La-140	7.00E-13	2.00E-11	4.43E-02	5.29E+00	4.42E-02	4.47E-02	1.71E-01
	Ce-141	4.00E-13	8.00E-12	7.80E-03	1.39E+00	7.01E-03	1.74E-02	1.87E-01
	Ce-143	2.00E-13	3.00E-12	1.16E-03	2.22E-01	1.16E-03	1.21E-03	1.85E-02
	Ce-144	2.00E-13	9.00E-11	8.68E-02	9.67E+01	3.55E-02	9.92E-01	1.56E+00
	Pr-143	3.00E-13	7.00E-12	1.70E-04	1.54E+00	3.95E-06	3.37E-03	9.10E-02
	Pr-144	2.00E-13	5.00E-12	3.07E-05	3.07E-05	3.07E-05	3.07E-05	2.31E-04
	Np-239	5.00E-13	8.00E-12	2.47E-02	7.20E+00	2.46E-02	2.68E-02	3.28E-01
BWR	H-3	7.00E-03	1.00E-03	8.01E+03	8.01E+03	8.01E+03	0.0	8.01E+03
	C-14	3.00E-01		1.63E+04	1.63E+04	1.63E+04	8.15E+04	1.63E+04
	Na-24		5.00E-05	4.94E-02	4.94E-02	4.94E-02	4.94E-02	4.94E-02
	P-32		2.00E-06	2.90E-01	8.44E-01	2.19E-06	7.49E+00	2.19E-06
	Cr-51	3.00E-06	2.00E-07	1.57E+00	5.22E+00	1.55E+00	1.53E+00	6.56E+00
	Mn-54	3.00E-05	7.00E-08	1.10E+02	1.40E+02	1.08E+02	1.08E+02	2.30E+02
	Mn-56		2.00E-07	2.68E-05	1.92E-03	1.62E-05	1.62E-05	1.62E-05
	Fe-55		2.00E-07	2.20E-02	5.40E-02	3.87E-08	1.36E-01	5.25E-02
	Fe-59	2.00E-05	8.00E-08	8.48E+00	2.49E+01	6.67E+00	8.68E+00	3.47E+01
	Co-58	1.00E-06	3.00E-08	7.85E+00	1.43E+01	7.27E+00	7.27E+00	2.66E+01
	Co-60	1.00E-03	6.00E-06	4.25E+03	4.48E+03	4.22E+03	4.22E+03	5.53E+03
	Ni-65		6.00E-08	3.48E-08	8.82E-07	1.93E-08	2.81E-07	1.93E-08
	Cu-64		2.00E-06	2.01E-03	2.41E-01	6.88E-04	6.88E-04	6.88E-04
	Zn-65	5.00E-03	7.00E-05	5.07E+01	5.88E+01	2.90E+01	4.41E+01	6.68E+01
	Br-83		5.00E-11	6.44E-07	9.25E-07	2.51E-09	2.51E-09	2.51E-09
	Br-84		2.00E-12	3.05E-18	1.16E-18	1.16E-18	1.16E-18	1.16E-18
	Kr-83M	1.00E-06		2.35E-03	2.35E-03	2.35E-03	2.35E-03	9.13E-02
	Kr-85	1.00E-03		9.83E+01	9.83E+01	9.83E+01	9.83E+01	1.88E+02
	Kr-85M	3.00E-05		2.41E+03	2.41E+03	2.41E+03	2.41E+03	2.45E+03
	Kr-87	4.00E-05		5.73E+04	5.73E+04	5.73E+04	5.73E+04	5.80E+04
	Kr-88	3.00E-05		1.07E+05	1.07E+05	1.07E+05	1.07E+05	1.09E+05
	Kr-89	1.00E-07		6.08E+01	6.08E+01	6.08E+01	6.08E+01	6.48E+01
	Rb-89		2.00E-12	3.47E-32	8.19E-33	8.19E-33	8.19E-33	8.19E-33
	Sr-89	6.00E-10	2.00E-12	2.32E+01	1.76E+02	5.99E-03	8.07E+02	2.13E+02
	Sr-90	2.00E-11		1.60E+02	1.88E+01	1.50E-06	7.00E+02	6.24E+00
	Sr-91		2.00E-11	7.16E-04	4.86E-02	3.04E-04	1.05E-02	3.04E-04
	Sr-92		1.00E-11	3.22E-06	3.22E-04	2.53E-06	1.86E-05	2.53E-06
	Y-91		6.00E-13	5.94E-06	1.03E-01	9.64E-07	1.87E-04	9.64E-07
	Y-91M		2.00E-11	3.34E-12	3.35E-12	3.34E-12	3.34E-12	3.34E-12
	Y-92		2.00E-11	4.25E-06	9.07E-04	4.25E-06	4.31E-06	4.25E-06
	Y-93		2.00E-11	4.25E-05	1.99E-01	4.25E-05	4.85E-05	4.25E-05
	Zr-95	2.00E-11		2.41E+00	7.68E+00	2.19E+00	3.21E+00	1.91E+01
	Mo-99		1.00E-11	1.05E-02	1.24E-01	3.31E-04	3.31E-04	3.31E-04
	Tc-99M		5.00E-11	5.95E-05	4.94E-04	5.00E-05	5.02E-05	5.03E-05
	Tc-101		1.00E-13	1.37E-36	1.34E-36	1.34E-36	1.34E-36	1.34E-36
	Ru-103		2.00E-13	8.02E-05	1.01E-02	4.30E-05	1.29E-04	4.30E-05
	Ru-105		5.00E-12	6.53E-06	1.61E-04	6.42E-06	6.68E-06	6.42E-06

TABLE A.4. (contd)

Plant	Nuclide	Release Factor		Relative Ranking Factors				
		Air	Water	Total Body	GI Tract	Thyroid	Bone	Lung
BWR	Rh-105		2.00E-12	5.32E-05	1.08E-02	8.46E-06	1.01E-04	8.46E-06
	Sb-124	7.00E-08		6.15E+00	2.30E+01	5.86E+00	6.62E+00	3.27E+01
	Te-129M		7.00E-12	5.46E-03	1.73E-01	1.18E-02	3.44E-02	1.35E-05
	Te-131		2.00E-13	5.04E-23	3.74E-23	8.80E-23	1.01E-22	2.70E-23
	Te-131M		6.00E-12	1.80E-03	2.09E-01	3.38E-03	4.35E-03	5.15E-05
	Te-132		6.00E-14	5.20E-04	2.62E-02	6.12E-04	8.55E-04	1.41E-06
	I-131	4.00E-08	6.00E-11	5.48E+03	3.49E+03	2.10E+06	6.32E+03	1.85E+03
	I-132		2.00E-11	4.28E-06	3.98E-06	6.46E-05	4.32E-06	3.65E-06
	I-133	7.00E-08	8.00E-11	1.20E+03	1.40E+03	9.24E+04	1.38E+03	1.01E+03
	I-134		6.00E-12	1.39E-11	1.27E-11	7.13E-11	1.40E-11	1.27E-11
	I-135		4.00E-11	1.28E-03	2.39E-03	9.69E-02	1.30E-03	7.47E-04
	Xe-131M	5.00E-05		3.19E+00	3.19E+00	3.19E+00	3.19E+00	4.52E+00
	Xe-133	1.00E-04		1.33E+04	1.33E+04	1.33E+04	1.33E+04	1.40E+04
	Xe-133M	2.00E-06		6.93E+00	6.93E+00	6.93E+00	6.93E+00	7.33E+00
	Xe-135	2.00E-04		6.03E+04	6.03E+04	6.03E+04	6.03E+04	6.14E+04
	Xe-135M	1.00E-04		2.89E+04	2.89E+04	2.89E+04	2.89E+04	2.92E+04
	Xe-137	4.00E-08		2.86E+00	2.86E+00	2.86E+00	2.86E+00	5.84E+00
	Xe-138	6.00E-05		4.97E+05	4.97E+05	4.97E+05	4.97E+05	5.04E+05
	Cs-134	1.00E-09	2.00E-10	1.02E+03	4.82E+02	4.68E+02	7.54E+02	5.43E+02
	Cs-136	4.00E-10	6.00E-10	1.88E+01	3.88E+00	1.14E+00	7.36E+00	3.01E+00
	Cs-137	3.00E-09	9.00E-10	1.94E+03	1.27E+03	1.25E+03	2.02E+03	1.38E+03
	Cs-138		4.00E-11	3.36E-15	4.21E-16	4.21E-16	3.42E-15	8.52E-16
	Ba-139		3.00E-12	1.15E-10	3.58E-10	1.11E-10	2.50E-10	1.11E-10
	Ba-140	5.00E-10	3.00E-12	7.34E+00	1.10E+02	5.10E+00	3.92E+01	3.24E+02
	La-140		6.00E-13	1.32E-04	5.61E-02	1.32E-04	1.34E-04	1.32E-04
	La-141		1.00E-12	4.74E-08	7.26E-05	4.72E-08	4.93E-08	4.72E-08
	La-142		2.00E-12	1.19E-08	1.91E-08	1.19E-08	1.19E-08	1.19E-08
	Ce-141	4.00E-11	2.00E-13	2.72E-01	7.23E+00	2.43E-01	6.24E-01	7.14E+00
	Ce-143		2.00E-13	4.55E-06	4.44E-03	4.52E-06	4.67E-06	4.52E-06
	Pr-143		3.00E-13	2.93E-07	2.35E-02	2.69E-08	5.39E-06	2.69E-08
	W-187		9.00E-09	5.42E-04	4.67E-01	4.57E-05	1.75E-03	4.57E-05
	Np-239		3.00E-12	5.68E-04	9.14E-01	5.66E-04	6.11E-04	5.66E-04

TABLE A.5. Relative Ranking Factors - Radionuclide Releases from the Reprocessing Without Recycle Fuel Cycle

Plant	Nuclide	Release Factor		Relative Ranking Factors				
		Air	Water	Total Body	GI Tract	Thyroid	Bone	Lung
Underground Mine	Rn-222	1.40E-10		2.38E+03	2.38E+03	2.38E+03	2.38E+03	5.09E+03
	Ra-226	4.00E-12	9.00E-12	3.08E+02	1.59E+01	1.53E+01	4.17E+01	9.10E+01
	U-234	6.21E-10	7.40E-09	1.85E-01	4.61E-02	3.22E-03	2.92E+00	1.24E+01
	U-235	8.18E-08	9.74E-07	7.69E-03	2.35E-03	1.76E-06	1.27E-01	5.28E-01
	U-238	1.14E-05	1.36E-04	1.55E-01	3.58E-02	9.48E-06	2.63E+00	1.07E+01
Surface Mine	Rn-222	2.50E-11		2.99E+02	2.99E+02	2.99E+02	2.99E+02	6.38E+02
	Ra-226	1.35E-11		2.74E+02	1.42E+01	1.37E+01	3.71E+02	8.13E+01
	U-234	2.11E-09		4.42E-01	1.10E-01	7.70E-03	6.98E+00	2.95E+01
	U-235	2.77E-07		1.83E-02	5.58E-03	4.20E-06	3.01E-01	1.26E+00
	U-238	3.87E-05		3.71E-01	8.54E-02	2.26E-05	6.28E+00	2.55E+01
Acid Leach Mill	Rn-222	1.30E-12		3.02E+01	3.02E+01	3.02E+01	3.02E+01	6.44E+01
	Ra-226	5.40E-13	6.00E-11	2.13E+01	1.10E+00	1.06E+00	2.88E+01	6.30E+00
	Th-230	3.00E-11	2.00E-07	5.21E+02	1.48E+00	1.18E-01	1.87E+04	5.06E+03
	U-234	1.36E-08	1.64E-08	5.52E+00	1.37E+00	9.62E-02	8.77E+01	3.69E+02
	U-235	1.76E-06	2.16E-06	2.25E-01	6.88E-02	5.17E-05	3.71E+00	1.55E+01
	U-238	2.46E-04	3.02E-04	4.57E+00	1.05E+00	2.79E-04	7.73E+01	3.14E+02
Aqueous Conversion	U-234	1.90E-10	5.78E-08	1.29E+03	1.47E+03	4.32E-01	2.09E+04	4.22E+03
	U-235	2.50E-08	7.61E-06	5.51E+01	8.51E+01	6.43E-03	9.05E+02	1.80E+02
	U-238	3.49E-06	1.06E-03	1.11E+03	1.30E+03	3.46E-02	1.89E+04	3.66E+03
Enrichment	Th-234		1.00E-13	8.32E-02	2.21E+03	3.80E-02	1.61E+00	3.80E-02
	U-234	1.52E-13	4.33E-09	1.59E+01	1.88E+01	3.15E-03	2.57E+02	5.87E-01
	U-235	3.37E-07	5.15E-07	6.92E+00	3.18E+00	1.47E-03	1.14E+02	4.21E+02
	U-238	9.22E-06	6.47E-05	3.62E+01	2.01E+01	1.81E-03	6.14E+02	1.67E+03
Uranium Fabrication	U-234	1.79E-10	1.82E-11	1.05E+01	2.91E+00	3.11E-02	1.69E+02	6.87E+02
	U-235	3.74E-08	3.81E-09	7.04E-01	2.50E-01	1.56E-04	1.16E+01	4.66E+01
	U-238	1.13E-06	1.15E-07	3.08E+00	8.28E-01	1.82E-04	5.23E+01	2.05E+02
PWR	H-3	2.00E-02	7.00E-02	6.29E+04	6.29E+04	6.29E+04	0.0	6.29E+04
	C-14	3.00E-01		2.68E+04	2.68E+04	2.68E+04	1.34E+05	2.68E+04
	Cr-51	6.00E-08	1.00E-06	7.10E-02	1.09E+00	6.90E-02	6.60E-02	2.70E-01
	Mn-54	2.00E-06	9.00E-06	1.99E+01	4.34E+01	1.83E+01	1.83E+01	3.86E+01
	Fe-55	3.00E-07	6.00E-06	1.27E+00	3.07E+00	5.61E-06	7.86E+00	3.70E+00
	Fe-59	2.00E-06	5.00E-05	7.58E+00	5.36E+01	1.66E+00	8.24E+00	1.19E+01
	Co-58	1.00E-06	4.00E-05	4.97E+01	2.82E+02	2.13E+01	2.13E+01	6.91E+01
	Co-60	4.00E-05	8.00E-04	4.66E+02	6.30E+02	4.44E+02	4.44E+02	5.72E+02
	Br-83	1.00E-10	6.00E-10	1.94E-03	1.90E-03	6.06E-04	6.06E-04	6.06E-04
	Br-84	3.00E-11	8.00E-12	5.72E-02	5.59E-02	5.59E-02	5.59E-02	5.59E-02
	Br-85	3.00E-12	5.00E-15	7.39E-06	1.60E-06	1.60E-06	1.60E-06	1.60E-06
	Kr-83M	5.00E-07		2.98E-03	2.98E-03	2.98E-03	2.98E-03	1.61E-01
	Kr-85	2.00E-03		4.05E+02	4.05E+02	4.05E+02	4.05E+02	7.74E+02
	Kr-85M	8.00E-07		1.64E+02	1.64E+02	1.64E+02	1.64E+02	1.67E+02
	Kr-87	2.00E-07		7.33E+02	7.33E+02	7.33E+02	7.33E+02	7.42E+02
	Kr-88	5.00E-07		4.58E+03	4.58E+03	4.58E+03	4.58E+03	4.64E+03
	Kr-89	1.00E-08		1.56E+01	1.56E+01	1.56E+01	1.56E+01	1.66E+01
	Rb-86	1.00E-09	3.00E-08	9.50E+00	4.01E+00	4.15E-03	4.15E-03	4.15E-03
	Rb-88	2.00E-09	3.00E-11	3.42E+00	3.24E+00	3.24E+00	3.24E+00	3.24E+00
	Sr-89	2.00E-12	8.00E-11	3.61E+00	2.05E+01	8.92E-05	1.25E+02	1.83E+00
	Sr-90	2.00E-12	2.00E-11	1.04E+02	1.23E+01	4.02E-07	4.35E+02	1.26E+00
	Sr-91	5.00E-12	3.00E-11	4.50E-02	1.01E+00	4.34E-02	8.27E-02	1.92E-01
	Y-90	1.00E-12	3.00E-11	1.23E-05	5.69E-01	7.15E-06	2.00E-04	1.15E-02
	Y-91	2.00E-11	4.00E-11	2.41E-01	2.02E+02	1.85E-02	8.26E+00	2.92E+01
	Y-91M	5.00E-12	3.00E-11	3.08E-02	3.08E-02	3.08E-02	3.08E-02	4.61E-02
	Y-93	7.00E-13	5.00E-13	7.07E-04	3.13E-01	7.04E-04	7.71E-04	3.51E-02
	Zr-95	3.00E-13	3.00E-11	1.37E-01	7.02E+00	1.27E-01	1.73E-01	7.83E-01
	Nb-95	3.00E-13	3.00E-11	1.51E-01	8.49E+02	7.37E-02	3.29E-01	2.63E-01
	Mo-99	2.00E-09	4.00E-08	1.25E+02	1.99E+03	1.88E+01	1.88E+01	2.68E+02
	Tc-99M	2.00E-09		2.84E+00	1.27E+01	2.84E+00	2.84E+00	4.64E+00
	Ru-103	3.00E-13	8.00E-12	4.17E-02	1.20E+00	3.74E-02	4.75E-02	2.02E-01
	Ru-106	1.00E-13	3.00E-12	2.45E-02	2.03E+00	2.02E-02	5.39E-02	4.65E-01
	Ag-110M		2.00E-09	9.24E-02	6.70E+00	8.27E-02	1.00E-01	8.27E-02
	Te-125M	6.00E-11	1.00E-09	2.64E-02	7.88E-01	5.88E-02	1.96E-01	5.07E-02
	Te-127	8.00E-11	1.00E-09	3.92E-03	1.69E-00	1.32E-02	1.78E-02	3.28E-02
	Te-127M	1.00E-10	3.00E-09	1.03E+00	2.84E+01	2.16E+00	8.47E+00	1.29E+00
	Te-129M	2.00E-10	4.00E-09	8.75E+00	2.75E+02	1.88E+01	5.42E+01	1.19E+01
	Te-131	1.00E-11	5.00E-11	1.59E-02	1.60E-02	1.59E-02	1.59E-02	2.52E-02

TABLE A.5. (contd)

Plant	Nuclide	Release Factor		Relative Ranking Factors				
		Air	Water	Total Body	GI Tract	Thyroid	Bone	Lung
PWR	Te-131M	1.00E-10	2.00E-09	1.75E+00	1.86E+02	3.11E+00	3.94E+00	1.89E+00
	Te-132	2.00E-10	3.00E-09	6.85E+01	3.50E+03	8.03E+01	1.12E+02	6.19E+01
	I-130	1.00E-10	3.00E-09	2.37E-01	2.73E-01	8.96E+00	2.31E-01	1.96E-01
	I-131	7.00E-10	4.00E-08	7.88E+02	4.10E+02	4.01E+05	9.44E+02	8.84E+01
	I-132	2.00E-10	3.00E-09	6.59E+00	6.43E+00	3.12E+01	6.59E+00	6.34E+00
	I-133	4.00E-10	2.00E-08	3.90E+01	7.96E+01	1.07E+04	5.87E+01	1.67E+01
	I-134	5.00E-11	4.00E-11	1.70E+00	1.65E+00	4.08E+00	1.71E+00	1.65E+00
	I-135	3.00E-10	3.00E-09	1.51E+01	1.63E+01	2.03E+02	1.51E+01	1.40E+01
	Xe-131M	1.00E-03		1.65E+02	1.65E+02	1.65E+02	1.65E+02	2.34E+02
	Xe-133	8.00E-05		2.74E+04	2.74E+04	2.74E+04	2.74E+04	2.88E+04
	Xe-133M	2.00E-05		1.79E+02	1.79E+02	1.79E+02	1.79E+02	1.89E+02
	Xe-135	1.00E-06		6.59E+02	6.59E+02	6.59E+02	6.59E+02	6.71E+02
	Xe-135M	4.00E-08		2.99E+01	2.99E+01	2.99E+01	2.99E+01	3.01E+01
	Xe-137	7.00E-09		1.29E+00	1.29E+00	1.29E+00	1.29E+00	2.64E+00
	Xe-138	4.00E-08		8.56E+02	8.56E+02	8.56E+02	8.56E+02	8.68E+02
	Cs-134	2.00E-10	2.00E-08	4.27E+04	1.26E+03	3.57E+02	2.22E+04	5.91E+03
	Cs-136	2.00E-09	3.00E-08	2.19E+03	3.59E+02	1.73E+01	7.82E+02	2.48E+02
	Cs-137	6.00E-10	3.00E-08	1.75E+04	1.11E+03	6.11E+02	1.94E+04	3.53E+03
	Ba-140	1.00E-12	2.00E-11	1.75E-01	4.75E+00	2.98E-02	2.24E+00	1.67E+00
	La-140	7.00E-13	2.00E-11	4.43E-02	5.29E+00	4.42E-02	4.47E-02	1.71E-01
	Ce-141	4.00E-13	8.00E-12	7.80E-03	1.39E+00	7.01E-03	1.74E-02	1.87E-01
	Ce-143	2.00E-13	3.00E-12	1.16E-03	2.22E-01	1.16E-03	1.21E-03	1.85E-02
	Ce-144	2.00E-13	9.00E-11	8.68E-02	9.67E+01	3.55E-02	9.92E-01	1.56E+00
	Pr-143	3.00E-13	7.00E-12	1.70E-04	1.54E+00	3.95E-06	3.37E-03	9.10E-02
	Pr-144	2.00E-13	5.00E-12	3.07E-05	3.07E-05	3.07E-05	3.07E-05	2.31E-04
	Np-239	5.00E-13	8.00E-12	2.47E-02	7.20E+00	2.46E-02	2.68E-02	3.28E-01
BWR	H-3	7.00E-03	1.00E-03	8.01E+03	8.01E+03	8.01E+03	0.0	8.01E+03
	C-14	3.00E-01		1.63E+04	1.63E+04	1.63E+04	8.15E+04	1.63E+04
	Na-24		5.00E-05	4.94E-02	4.94E-02	4.94E-02	4.94E-02	4.94E-02
	P-32		2.00E-06	2.90E-01	8.44E-01	2.19E-06	7.49E+00	2.19E-06
	Cr-51	3.00E-06	2.00E-07	1.57E+00	5.22E+00	1.55E+00	1.53E+00	6.56E+00
	Mn-54	3.00E-05	7.00E-08	1.10E+02	1.40E+02	1.08E+02	1.08E+02	2.30E+02
	Mn-56		2.00E-07	2.68E-05	1.92E-03	1.62E-05	1.62E-05	1.62E-05
	Fe-55		2.00E-07	2.20E-02	5.40E-02	3.87E-08	1.36E-01	5.25E-02
	Fe-59	2.00E-05	8.00E-08	8.48E+00	2.49E+01	6.67E+00	8.68E+00	3.47E+01
	Co-58	1.00E-06	3.00E-08	7.85E+00	1.43E+01	7.27E+00	7.27E+00	2.66E+01
	Co-60	1.00E-03	6.00E-06	4.25E+03	4.48E+03	4.22E+03	4.22E+03	5.53E+03
	Ni-65		6.00E-08	3.48E-08	8.82E-07	1.93E-08	2.81E-07	1.93E-08
	Cu-64		2.00E-06	2.01E-03	2.41E-01	6.88E-04	6.88E-04	6.88E-04
	Zn-65	5.00E-03	7.00E-05	5.07E+01	5.88E+01	2.90E+01	4.41E+01	6.68E+01
	Br-83		5.00E-11	6.44E-07	9.25E-07	2.51E-09	2.51E-09	2.51E-09
	Br-84		2.00E-12	3.05E-18	1.16E-18	1.16E-18	1.16E-18	1.16E-18
	Kr-83M	1.00E-06		2.35E-03	2.35E-03	2.35E-03	2.35E-03	9.13E-02
	Kr-85	1.00E-03		9.83E+01	9.83E+01	9.83E+01	9.83E+01	1.88E+02
	Kr-85M	3.00E-05		2.41E+03	2.41E+03	2.41E+03	2.41E+03	2.45E+03
	Kr-87	4.00E-05		5.73E+04	5.73E+04	5.73E+04	5.73E+04	5.80E+04
	Kr-88	3.00E-05		1.07E+05	1.07E+05	1.07E+05	1.07E+05	1.09E+05
	Kr-89	1.00E-07		6.08E+01	6.08E+01	6.08E+01	6.08E+01	6.48E+01
	Rb-89		2.00E-12	3.47E-32	8.19E-33	8.19E-33	8.19E-33	8.19E-33
	Sr-89	6.00E-10	2.00E-12	2.32E+01	1.76E+02	5.99E-03	8.07E+02	2.13E+02
	Sr-90	2.00E-11		1.60E+02	1.88E+01	1.50E-06	7.00E+02	6.24E+00
	Sr-91		2.00E-11	7.16E-04	4.86E-02	3.04E-04	1.05E-02	3.04E-04
	Sr-92		1.00E-11	3.22E-06	3.22E-04	2.53E-06	1.86E-05	2.53E-06
	Y-91		6.00E-13	5.94E-06	1.03E-01	9.64E-07	1.87E-04	9.64E-07
	Y-91M		2.00E-11	3.34E-12	3.35E-12	3.34E-12	3.34E-12	3.34E-12
	Y-92		2.00E-11	4.25E-06	9.07E-04	4.25E-06	4.31E-06	4.25E-06
	Y-93		2.00E-11	4.25E-05	1.99E-01	4.25E-05	4.85E-05	4.25E-05
	Zr-95	2.00E-11		2.41E+00	7.68E+00	2.19E+00	3.21E+00	1.91E+01
	Mo-99		1.00E-11	1.05E-02	1.24E-01	3.31E-04	3.31E-04	3.31E-04
	Tc-99M		5.00E-11	5.95E-05	4.94E-04	5.00E-05	5.02E-05	5.03E-05
	Tc-101		1.00E-13	1.37E-36	1.34E-36	1.34E-36	1.34E-36	1.34E-36
	Ru-103		2.00E-13	8.02E-05	1.01E-02	4.30E-05	1.29E-04	4.30E-05
	Ru-105		5.00E-12	6.53E-06	1.61E-04	6.42E-06	6.68E-06	6.42E-06

