Descriptions of Reference LWR Facilities for Analysis of Nuclear Fuel Cycles Appendixes

K. J. Schneider
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September 1979

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DESCRIPTIONS OF REFERENCE LWR FACILITIES
FOR ANALYSIS OF NUCLEAR FUEL CYCLES

APPENDIXES

K. J. Schneider, Study Coordinator
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Pacific Northwest Laboratory
Richland, Washington 99352

DESCRIPTIONS OF REFERENCE LWR FACILITIES FOR ANALYSIS OF NUCLEAR FUEL CYCLES

APPENDIXES

The appendixes present the calculations that were used to derive the release factors discussed for each fuel cycle facility in Volume I. Appendix A presents release factor calculations for a surface mine, underground mine, milling facility, conversion facility, diffusion enrichment facility, fuel fabrication facility, PWR, BWR and reprocessing facility. Appendix B contains additional release factors calculated for a BWR, PWR and a reprocessing facility. Appendix C presents release factors for a UO_2 fuel fabrication facility.

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EFFLUENT RELEASE FACTORS: A

APPENDIX A

DERIVATIONS OF EFFLUENT RELEASE FACTORS FOR THE REFERENCE FUEL CYCLE FACILITIES

T. B. Powers

Appendix A consists of ten sections, each pertaining to a separate facility of the nuclear fuel cycle. Two summary tables at the beginning of each section tabulate results of subsequent release factor calculations, as well as index the specific release factor calculations. One of the summary tables deals with chemical release factors and the other deals with radionuclide release factors.

Both tables include a column indicating the reliability of the release factor given. A reliability rating of 1, 2, or 3 was assigned based on the following assumptions:

1. A reasonable but unsubstantiated guess
2. Calculated or based on laboratory measurement
3. Based on some plant experience

The release factor calculations follow the summary tables. Release factors for mining, milling, purification and conversion, and fuel fabrication are the result of kilograms effluent per day as the numerator and kilograms of contained uranium input per day to the facility as the denominator; for diffusion enrichment, kilograms per day of product are used as the denominator. Chemical release factors for BWR, PWR and reprocessing are the result of kilograms effluent per day as the numerator and kilograms of contained uranium charged to the reactor as the denominator. Radioactive release factors for BWR, PWR or reprocessing use the total kilograms of the radioactive element or radioisotope processed each day for the denominator. This is done because the ENFORM code has the capability of following changes in isotopic content with time.

As an example of how to use Appendix A, suppose you want to find the release factor for rock dust as an airborne effluent in the surface mine.

- Find the surface mine section and look in the chemical release factor summary table to find the heading "rock dust."
- Under the airborne column you find the release factor is given (7×10^{-1}) as well as a reliability factor (1) and a reference calculation index number (1-6).
- If you want to see how the release factor was actually calculated, you find the reference calculation index number for "rock dust" (1-6) on the following pages of calculations.

Reference numbers given in the release factor calculations can be found in the reference list at the end of Appendix A.

CONTENTS

SURFACE MINE CHEMICAL RELEASE FACTORS	A.5
SURFACE MINE RADIONUCLIDE RELEASE FACTORS	A.7
REFERENCE CALCULATIONS: SURFACE MINE	A.8
UNDERGROUND MINE CHEMICAL RELEASE FACTORS	A.13
UNDERGROUND MINE RADIONUCLIDE RELEASE FACTORS.	A.15
REFERENCE CALCULATIONS: UNDERGROUND MINE	A.16
ACID LEACH MILL CHEMICAL RELEASE FACTORS	A.22
ACID LEACH MILL RADIONUCLIDE RELEASE FACTORS	A.24
REFERENCE CALCULATIONS: MILLING FACILITY	A.25
CONVERSION FACILITY CHEMICAL RELEASE FACTORS	A.35
CONVERSION FACILITY RADIONUCLIDE RELEASE FACTORS	A.36
REFERENCE CALCULATIONS: CONVERSION FACILITY	A.37
DIFFUSION ENRICHMENT CHEMICAL RELEASE FACTORS.	A.43
DIFFUSION ENRICHMENT RADIONUCLIDE RELEASE FACTORS	A.46
REFERENCE CALCULATIONS: DIFFUSION ENRICHMENT FACILITY	A.47
UO ₂ FUEL FABRICATION CHEMICAL RELEASE FACTORS	A.58
UO ₂ FUEL FABRICATION RADIONUCLIDE RELEASE FACTORS	A.60
REFERENCE CALCULATIONS: UO ₂ FUEL FABRICATION FACILITY	A.61
MOX FUEL FABRICATION CHEMICAL RELEASE FACTORS	A.68
MOX FUEL FABRICATION RADIONUCLIDE RELEASE FACTORS	A.69
REFERENCE CALCULATIONS: MOX FUEL FABRICATION FACILITY	A.70
PWR REACTOR CHEMICAL RELEASE FACTOR	A.77
PWR REACTOR RADIONUCLIDE RELEASE FACTORS	A.80
REFERENCE CALCULATIONS: PWR REACTOR	A.85