TABLE A.5. (contd)

Plant	Nuclide	Release Factor		Total Body	Relative Ranking Factors			
		Air	Water		GI Tract	Thyroid	Bone	Lung
BWR	Rh-105		2.00E-12	5.32E-05	1.08E-02	8.46E-06	1.01E-04	8.46E-06
	Sb-124	7.00E-08		6.15E+00	2.30E+01	5.86E+00	6.62E+00	3.27E+01
	Te-129M		7.00E-12	5.46E-03	1.73E-01	1.18E-02	3.44E-02	1.35E-05
	Te-131		2.00E-13	5.04E-23	3.74E-23	8.80E-23	1.01E-22	2.70E-23
	Te-131M		6.00E-12	1.80E-03	2.09E-01	3.38E-03	4.35E-03	5.15E-05
	Te-132		6.00E-14	5.20E-04	2.62E-02	6.12E-04	8.55E-04	1.41E-06
	I-131	4.00E-08	6.00E-11	5.48E+03	3.49E+03	2.10E+06	6.32E+03	1.85E+03
	I-132		2.00E-11	4.28E-06	3.98E-06	6.46E-05	4.32E-06	3.65E-06
	I-133	7.00E-08	8.00E-11	1.20E+03	1.40E+03	9.24E+04	1.38E+03	1.01E+03
	I-134		6.00E-12	1.39E-11	1.27E-11	7.13E-11	1.40E-11	1.27E-11
	I-135		4.00E-11	1.28E-03	2.39E-03	9.69E-02	1.30E-03	7.47E-04
	Xe-131M	5.00E-05		3.19E+00	3.19E+00	3.19E+00	3.19E+00	4.52E+00
	Xe-133	1.00E-04		1.33E+04	1.33E+04	1.33E+04	1.33E+04	1.40E+04
	Xe-133M	2.00E-06		6.93E+00	6.93E+00	6.93E+00	6.93E+00	7.33E+00
	Xe-135	2.00E-04		6.03E+04	6.03E+04	6.03E+04	6.03E+04	6.14E+04
	Xe-135M	1.00E-04		2.89E+04	2.89E+04	2.89E+04	2.89E+04	2.92E+04
	Xe-137	4.00E-08		2.86E+00	2.86E+00	2.86E+00	2.86E+00	5.84E+00
	Xe-138	6.00E-05		4.97E+05	4.97E+05	4.97E+05	4.97E+05	5.04E+05
	Cs-134	1.00E-09	2.00E-10	1.02E+03	4.82E+02	4.68E+02	7.54E+02	5.43E+02
	Cs-136	4.00E-10	6.00E-10	1.88E+01	3.88E+00	1.14E+00	7.36E+00	3.01E+00
	Cs-137	3.00E-09	9.00E-10	1.94E+03	1.27E+03	1.25E+03	2.02E+03	1.38E+03
	Cs-138		4.00E-11	3.36E-15	4.21E-16	4.21E-16	3.42E-15	8.52E-16
	Ba-139		3.00E-12	1.15E-10	3.58E-10	1.11E-10	2.50E-10	1.11E-10
	Ba-140	5.00E-10	3.00E-12	7.34E+00	1.10E+02	5.10E+00	3.92E+01	3.24E+02
	La-140		6.00E-13	1.32E-04	5.61E-02	1.32E-04	1.34E-04	1.32E-04
	La-141		1.00E-12	4.74E-08	7.26E-05	4.72E-08	4.93E-08	4.72E-08
	La-142		2.00E-12	1.19E-08	1.91E-08	1.19E-08	1.19E-08	1.19E-08
	Ce-141	4.00E-11	2.00E-13	2.72E-01	7.23E+00	2.43E-01	6.24E-01	7.14E+00
	Ce-143		2.00E-13	4.55E-06	4.44E-03	4.52E-06	4.67E-06	4.52E-06
	Pr-143		3.00E-13	2.93E-07	2.35E-02	2.69E-08	5.39E-06	2.69E-08
	W-187		9.00E-09	5.42E-04	4.67E-01	4.57E-05	1.75E-03	4.57E-05
	Np-239		3.00E-12	5.68E-04	9.14E-01	5.66E-04	6.11E-04	5.66E-04
Reprocessing	H-3	7.00E-01		1.97E+06	1.97E+06	1.97E+06	0.0	1.97E+06
	C-14	1.00E+00		1.40E+05	1.40E+05	1.40E+05	7.01E+05	1.40E+05
	Kr-85	8.00E-01		1.92E+05	1.92E+05	1.92E+05	1.92E+05	3.67E+05
	Sr-89	2.00E-09		3.07E-04	2.32E-03	7.94E-08	1.07E-02	2.82E-03
	Sr-90	2.00E-09		4.35E+04	5.12E+03	4.08E-04	1.91E+05	1.70E+03
	Y-90	2.00E-09		2.10E-02	9.06E+01	1.10E-02	3.80E-01	3.00E+01
	Y-91	2.00E-09		1.61E-04	1.75E-02	1.18E-05	5.54E-03	2.04E-02
	Zr-95	3.00E-09		1.96E-02	6.26E-02	1.78E-02	2.62E-02	1.55E-01
	Nb-95	3.00E-09		2.23E-02	8.25E-02	2.15E-02	2.39E-02	1.06E-01
	Ru-103	3.00E-09		9.26E-06	4.15E-05	9.14E-06	9.46E-06	5.48E-05
	Ru-106	3.00E-09		9.64E+01	1.14E+03	9.27E+01	1.22E+02	2.39E+03
	I-129	3.00E-02		2.46E+04	1.70E+04	6.28E+06	1.95E+04	1.67E+04
	Cs-134	2.00E-09		2.20E+03	1.22E+03	1.19E+03	1.71E+03	1.33E+03
	Cs-137	2.00E-09		3.09E+03	2.31E+03	2.29E+03	3.17E+03	2.43E+03
	Ce-141	3.00E-09		3.70E-08	9.85E-07	3.31E-08	8.51E-08	9.73E-07
	Ce-144	3.00E-09		6.77E+01	1.05E+03	1.70E+01	9.62E+02	2.15E+03
	Pm-147	3.00E-09		4.97E+00	4.34E+01	6.17E-05	1.31E+02	1.03E+02
	U-232	2.00E-05		1.31E+01	6.83E-01	2.27E-03	1.83E+02	6.46E+02
	U-233	2.00E-05		1.34E-02	3.63E-03	3.05E-05	2.21E-01	8.80E-01
	U-234	2.00E-05		1.76E+02	4.76E+01	5.22E-01	2.83E+03	1.15E+04
	U-235	2.00E-05		2.91E+00	1.01E+00	6.46E-04	4.80E+01	1.94E+02
	U-236	2.00E-05		3.87E+01	1.02E+01	3.50E-03	6.24E+02	2.54E+03
	U-237	2.00E-05		4.80E-01	9.47E+00	4.74E-01	5.01E-01	6.04E+00
	U-238	2.00E-05		4.92E+01	1.29E+01	2.92E-03	8.37E+02	3.29E+03
	Pu-238	1.00E-09		1.62E+03	5.42E+00	9.30E-03	6.45E+04	4.28E+03
	Pu-239	1.00E-09		2.55E+02	6.94E-01	8.41E-04	1.05E+04	5.67E+02
	Pu-240	1.00E-09		3.93E+02	1.09E+00	2.13E-03	1.62E+04	8.74E+02
	Pu-241	1.00E-09		1.41E+03	5.95E+00	1.17E+00	6.97E+04	1.67E+02
	Pu-242	1.00E-09		1.33E+00	3.70E-03	6.37E-06	5.28E+01	2.95E+00
	Am-241	2.00E-09		9.52E+02	4.12E+00	8.10E-01	1.43E+04	8.57E+02
	Am-242	2.00E-09		0.0	0.0	0.0	0.0	0.0
	Cm-242	6.00E-09		2.48E+01	5.61E+00	1.92E-03	3.74E+02	9.86E+02
	Cm-243	6.00E-09		1.17E+01	1.44E-01	7.89E-02	1.99E+02	1.60E+01
	Cm-244	6.00E-09		2.76E+03	1.95E+01	5.59E-02	4.63E+04	4.76E+03

TABLE A.6. Projected 50 Year Dose Commitment to the Population
for 100 Years - Full Plutonium and Uranium Recycle

Plant	Nuclide	Release Factor		Relative Ranking Factors				
		Air	Water	Total Body	GI Tract	Thyroid	Bone	Lung
Underground Mine	Rn-222	1.40E-10		1.75E+03	1.75E+03	1.75E+03	1.75E+03	3.74E+03
	Ra-226	4.00E-11	9.00E-12	8.51E+02	4.40E+01	4.25E+01	1.15E+03	2.52E+02
	U-234	6.21E-10	7.40E-09	1.36E-01	3.39E-02	2.37E-03	2.15E+00	9.09E+00
	U-235	8.18E-08	4.43E-01	5.66E-03	1.73E-03	1.30E-06	9.32E-02	3.89E-01
	U-238	1.14E-05	1.36E-04	1.14E-01	2.63E-02	6.98E-06	1.94E+00	7.86E+00
Surface Mine	Rn-222	2.50E-11		1.44E+02	1.44E+02	1.44E+02	1.44E+02	3.07E+02
	Ra-226	1.42E-11		1.39E+02	7.16E+06	6.92E+00	1.87E+02	4.10E+01
	U-234	2.11E-09		2.12E-01	5.28E-02	3.70E-03	3.35E+00	1.42E+02
	U-235	2.77E-07		8.79E-03	2.68E-03	2.02E-06	1.45E-01	6.04E-01
	U-238	3.87E-05		1.78E-01	4.10E-02	1.09E-05	3.01E+00	1.22E+01
Acid Leach Mill	Rn-222	1.30E-12		1.90E+01	1.90E+01	1.90E+01	1.90E+01	4.06E+01
	Ra-226	5.40E-13	6.00E-11	1.34E+01	6.93E-01	6.69E-01	1.82E+01	3.97E+00
	Th-230	3.00E-11	2.00E-07	3.28E+02	9.31E-01	7.47E-02	1.18E+04	3.19E+03
	U-234	1.36E-08	1.64E-08	3.48E+00	8.66E-01	6.06E-02	5.49E-01	2.32E+02
	U-235	1.76E-06	2.16E-06	1.42E-01	4.34E-02	3.26E-05	2.34E+00	9.76E+00
	U-238	2.46E-04	3.02E-04	2.88E+00	6.63E-01	1.76E-04	4.88E+01	1.98E+02
Aqueous Conversion	U-234	1.90E-10	5.78E-08	1.04E+03	1.19E+03	3.49E-01	1.69E+04	3.41E+03
	U-235	2.50E-08	7.61E-06	4.45E+01	6.88E+01	5.20E-03	7.32E+02	1.46E+02
	U-238	3.49E-06	1.06E-03	9.00E+02	1.05E+03	2.79E-02	1.53E+04	2.96E+03
Enrichment	Th-234		1.00E-13	8.22E-02	2.18E+03	3.75E-02	1.59E+00	3.75E-02
	U-234	1.52E-13	4.33E-09	1.57E+01	1.86E+01	3.11E-03	2.54E+02	5.79E-01
	U-235	3.37E-07	5.15E-07	6.83E+00	3.14E+00	1.45E-03	1.13E+02	4.15E+02
	U-238	9.22E-06	6.47E-05	3.57E+01	1.99E+01	1.79E-03	6.07E+02	1.65E+03
Uranium Fabrication	U-234	1.79E-10	1.82E-11	7.81E+00	2.16E+00	2.31E-02	1.26E+02	5.09E+02
	U-235	3.74E-08	3.81E-09	5.22E-01	1.86E-01	1.16E-04	8.62E+00	3.46E+01
	U-238	1.13E-06	1.15E-07	2.28E+00	6.14E-01	1.35E-04	3.88E+01	1.52E+02
MOX Fabrication	U-234	2.25E-15	2.40E-14	5.67E-05	3.61E-05	1.05E-07	9.14E-04	2.23E-03
	U-235	4.70E-13	5.02E-12	3.81E-06	3.27E-06	6.76E-10	6.29E-05	1.51E-04
	U-238	1.42E-11	1.52E-10	1.67E-05	1.08E-05	7.89E-10	2.84E-04	6.65E-04
	Pu-238	1.74E-14	1.85E-13	6.24E+01	8.43E+01	3.73E-04	2.48E+03	1.64E+02
	Pu-239	3.16E-13	3.37E-12	4.61E+00	5.06E-02	1.58E-05	1.90E+02	1.02E+01
	Pu-240	1.87E-13	2.00E-12	9.81E+00	1.10E-01	5.54E-05	4.04E+02	2.18E+01
	Pu-241	1.11E-13	1.18E-12	4.41E+01	6.45E-01	3.82E-02	2.18E+03	5.21E+00
	Pu-242	6.25E-14	6.66E-13	5.59E-02	6.25E-04	2.78E-07	2.21E+00	1.23E-01
PWR	H-3	2.00E-02	7.00E-02	6.59E+04	6.59E+04	6.59E+04	0.	6.59E+04
	C-14	3.00E-01		2.28E+04	2.28E+04	2.28E+04	1.14E+05	2.28E+04
	Cr-51	6.00E-08	1.00E-06	5.81E-02	8.94E-01	5.65E-02	5.40E-02	2.21E-01
	Mn-54	2.00E-06	9.00E-06	1.94E+01	1.24E+01	1.78E+01	1.78E+01	3.77E+01
	Fe-55	3.00E-07	6.00E-06	1.02E+00	2.48E+00	4.53E-06	6.34E+00	2.99E+00
	Fe-59	2.00E-06	5.00E-05	6.67E+00	4.72E+01	1.47E+00	7.26E+00	1.05E+01
	Co-58	1.00E-06	4.00E-05	5.17E+01	2.94E+02	2.22E+01	2.22E+01	7.20E+01
	Co-60	4.00E-05	8.00E-04	3.90E+02	5.27E+02	3.71E+02	3.71E+02	4.78E+02
	Br-83	1.00E-10	6.00E-10	1.76E-03	1.72E-03	5.51E-04	5.51E-04	5.51E-04
	Br-84	3.00E-11	8.00E-12	5.48E-02	5.36E-02	5.36E-02	5.36E-02	5.36E-02
	Br-85	3.00E-12	5.00E-15	7.03E-06	1.52E-06	1.52E-06	1.52E-06	1.52E-06
	Kr-83M	5.00E-07		2.71E-03	2.71E-03	2.71E-03	2.71E-03	1.05E-01
	Kr-85	2.00E-07		3.67E+02	3.67E+02	3.67E+02	3.67E+02	7.02E+02
	Kr-85M	8.00E-03		1.56E+02	1.56E+02	1.56E+02	1.56E+02	1.59E+02
	Kr-87	2.00E-07		6.93E+02	6.93E+03	6.93E+02	6.93E+02	7.01E+02
	Kr-88	5.00E-07		4.35E+03	4.35E+03	4.35E+03	4.35E+03	4.41E+03
	Kr-89	1.00E-08		1.47E+01	1.47E+01	1.47E+01	1.47E+01	1.56E+01
	Rb-86	1.00E-09	3.00E-08	7.73E+00	3.27E+00	3.38E-03	3.38E-03	3.38E-03
	Rb-88	2.00E-09	3.00E-11	3.25E+00	3.08E+00	3.08E+00	3.08E+00	3.08E+00
	Sr-89	2.00E-12	8.00E-11	3.38E+00	1.92E+01	8.37E-05	1.17E+02	1.72E+00
	Sr-90	2.00E-12	2.00E-11	9.36E+01	1.11E+01	3.61E-07	3.91E+02	1.13E+00
	Sr-91	5.00E-12	3.00E-11	4.28E-02	9.62E-01	4.13E-02	7.87E-02	1.83E-01
	Y-90	1.00E-12	3.00E-11	1.10E-05	5.10E-01	6.40E-06	1.79E-04	1.03E-02
	Y-91	2.00E-11	4.00E-10	2.28E-01	1.91E+02	1.75E-02	7.81E+00	2.76E+01
	Y-91M	5.00E-12	3.00E-11	2.93E-02	2.93E-02	2.93E-02	2.93E-02	4.39E-02
	Y-93	7.00E-13	5.00E-13	6.89E-04	3.04E-01	6.86E-04	7.51E-04	3.42E-02
	Zr-95	3.00E-13	3.00E-11	1.35E-01	6.91E+00	1.25E-01	1.71E-01	7.71E-01

TABLE A.6. (contd)