BWR REACTOR CHEMICAL RELEASE FACTORS	.	.	.	.	.	.	A.109
BWR REACTOR RADIONUCLIDE RELEASE FACTORS.	.	.	.	.	.	.	A.110
REFERENCE CALCULATIONS: BWR REACTOR	.	.	.	.	.	.	A.115
REPROCESSING CHEMICAL RELEASE FACTORS	.	.	.	.	.	.	A.133
REPROCESSING RADIONUCLIDE RELEASE FACTORS	.	.	.	.	.	.	A.135
REFERENCE CALCULATIONS: REPROCESSING	.	.	.	.	.	.	A.138
REFERENCES	.	.	.	.	.	.	A.160

SURFACE MINE CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)

F-4-14-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium (natural)	3.9×10^{-5}	2	1-1			
Thorium - 230						
Radium - 226	1.35×10^{-10}	2	1-2			
Radon - 222	2.5×10^{-11}	2	1-3			
Radon Daughters:						
Polonium - 218	1.4×10^{-14}	2	1-4			
Lead - 214	1.2×10^{-13}	2	1-4			
Bismuth - 214	9.1×10^{-14}	2	1-4			
Polonium - 214	1.3×10^{-20}	2	1-4			
Lead - 210						
Polonium - 210						
Carbon Monoxide (CO)	4×10^{-2}	2	1-5			
Nitrogen Oxides (NO_x)	3×10^{-2}	2	1-5			
Sulfur Oxides (SO_x)	1×10^{-2}	2	1-5			
Aldehydes	3×10^{-3}	2	1-5			
Nonradioactive						
Particulate	1×10^{-2}	2	1-5			
Hydrocarbons	1×10^{-2}	2	1-5			
Rock Dust	9×10^{-2}	1	1-6			
Vanadium (V)						
Selenium (Se)						

SURFACE MINE (Cont'd) CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)

F-4-14-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Molybdenum (Mo)						
Arsenic (As)						
Suspended Solids						
Chloride (Cl)						
Nitrate (NO ₃)						
Sulfate (SO ₄)						
Rock						

SURFACE MINE RADIONUCLIDE RELEASE FACTOR Kg/Kg U (INPUT)

F 4-14-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium (natural)	3.9×10^{-5}	2				
*Uranium - 238	3.87×10^{-5}	2	1-7			
*Uranium - 235	2.77×10^{-7}	2	1-7			
*Uranium - 234	2.11×10^{-9}	2	1-7			
*Thorium - 230						
*Radium - 226	1.35×10^{-11}	2	1-2			
*Radon - 222	2.5×10^{-11}	2	1-3			
Radon Daughters:						
Polonium - 218	1.4×10^{-14}	1	1-4			
Lead - 214	1.2×10^{-13}	1	1-4			
Bismuth - 214	9.1×10^{-14}	1	1-4			
Polonium - 214	1.3×10^{-20}	1	1-4			
*Lead - 210						
*Polonium - 210						

*Has Data Base In Computer Model

REFERENCE CALCULATIONS: SURFACE MINE (312 Operating Day/yr)

1-1. Uranium dust

from Rock dust calculations, 1-6, and ore grade of 0.0015% U in ore, 0.000085% U in waste rock

$$\begin{array}{ccc} \text{mining} & \text{crushing} & \text{waste rock} \\ (111 \times 0.0015) + (30 \times 0.0015) + (457 \times 0.000085) \end{array}$$

$$= \frac{0.25 \text{ kg}}{6350 \text{ kg/day}} = 3.9 \times 10^{-5} \frac{\text{Kg U dust}}{\text{Kg U}}$$

1-2. Radium 226

radium in equilibrium with U content

$$= 3.42 \times 10^{-7} \text{ fraction of U content}$$

$$3.42 \times 10^{-7} \times 0.25 \frac{\text{kg}}{\text{day}} \text{ from 1-1} = 8.555 \text{ E-08 } \frac{\text{kg}}{\text{day}}$$

$$\text{Release factor} = \frac{8.555 \text{ E-08}}{6350} = 1.35 \times 10^{-11} \frac{\text{kg Ra226}}{\text{Kg U}}$$

1-3. Rn-222 Surface mine (Ref. 35 p. 10)

$$1961 \frac{\text{Ci}}{\text{yr}} \times \frac{\text{yr}}{330 \text{ day}} \times \frac{\text{d}}{1722 \text{ tons}} \times \frac{\text{ton}}{0.00115 \text{ ton U}_3\text{O}_8}$$

$$\times \frac{\text{ton}}{0.9072 \text{ MT}} \times \frac{\text{t U}_3\text{O}_8}{0.848 \text{ ton U}} \times \frac{6.5 \times 10^{-6} \text{ g Rn222}}{\text{Ci Rn222}}$$

$$\times \frac{\text{kg}}{10^3 \text{ g}} \times \frac{\text{MTU}}{10^3 \text{ kg U}}$$

$$= 2.535 \times 10^{-11} \frac{\text{kg Rn222}}{\text{Kg U}}$$

REFERENCE CALCULATIONS: Surface Mine (contd)

- 1-4. Assuming secular equilibrium exists between radon-222 and its shorter half-lived daughters then the daughter products vary inversely as the ratio of the radon-222 decay constant and the daughter product decay constant.

(from ref. calc. 1-3)

$$2.54 \times 10^{-11} \frac{\text{kg}^{222}\text{Rn}}{\text{kg U}} \times \frac{2.10 \times 10^{-6} (\lambda^{222}\text{Rn})}{3.79 \times 10^{-3} (\lambda^{218}\text{Po})} = 1.41 \times 10^{-14} \frac{\text{kg}^{218}\text{Po}}{\text{kg U (input)}}$$

(from ref. cal. 1-3)

$$2.54 \times 10^{-11} \frac{\text{kg}^{222}\text{Rn}}{\text{kg U}} \times \frac{2.10 \times 10^{-6} (\lambda^{222}\text{Rn})}{4.31 \times 10^{-4} (\lambda^{214}\text{Pb})} = 1.24 \times 10^{-13} \frac{\text{kg}^{214}\text{Pb}}{\text{kg U (input)}}$$

(from ref. calc. 1-3)

$$2.54 \times 10^{-11} \frac{\text{kg}^{222}\text{Rn}}{\text{kg U}} \times \frac{2.10 \times 10^{-6} (\lambda^{222}\text{Rn})}{5.86 \times 10^{-4} (\lambda^{214}\text{Bi})} = 9.10 \times 10^{-14} \frac{\text{kg}^{214}\text{Bi}}{\text{kg U (input)}}$$

(from ref. calc. 1-3)

$$2.54 \times 10^{-11} \frac{\text{kg}^{222}\text{Rn}}{\text{kg U}} \times \frac{2.10 \times 10^{-6} (\lambda^{222}\text{Rn})}{4.23 \times 10^{-3} (\lambda^{214}\text{Po})} = 1.26 \times 10^{-20} \frac{\text{kg}^{214}\text{Po}}{\text{kg U (input)}}$$

REFERENCE CALCULATIONS: SURFACE MINE (contd)

1-5. Basis for the following numbers is 6500 gallons of diesel fuel per day at the reference surface mine and EPA emission factors, (1, pp. 3.2.7-2, 3). Mine throughput is 6350 kgU/day.

$$\text{CO} \quad \frac{85 \text{ lb}}{10^3 \text{ gal}} \times 6.5 \times 10^3 \frac{\text{gal}}{\text{day}} \times \frac{\text{kg}}{2.2 \text{ lb}} \times \frac{1 \text{ day}}{6350 \text{ kgU}} = 4.0 \text{ E-2}$$

$$\text{NO}_x \quad \frac{55 \text{ lb}}{10^3 \text{ gal}} \times 6.5 \times 10^3 \frac{\text{gal}}{\text{day}} \times \frac{\text{kg}}{2.2 \text{ lb}} \times \frac{1 \text{ day}}{6350 \text{ kgU}} = 2.6 \text{ E-2}$$

$$\text{SO}_x \quad \frac{31.2 \text{ lb}}{10^3 \text{ gal}} \times 6.5 \times 10^3 \frac{\text{gal}}{\text{day}} \times \frac{\text{kg}}{2.2 \text{ lb}} \times \frac{1 \text{ day}}{6350 \text{ kgU}} = 1.45 \text{ E-2}$$

$$\text{Aldehydes} \quad \frac{6.8 \text{ lb}}{10^3 \text{ gal}} \times 6.5 \times 10^3 \frac{\text{gal}}{\text{day}} \times \frac{\text{kg}}{2.2 \text{ lb}} \times \frac{1 \text{ day}}{6350 \text{ kgU}} = 3.2 \text{ E-3}$$

$$\text{Particulate} \quad \frac{25 \text{ lb}}{10^3 \text{ gal}} \times 6.5 \times 10^3 \frac{\text{gal}}{\text{day}} \times \frac{\text{kg}}{2.2 \text{ lb}} \times \frac{1 \text{ day}}{6350 \text{ kgU}} = 1.2 \text{ E-2}$$

$$\text{Hydrocarbon} \quad \frac{30 \text{ lb}}{10^3 \text{ gal}} \times 6.5 \times 10^3 \frac{\text{gal}}{\text{day}} \times \frac{\text{kg}}{2.2 \text{ lb}} \times \frac{1 \text{ day}}{6350 \text{ kgU}} = 1.4 \text{ E-2}$$

1-6. Rock Dust

Mining (34, p. 57 Table 21)

$$750 \frac{\text{pCi}}{\text{sec}} \times \frac{2337}{3000} \times \frac{0.0025}{0.0015} \times \frac{2.97\text{E}+6 \text{ g U}}{10^{12} \text{ pCi}} \times \frac{\text{g dust}}{0.0015 \text{ g U}} \times \frac{\text{kg}}{10^3 \text{ g}} \times \frac{8.64\text{E}+4 \text{ sec}}{\text{day}}$$

production rate grade gram to curie
ratio ratio conversion

REFERENCE CALCULATIONS: SURFACE MINE (contd)

$$\frac{16 \text{ hr}}{\frac{\text{day}}{24 \text{ hr}}} = 111 \frac{\text{kg}}{\text{day}}$$

$$\frac{111 \frac{\text{kg}}{\text{day}}}{6350 \frac{\text{kg U}}{\text{day}}} = 1.75 \text{ E-2 } \frac{\text{kg}}{\text{kg U}}$$

(34, p. 29)

$$\text{blasting} = 0.95\% \quad 111 = 105 \frac{\text{kg}}{\text{day}} = 1.65 \text{ E-2 } \frac{\text{kg}}{\text{kg U}}$$

$$\text{haulage} = 0.05\% \quad 111 = 6 \frac{\text{kg}}{\text{day}} = 9.45 \text{ E-4 } \frac{\text{kg}}{\text{kg U}}$$

Crushing (primary only)

primary crushing contributes about 2% of the fine dust from primary, secondary and tertiary crushing (1, p. 8.20-1). For conservatism, assume 5% is from primary crushing.