Plant	Nuclide	Release Factor		Total Body	Relative Ranking Factors			
		Air	Water		GI Tract	Thyroid	Bone	Lung
BWR	Y-91		6.00E-13	5.62E-06	9.71E-02	9.12E-07	1.77E-04	9.12E-07
	Y-91M		2.00E-11	3.18E-12	3.19E-12	3.18E-12	3.18E-12	3.18E-12
	Y-92		2.00E-11	4.10E-06	8.75E-04	4.10E-06	4.16E-06	4.10E-06
	Y-93		2.00E-11	4.15E-05	1.94E-01	4.15E-05	4.73E-05	4.15E-05
	Zr-95	2.00E-11		2.37E+00	7.58E+00	2.16E+00	3.17E+00	1.88E+01
	Mo-99		1.00E-11	1.05E-02	1.24E-01	3.32E-04	3.32E-04	3.32E-04
	Tc-99M		5.00E-11	5.96E-05	4.95E-04	5.01E-05	5.03E-05	5.04E-05
	Tc-101		1.00E-13	1.38E-36	1.35E-36	1.35E-36	1.36E-36	1.36E-36
	Ru-103		2.00E-13	8.28E-05	1.04E-02	4.45E-05	1.33E-04	4.45E-05
	Ru-105		5.00E-12	6.98E-06	1.72E-04	6.86E-06	7.13E-06	6.86E-06
	Rh-105		2.00E-12	5.70E-05	1.16E-02	9.06E-06	1.08E-04	9.06E-06
	Sb-124	7.00E-08		7.18E+00	2.68E+01	6.85E+00	7.74E+00	3.83E+01
	Te-129M		7.00E-12	5.63E-03	1.78E-01	1.22E-02	3.55E-02	1.39E-05
	Te-131		2.00E-13	5.12E-23	3.80E-23	8.95E-23	1.03E-22	2.75E-23
	Te-131M		6.00E-12	1.83E-03	2.12E-01	3.44E-03	4.42E-03	5.24E-05
	Te-132		6.00E-14	5.27E-04	2.66E-02	6.19E-04	8.66E-04	1.43E-06
	I-131	4.00E-08	6.00E-11	5.57E+03	3.55E+03	2.13E+06	6.42E+03	1.88E+03
	I-132		2.00E-11	4.35E-06	4.03E-06	6.54E-05	4.37E-06	3.69E-06
	I-133	7.00E-08	8.00E-11	1.20E+03	1.41E+03	9.26E+04	1.38E+03	1.01E+03
	I-134		6.00E-12	1.39E-11	1.27E-11	7.12E-11	1.40E-11	1.27E-11
	I-135		4.00E-11	1.28E-03	2.39E-03	9.68E-02	1.30E-03	7.47E-04
	Xe-131M	5.00E-05		3.23E+00	3.23E+00	3.23E+00	3.23E+00	4.58E+00
	Xe-133	1.00E-04		1.33E+04	1.33E+04	1.33E+04	1.33E+04	1.40E+04
	Xe-133M	2.00E-06		6.94E+00	6.94E+00	6.94E+00	6.94E+00	7.35E+00
	Xe-135	2.00E-04		7.93E+04	7.93E+04	7.93E+04	7.93E+04	8.07E+04
	Xe-135M	1.00E-04		2.89E+04	2.89E+04	2.89E+04	2.89E+04	2.91E+04
	Xe-137	4.00E-08		2.88E+00	2.88E+00	2.88E+00	2.88E+00	5.88E+00
	Xe-138	6.00E-05		5.01E+05	5.01E+05	5.01E+05	5.01E+05	5.08E+05
	Cs-134	1.00E-09	2.00E-10	1.04E+03	4.91E+02	4.77E+02	7.68E+02	5.53E+02
	Cs-136	4.00E-10	6.00E-10	2.29E+01	4.73E+00	1.39E+00	8.96E+00	3.67E+00
	Cs-137	3.00E-09	9.00E-10	1.95E+03	1.28E+03	1.26E+03	2.03E+03	1.38E+03
	Cs-138		4.00E-11	3.38E-15	4.24E-16	4.24E-16	3.45E-15	8.58E-16
	Ba-139		3.00E-12	1.14E-10	3.57E-10	1.11E-10	2.49E-10	1.11E-10
	Ba-140	5.00E-10	3.00E-12	7.31E+00	1.09E+02	5.08E+00	3.90E+01	3.22E+02
	La-140		6.00E-13	1.31E-04	5.56E-02	1.31E-04	1.33E-04	1.31E-04
	La-141		1.00E-12	4.69E-08	7.18E-05	4.67E-08	4.88E-08	4.67E-08
	La-142		2.00E-12	1.18E-08	1.89E-08	1.18E-08	1.18E-08	1.18E-08
	Ce-141	4.00E-11	2.00E-13	2.69E-01	7.16E+00	2.40E-01	6.17E-01	7.06E+00
	Ce-143		2.00E-13	4.50E-06	4.39E-03	4.47E-06	4.62E-06	4.47E-06
	Pr-143		3.00E-13	2.90E-07	2.32E-02	2.67E-08	5.34E-06	2.67E-08
	W-187		9.00E-09	5.40E-04	4.66E-01	4.56E-05	1.74E-03	4.56E-05
	Np-239		3.00E-12	5.72E-04	9.19E-01	5.69E-04	6.14E-04	5.69E-04
Reprocessing	H-3	7.00E-01		2.07E+06	2.07E+06	2.07E+06	0.	2.07E+06
	C-14	1.00E+00		1.18E+05	1.18E+05	1.18E+05	5.90E+05	1.18E+05
	Kr-85	8.00E-01		1.73E+05	1.73E+05	1.73E+05	1.73E+05	3.32E+05
	Sr-89	2.00E-09		2.90E-04	2.19E-03	7.50E-08	1.01E-02	2.66E-03
	Sr-90	2.00E-09		3.90E+04	4.59E+03	3.66E-04	1.71E+05	1.52E+03
	Y-90	2.00E-09		1.88E-02	8.12E+01	9.88E-03	3.41E-01	2.69E+01
	Y-91	2.00E-09		1.53E-04	1.66E-02	1.12E-05	5.26E-03	1.94E-02
	Zr-95	3.00E-09		1.94E-02	6.18E-02	1.76E-02	2.58E-02	1.53E-01
	Nb-95	3.00E-09		2.20E-02	8.14E-02	2.12E-02	2.36E-02	1.05E-01
	Ru-103	3.00E-09		9.51E-06	4.26E-05	9.38E-06	9.72E-06	5.62E-05
	Ru-106	3.00E-09		1.11E+02	1.31E+03	1.07E+02	1.41E+02	2.76E+03
	I-129	3.00E-02		2.64E+04	1.82E+04	6.72E+06	2.09E+04	1.78E+04
	Cs-134	2.00E-09		2.21E+03	1.22E+03	1.19E+03	1.72E+03	1.33E+03
	Cs-137	2.00E-09		3.10E+03	2.32E+03	2.30E+03	3.19E+03	2.44E+03
	Ce-141	3.00E-09		3.67E-08	9.75E-07	3.28E-08	8.42E-08	9.63E-07
	Ce-144	3.00E-09		6.54E+01	1.02E+03	1.64E+01	9.30E+02	2.08E+03
	Pm-147	3.00E-09		4.91E+00	4.29E+01	6.10E-05	1.29E+02	1.02E+02
	U-232	2.00E-05		1.14E+04	7.35E+02	2.44E+00	1.97E+05	6.95E+05
	U-233	2.00E-05		1.43E-01	3.86E-02	3.24E-04	2.35E+00	9.36E+00
	U-234	2.00E-05		2.26E+02	6.10E+01	6.70E-01	3.63E+03	1.48E+04
	U-235	2.00E-05		2.74E+00	9.52E-01	6.08E-04	4.52E+01	1.83E+02
	U-236	2.00E-05		5.53E+01	1.45E+01	5.01E-03	8.93E+02	3.63E+03
	U-237	2.00E-05		1.09E+00	2.15E+01	1.07E+00	1.14E+00	1.37E+01

TABLE A.6. (contd)

Plant	Nuclide	Release Factor		Relative Ranking Factors				
		Air	Water	Total Body	GI Tract	Thyroid	Bone	Lung
Reprocessing	U-238	2.00E-05		4.88E+01	1.28E+01	2.89E-03	8.29E+02	3.26E+03
	Pu-238	1.00E-09		6.21E+03	2.07E+01	3.56E-02	2.47E+05	1.64E+04
	Pu-239	1.00E-09		3.69E+02	1.00E+00	1.22E-03	1.52E+04	8.21E+02
	Pu-240	1.00E-09		8.40E+02	2.33E+00	4.55E-03	3.46E+04	1.87E+03
	Pu-241	1.00E-09		3.19E+03	1.35E+01	2.65E+00	1.58E+05	3.78E+02
	Pu-242	1.00E-09		4.99E+00	1.38E-02	2.38E-05	1.97E+02	1.10E+01
	Am-241	2.00E-09		2.40E+03	1.04E+01	2.04E+00	3.61E+04	2.16E+03
	Am-242	2.00E-09		0.	0.	0.	0.	0.
	Cm-242	6.00E-09		9.51E+01	2.16E+01	7.36E-03	1.43E+03	3.78E+03
	Cm-243	6.00E-09		2.90E+01	3.57E-01	1.95E-01	4.92E+02	3.95E+01
	Cm-244	6.00E-09		2.60E+04	1.83E+02	5.26E-01	4.36E+05	4.48E+04

APPENDIX B

PROJECTED NONRADIOACTIVE EFFLUENTS

APPENDIX B

PROJECTED NONRADIOACTIVE EFFLUENTS

The tables in Appendix B identify the nonradioactive effluents projected by ENFORM for the nuclear fuel cycle. Material included in each table is shown below.

Table

- B.1. Releases by Plant - Stowaway Cycle
- B.2. Releases by Plant - Reprocessing without Recycle
- B.3. Releases by Plant - Full Recycle
- B.4. Ranked Air Dilution Factors - Stowaway Cycle
- B.5. Ranked Air Dilution Factors - Reprocessing without Recycle
- B.6. Ranked Air Dilution Factors - Full Recycle
- B.7. Ranked Water Dilution Factors - Stowaway Cycle
- B.8. Ranked Water Dilution Factors - Reprocessing without Recycle
- B.9. Ranked Water Dilution Factors - Full Recycle

TABLE B.1. Non-Radioactive Releases - Stowaway Cycle

Plant	Species	Type	Release Factor	Amount Released (kg)	
				Year 2000	100 yr. Total
Underground Mine	Benzo (A) Pyrene	Air	.7E-07	2.76E+00	1.57E+02
	Aldehydes	Air	.8E-03	3.15E+04	1.80E+06
	Hydrocarbons	Air	.4E-02	1.56E+05	9.00E+06
	Carbon Monoxide	Air	.7E-02	2.76E+05	1.58E+07
	Nitrogen Oxides	Air	.1E-01	3.94E+05	2.25E+07
	Sulfur Oxides	Air	.4E-02	1.58E+05	1.00E+07
	Rock Dust	Air	.4E-01	1.58E+06	8.97E+07
	Non-Rad. Particulates	Air	.2E-02	7.87E+04	4.50E+06
	Cadmium	Air	.2E-05	7.87E+01	4.50E+03
	Sulfur	Air	.5E-03	1.97E+04	1.12E+06
	Uranium	Air	.1E-04	3.93E+02	2.24E+04
	Uranium	Water	.1E-03	3.94E+03	2.25E+05
	Lead	Air	.2E-04	7.87E+02	4.50E+04
	Lead	Water	.2E-03	7.87E+03	4.50E+05
	Beryllium	Air	.1E-05	3.94E+01	2.25E+03
	Beryllium	Water	.1E-04	3.94E+02	2.25E+04
	Zinc	Air	.2E-04	7.87E+02	4.50E+04
	Zinc	Water	.3E-04	1.18E+03	6.75E+04
	Nitrogen (Kjekdahl)	Water	.5E-01	1.97E+06	1.12E+08
	Phosphate	Water	.2E-03	7.87E+03	4.50E+05
	Selenium	Water	.6E-04	2.36E+03	1.35E+05
	Copper	Water	.1E-03	3.94E+03	2.25E+05
	Fluoride	Water	.1E-02	3.94E+04	2.25E+06
	Silica	Water	.2E-01	7.87E+05	4.50E+07
	Chloride	Water	.2E-01	7.87E+07	4.50E+09
	Magnesium	Water	.2E-01	7.87E+05	4.50E+07
	Calcium	Water	.4E-01	1.57E+06	9.00E+07
	Nitrate	Water	.1E-01	3.94E+05	2.25E+07
	Sulfate	Water	.3E+00	1.18E+07	6.75E+08
	Sodium	Water	.1E-01	3.94E+07	2.25E+09
	Ammonia	Water	.1E-02	3.94E+04	2.25E+06
	Aluminum	Water	.5E-03	1.97E+04	1.12E+06
	Titanium	Water	.1E-02	3.94E+04	2.25E+06
	Arsenic	Water	.2E-04	7.87E+02	4.50E+04
	Molybdenum	Water	.9E-03	3.54E+04	2.02E+06
	Vanadium	Water	.1E-02	3.94E+04	2.25E+06
	Suspended Solids	Water	.5E-01	1.97E+06	1.12E+08
	Manganese	Water	.3E-03	1.18E+04	6.75E+05
	Iron	Water	.2E-03	7.87E+03	4.50E+05
Surface Mine	Uranium	Air	3.9E-05	6.90E+02	6.16E+04
	Carbon Monoxide	Air	.4E-01	7.08E+05	6.32E+07
	Nitrogen Oxides	Air	.3E-01	5.31E+05	4.74E+07
	Sulfur Oxides	Air	.1E-01	1.77E+05	1.58E+07
	Aldehydes	Air	.3E-02	5.31E+04	4.74E+06
	Non-Rad. Particulates	Air	.1E-01	1.77E+05	1.58E+07
	Hydrocarbons	Air	.1E-01	1.77E+05	1.58E+07
	Rock Dust	Air	.9E-01	1.61E+06	1.43E+08
	Kjeldahl Nitrogen	Water	.8E-03	1.42E+04	1.26E+06
	Nitrate	Water	.1E-03	1.77E+03	1.58E+05
	Selenium	Water	.2E-04	3.54E+02	3.16E+04
	Ammonia	Water	.8E-03	1.42E+04	1.26E+06
	Phosphorous	Water	.6E-03	1.06E+04	9.48E+05
	Fluoride	Water	.4E-03	7.08E+03	6.32E+05
	Aluminum	Water	.4E-03	7.08E+03	6.32E+05
	Beryllium	Water	.8E-05	1.42E+02	1.26E+04
	Calcium	Water	.8E-01	1.42E+06	1.26E+08
	Magnesium	Water	.3E-01	5.31E+05	4.74E+07
	Titanium	Water	.7E-03	1.24E+04	1.11E+06
	Molybdenum	Water	.7E-03	1.24E+04	1.11E+06
	Vanadium	Water	.1E-02	1.77E+04	1.58E+06
	Arsenic	Water	.4E-04	7.08E+02	6.32E+04
	Iron	Water	.6E-02	1.06E+05	9.48E+06
	Lead	Water	.1E-03	1.77E+03	1.58E+05
	Zinc	Water	.2E-04	3.54E+02	3.16E+04

TABLE B.1. (contd)

Plant	Species	Type	Release Factor	Amount Released (kg)	
				Year 2000	100 yr. Total
Acid Leach Mill	Non-Rad. Particulates	Air	.8E-03	3.65E+04	2.45E+06
	Rock Dust	Air	.3E-02	1.37E+05	9.20E+06
	Sulfur Oxides	Air	.2E-03	9.13E+03	6.13E+05
	Nitrogen Oxides	Air	.2E-01	9.13E+05	6.13E+07
	Hydrocarbon	Air	.3E-02	1.37E+05	9.19E+06
	Aldehydes	Air	.8E-03	3.65E+04	2.45E+06
	Kerosene	Air	.9E-01	4.11E+06	2.76E+08
	Uranium	Air	2.5E-04	1.14E+04	7.67E+05
	Uranium	Water	.3E-03	1.37E+04	9.19E+05
	Ammonia	Air	.2E-02	9.13E+04	6.13E+06
	Ammonia	Water	.8E-01	3.65E+06	2.45E+08
	Isodecanol	Water	.2E-02	9.13E+04	6.13E+06
	Organic Acids	Air	.5E-02	2.28E+05	1.53E+07
	Magnesium	Water	.9E-01	4.11E+06	2.76E+08
	Manganese	Water	.2E-01	9.13E+05	6.13E+07
	Silver	Water	.8E-06	3.65E+01	2.45E+03
	Cyanide	Water	.8E-06	3.65E+01	2.45E+03
	Sulfide	Water	.4E-04	1.83E+03	1.22E+05
	Titanium	Water	.1E-02	4.56E+04	3.06E+06
	Zinc	Water	.5E-03	2.28E+04	1.53E+06
	Lead	Water	.2E-03	9.13E+03	6.13E+05
	Nickel	Water	.2E-03	9.13E+03	6.13E+05
	Copper	Water	.3E-03	1.37E+04	9.19E+05
	Molybdenum	Water	.1E-02	4.56E+04	3.06E+06
	Chromium	Water	.9E-03	4.11E+04	2.76E+06
	Beryllium	Water	.1E-04	4.56E+02	3.06E+04
	Vanadium	Water	.2E-04	9.13E+02	6.13E+04
	Fluoride	Water	.8E-03	3.65E+04	2.45E+06
	Sulfate	Water	.5E+01	2.28E+08	1.53E+10
	Chloride	Water	.5E-01	2.28E+06	1.53E+08
	Aluminum	Water	.3E+00	1.37E+07	9.19E+08
	Iron	Water	.2E+00	9.13E+06	6.13E+08
	Sodium	Water	.3E-01	1.37E+06	9.19E+07
	Tertiary Amine	Water	.1E-02	4.56E+04	3.06E+06
	Calcium	Water	.8E-01	3.65E+06	2.45E+08
	Arsenic	Water	.3E-04	1.37E+03	9.19E+04
Aqueous Conversion	Non-Rad. Particulates	Air	.7E-03	4.00E+04	2.68E+06
	Sulfur Oxides	Air	.5E-02	2.86E+05	1.91E+07
	Nitrogen Oxides	Air	.2E-01	1.14E+06	7.64E+07
	Carbon Monoxide	Air	.7E-03	4.00E+04	2.68E+06
	Hydrocarbons	Air	.1E-03	5.71E+03	3.82E+05
	Hydrogen Fluoride	Air	.3E-03	1.71E+04	1.15E+06
	Hexane	Air	1.7E-02	9.69E+05	6.49E+07
	Fluorine	Air	.1E-04	5.71E+02	3.82E+04
	Uranium	Air	.4E-05	2.28E+02	1.53E+04
	Uranium	Water	.1E-02	5.71E+04	3.82E+06
	Fluoride	Water	.4E-03	2.28E+04	1.53E+06
	Copper	Water	.5E-04	2.86E+03	1.91E+05
	Sodium	Water	.2E-01	1.14E+06	7.64E+07
	Iron	Water	.5E-03	2.86E+04	1.91E+06
	Barium	Water	.7E-04	4.00E+04	2.68E+05
	Aluminum	Water	.2E-03	1.14E+04	7.64E+05
	Chloride	Water	.3E-01	1.71E+06	1.15E+08
	Sulfate	Water	.8E-02	4.57E+05	3.06E+07
	Calcium	Water	.7E-02	4.00E+05	2.68E+07
	Nitrate	Water	.7E-03	4.00E+04	2.68E+06
	Zinc	Water	.2E-04	1.14E+03	7.64E+04
Enrichment Cascade	Non-Rad. Particulates	Air	.2E-01	1.99E+05	1.32E+07
	Hydrogen Fluoride	Air	.1E-02	9.96E+03	6.62E+05
	Sulfur Oxides	Air	.3E+00	2.99E+06	1.99E+08
	Nitrogen Oxides	Air	.3E+00	2.99E+06	1.99E+08
	Carbon Monoxide	Air	.4E-01	3.98E+05	2.65E+07
	Kerosene	Air	.5E-03	4.98E+03	3.31E+05

TABLE B.1. (contd)

Plant	Species	Type	Release Factor	Amount Released (kg)	
				Year 2000	100 yr. Total
Enrichment Cascade	Hydrocarbons	Air	.7E-02	6.97E+04	4.63E+06
	Freon	Air	.6E-02	5.98E+04	3.97E+06
	Xylol	Air	.8E-04	7.97E+02	5.29E+04
	Acetone	Air	.6E-03	5.98E+03	3.97E+05
	Trichlorethylene	Air	.2E-01	1.99E+05	1.32E+07
	Chlorothene	Air	.1E-02	9.96E+03	6.62E+05
	Ozone	Air	.2E-04	1.99E+02	1.32E+04
	Uranium	Air	.1E-04	9.96E+01	6.62E+03
	Uranium	Water	.7E-04	6.97E+02	4.63E+04
	Ammonia	Air	.2E-03	1.99E+03	1.32E+05
	Ammonia	Water	.3E-02	2.99E+04	1.98E+06
	Tributylphosphate	Water	.3E-04	2.99E+02	1.98E+04
	Varsol	Water	.9E-04	8.96E+02	5.95E+04
	Nickel	Water	.6E-03	5.98E+03	3.97E+05
	Iron	Water	.6E-02	5.98E+04	3.97E+06
	Copper	Water	.2E-03	1.99E+03	1.32E+05
	Chloride	Water	.1E+00	9.96E+05	6.62E+07
	Calcium	Water	.9E-01	8.96E+05	5.95E+07
	Cadmium	Water	.1E-04	9.96E+01	6.62E+03
	Fluoride	Water	.2E-03	1.99E+03	1.32E+05
	Nitrate	Water	.2E-01	1.99E+05	1.32E+07
	Chromium	Water	.1E-03	9.96E+02	6.62E+04
	Aluminum	Water	.1E-03	9.96E+02	6.62E+04
	Chlorine	Water	.9E-03	8.96E+03	5.95E+05
	Zinc	Water	.1E-02	9.96E+03	6.62E+05
	Phosphate	Water	.2E-02	1.99E+04	1.32E+06
	Sodium	Water	.1E+00	9.96E+05	6.62E+07
	Manganese	Water	.1E-03	9.96E+02	6.62E+04
	Silver	Water	.1E-03	9.96E+02	6.62E+04
	Molybdenum	Water	.1E-03	9.96E+02	6.62E+04
	Magnesium	Water	.1E-03	9.96E+02	6.62E+04
	Boron	Water	.1E-03	9.96E+02	6.62E+04
	Sulfite	Water	.1E-03	9.96E+02	6.62E+04
	Sulfate	Water	.9E-01	8.96E+05	5.95E+07
Uranium Fuel Fabrication	Isopropyl Alcohol	Air	.5E-02	4.98E+04	3.30E+06
	Glycol Ethyl Ether	Air	.7E-03	6.97E+03	4.63E+05
	Methyl Butyl Ketone	Air	.9E-03	8.96E+03	5.95E+05
	Butanol	Air	.1E-02	9.96E+03	6.61E+05
	Xylol	Air	.1E-02	9.96E+03	6.61E+05
	Nitric Acid	Air	.5E-02	4.98E+04	3.30E+06
	Non-Rad. Particulates	Air	.7E-05	6.97E+01	4.63E+03
	Hydrogen Fluoride	Air	.1E-03	9.96E+02	6.61E+04
	Sulfur Oxides	Air	.2E-06	1.99E+00	1.32E+02
	Nitrogen Oxides	Air	.2E-02	1.99E+04	1.32E+06
	Carbon Monoxide	Air	.7E-05	6.97E+01	4.63E+03
	Hydrocarbons	Air	.1E-05	9.96E+00	6.61E+02
	Ammonium Fluoride	Air	.1E-03	9.96E+02	6.61E+04
	Uranium (Enriched)	Air	.1E-05	9.96E+00	6.61E+02
	Uranium (Enriched)	Water	.1E-06	9.96E-01	6.61E+01
	Ammonia	Air	.2E+00	1.99E+06	1.32E+08
	Ammonia	Water	.2E-02	1.99E+04	1.32E+06
	Phosphorous	Water	.5E-03	4.98E+03	3.30E+05
	Boron	Water	.3E-03	2.99E+03	1.98E+05
	Chloride	Water	.2E-01	1.99E+05	1.32E+07
	Oil and Grease	Water	.1E-02	9.96E+03	6.61E+05
	Sulfite	Water	.4E-03	3.98E+03	2.64E+05
	Iron	Water	.3E-03	2.99E+03	1.98E+05
	Sulfate	Water	.3E-01	2.99E+05	1.98E+07
	Copper	Water	.1E-04	2.96E+01	6.61E+03
	Fluoride	Water	.3E-02	2.99E+04	1.98E+06
	Nitrate	Water	.8E-02	7.96E+04	5.29E+06
	Calcium	Water	.4E+00	3.98E+06	2.64E+08
	Sodium	Water	.2E-01	1.99E+05	1.32E+07
	Silver	Water	.6E-04	5.97E+02	3.96E+04
	Nickel	Water	.2E-03	1.99E+03	1.32E+05

TABLE B.1. (contd)