(1, p. 8.20-1) (34, p. 57 Table 21)

$$0.05 \times 4044 \frac{\text{pCi}}{\text{sec}} \times \frac{2337}{3000} \times \frac{0.25\%}{0.15\%} \times \frac{2.97 \text{ E+6 g U}}{10^{12} \text{ pCi}}$$

production ratio grade ratio

$$\times \frac{\text{g dust}}{0.0015 \text{ g U}} \times \frac{\text{kg}}{10^3 \text{ g}} \times 8.64 \text{ E+4 } \frac{\text{sec}}{\text{day}} \times \frac{16 \text{ hr}}{24 \text{ hr}} = 30 \frac{\text{kg}}{\text{day}}$$

$$\frac{30 \frac{\text{kg dust}}{\text{day}}}{6350 \frac{\text{kg U}}{\text{day}}} = 4.7 \text{ E-3 } \frac{\text{kg dust}}{\text{kg U}}$$

REFERENCE CALCULATIONS: SURFACE MINE (contd)

Waste Rock Pile

assume wind speed = 16 km/hr = 4.4 m/sec (p. 5-19, site description).

(34, p. 57 Table 22, interpolated) tails 0.01% U_3O_8

$$9.0 \times 10^{-4} \frac{\text{g U}}{\text{sec}} \times \frac{\text{g dust}}{0.000085 \text{ g U}} \times 86,400 \frac{\text{sec}}{\text{day}} \times \frac{\text{kg}}{10^3 \text{ g}} \times \frac{1}{2} = 457 \frac{\text{kg}}{\text{day}}$$

(size of waste rock pile average over mine life)

$$\frac{457 \frac{\text{kg}}{\text{day}}}{6350 \frac{\text{kg U}}{\text{day}}} = 7.20 \times 10^{-2} \frac{\text{kg dust}}{\text{kg U}}$$

$$\text{Total release factor} = \frac{111 \text{ kg} + 30 \text{ kg} + 457 \text{ kg}}{6350 \text{ kg U}} = 9.4 \times 10^{-2} \frac{\text{kg rock dust}}{\text{kg U}}$$

1-7. (from ref. calc. 1-1) (4, p. B-35)

$$3.9 \times 10^{-5} \frac{\text{kg U in dust}}{\text{kg U (input)}} \times 99.2830 \text{ wt\% } ^{238}\text{U in natural U} = 3.87 \times 10^{-5} \frac{\text{kg } ^{238}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 1-1) (4, p. B-35)

$$3.9 \times 10^{-5} \frac{\text{kg U in dust}}{\text{kg U (input)}} \times 0.7110\% \text{ } ^{235}\text{U in natural U} = 2.77 \times 10^{-7} \frac{\text{kg } ^{235}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 1-1) (4, p. B-35)

$$3.9 \times 10^{-5} \frac{\text{kg U in dust}}{\text{kg U (input)}} \times 0.0054\% \text{ } ^{234}\text{U in natural U} = 2.11 \times 10^{-9} \frac{\text{kg } ^{234}\text{U}}{\text{kg U (input)}}$$

UNDERGROUND MINE CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)

F-4-14-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium (natural)	1×10^{-5}	1	2-1	1×10^{-4}	1	2-11
Thorium - 230						
Radium - 226	4×10^{-11}	2	2-2	9×10^{-12}	1	2-12
Radon - 222	1.4×10^{-10}	2	2-3			
Radon Daughters:						
Polonium - 218	2×10^{-13}	1	2-4			
Lead - 214	2×10^{-12}	1	2-4			
Bismuth - 214	1×10^{-12}	1	2-4			
Polonium - 214	2×10^{-19}	1	2-4			
Lead - 210						
Polonium - 210						
Carbon Monoxide (CO)	7×10^{-3}	1	2-5			
Nitrogen Oxides (NO _x)	1×10^{-2}	1	2-5			
Sulfur Oxides (SO _x)	7×10^{-3}	1	2-5			
Aldehydes	8×10^{-4}	1	2-5			
Nonradioactive						
Particulate	6×10^{-3}	1	2-5			
Hydrocarbons	4×10^{-3}	1	2-5			
Zinc (5, table 1) (Zn)						
Lead (5, table 1) (Pb)						

UNDERGROUND MINE (Cont'd) CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT) F-4-14-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Sulfur (5, table 1)						
Beryllium (5, table 1) (Be)						
Cadmium (5, table 1) (Ca)						
Rock Dust	4×10^{-2}	2	2-6			
Vanadium (V)				8×10^{-4}	1	2-8
Selenium (Se)				6×10^{-5}	1	2-9
Molybdenum (Mo)						
Arsenic (As)						
Suspended Solids				5×10^{-2}	1	2-10
Chloride (Cl)						
Nitrate (NO ₃)						
Sulfates (SO ₄)						
Rock						

UNDERGROUND MINE RADIONUCLIDE RELEASE FACTOR Kg/Kg U (INPUT)