Plant	Species	Type	Release Factor	Amount Released (kg)	
				Year 2000	100 yr. Total
Uranium Fuel Fabrication	Magnesium	Water	.9E-03	8.96E+03	5.95E+05
	Manganese	Water	.2E-04	1.99E+02	1.32E+04
	Molybdenum	Water	.7E-04	6.97E+02	4.63E+04
PWR	Particulates	Air	.1E-02	5.11E+03	3.98E+05
	Sulfur Oxides	Air	.3E-02	1.53E+04	1.20E+06
	Nitrogen Oxides	Air	.8E-02	4.09E+04	3.19E+06
	Hydrocarbons	Air	.3E-03	1.53E+03	1.20E+05
	Aldehydes	Air	.2E-03	1.02E+03	7.97E+04
	Carbon Monoxide	Air	.4E-03	2.04E+03	1.59E+05
	Bicarbonate	Air	.8E-01	4.09E+05	3.19E+07
	Magnesium	Air	.1E+00	5.11E+05	3.98E+07
	Chloride	Air	.2E+00	1.02E+06	7.97E+07
	Calcium	Air	.1E+01	5.11E+06	3.98E+08
	Silica	Air	.3E+00	1.53E+06	1.20E+08
	Potassium	Air	.2E-01	1.02E+05	7.97E+06
	Sodium	Air	.2E+00	1.02E+06	7.97E+07
	Sodium	Water	.7E+01	3.58E+07	2.79E+08
	Sulfate	Air	.2E+01	1.02E+07	7.97E+08
	Sulfate	Water	.7E+02	3.58E+08	2.79E+10
	Phosphates	Water	.2E-01	1.02E+05	7.97E+06
	Sulfite	Water	.7E-04	3.58E+02	2.79E+04
	Lithium	Water	.4E-02	2.04E+04	1.59E+06
	Volatile Amines	Water	.9E-03	4.60E+03	3.58E+05
	Chlorine	Water	.5E-02	2.55E+04	1.99E+06
	Boron	Water	.6E-02	3.06E+04	2.39E+06
BWR	Non-Rad. Particulates	Air	.7E-03	2.22E+03	1.76E+05
	Hydrocarbons	Air	.8E-02	2.54E+04	2.01E+06
	Sulfur Oxides	Air	.3E+00	9.51E+07	7.53E+09
	Nitrogen Oxides	Air	.2E+00	6.34E+07	5.02E+09
	Silica	Air	.5E+00	1.59E+06	1.26E+08
	Phosphate	Air	.1E-02	3.17E+03	2.51E+05
	Phosphate	Water	.1E-01	3.17E+04	2.51E+06
	Magnesium	Air	.4E+00	1.27E+06	1.01E+08
	Magnesium	Water	.4E+01	1.27E+07	1.01E+09
	Chloride	Air	.9E-01	2.86E+05	2.26E+07
	Chloride	Water	.8E+00	2.54E+06	2.01E+08
	Nitrate	Air	.2E-01	6.35E+04	5.03E+06
	Nitrate	Water	.2E+00	6.35E+05	5.03E+07
	Chlorine	Air	.6E-01	1.90E+05	1.51E+07
	Chlorine	Water	.8E-02	2.54E+04	2.01E+06
	Calcium	Air	.2E+01	6.35E+06	5.03E+08
	Calcium	Water	.2E+02	6.35E+07	5.03E+09
	Sulfate	Air	.4E+01	1.27E+07	1.01E+09
	Sulfate	Water	.4E+02	1.27E+08	1.01E+10
	Sodium	Air	.2E+00	6.35E+05	5.03E+07
	Sodium	Water	.2E+01	6.35E+06	5.03E+08
	Bicarbonate	Air	.2E+01	6.35E+06	5.03E+08
	Bicarbonate	Water	.2E+02	6.35E+07	5.03E+09

TABLE B.2. Non-Radioactive Releases - Reprocessing Without Recycle

Plant	Species	Type	Release Factor	Amount Released (kg)	
				Year 2000	100 yr. Total
Underground Mine	Benzo (A) Pyrene	Air	.7E-07	2.76E+00	1.57E+02
	Aldehydes	Air	.8E-03	3.15E+04	1.80E+06
	Hydrocarbons	Air	.4E-02	1.56E+05	9.00E+06
	Carbon Monoxide	Air	.7E-02	2.76E+05	1.58E+07
	Nitrogen Oxides	Air	.1E-01	3.94E+05	2.25E+07
	Sulfur Oxides	Air	.4E-02	1.58E+05	1.00E+07
	Rock Dust	Air	.4E-01	1.58E+06	8.97E+05
	Non-Rad. Particulates	Air	.2E-02	7.87E+04	4.50E+06
	Cadmium	Air	.2E-05	7.87E+01	4.50E+03
	Sulfur	Air	.5E-03	1.97E+04	1.12E+06
	Uranium	Air	.1E-04	3.93E+02	2.24E+04
	Uranium	Water	.1E-03	3.94E+03	2.25E+05
	Lead	Air	.2E-04	7.87E+02	4.50E+04
	Lead	Water	.2E-03	7.87E+03	4.50E+05
	Beryllium	Air	.1E-05	3.94E+01	2.25E+03
	Beryllium	Water	.1E-04	3.94E+02	2.25E+04
	Zinc	Air	.2E-04	7.87E+02	4.50E+04
	Zinc	Water	.3E-04	1.18E+03	6.75E+04
	Nitrogen (Kjekdahl)	Water	.5E-01	1.97E+06	1.12E+08
	Phosphate	Water	.2E-03	7.87E+03	4.50E+05
	Selenium	Water	.6E-04	2.36E+03	1.35E+05
	Copper	Water	.1E-03	3.94E+03	2.25E+05
	Fluoride	Water	.1E-02	3.94E+04	2.25E+06
	Silica	Water	.2E-01	7.87E+05	4.50E+07
	Chloride	Water	.2E-01	7.87E+07	4.50E+09
	Magnesium	Water	.2E-01	7.87E+05	4.50E+07
	Calcium	Water	.4E-01	1.57E+06	9.00E+07
	Nitrate	Water	.1E-01	3.94E+05	2.25E+07
	Sulfate	Water	.3E+00	1.18E+07	6.75E+08
	Sodium	Water	.1E-01	3.94E+07	2.25E+09
	Ammonia	Water	.1E-02	3.94E+04	2.25E+06
	Aluminum	Water	.5E-03	1.97E+04	1.12E+06
	Titanium	Water	.1E-02	3.94E+04	2.25E+06
	Arsenic	Water	.2E-04	7.87E+02	4.50E+04
	Molybdenum	Water	.9E-03	3.54E+04	2.02E+06
	Vanadium	Water	.1E-02	3.94E+04	2.25E+06
	Suspended Solids	Water	.5E-01	1.97E+06	1.12E+08
	Manganese	Water	.3E-03	1.18E+04	6.75E+05
	Iron	Water	.2E-03	7.87E+03	4.50E+05
Surface Mine	Uranium	Air	3.9E-05	6.90E+02	6.16E+04
	Carbon Monoxide	Air	.4E-01	7.08E+05	6.32E+07
	Nitrogen Oxides	Air	.3E-01	5.31E+05	4.74E+07
	Sulfur Oxides	Air	.1E-01	1.77E+05	1.58E+07
	Aldehydes	Air	.3E-02	5.31E+04	4.74E+06
	Non-Rad. Particulates	Air	.1E-01	1.77E+05	1.58E+07
	Hydrocarbons	Air	.1E-01	1.77E+05	1.58E+07
	Rock Dust	Air	.9E-01	1.61E+06	1.43E+08
	Kjeldahl Nitrogen	Water	.8E-03	1.42E+04	1.26E+06
	Nitrate	Water	.1E-03	1.77E+03	1.58E+05
	Selenium	Water	.2E-04	3.54E+02	3.16E+04
	Ammonia	Water	.8E-03	1.42E+04	1.26E+06
	Phosphorous	Water	.6E-03	1.06E+04	9.48E+05
	Fluoride	Water	.4E-03	7.08E+03	6.32E+05
	Aluminum	Water	.4E-03	7.08E+03	6.32E+05
	Beryllium	Water	.8E-05	1.42E+02	1.26E+04
	Calcium	Water	.8E-01	1.42E+06	1.26E+08
	Magnesium	Water	.3E-01	5.31E+05	4.74E+07
	Titanium	Water	.7E-03	1.24E+04	1.11E+06
	Molybdenum	Water	.7E-03	1.24E+04	1.11E+06
	Vanadium	Water	.1E-02	1.77E+04	1.58E+06
	Arsenic	Water	.4E-04	7.08E+02	6.32E+04
	Iron	Water	.6E-02	1.06E+05	9.48E+06
	Lead	Water	.1E-03	1.77E+03	1.58E+05
	Zinc	Water	.2E-04	3.54E+02	3.16E+04

TABLE B.2. (contd)

Plant	Species	Type	Release Factor	Amount Released (kg)	
				Year 2000	100 yr. Total
Acid Leach Mill	Non-Rad. Particulates	Air	.8E-03	3.65E+04	2.45E+06
	Rock Dust	Air	.3E-02	1.37E+05	9.20E+06
	Sulfur Oxides	Air	.2E-03	9.13E+03	6.13E+05
	Nitrogen Oxides	Air	.2E-01	9.13E+05	6.13E+07
	Hydrocarbon	Air	.3E-02	1.37E+05	9.19E+06
	Aldehydes	Air	.8E-03	3.65E+04	2.45E+06
	Kerosene	Air	.9E-01	4.11E+06	2.76E+08
	Uranium	Air	2.5E-04	1.14E+04	7.67E+05
	Uranium	Water	.3E-03	1.37E+04	9.19E+05
	Ammonia	Air	.2E-02	9.13E+04	6.13E+06
	Ammonia	Water	.8E-01	3.65E+06	2.45E+08
	Isodecanol	Water	.2E-02	9.13E+04	6.13E+06
	Organic Acids	Air	.5E-02	2.28E+05	1.53E+07
	Magnesium	Water	.9E-01	4.11E+06	2.76E+08
	Manganese	Water	.2E-01	9.13E+05	6.13E+07
	Silver	Water	.8E-06	3.65E+01	2.45E+03
	Cyanide	Water	.8E-06	3.65E+01	2.45E+03
	Sulfide	Water	.4E-04	1.83E+03	1.22E+05
	Titanium	Water	.1E-02	4.56E+04	3.06E+06
	Zinc	Water	.5E-03	2.28E+04	1.53E+06
	Lead	Water	.2E-03	9.13E+03	6.13E+05
	Nickel	Water	.2E-03	9.13E+03	6.13E+05
	Copper	Water	.3E-03	1.37E+04	9.19E+05
	Molybdenum	Water	.1E-02	4.56E+04	3.06E+06
	Chromium	Water	.9E-03	4.11E+04	2.76E+06
	Beryllium	Water	.1E-04	4.56E+02	3.06E+04
	Vanadium	Water	.2E-04	9.13E+02	6.13E+04
	Fluoride	Water	.8E-03	3.65E+04	2.45E+06
	Sulfate	Water	.5E+01	2.28E+08	1.53E+10
	Chloride	Water	.5E-01	2.28E+06	1.53E+08
	Aluminum	Water	.3E+00	1.37E+07	9.19E+08
	Iron	Water	.2E+00	9.13E+06	6.13E+08
	Sodium	Water	.3E-01	1.37E+06	9.19E+07
	Tertiary Amine	Water	.1E-02	4.56E+04	3.06E+06
	Calcium	Water	.8E-01	3.65E+06	2.45E+08
	Arsenic	Water	.3E-04	1.37E+03	9.19E+04
Aqueous Conversion	Non-Rad. Particulates	Air	.7E-03	4.00E+04	2.68E+06
	Sulfur Oxides	Air	.5E-02	2.86E+05	1.91E+07
	Nitrogen Oxides	Air	.2E-01	1.14E+06	7.64E+07
	Carbon Monoxide	Air	.7E-03	4.00E+04	2.68E+06
	Hydrocarbons	Air	.1E-03	5.71E+03	3.82E+05
	Hydrogen Fluoride	Air	.3E-03	1.71E+04	1.15E+06
	Hexane	Air	1.7E-02	9.69E+05	6.49E+07
	Fluorine	Air	.1E-04	5.71E+02	3.82E+04
	Uranium	Air	.4E-05	2.28E+02	1.53E+04
	Uranium	Water	.1E-02	5.71E+04	3.82E+06
	Fluoride	Water	.4E-03	2.28E+04	1.53E+06
	Copper	Water	.5E-04	2.86E+03	1.91E+05
	Sodium	Water	.2E-01	1.14E+06	7.64E+07
	Iron	Water	.5E-03	2.86E+04	1.91E+06
	Barium	Water	.7E-04	4.00E+04	2.68E+06
	Aluminum	Water	.2E-03	1.14E+04	7.64E+05
	Chloride	Water	.3E-01	1.71E+06	1.15E+08
	Sulfate	Water	.8E-02	4.57E+05	3.06E+07
	Calcium	Water	.7E-02	4.00E+05	2.68E+07
	Nitrate	Water	.7E-03	4.00E+04	2.68E+06
	Zinc	Water	.2E-04	1.14E+03	7.64E+04
Enrichment Cascade	Non-Rad. Particulates	Air	.2E-01	1.99E+05	1.32E+07
	Hydrogen Fluoride	Air	.1E-02	9.96E+03	6.62E+05
	Sulfur Oxides	Air	.3E+00	2.99E+06	1.99E+08
	Nitrogen Oxides	Air	.3E+00	2.99E+06	1.99E+08
	Carbon Monoxide	Air	.4E-01	3.98E+05	2.65E+07
	Kerosene	Air	.5E-03	4.98E+03	3.31E+05

TABLE B.2. (contd)

Plant	Species	Type	Release Factor	Amount Released (kg)	
				Year 2000	100 yr. Total
Enrichment Cascade	Hydrocarbons	Air	.7E-02	6.97E+04	4.63E+06
	Freon	Air	.6E-02	5.98E+04	3.97E+06
	Xylol	Air	.8E-04	7.97E+02	5.29E+04
	Acetone	Air	.6E-03	5.98E+03	3.97E+05
	Trichlorethylene	Air	.2E-01	1.99E+05	1.32E+07
	Chlorothene	Air	.1E-02	9.96E+03	6.62E+05
	Ozone	Air	.2E-04	1.99E+02	1.32E+04
	Uranium	Air	.1E-04	9.96E+01	6.62E+03
	Uranium	Water	.7E-04	6.97E+02	4.63E+04
	Ammonia	Air	.2E-03	1.99E+03	1.32E+05
	Ammonia	Water	.3E-02	2.99E+04	1.98E+06
	Tributylphosphate	Water	.3E-04	2.99E+02	1.98E+04
	Varsol	Water	.9E-04	8.96E+02	5.95E+04
	Nickel	Water	.6E-03	5.98E+03	3.97E+05
	Iron	Water	.6E-02	5.98E+04	3.97E+06
	Copper	Water	.2E-03	1.99E+03	1.32E+05
	Chloride	Water	.1E+00	9.96E+05	6.62E+07
	Calcium	Water	.9E-01	8.96E+05	5.95E+07
	Cadmium	Water	.1E-04	9.96E+01	6.62E+03
	Fluoride	Water	.2E-03	1.99E+03	1.32E+05
	Nitrate	Water	.2E-01	1.99E+05	1.32E+07
	Chromium	Water	.1E-03	9.96E+02	6.62E+04
	Aluminum	Water	.1E-03	9.96E+02	6.62E+04
	Chlorine	Water	.9E-03	8.96E+03	5.95E+05
	Zinc	Water	.1E-02	9.96E+03	6.62E+05
	Phosphate	Water	.2E-02	1.99E+04	1.32E+06
	Sodium	Water	.1E+00	9.96E+05	6.62E+07
	Manganese	Water	.1E-03	9.96E+02	6.62E+04
	Silver	Water	.1E-03	9.96E+02	6.62E+04
	Molybdenum	Water	.1E-03	9.96E+02	6.62E+04
	Magnesium	Water	.1E-03	9.96E+02	6.62E+04
	Boron	Water	.1E-03	9.96E+02	6.62E+04
	Sulfite	Water	.1E-03	9.96E+02	6.62E+04
	Sulfate	Water	.9E-01	8.96E+05	5.95E+07
Uranium Fuel Fabrication	Isopropyl Alcohol	Air	.5E-02	4.98E+04	3.30E+06
	Glycol Ethyl Ether	Air	.7E-03	6.97E+03	4.63E+05
	Methyl Butyl Ketone	Air	.9E-03	8.96E+03	5.95E+05
	Butanol	Air	.1E-02	9.96E+03	6.61E+05
	Xylol	Air	.1E-02	9.96E+03	6.61E+05
	Nitric Acid	Air	.5E-02	4.98E+04	3.30E+06
	Non-Rad. Particulates	Air	.7E-05	6.97E+01	4.63E+03
	Hydrogen Fluoride	Air	.1E-03	9.96E+02	6.61E+04
	Sulfur Oxides	Air	.2E-06	1.99E+00	1.32E+02
	Nitrogen Oxides	Air	.2E-02	1.99E+04	1.32E+06
	Carbon Monoxide	Air	.7E-05	6.97E+01	4.63E+03
	Hydrocarbons	Air	.1E-05	9.96E+00	6.61E+02
	Ammonium Fluoride	Air	.1E-03	9.96E+02	6.61E+04
	Uranium (Enriched)	Air	.1E-05	9.96E+00	6.61E+02
	Uranium (Enriched)	Water	.1E-06	9.96E-01	6.61E+01
	Ammonia	Air	.2E+00	1.99E+06	1.32E+08
	Ammonia	Water	.2E-02	1.99E+04	1.32E+06
	Phosphorous	Water	.5E-03	4.98E+03	3.30E+05
	Boron	Water	.3E-03	2.99E+03	1.98E+05
	Chloride	Water	.2E-01	1.99E+05	1.32E+07
	Oil and Grease	Water	.1E-02	9.96E+03	6.61E+05
	Sulfite	Water	.4E-03	3.98E+03	2.64E+05
	Iron	Water	.3E-03	2.99E+03	1.98E+05
	Sulfate	Water	.3E-01	2.99E+05	1.98E+07
	Copper	Water	.1E-04	2.96E+01	6.61E+03
	Fluoride	Water	.3E-02	2.99E+04	1.98E+06
	Nitrate	Water	.8E-02	7.96E+04	5.29E+06
	Calcium	Water	.4E+00	3.98E+06	2.64E+08
	Sodium	Water	.2E-01	1.99E+05	1.32E+07
	Silver	Water	.6E-04	5.97E+02	3.96E+04
	Nickel	Water	.2E-03	1.99E+03	1.32E+05

TABLE B.2. (contd)

Plant	Species	Type	Release Factor	Amount Released (kg)		
				Year 2000	100 yr.	Total
Uranium Fuel Fabrication	Magnesium	Water	.9E-03	8.96E+03	5.95E+05	
	Manganese	Water	.2E-04	1.99E+02	1.32E+04	
	Molybdenum	Water	.7E-04	6.97E+02	4.63E+04	
PWR	Particulates	Air	.1E-02	5.11E+03	3.98E+05	
	Sulfur Oxides	Air	.3E-02	1.53E+04	1.20E+06	
	Nitrogen Oxides	Air	.8E-02	4.09E+04	3.19E+06	
	Hydrocarbons	Air	.3E-03	1.53E+03	1.20E+05	
	Aldehydes	Air	.2E-03	1.02E+03	7.97E+04	
	Carbon Monoxide	Air	.4E-03	2.04E+03	1.59E+05	
	Bicarbonate	Air	.8E-01	4.09E+05	3.19E+07	
	Magnesium	Air	.1E+00	5.11E+05	3.98E+07	
	Chloride	Air	.2E+00	1.02E+06	7.97E+07	
	Calcium	Air	.1E+01	5.11E+06	3.98E+08	
	Silica	Air	.3E+00	1.53E+06	1.20E+08	
	Potassium	Air	.2E-01	1.02E+05	7.97E+06	
	Sodium	Air	.2E+00	1.02E+06	7.97E+07	
	Sodium	Water	.7E+01	3.58E+07	2.79E+08	
	Sulfate	Air	.2E+01	1.02E+07	7.97E+08	
	Sulfate	Water	.7E+02	3.58E+08	2.79E+10	
	Phosphates	Water	.2E-01	1.02E+05	7.97E+06	
	Sulfite	Water	.7E-04	3.58E+02	2.79E+04	
	Lithium	Water	.4E-02	2.04E+04	1.59E+06	
	Volatile Amines	Water	.9E-03	4.60E+03	3.58E+05	
	Chlorine	Water	.5E-02	2.55E+04	1.99E+06	
	Boron	Water	.6E-02	3.06E+04	2.39E+06	
BWR	Non-Rad. Particulates	Air	.7E-03	2.22E+03	1.76E+05	
	Hydrocarbons	Air	.8E-02	2.54E+04	2.01E+06	
	Sulfur Oxides	Air	.3E+00	9.51E+07	7.53E+09	
	Nitrogen Oxides	Air	.2E+00	6.34E+07	5.02E+09	
	Silica	Air	.5E+00	1.59E+06	1.26E+08	
	Phosphate	Air	.1E-02	3.17E+03	2.51E+05	
	Phosphate	Water	.1E-01	3.17E+04	2.51E+06	
	Magnesium	Air	.4E+00	1.27E+06	1.01E+08	
	Magnesium	Water	.4E+01	1.27E+07	1.01E+09	
	Chloride	Air	.9E-01	2.86E+05	2.26E+07	
	Chloride	Water	.8E+00	2.54E+06	2.01E+08	
	Nitrate	Air	.2E-01	6.35E+04	5.03E+06	
	Nitrate	Water	.2E+00	6.35E+05	5.03E+07	
	Chlorine	Air	.6E-01	1.90E+05	1.51E+07	
	Chlorine	Water	.8E-02	2.54E+04	2.01E+06	
	Calcium	Air	.2E+01	6.35E+06	5.03E+08	
	Calcium	Water	.2E+02	6.35E+07	5.03E+09	
	Sulfate	Air	.4E+01	1.27E+07	1.01E+09	
	Sulfate	Water	.4E+02	1.27E+08	1.01E+10	
	Sodium	Air	.2E+00	6.35E+05	5.03E+07	
	Sodium	Water	.2E+01	6.35E+06	5.03E+08	
	Bicarbonate	Air	.2E+01	6.35E+06	5.03E+08	
	Bicarbonate	Water	.2E+02	6.35E+07	5.03E+09	
Reprocessing	Fluorine	Air	.1E-03	6.83E+02	6.33E+04	
	Hydrogen Sulfide	Air	.4E-02	2.73E+04	2.53E+06	
	Hydrocarbons	Air	.2E-02	1.37E+04	1.27E+06	
	Nitrogen Oxides	Air	.4E+00	2.73E+06	2.53E+08	
	Sulfur Oxides	Air	.8E-01	5.47E+05	5.06E+07	
	Hydrogen Fluoride	Air	.1E-02	6.83E+03	6.33E+05	
	Ammonia	Air	.2E-03	1.37E+03	1.27E+05	
	Non-Rad. Particulates	Air	.2E-01	1.37E+05	1.27E+07	
	Carbon Monoxide	Air	.1E-01	6.83E+04	6.33E+06	
	Chloride	Water	.7E-02	4.78E+04	4.43E+06	
	Potassium	Water	.4E-01	2.73E+05	2.53E+07	
	Calcium	Water	.3E-02	2.05E+04	1.90E+06	
	Magnesium	Water	.1E-02	6.83E+03	6.33E+05	
	Iron	Water	.1E-02	6.83E+03	6.33E+05	
	Phosphate-Ortho	Water	.1E-03	6.83E+02	6.33E+04	