F-4-14-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium (natural)	1.15×10^{-5}	2				
*Uranium - 238	1.14×10^{-5}	2	2-13	1.36×10^{-4}	1	2-14
*Uranium - 235	8.18×10^{-8}	2	2-13	9.74×10^{-7}	1	2-14
*Uranium - 234	6.21×10^{-10}	2	2-13	7.40×10^{-9}	1	2-14
*Thorium - 230						
*Radium - 226	4×10^{-12}	2	2-2	9×10^{-12}	1	2-12
*Radon - 222	1.4×10^{-10}	2	2-3			
*Radon Daughters:						
Polonium - 218	7.8×10^{-14}	1	2-4			
Lead - 214	6.9×10^{-13}	1	2-4			
Bismuth - 214	5×10^{-13}	1	2-4			
Polonium - 214	7×10^{-20}	1	2-4			
*Lead - 210						
*Polonium - 210						

*Has Data Base In Computer Model

A.16

2-1. Uranium Dust

from Rock dust calculations, 2-6. and grade assumption: 0.15% U in ore;
0.0085% U in waste rock

$$(6 \times 0.0015) + (30 \times 0.0015) + (229 \times 0.000085)$$

$$\frac{0.073 \text{ kg U}}{6350 \text{ kg U}} = 1.15 \times 10^{-5} \frac{\text{kg U dust}}{\text{kg U}}$$

2-2. Radium 226

radium in equilibrium with natural uranium = 3.42×10^{-7} fraction of U content

$$0.073 \frac{\text{kg U}}{\text{kg U}} \times 3.42 \times 10^{-7} = 2.50 \times 10^{-8} \frac{\text{kg Ra}}{\text{kg U}} \frac{226}{226}$$

$$\frac{2.50 \times 10^{-7}}{6350} \text{ kg} = 3.9 \times 10^{-12} \frac{\text{kg Ra226}}{\text{kg U}}$$

2-3. Radium 222 (36, p. 19)

$$\left(15.9 \frac{Ci}{\text{ton } U_{308}} + 0.8 \frac{Ci}{\text{ton } U_{308}}\right) \times \frac{t}{0.9072 \text{ MT}}$$

from vents above ground
sources

$$\times \frac{\text{ton U}_3\text{O}_8}{0.848 \text{ ton U}} \times \frac{6.5 \times 10^{-6} \text{ g Rn 222}}{\text{Ci Rn 222}} \times \frac{\text{kg}}{10^3 \text{ g}} \times \frac{\text{MT}}{10^3 \text{ kg}} = 1.41 \times 10^{-10} \frac{\text{kg Rn 222}}{\text{kg U}}$$

2-4. Assuming secular equilibrium exists between radon-222 and its shorter half-lived daughters then the daughter products vary inversely as the ratio of the radon-222 decay constant and the daughter product decay constant. (from ref. calc. 2-3)

REFERENCE CALCULATIONS: UNDERGROUND MINE (contd)

$$1.41 \times 10^{-10} \frac{\text{kg } ^{222}\text{Rn}}{\text{kg U}} \times \frac{2.10 \times 10^{-6} (\lambda - ^{222}\text{Rn})}{3.79 \times 10^{-3} (\lambda - ^{218}\text{Po})} = 7.78 \times 10^{-14} \frac{\text{kg } ^{218}\text{Po}}{\text{kg U (input)}}$$

$$1.41 \times 10^{-10} \frac{\text{kg } ^{222}\text{Rn}}{\text{kg U}} \times \frac{2.10 \times 10^{-6} (\lambda - ^{222}\text{Rn})}{4.31 \times 10^{-4} (\lambda - ^{214}\text{Pb})} = 6.85 \times 10^{-13} \frac{\text{kg } ^{214}\text{Pb}}{\text{kg U (input)}}$$

$$1.41 \times 10^{-10} \frac{\text{kg } ^{222}\text{Rn}}{\text{kg U}} \times \frac{2.10 \times 10^{-6} (\lambda - ^{222}\text{Rn})}{5.86 \times 10^{-4} (\lambda - ^{214}\text{Bi})} = 5.04 \times 10^{-13} \frac{\text{kg } ^{214}\text{Bi}}{\text{kg U (input)}}$$

$$1.41 \times 10^{-10} \frac{\text{kg } ^{222}\text{Ra}}{\text{kg U}} \times \frac{2.10 \times 10^{-6} (\lambda - ^{222}\text{Rn})}{4.23 \times 10^{-3} (\lambda - ^{214}\text{Po})} = 7.00 \times 10^{-20} \frac{\text{kg } ^{214}\text{Po}}{\text{kg U (input)}}$$

A.17

2-5. The release factors for combustion products from diesel exhaust are taken as half the quantity from the surface mine plus the assumption that catalytic exhaust purities are used (37).

(37, p. 5) CO $\frac{251}{2} \text{ kg} \times 0.35 = 44 \frac{\text{kg}}{\text{day}}$ RF = $\frac{44}{6350} = 6.9 \times 10^{-3}$

NO_x $\frac{163}{2} \text{ kg} \times 0.35 = 82 \frac{\text{kg}}{\text{day}}$ RF = $\frac{82}{6350} = 1.3 \times 10^{-2}$

SO_x $\frac{92}{2} \text{ kg} \times 0.35 = 46 \frac{\text{kg}}{\text{day}}$ RF = $\frac{46}{6350} = 7.2 \times 10^{-3}$

(37, p. 8) Aldehydes $\frac{20}{2} \text{ kg} \times 0.5 = 5 \frac{\text{kg}}{\text{day}}$ RF = $\frac{5}{6350} = 7.9 \times 10^{-4}$

Particulate $\frac{74}{2} \text{ kg} \times 0.5 = 37 \frac{\text{kg}}{\text{day}}$ RF = $\frac{37}{6350} = 5.8 \times 10^{-3}$

(37, p. 5) Hydrocarbon $\frac{87}{2} \text{ kg} \times 0.6 = 26 \frac{\text{kg}}{\text{day}}$ RF = $\frac{26}{6350} = 4.1 \times 10^{-3}$

REFERENCE CALCULATIONS: UNDERGROUND MINE (contd)

2-6. Rock dust

(from calculation 1-6, with no contribution from blasting and only 1/2 as much waste rock)

hauling	crushing	Waste rock
$6 \frac{\text{kg}}{\text{day}}$	$30 \frac{\text{kg}}{\text{day}}$	$229 \frac{\text{kg}}{\text{day}}$

$$\frac{265 \text{ kg Rock dust}}{6350 \text{ kg U}} = 4.17 \text{ E-2 } \frac{\text{kg Rock Dust}}{\text{kg U}}$$

2-7. Kerr-McGee Ambrosia Lake mines (sections 19, 30W, 35, 36) are assumed to be the only mines in the reference facility that discharge water to the environment (3, p. 23). Of this water only 25% is assumed to be discharged to surface water (no real basis for this number - arbitrary) following ion exchange at the mines.

(for mines 19, 30W, 35, 36; 3, p. 22)

(see above) (assumed to surface water)

$$(1.36 + 0.15 + 3.77 + 2.07 + 0.14) \times \frac{10^6 \text{ gals}}{\text{day}} \times 25\% = 1.87 \times \frac{10^6 \text{ gal}}{\text{day}}$$

(average of values for mines
19, 30W, 35, 36; 3, p.22)

(from ref. calc. 2-7)

$$2-8. \left(\frac{0.7 + 0.6 + 0.8 + 0.9 + 0.6}{5} \right) \frac{\text{mg V}}{\text{liter}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times 1.87 \times 10^6 \frac{\text{gal}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 5.10 \frac{\text{kg V}}{\text{day}}$$

$$\therefore \frac{5.10 \text{ kg V/day}}{6351 \text{ kg U/day}} = 8.03 \times 10^{-4} \frac{\text{kg V}}{\text{kg U (input)}}$$

2-9. Assumed an average concentration for Se at 0.05 mg/liter after referring to (3, p.22).

(see above)

(from ref. calc. 2-7)

$$0.05 \frac{\text{mg Se}}{\text{liter}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times 1.87 \times 10^6 \frac{\text{gal}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 3.54 \times 10^{-1} \frac{\text{kg Se}}{\text{day}}$$

REFERENCE CALCULATIONS: UNDERGROUND MINE (contd)

$$\therefore \frac{3.54 \times 10^{-1} \text{ kg Se/day}}{6351 \text{ kg U/day}} = \frac{5.57 \times 10^{-5} \text{ kg Se}}{\text{kg U (input)}}$$

(average of values for mines
19, 30W, 35, 36; 3, p.22)

$$2-10. \left(\frac{22 + 16 + 100 + 38 + 29}{5} \right) \frac{\text{mg suspended solids}}{\text{liter}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times$$

(from ref. calc. 2-7)

$$1.87 \times 10^6 \frac{\text{gal}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 2.90 \times 10^2 \frac{\text{kg suspended solids}}{\text{day}}$$

$$\therefore \frac{2.90 \times 10^2 \text{ kg suspended solids/day}}{6351 \text{ kg U/day}} = \frac{4.57 \times 10^{-2} \text{ kg suspended solids}}{\text{kg U (input)}}$$

A.19

4-18-77

2-11. Assuming that uranium recovery of the ion exchange treatment of groundwater and surface water is 98% efficient then the following is the calculation of the amount of uranium in the surface water discharge.

(average of values for mines
19, 30W, 35, 36; 3, p.22)

(from ref. calc. 2-7)

$$\left(\frac{6.2 + 0.23 + 19 + 3.0 + 2.4}{5} \right) \frac{\text{mg U}}{\text{liter}} \times \frac{3.785 \text{ liters}}{\text{gal}} \times 1.87 \times 10^6 \frac{\text{gal}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} \times$$

(amount remaining after
ion exchange, see above)
2%

$$= 8.73 \times 10^{-1} \frac{\text{kg U}}{\text{day}}$$

$$\therefore \frac{8.73 \times 10^{-1} \text{ kg U/day}}{6351 \text{ kg U/day}} = \frac{1.37 \times 10^{-4} \text{ kg U}}{\text{kg U (input)}}$$

REFERENCE CALCULATIONS: UNDERGROUND MINE (contd)