TABLE B.2. (contd)

<u>Plant</u>	<u>Species</u>	<u>Type</u>	<u>Release Factor</u>	<u>Amount Released (kg)</u>	
				<u>Year 2000</u>	<u>100 yr. Total</u>
Reprocessing	Nitrate	Water	.2E-02	1.37E+04	1.27E+06
	Carbon Dioxide	Water	.1E+00	6.83E+05	6.33E+07
	Sulfate	Water	.8E-02	5.47E+04	5.06E+06
	Sodium	Water	.2E+00	1.37E+06	1.27E+08
	Sulfite	Water	.1E-03	6.83E+02	6.33E+04

TABLE B.3. Non-Radioactive Releases - Full Reprocessing

Plant	Species	Type	Release Factor	Amount Released (kg)	
				Year 2000	100 yr. Total
Underground Mine	Benzo (A) Pyrene	Air	.7E-07	2.03E+00	1.16E+02
	Aldehydes	Air	.8E-03	2.32E+04	1.32E+06
	Hydrocarbons	Air	.4E-02	1.16E+05	6.62E+06
	Carbon Monoxide	Air	.7E-02	2.03E+05	1.16E+07
	Nitrogen Oxides	Air	.1E-01	2.91E+05	1.66E+07
	Sulfur Oxides	Air	.4E-02	1.16E+05	6.64E+06
	Rock Dust	Air	.4E-01	1.16E+06	6.63E+07
	Non-Rad. Particulates	Air	.2E-02	5.80E+04	3.31E+06
	Cadmium	Air	.2E-05	5.81E+01	3.31E+03
	Sulfur	Air	.5E-03	1.45E+04	8.28E+05
	Uranium	Air	.1E-04	2.90E+02	1.66E+04
	Uranium	Water	.1E-03	2.90E+03	1.66E+05
	Lead	Air	.2E-04	5.81E+02	3.31E+04
	Lead	Water	.2E-03	5.81E+03	3.31E+05
	Beryllium	Air	.1E-05	2.90E+01	1.66E+03
	Beryllium	Water	.1E-04	2.90E+02	1.66E+04
	Zinc	Air	.2E-04	5.81E+02	3.31E+04
	Zinc	Water	.3E-04	8.71E+02	4.96E+04
	Nitrogen (Kjekdahl)	Water	.5E-01	1.45E+06	8.28E+07
	Phosphate	Water	.2E-03	5.81E+03	3.31E+05
	Selenium	Water	.6E-04	1.74E+03	9.93E+04
	Copper	Water	.1E-03	2.90E+03	1.66E+05
	Fluoride	Water	.1E-02	2.90E+04	1.66E+06
	Silica	Water	.2E-01	5.81E+05	3.31E+07
	Chloride	Water	.2E-01	5.81E+07	3.31E+09
	Magnesium	Water	.2E-01	5.81E+05	3.31E+07
	Calcium	Water	.4E-01	1.16E+06	6.62E+07
	Nitrate	Water	.1E-01	2.90E+05	1.66E+07
	Sulfate	Water	.3E+00	8.71E+06	4.96E+08
	Sodium	Water	.1E-01	2.90E+07	1.66E+09
	Ammonia	Water	.1E-02	2.90E+04	1.66E+06
	Aluminum	Water	.5E-03	1.45E+04	8.28E+05
	Titanium	Water	.1E-02	2.90E+04	1.66E+06
	Arsenic	Water	.2E-04	5.81E+02	3.31E+04
	Molybdenum	Water	.9E-03	2.61E+04	1.49E+06
	Vanadium	Water	.1E-02	2.90E+04	1.66E+06
	Suspended Solids	Water	.5E-01	1.45E+06	8.28E+07
	Manganese	Water	.3E-03	8.71E+03	4.96E+05
	Iron	Water	.2E-03	5.81E+03	3.31E+05
Surface Mine	Uranium	Air	3.9E-05	4.68E+02	2.96E+04
	Carbon Monoxide	Air	.4E-01	4.80E+05	3.04E+07
	Nitrogen Oxides	Air	.3E-01	3.60E+05	2.28E+07
	Sulfur Oxides	Air	.1E-01	1.20E+05	7.59E+06
	Aldehydes	Air	.3E-02	3.60E+04	2.28E+06
	Non-Rad. Particulates	Air	.1E-01	1.20E+05	7.60E+06
	Hydrocarbons	Air	.1E-01	1.20E+05	7.60E+06
	Rock Dust	Air	.9E-01	1.08E+06	6.83E+07
	Kjeldahl Nitrogen	Water	.8E-03	9.61E+03	6.07E+05
	Nitrate	Water	.1E-03	1.20E+03	7.59E+04
	Selenium	Water	.2E-04	2.40E+02	1.52E+04
	Ammonia	Water	.8E-03	9.61E+03	6.07E+05
	Phosphorous	Water	.6E-03	7.20E+03	4.56E+05
	Fluoride	Water	.4E-03	4.80E+03	3.04E+05
	Aluminum	Water	.4E-03	4.80E+03	3.04E+05
	Beryllium	Water	.8E-05	9.61E+01	6.07E+03
	Calcium	Water	.8E-01	9.61E+05	6.07E+07
	Magnesium	Water	.3E-01	3.60E+05	2.28E+07
	Titanium	Water	.7E-03	8.40E+03	5.31E+05
	Molybdenum	Water	.7E-03	8.40E+03	5.31E+05
	Vanadium	Water	.1E-02	1.20E+04	7.59E+05
	Arsenic	Water	.4E-04	4.80E+02	3.04E+04
	Iron	Water	.6E-02	7.20E+04	4.56E+06
	Lead	Water	.1E-03	1.20E+03	7.59E+04
	Zinc	Water	.2E-04	2.40E+02	1.52E+04

TABLE B.3. (contd)

Plant	Species	Type	Release Factor	Amount Released (kg)	
				Year 2000	100 yr. Total
Acid Leach Mill	Non-Rad. Particulates	Air	.8E-03	2.63E+04	1.54E+06
	Rock Dust	Air	.3E-02	9.86E+04	5.79E+06
	Sulfur Oxides	Air	.2E-03	6.57E+03	3.86E+05
	Nitrogen Oxides	Air	.2E-01	6.57E+05	3.86E+07
	Hydrocarbon	Air	.3E-02	9.85E+04	5.79E+06
	Aldehydes	Air	.8E-03	2.63E+04	1.54E+06
	Kerosene	Air	.9E-01	2.96E+06	1.74E+08
	Uranium	Air	2.5E-04	8.21E+03	4.83E+05
	Uranium	Water	.3E-03	9.85E+03	5.79E+05
	Ammonia	Air	.2E-02	6.57E+04	3.86E+06
	Ammonia	Water	.8E-01	2.63E+06	1.54E+08
	Isodecanol	Water	.2E-02	6.57E+04	3.86E+06
	Organic Acids	Air	.5E-02	1.64E+05	9.66E+06
	Magnesium	Water	.9E-01	2.96E+06	1.74E+08
	Manganese	Water	.2E-01	6.57E+05	3.86E+07
	Silver	Water	.8E-06	2.63E+01	1.54E+03
	Cyanide	Water	.8E-06	2.63E+01	1.54E+03
	Sulfide	Water	.4E-04	1.31E+03	7.72E+04
	Titanium	Water	.1E-02	3.28E+04	1.93E+06
	Zinc	Water	.5E-03	1.65E+04	9.66E+05
	Lead	Water	.2E-03	6.57E+03	3.86E+05
	Nickel	Water	.2E-03	6.57E+03	3.86E+05
	Copper	Water	.3E-03	9.85E+03	5.79E+05
	Molybdenum	Water	.1E-02	3.28E+04	1.93E+06
	Chromium	Water	.9E-03	2.96E+04	1.74E+06
	Beryllium	Water	.1E-04	3.28E+02	1.93E+04
	Vanadium	Water	.2E-04	6.57E+02	3.86E+04
	Fluoride	Water	.8E-03	2.63E+04	1.54E+06
	Sulfate	Water	.5E+01	1.64E+08	9.66E+09
	Chloride	Water	.5E+01	1.64E+06	9.66E+07
	Aluminum	Water	.3E+00	9.85E+06	5.79E+08
	Iron	Water	.2E+00	6.57E+06	3.86E+08
	Sodium	Water	.3E-01	9.85E+05	5.79E+07
	Tertiary Amine	Water	.1E-02	3.28E+04	1.93E+06
	Calcium	Water	.8E-01	2.63E+06	1.54E+08
	Arsenic	Water	.3E-04	9.85E+02	5.79E+04
Aqueous Conversion	Non-Rad. Particulates	Air	.7E-03	3.42E+04	2.16E+06
	Sulfur Oxides	Air	.5E-02	2.44E+05	1.54E+07
	Nitrogen Oxides	Air	.2E-01	9.76E+05	6.18E+07
	Carbon Monoxide	Air	.7E-03	3.42E+04	2.16E+06
	Hydrocarbons	Air	.1E-03	4.88E+03	3.09E+05
	Hydrogen Fluoride	Air	.3E-03	1.46E+04	9.27E+05
	Hexane	Air	1.7E-02	8.30E+04	5.25E+06
	Fluorine	Air	.1E-04	4.88E+02	3.09E+04
	Uranium	Air	.4E-05	1.95E+02	1.24E+04
	Uranium	Water	.1E-02	4.88E+04	3.09E+06
	Fluoride	Water	.4E-03	1.95E+04	1.24E+06
	Copper	Water	.5E-04	2.44E+03	1.54E+05
	Sodium	Water	.2E-01	9.76E+05	6.18E+07
	Iron	Water	.5E-03	2.44E+04	1.54E+06
	Barium	Water	.7E-04	3.42E+03	2.16E+05
	Aluminum	Water	.2E-03	9.76E+03	6.18E+05
	Chloride	Water	.3E-01	1.46E+06	9.27E+07
	Sulfate	Water	.8E-02	3.90E+05	2.47E+07
	Calcium	Water	.7E-02	3.42E+05	2.16E+07
	Nitrate	Water	.7E-03	3.42E+04	2.16E+06
	Zinc	Water	.2E-04	9.76E+02	6.18E+04
Enrichment Cascade	Non-Rad. Particulates	Air	.2E-01	1.98E+05	1.31E+07
	Hydrogen Fluoride	Air	.1E-02	9.88E+03	6.53E+05
	Sulfur Oxides	Air	.3E+00	2.96E+06	1.96E+08
	Nitrogen Oxides	Air	.3E+00	2.96E+06	1.96E+08
	Carbon Monoxide	Air	.4E-01	3.95E+05	2.61E+07
	Kerosene	Air	.5E-03	4.94E+03	3.27E+05

TABLE B.3. (contd)

Plant	Species	Type	Release Factor	Amount Released (kg)	
				Year 2000	100 yr. Total
Enrichment Cascade	Hydrocarbons	Air	.7E-02	6.92E+04	4.57E+06
	Freon	Air	.6E-02	5.93E+04	3.92E+06
	Xylol	Air	.8E-04	7.90E+02	5.22E+04
	Acetone	Air	.6E-03	5.93E+03	3.92E+05
	Trichlorethylene	Air	.2E-01	1.98E+05	1.31E+07
	Chlorothene	Air	.1E-02	9.83E+03	6.53E+05
	Ozone	Air	.2E-04	1.98E+02	1.31E+04
	Uranium	Air	.1E-04	9.88E+01	6.53E+03
	Uranium	Water	.7E-04	6.92E+02	4.57E+04
	Ammonia	Air	.2E-03	1.98E+03	1.31E+05
	Ammonia	Water	.3E-02	2.96E+04	1.96E+06
	Tributylphosphate	Water	.3E-04	2.96E+02	1.96E+04
	Varsol	Water	.9E-04	8.89E+02	5.88E+04
	Nickel	Water	.6E-03	5.93E+03	3.92E+05
	Iron	Water	.6E-02	5.93E+04	3.92E+06
	Copper	Water	.2E-03	1.98E+03	1.31E+05
	Chloride	Water	.1E+00	9.88E+05	6.53E+07
	Calcium	Water	.9E-01	8.89E+05	5.88E+07
	Cadmium	Water	.1E-04	9.88E+01	6.53E+03
	Fluoride	Water	.2E-03	1.98E+03	1.31E+05
	Nitrate	Water	.2E-01	1.99E+05	1.31E+07
	Chromium	Water	.1E-03	9.88E+02	6.53E+04
	Aluminum	Water	.1E-03	9.88E+02	6.53E+04
	Chlorine	Water	.9E-03	8.89E+03	5.88E+05
	Zinc	Water	.1E-02	9.88E+03	6.53E+05
	Phosphate	Water	.2E-02	1.98E+04	1.31E+06
	Sodium	Water	.1E+00	9.88E+05	6.53E+07
	Manganese	Water	.1E-03	9.88E+02	6.53E+04
	Silver	Water	.1E-03	9.88E+02	6.53E+04
	Molybdenum	Water	.1E-03	9.88E+02	6.53E+04
	Magnesium	Water	.1E-03	9.88E+02	6.53E+04
	Boron	Water	.1E-03	9.88E+02	6.53E+04
	Sulfite	Water	.1E-03	9.88E+02	6.53E+04
	Sulfate	Water	.9E-01	8.89E+05	5.88E+07
Uranium Fuel Fabrication	Isopropyl Alcohol	Air	.5E-02	4.09E+04	2.45E+06
	Glycol Ethyl Ether	Air	.7E-03	5.73E+03	3.43E+05
	Methyl Butyl Ketone	Air	.9E-03	7.36E+03	4.41E+05
	Butanol	Air	.1E-02	3.18E+03	4.90E+05
	Xylol	Air	.1E-02	8.18E+03	4.90E+05
	Nitric Acid	Air	.5E-02	4.09E+04	2.45E+06
	Non-Rad. Particulates	Air	.7E-05	5.73E+01	3.43E+03
	Hydrogen Fluoride	Air	.1E-03	8.18E+02	4.90E+04
	Sulfur Oxides	Air	.2E-06	1.64E+00	9.80E+01
	Nitrogen Oxides	Air	.2E-02	1.64E+04	9.80E+05
	Carbon Monoxide	Air	.7E-05	5.73E+01	3.43E+03
	Hydrocarbons	Air	.1E-05	8.18E+00	4.90E+02
	Ammonium Fluoride	Air	.1E-03	8.18E+02	4.90E+04
	Uranium (Enriched)	Air	.1E-05	8.18E+00	4.90E+02
	Uranium (Enriched)	Water	.1E-06	8.18E-01	4.90E+01
	Ammonia	Air	.2E+00	1.64E+06	9.80E+07
	Ammonia	Water	.2E-02	1.64E+04	9.80E+05
	Phosphorous	Water	.5E-03	4.09E+03	2.45E+05
	Boron	Water	.3E-03	2.45E+03	1.47E+05
	Chloride	Water	.2E-01	1.64E+05	9.80E+06
	Oil and Grease	Water	.1E-02	8.18E+03	4.90E+05
	Sulfite	Water	.4E-03	3.27E+03	1.96E+05
	Iron	Water	.3E-03	2.45E+03	1.47E+05
	Sulfate	Water	.3E-01	2.45E+05	1.47E+07
	Copper	Water	.1E-04	8.18E+01	4.90E+03
	Fluoride	Water	.3E-02	2.45E+04	1.47E+06
	Nitrate	Water	.8E-02	6.54E+04	3.92E+06
	Calcium	Water	.4E+00	3.27E+06	1.96E+08
	Sodium	Water	.2E-01	1.64E+05	9.80E+06
	Silver	Water	.6E-04	4.91E+02	2.94E+04
	Nickel	Water	.2E-03	1.64E+03	9.80E+04

TABLE B.3. (contd)

Plant	Species	Type	Release Factor	Amount Released (kg)	
				Year 2000	100 yr. Total
Uranium Fuel Fabrication	Magnesium	Water	.9E-03	7.36E+03	4.41E+05
	Manganese	Water	.2E-04	1.64E+02	9.80E+03
	Molybdenum	Water	.7E-04	5.73E+02	3.43E+04
Mixed Oxide Fabrication	Sulfur Oxides	Air	.1E-04	1.78E+01	1.71E+03
	Hydrocarbons	Air	.1E-02	1.78E+03	1.71E+05
	Nitrogen Dioxide	Air	.1E-03	1.78E+02	1.71E+04
	Uranium (Enriched)	Air	.1E-01	1.73E-05	1.71E-03
	Uranium (Enriched)	Water	.2E-09	3.55E-04	3.41E-02
	Plutonium	Air	.7E-12	1.24E-06	1.20E-04
	Plutonium	Water	.7E-11	1.24E-05	1.20E-03
	Phosphates	Water	.9E-04	1.60E+02	1.54E+04
	Sulfate	Water	.7E-04	1.24E+02	1.20E+04
	Nitrate	Water	.3E-02	5.33E+03	5.12E+05
	Chloride	Water	.2E-04	3.55E+01	3.41E+03
	Sodium	Water	.1E-02	1.78E+03	1.71E+05
PWR	Particulates	Air	.1E-02	5.11E+03	3.98E+05
	Sulfur Oxides	Air	.3E-02	1.53E+04	1.20E+06
	Nitrogen Oxides	Air	.8E-02	4.09E+04	3.19E+06
	Hydrocarbons	Air	.3E-03	1.53E+03	1.20E+05
	Aldehydes	Air	.2E-03	1.02E+03	7.97E+04
	Carbon Monoxide	Air	.4E-03	2.04E+03	1.59E+05
	Bicarbonate	Air	.8E-01	4.09E+05	3.19E+07
	Magnesium	Air	.1E+00	5.11E+05	3.98E+07
	Chloride	Air	.2E+00	1.02E+06	7.97E+07
	Calcium	Air	.1E+01	5.11E+06	3.98E+08
	Silica	Air	.3E+00	1.53E+06	1.20E+08
	Potassium	Air	.2E-01	1.02E+05	7.97E+06
	Sodium	Air	.2E+00	1.02E+06	7.97E+07
	Sodium	Water	.7E+01	3.58E+07	2.79E+08
	Sulfate	Air	.2E+01	1.02E+07	7.97E+08
	Sulfate	Water	.7E+02	3.58E+08	2.79E+10
	Phosphates	Water	.2E-01	1.02E+05	7.97E+06
	Sulfite	Water	.7E-04	3.58E+02	2.79E+04
	Lithium	Water	.4E-02	2.04E+04	1.59E+06
	Volatile Amines	Water	.9E-03	4.60E+03	3.58E+05
	Chlorine	Water	.5E-02	2.55E+04	1.99E+06
	Boron	Water	.6E-02	3.06E+04	2.39E+06
BWR	Non-Rad. Particulates	Air	.7E-03	2.22E+03	1.76E+05
	Hydrocarbons	Air	.8E-02	2.54E+04	2.01E+06
	Sulfur Oxides	Air	.3E+00	9.51E+07	7.53E+09
	Nitrogen Oxides	Air	.2E+00	6.34E+07	5.02E+09
	Silica	Air	.5E+00	1.59E+06	1.26E+08
	Phosphate	Air	.1E-02	3.17E+03	2.51E+05
	Phosphate	Water	.1E-01	3.17E+04	2.51E+06
	Magnesium	Air	.4E+00	1.27E+06	1.01E+08
	Magnesium	Water	.4E+01	1.27E+07	1.01E+09
	Chloride	Air	.9E-01	2.86E+05	2.26E+07
	Chloride	Water	.8E+00	2.54E+06	2.01E+08
	Nitrate	Air	.2E-01	6.35E+04	5.03E+06
	Nitrate	Water	.2E+00	6.35E+05	5.03E+07
	Chlorine	Air	.6E-01	1.90E+05	1.51E+07
	Chlorine	Water	.8E-02	2.54E+04	2.01E+06
	Calcium	Air	.2E+01	6.35E+06	5.03E+08
	Calcium	Water	.2E+02	6.35E+07	5.03E+09
	Sulfate	Air	.4E+01	1.27E+07	1.01E+09
	Sulfate	Water	.4E+02	1.27E+08	1.01E+10
	Sodium	Air	.2E+00	6.35E+05	5.03E+07
	Sodium	Water	.2E+01	6.35E+06	5.03E+08
	Bicarbonate	Air	.2E+01	6.35E+06	5.03E+08
	Bicarbonate	Water	.2E+02	6.35E+07	5.03E+09
Reprocessing	Fluorine	Air	.1E-03	6.83E+02	6.33E+04
	Hydrogen Sulfide	Air	.4E-02	2.73E+04	2.53E+06
	Hydrocarbons	Air	.2E-02	1.37E+04	1.27E+06

TABLE B.3. (contd)

Plant	Species	Type	Release Factor	Amount Released (kg)	
				Year 2000	100 yr. Total
Reprocessing	Nitrogen Oxides	Air	.4E+00	2.73E+06	2.63E+08
	Sulfur Oxides	Air	.8E-01	5.47E+05	5.06E+07
	Hydrogen Fluoride	Air	.1E-02	6.83E+03	6.33E+05
	Ammonia	Air	.2E-03	1.37E+03	1.27E+05
	Non-Rad. Particulates	Air	.2E-01	1.37E+05	1.27E+07
	Carbon Monoxide	Air	.1E-01	6.83E+04	6.33E+06
	Chloride	Water	.7E-02	4.78E+04	4.43E+06
	Potassium	Water	.4E-01	2.73E+05	2.53E+07
	Calcium	Water	.3E-02	2.05E+04	1.90E+06
	Magnesium	Water	.1E-02	6.83E+03	6.33E+05
	Iron	Water	.1E-02	6.83E+03	6.33E+05
	Phosphate-Ortho	Water	.1E-03	6.83E+02	6.33E+04
	Nitrate	Water	.2E-02	1.37E+04	1.27E+06
	Carbon Dioxide	Water	.1E+00	6.83E+05	6.33E+07
	Sulfate	Water	.8E-02	5.47E+04	5.06E+06
	Sodium	Water	.2E+00	1.37E+06	1.27E+08
	Sulfite	Water	.1E-03	6.83E+02	6.33E+04

TABLE B.4. Non-Radioactive Substance Air Dilution Factors - Stowaway Cycle

Rank	Species	Plant	Quality	Dilution Factor (M ³) 100 yr. Total
1	Ammonia	Uranium Fuel Fabrication	2	4.406E+15
2	Sulfur Oxides	Enrichment Cascade	1	3.308E+15
3	Uranium	Acid Leach Mill	3	2.553E+15
4	Rock Dust	Surface Mine	1	2.371E+15
5	Nitrogen Oxides	Enrichment Cascade	1	1.985E+15
6	Rock Dust	Underground Mine	1	1.499E+15
7	Sulfur Oxides	BWR	2	1.257E+15
8	Aldehydes	Surface Mine	2	9.484E+14
9	Nitrogen Oxides	Aqueous Conversion	2	7.643E+14
10	Nitrogen Oxides	Acid Leach Mill	2	6.127E+14
11	Nitrogen Oxides	BWR	2	5.029E+14
12	Aldehydes	Acid Leach Mill	2	4.902E+14
13	Nitrogen Oxides	Surface Mine	2	4.742E+14
14	Hexane	Aqueous Conversion	3	4.061E+14
15	Nitric Acid	Uranium Fuel Fabrication	1	3.981E+14
16	Aldehydes	Underground Mine	1	3.598E+14
17	Hydrogen Fluoride	Aqueous Conversion	2	3.474E+14
18	Sulfur Oxides	Aqueous Conversion	2	3.185E+14
19	Sulfur Oxides	Surface Mine	2	2.634E+14
20	Non-Rad. Particulates	Surface Mine	2	2.634E+14
21	Nitrogen Oxides	Underground Mine	1	2.249E+14
22	Beryllium	Underground Mine	2	2.249E+14
23	Non-Rad. Particulates	Enrichment Cascade	1	2.205E+14
24	Uranium	Surface Mine	1	2.055E+14
25	Ammonia	Acid Leach Mill	2	2.042E+14
26	Hydrogen Fluoride	Enrichment Cascade	1	2.005E+14
27	Lead	Underground Mine	2	1.799E+14
28	Rock Dust	Acid Leach Mill	2	1.532E+14
29	Sulfur Oxides	Underground Mine	1	1.499E+14
30	Hydrocarbons	Surface Mine	2	9.879E+13
31	Kerosene	Acid Leach Mill	2	8.356E+13
32	Non-Rad. Particulates	Underground Mine	1	7.497E+13
33	Uranium	Underground Mine	1	7.497E+13
34	Hydrocarbon	Acid Leach Mill	2	5.745E+13
35	Hydrocarbons	Underground Mine	1	5.623E+13
36	Cadmium	Underground Mine	2	5.623E+13
37	Benzo (A) Pyrene	Underground Mine	2	5.248E+13
38	Uranium	Aqueous Conversion	2	5.096E+13
39	Non-Rad. Particulates	Aqueous Conversion	2	4.459E+13
40	Non-Rad. Particulates	Acid Leach Mill	2	4.085E+13
41	Nitrogen Oxides	PWR	1	3.187E+13
42	Hydrocarbons	Enrichment Cascade	1	2.894E+13
43	Uranium	Enrichment Cascade	1	2.205E+13
44	Hydrogen Fluoride	Uranium Fuel Fabrication	2	2.003E+13
45	Sulfur Oxides	PWR	1	1.992E+13
46	Ammonium Fluoride	Uranium Fuel Fabrication	2	1.612E+13
47	Aldehydes	PWR	1	1.593E+13
48	Trichlorethylene	Enrichment Cascade	1	1.498E+13
49	Nitrogen Oxides	Uranium Fuel Fabrication	1	1.322E+13
50	Hydrocarbons	BWR	2	1.257E+13
51	Fluorine	Aqueous Conversion	2	1.158E+13
52	Sulfur Oxides	Acid Leach Mill	2	1.021E+13
53	Particulates	PWR	1	6.639E+12
54	Carbon Monoxide	Surface Mine	2	6.323E+12
55	Zinc	Underground Mine	2	5.623E+12
56	Ammonia	Enrichment Cascade	1	4.410E+12
57	Chloroethene	Enrichment Cascade	1	3.961E+12
58	Methyl Butyl Ketone	Uranium Fuel Fabrication	1	3.605E+12
59	Non-Rad. Particulates	BWR	2	2.933E+12
60	Carbon Monoxide	Enrichment Cascade	1	2.646E+12
61	Hydrocarbons	Aqueous Conversion	2	2.389E+12
62	Uranium (Enriched)	Uranium Fuel Fabrication	2	2.203E+12
63	Isopropyl Alcohol	Uranium Fuel Fabrication	1	2.043E+12
64	Carbon Monoxide	Underground Mine	1	1.574E+12
65	Butanol	Uranium Fuel Fabrication	1	1.335E+12

TABLE B.4. (contd)

Rank	Species	Plant	Quantity	Dilution Factor (M ³)
				100 yr. Total
66	Xylol	Uranium Fuel Fabrication	1	9.204E+11
67	Glycol Ethyl Ether	Uranium Fuel Fabrication	1	7.584E+11
68	Hydrocarbons	PWR	1	7.469E+11
69	Freon	Enrichment Cascade	1	5.727E+11
70	Carbon Monoxide	Aqueous Conversion	2	2.675E+11
71	Kerosene	Enrichment Cascade	1	1.002E+11
72	Acetone	Enrichment Cascade	1	9.923E+10
73	Ozone	Enrichment Cascade	1	8.269E+10
74	Non-Rad. Particulates	Uranium Fuel Fabrication	2	7.710E+10
75	Xylol	Enrichment Cascade	1	7.371E+10
76	Carbon Monoxide	PWR	1	1.593E+10
77	Hydrocarbons	Uranium Fuel Fabrication	2	4.130E+09
78	Sulfur Oxides	Uranium Fuel Fabrication	2	2.203E+09
79	Carbon Monoxide	Uranium Fuel Fabrication	2	4.626E+08

TABLE B.5. Non-Radioactive Substance Air Dilution Factors - Reprocessing, No Recycle

Rank	Species	Plant	Quality	Dilution Factor (M ³)
				100 yr. Total
1	Ammonia	Uranium Fuel Fabrication	2	4.406E+15
2	Sulfur Oxides	Enrichment Cascade	1	3.308E+15
3	Uranium	Acid Leach Mill	3	2.553E+15
4	Nitrogen Oxides	Reprocessing	2	2.533E+15
5	Rock Dust	Surface Mine	1	2.371E+15
6	Nitrogen Oxides	Enrichment Cascade	1	1.985E+15
7	Rock Dust	Underground Mine	1	1.499E+15
8	Sulfur Oxides	BWR	2	1.257E+15
9	Aldehydes	Surface Mine	2	9.484E+14
10	Sulfur Oxides	Reprocessing	2	8.442E+14
11	Nitrogen Oxides	Aqueous Conversion	2	7.643E+14
12	Nitrogen Oxides	Acid Leach Mill	2	6.127E+14
13	Nitrogen Oxides	BWR	2	5.029E+14
14	Aldehydes	Acid Leach Mill	2	4.902E+14
15	Nitrogen Oxides	Surface Mine	2	4.742E+14
16	Hexane	Aqueous Conversion	3	4.061E+14
17	Nitric Acid	Uranium Fuel Fabrication	1	3.981E+14
18	Aldehydes	Underground Mine	1	3.598E+14
19	Hydrogen Fluoride	Aqueous Conversion	2	3.474E+14
20	Sulfur Oxides	Aqueous Conversion	2	3.185E+14
21	Sulfur Oxides	Surface Mine	2	2.634E+14
22	Non-Rad. Particulates	Surface Mine	2	2.634E+14
23	Nitrogen Oxides	Underground Mine	1	2.249E+14
24	Beryllium	Underground Mine	2	2.249E+14
25	Non-Rad. Particulates	Enrichment Cascade	1	2.205E+14
26	Non-Rad. Particulates	Reprocessing	2	2.111E+14
27	Uranium	Surface Mine	1	2.055E+14
28	Ammonia	Acid Leach Mill	2	2.042E+14
29	Hydrogen Fluoride	Enrichment Cascade	1	2.005E+14
30	Hydrogen Fluoride	Reprocessing	2	1.919E+14
31	Lead	Underground Mine	2	1.799E+14
32	Rock Dust	Acid Leach Mill	2	1.532E+14
33	Sulfur Oxides	Underground Mine	1	1.499E+14
34	Hydrogen Sulfide	Reprocessing	2	1.013E+14
35	Hydrocarbons	Surface Mine	2	9.879E+13
36	Kerosene	Acid Leach Mill	2	8.356E+13
37	Non-Rad. Particulates	Underground Mine	1	7.497E+13
38	Uranium	Underground Mine	1	7.497E+13
39	Hydrocarbon	Acid Leach Mill	2	5.743E+13
40	Hydrocarbons	Underground Mine	1	5.623E+13
41	Cadmium	Underground Mine	2	5.623E+13
42	Benzo (A) Pyrene	Underground Mine	2	5.248E+13
43	Uranium	Aqueous Conversion	2	5.096E+13
44	Non-Rad. Particulates	Aqueous Conversion	2	4.459E+13
45	Non-Rad. Particulates	Acid Leach Mill	2	4.085E+13
46	Nitrogen Oxides	PWR	1	3.187E+13
47	Hydrocarbons	Enrichment Cascade	1	2.894E+13
48	Uranium	Enrichment Cascade	1	2.205E+13
49	Hydrogen Fluoride	Uranium Fuel Fabrication	2	2.003E+13
50	Sulfur Oxides	PWR	1	1.992E+13
51	Fluorine	Reprocessing	1	1.907E+13
52	Ammonium Fluoride	Uranium Fuel Fabrication	2	1.612E+13
53	Aldehydes	PWR	1	1.593E+13
54	Trichlorethylene	Enrichment Cascade	1	1.498E+13
55	Nitrogen Oxides	Uranium Fuel Fabrication	1	1.322E+13
56	Hydrocarbons	BWR	1	1.257E+13
57	Fluorine	Aqueous Conversion	2	1.158E+13
58	Sulfur Oxides	Acid Leach Mill	2	1.021E+13
59	Hydrocarbons	Reprocessing	2	7.915E+12
60	Particulates	PWR	1	6.639E+12
61	Carbon Monoxide	Surface Mine	2	6.323E+12
62	Zinc	Underground Mine	2	5.623E+12
63	Ammonia	Enrichment Cascade	1	4.410E+12
64	Ammonia	Reprocessing	2	4.221E+12
65	Chlorothene	Enrichment Cascade	1	3.961E+12

TABLE B.5. (contd)

Rank	Species	Plant	Quality	Dilution Factor (M ³) 100 yr. Total
66	Methyl Butyl Ketone	Uranium Fuel Fabrication	1	3.605E+12
67	Non-Rad. Particulates	BWR	2	2.933E+12
68	Carbon Monoxide	Enrichment Cascade	1	2.646E+12
69	Hydrocarbons	Aqueous Conversion	2	2.389E+12
70	Uranium (Enriched)	Uranium Fuel Fabrication	2	2.203E+12
71	Isopropyl Alcohol	Uranium Fuel Fabrication	1	2.043E+12
72	Carbon Monoxide	Underground Mine	1	1.574E+12
73	Butanol	Uranium Fuel Fabrication	1	1.335E+12
74	Xylol	Uranium Fuel Fabrication	1	9.204E+11
75	Glycol Ethyl Ether	Uranium Fuel Fabrication	1	7.584E+11
76	Hydrocarbons	PWR	1	7.469E+11
77	Carbon Monoxide	Reprocessing	2	6.332E+11
78	Freon	Enrichment Cascade	1	5.727E+11
79	Carbon Monoxide	Aqueous Conversion	2	2.675E+11
80	Kerosene	Enrichment Cascade	1	1.002E+11
81	Acetone	Enrichment Cascade	1	9.923E+10
82	Ozone	Enrichment Cascade	1	8.269E+10
83	Non-Rad. Particulates	Uranium Fuel Fabrication	2	7.710E+10
84	Xylol	Enrichment Cascade	1	7.371E+10
85	Carbon Monoxide	PWR	1	1.593E+10
86	Hydrocarbons	Uranium Fuel Fabrication	2	4.130E+09
87	Sulfur Oxides	Uranium Fuel Fabrication	2	2.203E+09
88	Carbon Monoxide	Uranium Fuel Fabrication	2	4.626E+08

**TABLE B.6. Non-Radioactive Substance Air Dilution
Factors - Full Recycle**

Rank	Species	Plant	Quality	Dilution Factor (M ³) 100 yr. Total
1	Ammonia	Uranium Fuel Fabrication	2	3.268E+15
2	Sulfur Oxides	Enrichment Cascade	1	3.266E+15
3	Nitrogen Oxides	Reprocessing	2	2.533E+15
4	Nitrogen Oxides	Enrichment Cascade	1	1.960E+15
5	Uranium	Acid Leach Mill	3	1.609E+15
6	Sulfur Oxides	BWR	2	1.257E+15
7	Rock Dust	Surface Mine	1	1.139E+15
8	Rock Dust	Underground Mine	1	1.103E+15
9	Sulfur Oxides	Reprocessing	2	8.442E+14
10	Nitrogen Oxides	Aqueous Conversion	2	6.179E+14
11	Nitrogen Oxides	BWR	2	5.029E+14
12	Aldehydes	Surface Mine	2	4.555E+14
13	Nitrogen Oxides	Acid Leach Mill	2	3.862E+14
14	Hexane	Aqueous Conversion	3	3.282E+14
15	Aldehydes	Acid Leach Mill	2	3.090E+14
16	Nitric Acid	Uranium Fuel Fabrication	1	2.953E+14
17	Hydrogen Fluoride	Aqueous Conversion	2	2.809E+14
18	Aldehydes	Underground Mine	1	2.648E+14
19	Sulfur Oxides	Aqueous Conversion	2	2.575E+14
20	Nitrogen Oxides	Surface Mine	2	2.277E+14
21	Non-Rad. Particulates	Enrichment Cascade	1	2.177E+14
22	Non-Rad. Particulates	Reprocessing	2	2.111E+14
23	Hydrogen Fluoride	Enrichment Cascade	1	1.979E+14
24	Hydrogen Fluoride	Reprocessing	2	1.919E+14
25	Nitrogen Oxides	Underground Mine	1	1.655E+14
26	Beryllium	Underground Mine	2	1.655E+14
27	Lead	Underground Mine	2	1.324E+14
28	Ammonia	Acid Leach Mill	2	1.287E+14
29	Sulfur Oxides	Surface Mine	2	1.265E+14
30	Non-Rad. Particulates	Surface Mine	2	1.265E+14
31	Sulfur Oxides	Underground Mine	1	1.103E+14
32	Hydrogen Sulfide	Reprocessing	2	1.013E+14
33	Uranium	Surface Mine	1	9.869E+13
34	Rock Dust	Acid Leach Mill	2	9.656E+13
35	Non-Rad. Particulates	Underground Mine	1	5.516E+13
36	Uranium	Underground Mine	1	5.516E+13
37	Kerosene	Acid Leach Mill	2	5.267E+13
38	Hydrocarbons	Surface Mine	2	4.745E+13
39	Hydrocarbons	Underground Mine	1	4.137E+13
40	Cadmium	Underground Mine	2	4.137E+13
41	Uranium	Aqueous Conversion	2	4.119E+13
42	Benzo (A) Pyrene	Underground Mine	2	3.861E+13
43	Hydrocarbon	Acid Leach Mill	2	3.621E+13
44	Non-Rad. Particulates	Aqueous Conversion	2	3.604E+13
45	Nitrogen Oxides	PWR	1	3.187E+13
46	Hydrocarbons	Enrichment Cascade	1	2.858E+13
47	Non-Rad. Particulates	Acid Leach Mill	2	2.575E+13
48	Uranium	Enrichment Cascade	1	2.177E+13
49	Sulfur Oxides	PWR	1	1.992E+13
50	Fluorine	Reprocessing	1	1.907E+13
51	Aldehydes	PWR	1	1.593E+13
52	Hydrogen Fluoride	Uranium Fuel Fabrication	2	1.485E+13
53	Trichlorethylene	Enrichment Cascade	1	1.479E+13
54	Hydrocarbons	BWR	2	1.257E+13
55	Ammonium Fluoride	Uranium Fuel Fabrication	2	1.195E+13
56	Nitrogen Oxides	Uranium Fuel Fabrication	1	9.803E+12
57	Fluorine	Aqueous Conversion	2	9.362E+12
58	Hydrocarbons	Reprocessing	2	7.915E+12
59	Particulates	PWR	1	6.639E+12
60	Sulfur Oxides	Acid Leach Mill	2	6.437E+12
61	Ammonia	Enrichment Cascade	1	4.355E+12
62	Ammonia	Reprocessing	2	4.221E+12
63	Zinc	Underground Mine	2	4.137E+12
64	Chlorothene	Enrichment Cascade	1	3.911E+12
65	Carbon Monoxide	Surface Mine	2	3.037E+12

TABLE B.6. (contd)

Rank	Species	Plant	Quality	Dilution Factor (M ³)
				100 yr. Total
66	Non-Rad. Particulates	BWR	2	2.933E+12
67	Methyl Butyl Ketone	Uranium Fuel Fabrication	1	2.673E+12
68	Carbon Monoxide	Enrichment Cascade	1	2.613E+12
69	Hydrocarbons	Aqueous Conversion	2	1.931E+12
70	Uranium (Enriched)	Uranium Fuel Fabrication	2	1.634E+12
71	Isopropyl Alcohol	Uranium Fuel Fabrication	1	1.516E+12
72	Carbon Monoxide	Underground Mine	1	1.158E+12
73	Hydrocarbons	Mixed Oxide Fabrication	1	1.067E+12
74	Butanol	Uranium Fuel Fabrication	1	9.902E+11
75	Hydrocarbons	PWR	1	7.469E+11
76	Xylol	Uranium Fuel Fabrication	1	6.826E+11
77	Carbon Monoxide	Reprocessing	2	6.332E+11
78	Freon	Enrichment Cascade	1	5.655E+11
79	Glycol Ethyl Ether	Uranium Fuel Fabrication	1	5.625E+11
80	Carbon Monoxide	Aqueous Conversion	2	2.163E+11
81	Nitrogen Dioxide	Mixed Oxide Fabrication	2	1.707E+11
82	Kerosene	Enrichment Cascade	1	9.897E+10
83	Acetone	Enrichment Cascade	1	9.798E+10
84	Ozone	Enrichment Cascade	1	8.165E+10
85	Xylol	Enrichment Cascade	1	7.278E+10
86	Non-Rad. Particulates	Uranium Fuel Fabrication	2	5.718E+10
87	Sulfur Oxides	Mixed Oxide Fabrication	2	2.845E+10
88	Carbon Monoxide	PWR	1	1.593E+10
89	Hydrocarbons	Uranium Fuel Fabrication	2	3.063E+09
90	Sulfur Oxides	Uranium Fuel Fabrication	2	1.634E+09
91	Carbon Monoxide	Uranium Fuel Fabrication	2	3.431E+08
92	Uranium (Enriched)	Mixed Oxide Fabrication	2	5.691E+06

**TABLE B.7. Non-Radioactive Substance Water Dilution
Factors - Stowaway Cycle**

Rank	Species	Plant	Quality	Dilution Factor (%) 100 yr. Total
1	Ammonia	Acid Leach Mill	1	1.225E+16
2	Iron	Acid Leach Mill	1	2.042E+15
3	Manganese	Acid Leach Mill	2	1.225E+15
4	Aluminum	Acid Leach Mill	1	6.127E+14
5	Chloride	Underground Mine	1	4.498E+14
6	Lithium	PWR	2	3.187E+14
7	Ammonia	Underground Mine	1	1.125E+14
8	Sulfate	PWR	2	1.115E+14
9	Ammonia	Enrichment Cascade	2	9.923E+13
10	Phosphorous	Surface Mine	1	9.484E+13
11	Ammonia	Uranium Fuel Fabrication	2	6.609E+13
12	Iron	Aqueous Conversion	2	6.370E+13
13	Ammonia	Surface Mine	1	6.323E+13
14	Sulfide	Acid Leach Mill	2	6.127E+13
15	Sulfate	Acid Leach Mill	1	6.127E+13
16	Chromium	Acid Leach Mill	2	5.515E+13
17	Sulfate	BWR	2	4.023E+13
18	Phosphorous	Uranium Fuel Fabrication	2	3.304E+13
19	Iron	Surface Mine	1	3.161E+13
20	Titanium	Acid Leach Mill	2	2.042E+13
21	Chloride	BWR	2	2.011E+13
22	Uranium	Aqueous Conversion	2	1.911E+13
23	Chloride	Acid Leach Mill	1	1.532E+13
24	Zinc	Acid Leach Mill	2	1.532E+13
25	Titanium	Underground Mine	1	1.499E+13
26	Manganese	Underground Mine	1	1.349E+13
27	Iron	Enrichment Cascade	2	1.323E+13
28	Lead	Acid Leach Mill	2	1.225E+13
29	Chloride	Aqueous Conversion	2	1.147E+13
30	Chlorine	BWR	2	1.006E+13
31	Calcium	BWR	2	1.006E+13
32	Chlorine	PWR	2	9.958E+12
33	Lead	Underground Mine	1	8.996E+12
34	Titanium	Surface Mine	1	7.376E+12
35	Chloride	Enrichment Cascade	2	6.615E+12
36	Zinc	Enrichment Cascade	1	6.615E+12
37	Nickel	Acid Leach Mill	2	6.127E+12
38	Suspended Solids	Underground Mine	1	5.623E+12
39	Sodium	PWR	2	5.577E+12
40	Barium	Aqueous Conversion	2	5.350E+12
41	Nitrate	BWR	2	5.029E+12
42	Fluoride	Acid Leach Mill	1	4.902E+12
43	Uranium	Acid Leach Mill	2	4.596E+12
44	Fluoride	Underground Mine	1	4.498E+12
45	Sodium	Underground Mine	1	4.498E+12
46	Magnesium	BWR	2	4.023E+12
47	Nickel	Enrichment Cascade	2	3.969E+12
48	Fluoride	Uranium Fuel Fabrication	2	3.965E+12
49	Boron	PWR	2	3.187E+12
50	Lead	Surface Mine	1	3.161E+12
51	Molybdenum	Acid Leach Mill	2	3.064E+12
52	Fluoride	Aqueous Conversion	2	3.057E+12
53	Chlorine	Enrichment Cascade	1	2.977E+12
54	Selenium	Underground Mine	1	2.699E+12
55	Sulfate	Underground Mine	1	2.699E+12
56	Nitrate	Underground Mine	1	2.249E+12
57	Tertiary Amine	Acid Leach Mill	2	2.042E+12
58	Molybdenum	Underground Mine	1	2.024E+12
59	Iron	Underground Mine	1	1.499E+12
60	Nitrate	Enrichment Cascade	1	1.323E+12
61	Chromium	Enrichment Cascade	1	1.323E+12
62	Manganese	Enrichment Cascade	1	1.323E+12
63	Silver	Enrichment Cascade	1	1.323E+12
64	Chloride	Uranium Fuel Fabrication	2	1.322E+12
65	Nickel	Uranium Fuel Fabrication	2	1.322E+12