(average of values for mines 19, 30W, 35, 36; 3, p.22) (from ref. calc. 2-7)

$$2-12. \left(\frac{163 + 9.3 + 51 + 131 + 65}{5} \right) \times \frac{10^{-12} \text{ Ci}}{\text{liter}} \times \frac{3.785 \text{ liters}}{\text{gal}} \times 1.87 \times 10^6 \frac{\text{gal}}{\text{day}} \times \frac{\text{g}}{.99 \text{ Ci}} \times \frac{\text{kg}}{10^3 \text{ g}} \times$$

(assumed amount of ^{226}Ra released after barium chloride treatment)

$$\downarrow$$

$$10\% = 6.00 \times 10^{-8} \frac{\text{kg } ^{226}\text{Ra}}{\text{day}} \therefore \frac{6.00 \times 10^{-8} \text{ kg } ^{226}\text{Ra/day}}{6351 \text{ kg U/day}} = 9.45 \times 10^{-12} \frac{\text{kg } ^{226}\text{Ra}}{\text{kg U (input)}}$$

(from ref. calc. 2-1) (4, p. B-35)

$$2-13. 1.15 \times 10^{-5} \frac{\text{kg U dust}}{\text{kg U (input)}} \times 99.2830\% \text{ } ^{238}\text{U in nat'l U} = 1.14 \times 10^{-5} \frac{\text{kg } ^{238}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 2-1) (4, p. B-35)

$$1.15 \times 10^{-5} \frac{\text{kg U dust}}{\text{kg U (input)}} \times 0.7110\% \text{ } ^{235}\text{U in nat'l U} = 8.18 \times 10^{-8} \frac{\text{kg } ^{235}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 2-1) (4, p. B-35)

$$1.15 \times 10^{-5} \frac{\text{kg U dust}}{\text{kg U (input)}} \times 0.0054\% \text{ } ^{234}\text{U in nat'l U} = 6.21 \times 10^{-10} \frac{\text{kg } ^{234}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 2-11) (4, p. B-35)

$$2-14. 1.37 \times 10^{-4} \frac{\text{kg U}}{\text{kg U (input)}} \times 99.2830\% \text{ } ^{238}\text{U in nat'l U} = 1.36 \times 10^{-4} \frac{\text{kg } ^{238}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 2-11) (4, p. B-35)

$$1.37 \times 10^{-4} \frac{\text{kg U}}{\text{kg U (input)}} \times 0.7110\% \text{ } ^{235}\text{U in nat'l U} = 9.74 \times 10^{-7} \frac{\text{kg } ^{235}\text{U}}{\text{kg U (input)}}$$

REFERENCE CALCULATIONS: UNDERGROUND MINE (contd)

$$\begin{array}{l}
 \text{(from ref. calc. 2-11)} \quad \text{(4, p. B-35)} \\
 1.37 \times 10^{-4} \frac{\text{kg U}}{\text{kg U (input)}} \times 0.0054\% \text{ } ^{234}\text{U in nat'l U} = 7.40 \times 10^{-9} \frac{\text{kg } ^{234}\text{U}}{\text{kg U (input)}}
 \end{array}$$

ACID LEACH MILL CHEMICAL RELEASE FACTOR ^{Kg/Kg U (INPUT)}

F-4-19-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium (natural)	2.5×10^{-4}	3	3-1	3×10^{-4}	2	3-2
Thorium - 230	3×10^{-11}	3	3-3	2×10^{-7}	2	3-4
Radium - 226	5.4×10^{-13}	3	3-5	6×10^{-11}	2	3-6
Radon - 222	1.3×10^{-12}	3	3-7			
Radon Daughters:						
Lead - 210						
Polonium - 210						
Rock Dust	3×10^{-3}	2	3-8			
Sulfuric Acid (H_2SO_4)						
Sulfur Oxides (SO_x)	2×10^{-4}	2	3-9			
Arsine (AsH_3)						
Stibine (SbH_3)						
Hydrogen Sulfide (H_2S)						
Kerosene	2×10^{-4}	2	3-10			
Amine						
Isodecanol						
Ammonia (NH_3)	$*2 \times 10^{-3}$ just from boilers	2	3-28	8×10^{-2}	1	3-19
Nonradionactive						
Particulate	8×10^{-4}	2	3-11			
Nitrogen Oxides (NO_x)	2×10^{-2}	2	3-12			
Hydrocarbons	3×10^{-3}	2	3-13			
Organic Acids	5×10^{-3}	2	3-14			
Aldehydes	8×10^{-4}	2	3-15			

* ; Data Base in Computer Model

ACID LEACH MILL (Cont'd) CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)

F-4-19-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Calcium (Ca)				8×10^{-2}	1	3-16
Iron (Fe)				2×10^{-1}	1	3-17
Aluminum (AL)				3×10^{-1}	1	3-18
Sodium (Na)				3×10^{-2}	1	3-20
Arsenic (As)				3×10^{-5}	1	2-21
Fluoride (F)				8×10^{-4}	1	3-22
Vanadium (V)				2×10^{-5}	1	3-23
Sulfate (SO ₄)				5	1	3-24
Chloride (Cl)				5×10^{-2}	1	3-25
Nitrates (NO ₃)						
Copper (Cu)						
Beryllium (Be)						
Manganese (Mn)						
Magnesium (Mg)						
Lead (Pb)						
Boron (B)						

ACID LEACH MILL RADIONUCLIDE RELEASE FACTOR Kg/Kg U (INPUT)