TABLE B.7. (contd)

Rank	Species	Plant	Quality	Dilution Factor (2)	
				100 yr. Total	
66	Fluoride	Surface Mine	1	1.265E+12	
67	Uranium	Underground Mine	1	1.125E+12	
68	Molybdenum	Surface Mine	1	1.106E+12	
69	Magnesium	Acid Leach Mill	2	1.103E+12	
70	Sodium	BWR	2	1.006E+12	
71	Copper	Acid Leach Mill	2	9.191E+11	
72	Silver	Uranium Fuel Fabrication	2	7.930E+11	
73	Zinc	Aqueous Conversion	2	7.643E+11	
74	Aluminum	Underground Mine	1	7.497E+11	
75	Zinc	Underground Mine	1	6.747E+11	
76	Iron	Uranium Fuel Fabrication	2	6.609E+11	
77	Selenium	Surface Mine	1	6.323E+11	
78	Calcium	Uranium Fuel Fabrication	2	5.287E+11	
79	Nitrate	Uranium Fuel Fabrication	2	5.287E+11	
80	Aluminum	Aqueous Conversion	2	5.096E+11	
81	Calcium	Acid Leach Mill	1	4.902E+11	
82	Vanadium	Underground Mine	1	4.498E+11	
83	Aluminum	Surface Mine	1	4.215E+11	
84	Vanadium	Surface Mine	1	3.161E+11	
85	Zinc	Surface Mine	1	3.161E+11	
86	Nitrate	Aqueous Conversion	2	2.675E+11	
87	Fluoride	Enrichment Cascade	1	2.646E+11	
88	Boron	Uranium Fuel Fabrication	2	2.643E+11	
89	Manganese	Uranium Fuel Fabrication	2	2.643E+11	
90	Calcium	Surface Mine	1	2.529E+11	
91	Volatile Amines	PWR	2	2.390E+11	
92	Sulfate	Enrichment Cascade	2	2.381E+11	
93	Uranium	Enrichment Cascade	1	2.315E+11	
94	Copper	Underground Mine	1	2.249E+11	
95	Copper	Aqueous Conversion	2	1.911E+11	
96	Magnesium	Surface Mine	1	1.897E+11	
97	Sodium	Acid Leach Mill	1	1.838E+11	
98	Arsenic	Acid Leach Mill	1	1.838E+11	
99	Magnesium	Underground Mine	1	1.799E+11	
100	Calcium	Underground Mine	1	1.799E+11	
101	Sodium	Aqueous Conversion	2	1.529E+11	
102	Copper	Enrichment Cascade	2	1.323E+11	
103	Cadmium	Enrichment Cascade	2	1.323E+11	
104	Sodium	Enrichment Cascade	2	1.323E+11	
105	Arsenic	Surface Mine	1	1.265E+11	
106	Sulfate	Aqueous Conversion	2	1.223E+11	
107	Calcium	Enrichment Cascade	2	1.191E+11	
108	Arsenic	Underground Mine	1	8.996E+10	
109	Boron	Enrichment Cascade	1	8.820E+10	
110	Sulfate	Uranium Fuel Fabrication	2	7.930E+10	
111	Molybdenum	Enrichment Cascade	1	6.615E+10	
112	Beryllium	Acid Leach Mill	2	6.127E+10	
113	Calcium	Aqueous Conversion	2	5.350E+10	
114	Silver	Acid Leach Mill	2	4.902E+10	
115	Molybdenum	Uranium Fuel Fabrication	2	4.626E+10	
116	Silica	Underground Mine	1	4.498E+10	
117	Aluminum	Enrichment Cascade	1	4.410E+10	
118	Oil and Grease	Uranium Fuel Fabrication	2	4.406E+10	
119	Tributylphosphate	Enrichment Cascade	1	3.969E+10	
120	Varsol	Enrichment Cascade	1	3.969E+10	
121	Sodium	Uranium Fuel Fabrication	2	2.643E+10	
122	Beryllium	Surface Mine	1	2.529E+10	
123	Nitrate	Surface Mine	1	1.581E+10	
124	Vanadium	Acid Leach Mill	1	1.225E+10	
125	Copper	Uranium Fuel Fabrication	1	6.609E+09	
126	Magnesium	Uranium Fuel Fabrication	2	2.379E+09	
127	Sulfite	Uranium Fuel Fabrication	2	1.057E+09	
128	Uranium (Enriched)	Uranium Fuel Fabrication	2	3.304E+08	
129	Magnesium	Enrichment Cascade	1	2.646E+08	
130	Sulfite	Enrichment Cascade	1	2.646E+08	
131	Sulfite	PWR	2	1.115E+08	

TABLE B.8. Non-Radioactive Substance Water Dilution Factors - Reprocessing, No Recycle

Rank	Species	Plant	Quality	Dilution Factor (2) 100 yr. Total
1	Ammonia	Acid Leach Mill	1	1.225E+16
2	Iron	Acid Leach Mill	1	2.042E+15
3	Manganese	Acid Leach Mill	2	1.225E+15
4	Aluminum	Acid Leach Mill	1	6.127E+14
5	Chloride	Underground Mine	1	4.498E+14
6	Lithium	PWR	2	3.187E+14
7	Ammonia	Underground Mine	1	1.125E+14
8	Sulfate	PWR	2	1.115E+14
9	Ammonia	Enrichment Cascade	2	9.923E+13
10	Phosphorous	Surface Mine	1	9.484E+13
11	Ammonia	Uranium Fuel Fabrication	2	6.609E+13
12	Iron	Aqueous Conversion	2	6.370E+13
13	Ammonia	Surface Mine	1	6.323E+13
14	Sulfide	Acid Leach Mill	2	6.127E+13
15	Sulfate	Acid Leach Mill	1	6.127E+13
16	Chromium	Acid Leach Mill	2	5.515E+13
17	Sulfate	BWR	2	4.023E+13
18	Phosphorous	Uranium Fuel Fabrication	2	3.304E+13
19	Iron	Surface Mine	1	3.161E+13
20	Titanium	Acid Leach Mill	2	2.042E+13
21	Chloride	BWR	2	2.011E+13
22	Uranium	Aqueous Conversion	2	1.911E+13
23	Chloride	Acid Leach Mill	1	1.532E+13
24	Zinc	Acid Leach Mill	2	1.532E+13
25	Titanium	Underground Mine	1	1.499E+13
26	Manganese	Underground Mine	1	1.349E+13
27	Iron	Enrichment Cascade	2	1.323E+13
28	Lead	Acid Leach Mill	2	1.225E+13
29	Chloride	Aqueous Conversion	2	1.147E+13
30	Chlorine	BWR	2	1.006E+13
31	Calcium	BWR	2	1.006E+13
32	Chlorine	PWR	2	9.958E+12
33	Lead	Underground Mine	1	8.996E+12
34	Titanium	Surface Mine	1	7.376E+12
35	Chloride	Enrichment Cascade	2	6.615E+12
36	Zinc	Enrichment Cascade	1	6.615E+12
37	Nickel	Acid Leach Mill	2	6.127E+12
38	Suspended Solids	Underground Mine	1	5.623E+12
39	Sodium	PWR	2	5.577E+12
40	Barium	Aqueous Conversion	2	5.350E+12
41	Nitrate	BWR	2	5.029E+12
42	Fluoride	Acid Leach Mill	1	4.902E+12
43	Uranium	Acid Leach Mill	2	4.596E+12
44	Fluoride	Underground Mine	1	4.498E+12
45	Sodium	Underground Mine	1	4.498E+12
46	Magnesium	BWR	2	4.023E+12
47	Nickel	Enrichment Cascade	2	3.969E+12
48	Fluoride	Uranium Fuel Fabrication	2	3.965E+12
49	Boron	PWR	2	3.187E+12
50	Lead	Surface Mine	1	3.161E+12
51	Molybdenum	Acid Leach Mill	2	3.064E+12
52	Fluoride	Aqueous Conversion	2	3.057E+12
53	Chlorine	Enrichment Cascade	1	2.977E+12
54	Selenium	Underground Mine	1	2.699E+12
55	Sulfate	Underground Mine	1	2.699E+12
56	Nitrate	Underground Mine	1	2.249E+12
57	Iron	Reprocessing	2	2.111E+12
58	Tertiary Amine	Acid Leach Mill	2	2.042E+12
59	Molybdenum	Underground Mine	1	2.024E+12
60	Iron	Underground Mine	1	1.499E+12
61	Nitrate	Enrichment Cascade	1	1.323E+12
62	Chromium	Enrichment Cascade	1	1.323E+12
63	Manganese	Enrichment Cascade	1	1.323E+12
64	Silver	Enrichment Cascade	1	1.323E+12
65	Chloride	Uranium Fuel Fabrication	2	1.322E+12

TABLE B.8. (contd)

Rank	Species	Plant	Quality	Dilution Factor (%) 100 yr. Total
66	Nickel	Uranium Fuel Fabrication	2	1.322E+12
67	Fluoride	Surface Mine	1	1.265E+12
68	Uranium	Underground Mine	1	1.125E+12
69	Molybdenum	Surface Mine	1	1.106E+12
70	Magnesium	Acid Leach Mill	1	1.103E+12
71	Sodium	BWR	2	1.006E+12
72	Copper	Acid Leach Mill	2	9.191E+11
73	Silver	Uranium Fuel Fabrication	2	7.930E+11
74	Zinc	Aqueous Conversion	2	7.643E+11
75	Aluminum	Underground Mine	1	7.497E+11
76	Zinc	Underground Mine	1	6.747E+11
77	Iron	Uranium Fuel Fabrication	2	6.609E+11
78	Selenium	Surface Mine	1	6.323E+11
79	Calcium	Uranium Fuel Fabrication	2	5.287E+11
80	Nitrate	Uranium Fuel Fabrication	2	5.287E+11
81	Aluminum	Aqueous Conversion	2	5.096E+11
82	Calcium	Acid Leach Mill	1	4.902E+11
83	Vanadium	Underground Mine	1	4.498E+11
84	Chloride	Reprocessing	1	4.432E+11
85	Aluminum	Surface Mine	1	4.215E+11
86	Vanadium	Surface Mine	1	3.161E+11
87	Zinc	Surface Mine	1	3.161E+11
88	Nitrate	Aqueous Conversion	2	2.675E+11
89	Fluoride	Enrichment Cascade	1	2.646E+11
90	Boron	Uranium Fuel Fabrication	2	2.643E+11
91	Manganese	Uranium Fuel Fabrication	2	2.643E+11
92	Sodium	Reprocessing	1	2.533E+11
93	Calcium	Surface Mine	1	2.529E+11
94	Volatile Amines	PWR	2	2.390E+11
95	Sulfate	Enrichment Cascade	2	2.381E+11
96	Uranium	Enrichment Cascade	2	2.315E+11
97	Copper	Underground Mine	1	2.249E+11
98	Copper	Aqueous Conversion	2	1.911E+11
99	Magnesium	Surface Mine	1	1.897E+11
100	Sodium	Acid Leach Mill	1	1.838E+11
101	Arsenic	Acid Leach Mill	1	1.838E+11
102	Magnesium	Underground Mine	1	1.799E+11
103	Calcium	Underground Mine	1	1.799E+11
104	Sodium	Aqueous Conversion	2	1.529E+11
105	Copper	Enrichment Cascade	2	1.323E+11
106	Cadmium	Enrichment Cascade	2	1.323E+11
107	Sodium	Enrichment Cascade	2	1.323E+11
108	Phosphate-Ortho	Reprocessing	2	1.266E+11
109	Nitrate	Reprocessing	2	1.266E+11
110	Arsenic	Surface Mine	1	1.265E+11
111	Sulfate	Aqueous Conversion	2	1.223E+11
112	Calcium	Enrichment Cascade	2	1.191E+11
113	Arsenic	Underground Mine	1	8.996E+10
114	Boron	Enrichment Cascade	1	8.820E+10
115	Sulfate	Uranium Fuel Fabrication	2	7.930E+10
116	Molybdenum	Enrichment Cascade	1	6.615E+10
117	Beryllium	Acid Leach Mill	2	6.127E+10
118	Calcium	Aqueous Conversion	2	5.350E+10
119	Potassium	Reprocessing	2	5.065E+10
120	Silver	Acid Leach Mill	2	4.902E+10
121	Molybdenum	Uranium Fuel Fabrication	2	4.626E+10
122	Silica	Underground Mine	1	4.498E+10
123	Aluminum	Enrichment Cascade	1	4.410E+10
124	Oil and Grease	Uranium Fuel Fabrication	2	4.406E+10
125	Tributylphosphate	Enrichment Cascade	1	3.969E+10
126	Varsoil	Enrichment Cascade	1	3.969E+10
127	Sodium	Uranium Fuel Fabrication	2	2.643E+10
128	Beryllium	Surface Mine	1	2.529E+10
129	Sulfate	Reprocessing	2	2.026E+10
130	Nitrate	Surface Mine	1	1.581E+10

TABLE B.8. (contd)

<u>Rank</u>	<u>Species</u>	<u>Plant</u>	<u>Quality</u>	<u>Dilution Factor (i)</u> <u>100 yr. Total</u>
131	Vanadium	Acid Leach Mill	1	1.225E+10
132	Copper	Uranium Fuel Fabrication	1	6.609E+09
133	Carbon Dioxide	Reprocessing	2	4.264E+09
134	Calcium	Reprocessing	2	3.799E+09
135	Magnesium	Reprocessing	2	2.533E+09
136	Magnesium	Uranium Fuel Fabrication	2	2.379E+09
137	Sulfite	Uranium Fuel Fabrication	2	1.057E+09
138	Uranium (Enriched)	Uranium Fuel Fabrication	2	3.304E+08
139	Magnesium	Enrichment Cascade	1	2.646E+08
140	Sulfite	Enrichment Cascade	1	2.646E+08
141	Sulfite	Reprocessing	2	2.533E+08
142	Sulfite	PWR	2	1.115E+08

TABLE B.9. Non-Radioactive Substance Water Dilution Factors - Full Recycle

Rank	Species	Plant	Quality	Dilution Factor (2) 100 yr. Total
1	Ammonia	Acid Leach Mill	1	7.725E+15
2	Iron	Acid Leach Mill	1	1.287E+15
3	Manganese	Acid Leach Mill	2	7.725E+14
4	Aluminum	Acid Leach Mill	1	3.862E+14
5	Chloride	Underground Mine	1	3.310E+14
6	Lithium	PWR	2	3.187E+14
7	Sulfate	PWR	2	1.115E+14
8	Ammonia	Enrichment Cascade	2	9.798E+13
9	Ammonia	Underground Mine	1	8.275E+13
10	Iron	Aqueous Conversion	2	5.149E+13
11	Ammonia	Uranium Fuel Fabrication	2	4.901E+13
12	Phosphorous	Surface Mine	1	4.555E+13
13	Sulfate	BWR	2	4.023E+13
14	Sulfide	Acid Leach Mill	2	3.862E+13
15	Sulfate	Acid Leach Mill	1	3.862E+13
16	Chromium	Acid Leach Mill	2	3.476E+13
17	Ammonia	Surface Mine	1	3.037E+13
18	Phosphorous	Uranium Fuel Fabrication	2	2.451E+13
19	Chloride	BWR	2	2.011E+13
20	Uranium	Aqueous Conversion	2	1.545E+13
21	Iron	Surface Mine	1	1.518E+13
22	Iron	Enrichment Cascade	2	1.306E+13
23	Titanium	Acid Leach Mill	2	1.287E+13
24	Titanium	Underground Mine	1	1.103E+13
25	Calcium	BWR	2	1.006E+13
26	Chlorine	BWR	2	1.006E+13
27	Chlorine	PWR	2	9.958E+12
28	Manganese	Underground Mine	1	9.929E+12
29	Chloride	Acid Leach Mill	1	9.656E+12
30	Zinc	Acid Leach Mill	2	9.656E+12
31	Chloride	Aqueous Conversion	2	9.268E+12
32	Lead	Acid Leach Mill	2	7.725E+12
33	Lead	Underground Mine	1	6.620E+12
34	Chloride	Enrichment Cascade	2	6.532E+12
35	Zinc	Enrichment Cascade	1	6.532E+12
36	Sodium	PWR	2	5.577E+12
37	Nitrate	BWR	2	5.029E+12
38	Barium	Aqueous Conversion	2	4.325E+12
39	Suspended Solids	Underground Mine	1	4.137E+12
40	Magnesium	BWR	2	4.023E+12
41	Nickel	Enrichment Cascade	2	3.919E+12
42	Nickel	Acid Leach Mill	2	3.862E+12
43	Titanium	Surface Mine	1	3.543E+12
44	Sodium	Underground Mine	1	3.310E+12
45	Fluoride	Underground Mine	1	3.310E+12
46	Boron	PWR	2	3.187E+12
47	Fluoride	Acid Leach Mill	1	3.090E+12
48	Fluoride	Uranium Fuel Fabrication	2	2.941E+12
49	Chlorine	Enrichment Cascade	1	2.939E+12
50	Uranium	Acid Leach Mill	2	2.897E+12
51	Fluoride	Aqueous Conversion	2	2.472E+12
52	Iron	Reprocessing	2	2.111E+12
53	Sulfate	Underground Mine	1	1.986E+12
54	Selenium	Underground Mine	1	1.986E+12
55	Molybdenum	Acid Leach Mill	2	1.931E+12
56	Nitrate	Underground Mine	1	1.655E+12
57	Lead	Surface Mine	1	1.518E+12
58	Molybdenum	Underground Mine	1	1.489E+12
59	Nitrate	Enrichment Cascade	1	1.306E+12
60	Chromium	Enrichment Cascade	1	1.306E+12
61	Manganese	Enrichment Cascade	1	1.306E+12
62	Silver	Enrichment Cascade	1	1.306E+12
63	Tertiary Amine	Acid Leach Mill	2	1.287E+12
64	Iron	Underground Mine	1	1.103E+12
65	Sodium	BWR	2	1.006E+12

TABLE B.9. (contd)

Rank	Species	Plant	Quality	Dilution Factor (2) 100 yr. Total
66	Chloride	Uranium Fuel Fabrication	2	9.803E+11
67	Nickel	Uranium Fuel Fabrication	2	9.803E+11
68	Uranium	Underground Mine	1	8.275E+11
69	Magnesium	Acid Leach Mill	2	6.952E+11
70	Zinc	Aqueous Conversion	2	6.179E+11
71	Fluoride	Surface Mine	1	6.073E+11
72	Silver	Uranium Fuel Fabrication	2	5.882E+11
73	Copper	Acid Leach Mill	2	5.794E+11
74	Aluminum	Underground Mine	1	5.516E+11
75	Molybdenum	Surface Mine	1	5.314E+11
76	Zinc	Underground Mine	1	4.965E+11
77	Iron	Uranium Fuel Fabrication	2	4.901E+11
78	Chloride	Reprocessing	1	4.432E+11
79	Aluminum	Aqueous Conversion	2	4.119E+11
80	Nitrate	Uranium Fuel Fabrication	2	3.921E+11
81	Calcium	Uranium Fuel Fabrication	2	3.921E+11
82	Vanadium	Underground Mine	1	3.310E+11
83	Calcium	Acid Leach Mill	1	3.090E+11
84	Selenium	Surface Mine	1	3.037E+11
85	Fluoride	Enrichment Cascade	1	2.613E+11
86	Sodium	Reprocessing	1	2.533E+11
87	Volatile Amines	PWR	2	2.390E+11
88	Sulfate	Enrichment Cascade	2	2.351E+11
89	Uranium	Enrichment Cascade	1	2.286E+11
90	Nitrate	Aqueous Conversion	2	2.163E+11
91	Aluminum	Surface Mine	1	2.024E+11
92	Boron	Uranium Fuel Fabrication	2	1.961E+11
93	Manganese	Uranium Fuel Fabrication	2	1.961E+11
94	Copper	Underground Mine	1	1.655E+11
95	Copper	Aqueous Conversion	2	1.545E+11
96	Vanadium	Surface Mine	1	1.518E+11
97	Zinc	Surface Mine	1	1.518E+11
98	Magnesium	Underground Mine	1	1.324E+11
99	Calcium	Underground Mine	1	1.324E+11
100	Sodium	Enrichment Cascade	2	1.306E+11
101	Copper	Enrichment Cascade	2	1.306E+11
102	Cadmium	Enrichment Cascade	2	1.306E+11
103	Phosphate-Ortho	Reprocessing	2	1.266E+11
104	Nitrate	Reprocessing	2	1.266E+11
105	Sodium	Aqueous Conversion	2	1.236E+11
106	Calcium	Surface Mine	1	1.215E+11
107	Calcium	Enrichment Cascade	2	1.176E+11
108	Sodium	Acid Leach Mill	1	1.159E+11
109	Arsenic	Acid Leach Mill	1	1.159E+11
110	Sulfate	Aqueous Conversion	2	9.886E+10
111	Magnesium	Surface Mine	1	9.110E+10
112	Boron	Enrichment Cascade	1	8.709E+10
113	Arsenic	Underground Mine	1	6.620E+10
114	Molybdenum	Enrichment Cascade	1	6.532E+10
115	Arsenic	Surface Mine	1	6.073E+10
116	Sulfate	Uranium Fuel Fabrication	2	5.882E+10
117	Nitrate	Mixed Oxide Fabrication	2	5.122E+10
118	Potassium	Reprocessing	2	5.065E+10
119	Aluminum	Enrichment Cascade	1	4.355E+10
120	Calcium	Aqueous Conversion	2	4.325E+10
121	Tributylphosphate	Enrichment Cascade	1	3.919E+10
122	Varsol	Enrichment Cascade	1	3.919E+10
123	Beryllium	Acid Leach Mill	2	3.862E+10
124	Molybdenum	Uranium Fuel Fabrication	2	3.431E+10
125	Silica	Underground Mine	1	3.310E+10
126	Oil and Grease	Uranium Fuel Fabrication	2	3.268E+10
127	Silver	Acid Leach Mill	2	3.090E+10
128	Sulfate	Reprocessing	2	2.026E+10
129	Sodium	Uranium Fuel Fabrication	2	1.961E+10
130	Beryllium	Surface Mine	1	1.215E+10

TABLE B.9. (contd)

Rank	Species	Plant	Quality	Dilution Factor (%)	
				100 yr. Total	
131	Vanadium	Acid Leach Mill	1	7.725E+09	
132	Nitrate	Surface Mine	1	7.591E+09	
133	Copper	Uranium Fuel Fabrication	1	4.901E+09	
134	Carbon Dioxide	Reprocessing	2	4.264E+09	
135	Calcium	Reprocessing	2	3.799E+09	
136	Magnesium	Reprocessing	2	2.533E+09	
137	Magnesium	Uranium Fuel Fabrication	2	1.765E+09	
138	Sulfite	Uranium Fuel Fabrication	2	7.842E+08	
139	Chloride	Mixed Oxide Fabrication	2	3.414E+08	
140	Sodium	Mixed Oxide Fabrication	2	3.414E+08	
141	Magnesium	Enrichment Cascade	1	2.613E+08	
142	Sulfite	Enrichment Cascade	1	2.613E+08	
143	Sulfite	Reprocessing	2	2.533E+08	
144	Uranium (Enriched)	Uranium Fuel Fabrication	2	2.451E+08	
145	Sulfite	PWR	2	1.115E+08	
146	Sulfate	Mixed Oxide Fabrication	2	4.780E+07	
147	Uranium (Enriched)	Mixed Oxide Fabrication	1	1.707E+05	

APPENDIX C

UNIT ACCUMULATED POPULATION DOSE FACTORS - MIDWESTERN SITE

APPENDIX C

UNIT ACCUMULATED POPULATION DOSE FACTORS - MIDWESTERN SITE

Accumulated population dose factors (APDs) are calculated to determine the total savings in population dose (in man-rem) and the cost-benefit ratios (in \$/man-rem of population dose saved) resulting from the effluent control technologies considered. The tables in this appendix contain the APDs calculated for a release of 1 Ci/year of each of the radionuclides of concern for a 40-year plant life with 30 years of dose commitment and exposure to environmental residuals. The resulting APDs are 70-year accumulated doses that should account correctly for population dose from radionuclides released from operating nuclear facilities. All facilities are assumed to be located on the midwestern site, with a total of 3.5×10^6 people residing within an 80 km radius of the plant site. Exposure pathways considered for atmospheric releases include: external (from air submersion or deposited ground contamination) and internal (from ingestion of farm products, and inhalation). Exposure pathways considered for liquid releases include: external (from liquids or sediments during swimming, boating, or shoreline activities and from irrigated farm land) and internal (from ingestion of irrigated farm products, ingestion of drinking water, and ingestion of aqueous food products).

The APDs included in each table are listed below:

Table

- C.1. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of Atmospheric Releases for 40 Years - External Exposure
- C.2. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of Atmospheric Releases for 40 Years - Ingestion
- C.3. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of Atmospheric Releases for 40-Years - Inhalation

- C.4. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of Atmospheric Releases for 40 Years - Total of All Atmospheric Exposure Pathways
- C.5. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of Liquid Releases for 40 Years - External Exposure
- C.6. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of Liquid Releases for 40 Years - Ingestion of Irrigated Foods
- C.7. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of Liquid Releases for 40 Years - Total of All Liquid Exposure Pathways

TABLE C.1. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of Releases for 40 Years^(a) - External Exposure^(b)

Radionuclide	Population Dose to Organs of Reference (man-rem)				
	Total Body	GI-Tract	Thyroid	Bone	Lung
^3H	--(c)	--	--	--	--
^{14}C	--	--	--	--	--
^{60}Co	1.3E+3	1.3E+3	1.3E+3	1.3E+3	1.3E+3
^{85}Kr	1.5E-3	1.5E-3	1.5E-3	1.5E-3	1.5E-3
$^{90}\text{Sr}+\text{D}^{(d)}$	--	--	--	--	--
$^{131}\text{I}+\text{D}$	--	--	--	--	--
^{134}Cs	3.7E+2	3.7E+2	3.7E+2	3.7E+2	3.7E+2
^{136}Cs	8.0E+0	8.0E+0	8.0E+0	8.0E+0	8.0E+0
$^{137}\text{Cs}+\text{D}$	1.3E+3	1.3E+3	1.3E+3	1.3E+3	1.3E+3
$^{232}\text{U}+\text{D}$	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0
^{238}Pu	5.5E-1	5.5E-1	5.5E-1	5.5E-1	5.5E-1
$^{244}\text{Cm}+\text{D}$	6.6E-1	6.6E-1	6.6E-1	6.6E-1	6.6E-1

(a) The 70-year accumulation period assumes a 40-year plant life and 30 years of exposure to environmental residuals.

(b) External exposure is the sum of exposure to ground contamination and air submersion.

(c) Two dashes indicate a value less than 1.0E-3.

(d) The notation +D indicates that the contribution from short-lived daughters is included in the values shown.

TABLE C.2. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of Atmospheric Release for 40 Years^(a) - Ingestion^(b)

Radionuclide	Population Dose to Organs of Reference (man-rem)				
	Total Body	GI-Tract	Thyroid	Bone	Lung
^3H	2.3E-1	2.3E-1	2.3E-1	-- ^(c)	2.3E-1
^{14}C	2.8E+1	2.8E+1	2.3E+1	1.4E+2	2.8E+1
^{60}Co	9.6E+0	--	--	--	--
^{85}Kr	--	--	--	--	--
$^{90}\text{Sr}+\text{D}^{(6)}$	2.1E+4	--	--	7.9E+4	--
$^{131}\text{I}+\text{D}$	2.6E+1	1.3E+1	1.5E+4	3.1E+1	--
^{134}Cs	3.9E+2	--	--	2.0E+2	4.8E+1
$^{136}\text{Cs}+\text{D}$	1.7E+1	--	--	6.0E+2	8.5E+1
$^{137}\text{Cs}+\text{D}$	2.6E+2	--	--	2.9E+2	4.6E+1
$^{232}\text{U}+\text{D}$	6.7E+2	--	--	9.3E+3	--
^{238}Pu	3.1E+1	1.5E+2	--	6.4E+2	--
$^{244}\text{Cm}+\text{D}$	5.6E+1	--	--	1.3E+3	--

(a) The 70-year accumulation period assumes a 40-year plant life and 30 years of exposure to environmental residuals.

(b) Ingestion of farm products raised within 80 km of the site for a fraction of the total diet.

(c) Two dashes indicate a value less than $1.0\text{E}-3$.

(d) The notation +D indicates that the contribution from short-lived daughters is included in the values shown.

TABLE C.3. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of Atmospheric Releases for 40 Years^(a) - Inhalation^(b)

Radionuclide	Population Dose to Organs of Reference (man-rem)				
	Total Body	GI-Tract	Thyroid	Bone	Lung
³ H	9.3E-2	--(c)	9.3E-2	--	9.3E-2
¹⁴ C	2.1E-1	9.6E-2	2.1E-1	1.1E+0	2.1E-1
⁶⁰ Co	5.0E+0	2.2E+0	--	--	5.8E+0
⁸⁵ Kr	--	--	--	--	--
⁹⁰ Sr+D ^(d)	2.0E+3	1.0E+0	--	8.1E+3	3.6E+0
¹³¹ I+D	1.3E+0	8.4E-2	6.9E+2	1.3E+0	2.3E+0
¹³⁴ Cs	4.3E+1	1.3E-1	--	1.8E+1	1.0E+1
¹³⁶ Cs	2.9E+0	8.2E-2	--	1.3E+0	3.1E+0
¹³⁷ Cs+D	2.6E+1	1.2E-1	--	3.0E+1	8.0E+0
²³² U+D	1.3E+3	2.4E+1	--	1.8E+4	1.6E+6
²³⁸ Pu	2.1E+4	2.5E+1	--	4.4E+5	4.8E+5
²⁴⁴ Cm+D	1.0E+4	2.6E+1	--	2.4E+5	4.8E+5

- (a) The 70-year accumulation period assumes a 40-year plant life and 30 years of exposure to environmental residuals.
- (b) Inhalation of the average air concentration for 40 years with no resuspension of residuals.
- (c) Two dashes indicate a value less than 1.0E-3.
- (d) The notation +D indicates that the contribution from short-lived daughters is included in the values shown.

TABLE C.4. 70-Year Accumulation Population Dose Factors for 1 Ci/yr of Atmospheric Releases for 40 Years^(a) - Total of All Atmospheric Exposure Pathways^(b)

Radionuclide	Population Dose to Organs of Reference (man-rem)				
	Total Body	GI-Tract	Thyroid	Bone	Lung
³ H	3.2E-1	2.3E-1	3.2E-1	-- ^(c)	3.2E-1
¹⁴ C	2.8E+1	2.8E+1	2.8E+1	1.4E+2	2.8E+1
⁶⁰ Co	1.3E+3	1.3E+3	1.3E+3	1.3E+3	1.3E+3
⁸⁵ Kr	1.5E-3	1.5E-3	1.5E-3	1.5E-3	1.5E-3
⁹⁰ Sr+D ^(d)	2.3E+4	1.0E+0	--	8.7E+4	3.6E+0
¹³¹ I+D	2.7E+1	1.3E+1	1.5E+4	3.2E+1	2.3E+0
¹³⁴ Cs	8.0E+2	3.7E+2	3.7E+2	5.9E+2	4.3E+2
¹³⁶ Cs	2.8E+1	8.0E+0	8.0E+0	1.5E+1	1.2E+1
¹³⁷ Cs+D	1.6E+3	1.3E+3	1.3E+3	1.6E+3	1.3E+3
²³² U+D	2.0E+3	2.5E+1	1.0E+0	2.7E+4	1.6E+6
²³⁸ Pu	2.1E+4	1.8E+2	5.5E-1	4.4E+5	4.8E+5
²⁴⁴ Cm+D	1.0E+4	2.6E+1	6.6E-1	2.4E+5	4.8E+5

(a) The 70-year accumulation period assumes a 40-year plant life and 30 years of exposure to environmental residuals.

(b) The totals listed are the sum of external, ingestion, and inhalation pathways.

(c) Two dashes indicate a value less than 1.0E-3.

(d) The notation +D indicates that the contribution from short-lived daughters is included in the values shown.

TABLE C.5. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of of Liquid Releases for 40 Years^(a) - External Exposure^(b)

Radionuclide	Population Dose to Organs of Reference (man-rem)				
	Total Body	GI-Tract	Thyroid	Bone	Lung
³ H	--(c)	--	--	--	--
¹⁴ C	--	--	--	--	--
⁶⁰ Co	1.6E+3	1.6E+3	1.6E+3	1.6E+3	1.6E+3
⁸⁵ Kr	--	--	--	--	--
⁹⁰ Sr+D ^(d)	--	--	--	--	--
¹³¹ I+D	--	--	--	--	--
¹³⁴ Cs	4.3E+2	4.3E+2	4.3E+2	4.3E+2	4.3E+2
¹³⁶ Cs	9.5E+0	9.5E+0	9.5E+0	9.5E+0	9.5E+0
¹³⁷ Cs+D	1.5E+3	1.5E+3	1.5E+3	1.5E+3	1.5E+3
²³² U+D	1.3E+0	1.3E+0	1.3E+0	1.3E+0	1.3E+0
²³⁸ Pu	6.5E-1	6.5E-1	6.5E-1	6.5E-1	6.5E-1
²⁴⁴ Cm+D	7.8E-1	7.8E-1	7.8E-1	7.8E-1	7.8E-1

(a) The 70-year accumulation period assumes a 40-year plant life and 30 years of exposure to environmental residuals.

(b) External exposure is from irrigated farm lands and swimming, boating, fishing, and shoreline activities.

(c) Two dashes indicate a value less than 1.0E-3.

(d) The notation +D indicates that the contribution from short-lived daughters is included in the values shown.

TABLE C.6. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of Liquid Releases for 40 Years^(a) - Ingestion^(b)

Radionuclide	Population Dose to Organs of Reference (man-rem)				
	Total Body	GI-Tract	Thyroid	Bone	Lung
³ H	3.1E-2	3.1E-2	3.1E-2	-- ^(c)	3.1E-2
¹⁴ C	1.1E+3	1.1E+3	1.1E+3	5.3E+3	1.1E+3
⁶⁰ Co	3.0E+0	--	--	--	--
⁸⁵ Kr	--	--	--	--	--
⁹⁰ Sr+D ^(d)	4.5E+3	--	--	1.7E+4	--
¹³¹ I+D	1.4E+0	7.3E-1	8.1E+2	1.7E+0	--
¹³⁴ Cs	9.2E+2	--	--	4.7E+2	1.1E+2
¹³⁶ Cs	1.2E+2	--	--	4.4E+1	6.2E+0
¹³⁷ Cs+D	5.5E+2	--	--	6.1E+2	9.6E+1
²³² U+D	2.0E+2	--	--	2.8E+3	--
²³⁸ Pu	9.9E+0	4.7E+1	--	2.0E+2	--
²⁴⁴ Cm+D	1.9E+1	--	--	4.6E+2	--

(a) The 70-year accumulation period assumes a 40-year plant life and 30 years of exposure to environmental residuals.

(b) Ingestion of farm products raised on irrigated land and aqueous food products within 80 μ m of the site for a fraction of the diet.

(c) Two dashes indicate a value less than 1.0E-3.

(d) The notation +D indicates that the contribution from short-lived daughters is included in the values shown.

TABLE C.7. 70-Year Accumulated Population Dose Factors for 1 Ci/yr of Liquid Releases for 40 Years^(a) - Total for All Liquid Exposure Pathways^(b)

Radionuclide	Population Dose to Organs of Reference (man-rem)				
	Total Body	GI-Tract	Thyroid	Bone	Lung
³ H	3.1E-2	3.1E-2	3.1E-2	-- ^(c)	3.1E-2
¹⁴ C	1.1E+3	1.1E+3	1.1E+3	5.3E+3	1.1E+3
⁶⁰ Co	1.6E+3	1.6E+3	1.6E+3	1.6E+3	1.6E+3
⁸⁵ Kr	--	--	--	--	--
⁹⁰ Sr+D ^(d)	4.5E+3	6.8E-6	6.8E-6	1.7E+4	--
¹³¹ I+D	1.4E+0	7.3E-1	8.1E+2	1.7E+0	--
¹³⁴ Cs	1.4E+3	4.3E+2	4.3E+2	9.0E+2	5.4E+2
¹³⁶ Cs	1.3E+2	9.5E+0	9.5E+0	5.4E+1	1.6E+1
¹³⁷ Cs+D	2.0E+3	1.5E+3	1.5E+3	2.1E+3	1.5E+3
²³² U+D	2.0E+2	1.3E+0	1.3E+0	2.8E+3	1.3E+0
²³⁸ Pu	1.0E+1	4.8E+1	6.5E-1	2.0E+2	6.5E-1
²⁴⁴ Cm+D	2.0E+1	7.8E-1	7.8E-1	4.6E+2	7.8E-1

(a) The 70-year accumulation period assumes a 40-year plant life and 30 years of exposure to environmental residuals.

(b) The totals listed are the sum of external and ingestion pathways.

(c) Two dashes indicate a value less than 1.0E-3.

(d) The notation +D indicates that the contribution from short-lived daughters are included in the values shown.

TABLE A.6. (contd)

Plant	Nuclide	Release Factor		Relative Ranking Factors				
		Air	Water	Total Body	GI Tract	Thyroid	Bone	Lung
PWR	Nb-95	3.00E-13	3.00E-11	1.48E-01	8.35E+02	7.25E-02	3.24E-01	2.59E-01
	Mo-99	2.00E-09	4.00E-08	1.25E+02	1.99E+03	1.88E+01	1.88E+01	2.68E+02
	Tc-99M	2.00E-09		2.84E+00	1.27E+01	2.84E+00	2.84E+00	4.64E+00
	Ru-103	3.00E-13	8.00E-12	4.29E-02	1.23E+00	3.85E-02	4.89E-02	2.07E-01
	Ru-106	1.00E-13	3.00E-12	2.83E-02	2.34E+00	2.34E-02	6.22E-02	5.37E-01
	Ag-110M		2.00E-09	1.22E-01	8.84E+00	1.09E-01	1.32E-01	1.09E-01
	Te-125M	6.00E-11	1.00E-09	3.09E-02	9.23E-01	6.89E-02	2.29E-01	5.94E-02
	Te-127	8.00E-11	1.00E-09	4.12E-03	1.77E+00	1.39E-02	1.87E-02	3.44E-02
	Te-127M	1.00E-10	3.00E-09	1.09E+00	3.02E+01	2.29E+00	8.98E+00	1.37E+00
	Te-129M	2.00E-10	4.00E-09	9.00E+00	2.83E+02	1.93E+01	5.57E+01	1.22E+01
	Te-131	1.00E-11	5.00E-11	1.61E-02	1.62E-02	1.61E-02	1.61E-02	2.56E-02
	Te-131M	1.00E-10	2.00E-09	1.77E+00	1.89E+02	3.15E+00	3.99E+00	1.92E+00
	Te-132	2.00E-10	3.00E-09	6.91E+01	3.54E+03	8.11E+01	1.13E+02	6.25E+01
	I-130	1.00E-10	3.00E-09	2.26E-01	2.61E-01	8.56E+00	2.20E-01	1.87E+01
	I-131	7.00E-10	4.00E-08	7.98E+02	4.15E+02	4.06E+05	9.57E+02	8.96E+01
	I-132	2.00E-10	3.00E-09	6.66E+00	6.49E+00	3.15E+01	6.66E+00	6.40E+00
	I-133	4.00E-10	2.00E-08	3.90E+01	7.96E+01	1.07E+04	5.87E+01	1.67E+01
	I-134	5.00E-11	4.00E-11	1.70E+00	1.65E+00	4.07E+00	1.70E+00	1.65E+00
	I-135	3.00E-10	3.00E-09	1.50E+01	1.63E+01	2.02E+02	1.51E+01	1.40E+01
	Xe-131M	1.00E-03		1.67E+02	1.67E+02	1.67E+02	1.67E+02	2.36E+02
	Xe-133	8.00E-05		2.74E+04	2.74E+04	2.74E+04	2.74E+04	2.89E+04
	Xe-133M	2.00E-05		1.79E+02	1.79E+02	1.79E+02	1.79E+02	1.89E+02
	Xe-135	1.00E-06		8.46E+02	8.46E+02	8.46E+02	8.46E+02	8.61E+02
	Xe-135M	4.00E-08		2.98E+01	2.98E+01	2.98E+01	2.98E+01	3.00E+01
	Xe-137	7.00E-09		1.30E+00	1.30E+00	1.30E+00	1.30E+00	2.65E+00
	Xe-138	4.00E-08		8.60E+02	8.60E+02	8.60E+02	8.60E+02	8.72E+02
	Cs-134	2.00E-10	2.00E-08	4.24E+04	1.26E+03	3.55E+02	2.21E+04	5.89E+03
	Cs-136	2.00E-09	3.00E-08	2.58E+03	4.24E+02	2.05E+01	9.23E+01	2.92E+02
	Cs-137	6.00E-10	3.00E-08	1.76E+04	1.12E+03	6.15E+02	1.95E+04	3.54E+03
	Ba-140	1.00E-12	2.00E-11	1.74E-01	4.72E+00	2.96E-02	2.22E+00	1.66E+00
	La-140	7.00E-13	2.00E-11	4.38E-02	5.23E+00	4.38E-02	4.42E-02	1.69E-01
	Ce-141	4.00E-13	8.00E-12	7.69E-03	1.37E+00	6.91E-03	1.72E-02	1.84E-01
	Ce-143	2.00E-13	3.00E-12	1.15E-03	2.19E-01	1.15E-03	1.19E-03	1.83E-02
	Ce-144	2.00E-13	9.00E-11	8.39E-02	9.35E+01	3.43E-02	9.59E-01	1.50E+00
	Pr-143	3.00E-13	7.00E-12	1.68E-04	1.52E+00	3.91E-06	3.33E-03	9.00E-02
	Pr-144	2.00E-13	5.00E-12	2.97E-05	2.97E-05	2.97E-05	2.97E-05	2.23E-04
	Np-239	5.00E-13	8.00E-12	2.44E-02	7.11E+00	2.43E-02	2.64E-02	3.24E-01
BWR	H-3	7.00E-03	1.00E-03	8.45E+03	8.45E+03	8.45E+03	0.	8.45E+03
	C-14	3.00E-01		1.35E+04	1.35E+04	1.35E+04	6.73E+04	1.35E+04
	Na-24		5.00E-05	4.92E-02	4.92E-02	4.92E-02	4.92E-02	4.92E-02
	P-32		2.00E-06	2.93E-01	8.54E-01	2.21E-06	7.58E+00	2.21E-06
	Cr-51	3.00E-06	2.00E-07	1.24E+00	4.15E+00	1.23E+00	1.21E+00	5.21E+00
	Mn-54	3.00E-05	7.00E-08	1.10E+02	1.40E+02	1.08E+02	1.08E+02	2.31E+02
	Mn-56		2.00E-07	2.32E-05	1.67E-03	1.40E-05	1.40E-05	1.40E-05
	Fe-55		2.00E-07	1.72E-02	4.22E-02	3.02E-08	1.07E-01	4.10E-02
	Fe-59	2.00E-05	8.00E-08	7.28E+00	2.14E+01	5.73E+00	7.45E+00	2.97E+01
	Co-58	1.00E-06	3.00E-08	8.34E+00	1.52E+01	7.72E+00	7.72E+00	2.83E+01
	Co-60	1.00E-03	6.00E-06	3.55E+03	3.75E+03	3.53E+03	3.53E+03	4.62E+03
	Ni-65		6.00E-08	2.75E-08	6.97E-07	1.52E-08	2.22E-07	1.52E-08
	Cu-64		2.00E-06	1.75E-03	2.10E-01	5.98E-04	5.98E-04	5.98E-04
	Zn-65	5.00E-03	7.00E-05	4.03E+01	4.67E+01	2.31E+01	3.50E+01	5.31E+01
	Br-83		5.00E-11	5.84E-07	8.39E-07	2.28E-09	2.28E-09	2.28E-09
	Br-84		2.00E-12	2.92E-18	1.12E-18	1.12E-18	1.12E-18	1.12E-18
	Kr-83M	1.00E-06		2.13E-03	2.13E-03	2.13E-03	2.13E-03	8.28E-02
	Kr-85	1.00E-03		8.85E+01	8.85E+01	8.85E+01	8.85E+01	1.69E+02
	Kr-85M	3.00E-05		2.29E+03	2.29E+03	2.29E+03	2.29E+03	2.33E+03
	Kr-87	4.00E-05		5.42E+04	5.42E+04	5.42E+04	5.42E+04	5.48E+04
	Kr-88	3.00E-05		1.02E+05	1.02E+05	1.02E+05	1.02E+05	1.03E+05
	Kr-89	1.00E-07		5.74E+01	5.74E+01	5.74E+01	5.74E+01	6.11E+01
	Rb-89		2.00E-12	3.27E-32	7.73E-33	7.73E-33	7.73E-33	7.73E-33
	Sr-89	6.00E-10	2.00E-12	2.17E+01	1.65E+02	5.62E-03	7.57E+02	1.99E+02
	Sr-90	2.00E-11		1.42E+02	1.67E+01	1.33E-06	6.23E+02	5.56E+00
	Sr-91		2.00E-11	6.81E-04	4.62E-02	2.89E-04	9.98E-03	2.89E-04
	Sr-92		1.00E-11	3.11E-06	3.11E-04	2.44E-06	1.80E-05	2.44E-06

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