F-4-19-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium (natural)						
*Uranium - 238	2.46×10^{-4}	3	3-26	3.02×10^{-4}	2	3-27
*Uranium - 235	1.76×10^{-6}	3	3-26	2.16×10^{-6}	2	3-27
*Uranium - 234	1.36×10^{-8}	3	3-26	1.64×10^{-8}	2	3-27
*Thorium - 230	3.0×10^{-11}	3	3-3	2×10^{-7}	2	3-4
*Radium - 226	5.4×10^{-13}	3	3-5	6×10^{-11}	2	3-6
*Radon - 222	1.3×10^{-12}	3	3-7			
Radon Daughters:						
*Lead - 210						
*Polonium - 210						

*Has Data Base In Computer Model

REFERENCE CALCULATIONS: MILLING FACILITY (365 Operating Days/Yr)

3-1. U input to the milling facility:

$$\frac{2000 \text{ short tons ore}}{\text{day}} \times \frac{907.2 \text{ kg}}{\text{short ton}} \times 0.0015 \text{ U in ore} = 2722 \frac{\text{kg U}}{\text{day}}$$

U output from the milling facility: (38, p. 5-11)

Crusher	2.37 $\mu\text{Ci/day}$
Fine ore bin	0.12
Leach	0.71
Ore sampling	0.10
Yellow cake dryer	226
	<hr/>
	229. $\mu\text{Ci/da}$

$$229 \frac{\mu\text{Ci}}{\text{da}} \times 2.95 \times 10^6 \frac{\text{g}}{\text{Ci}} \times \frac{\text{Ci}}{10^6 \mu\text{Ci}} \times \frac{\text{kg}}{10^3 \text{ g}} = 0.68 \frac{\text{kg}}{\text{da}}$$

$$\text{RF} = \frac{0.68 \text{ kg}}{2722 \text{ kg}} = 2.48 \times 10^{-4} \frac{\text{kg U}}{\text{kg U input}}$$

REFERENCE CALCULATIONS: Milling Facility (cont'd)

$$3-2. \quad \begin{array}{ccccccc} \text{(from ref.} & & \text{(amount of U} & & \text{(fraction of soluble U} & & \text{(ratio of assumed flow out} \\ \text{calc. 3-1)} & & \text{assumed soluble)} & & \text{assumed to go to tailings)} & & \text{over flow into pond)} \\ 2722 \frac{\text{kg U}}{\text{day}} \times .95 & \times & .2\% & \times & \frac{80 \text{ gal/min}}{500 \text{ gal/min}} & = \end{array}$$

$$8.27 \times 10^{-1} \frac{\text{kg U}}{\text{day}} \text{ (loss due to seepage)}$$

$$\therefore \frac{8.27 \times 10^{-1} \text{ kg U/day}}{2722 \text{ kg U/day}} = 3.04 \times 10^{-4} \frac{\text{kg U}}{\text{kg U (input)}}$$

3-3. Thorium-230 (38, p. 5-13)

$$1.63 \frac{\mu\text{Ci}}{\text{day}} \times \frac{49.6 \text{ g Th-230}}{\text{Ci Th-230}} \times \frac{\text{Ci}}{10^6 \mu\text{Ci}} \times \frac{\text{kg}}{10^3 \text{ g}} = 8.08 \times 10^{-8} \frac{\text{kg}}{\text{day}}$$

$$\frac{8.08 \times 10^{-8} \frac{\text{kg}}{\text{day}}}{2722 \frac{\text{kg U}}{\text{day}}} = 2.97 \times 10^{-11} \frac{\text{kg Th-230}}{\text{kg U}}$$

REFERENCE CALCULATIONS: Milling Facility (cont'd)

3-4. (7, p. 97) (6, p. 31)

$$\frac{80 \text{ gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3785 \text{ ml}}{\text{gal}} \times 2.2 \times 10^{-5} \frac{\mu\text{Ci}}{\text{ml}} \times \frac{\text{Ci}}{10^6 \mu\text{Ci}} \times \frac{\text{g } ^{230}\text{Th}}{1.95 \times 10^{-2} \text{ Ci}} \times \frac{\text{kg}}{10^3 \text{ g}} =$$

$$4.92 \times 10^{-4} \frac{\text{kg } ^{230}\text{Th}}{\text{day}} \therefore \frac{4.92 \times 10^{-4} \text{ kg } ^{230}\text{Th/day}}{2722 \text{ kg U/day}} = 1.81 \times 10^{-7} \frac{\text{kg } ^{230}\text{Th}}{\text{kg U (input)}}$$

3-5. Radium-226 (38, p. 5-12)

$$1.45 \frac{\mu\text{Ci}}{\text{day}} \times \frac{1.01 \text{ g Ra-226}}{\text{Ci Ra-226}} \times \frac{\text{Ci}}{10^6 \mu\text{Ci}} \times \frac{\text{kg}}{10^3 \text{ g}} = 1.46 \times 10^{-9} \frac{\text{kg}}{\text{day}}$$

$$\frac{1.46 \times 10^{-9} \frac{\text{kg}}{\text{day}}}{2722 \frac{\text{kg U}}{\text{day}}} \times 5.38 \times 10^{-13} \frac{\text{kg Ra-226}}{\text{kg U}}$$

REFERENCE CALCULATIONS: Milling Facility (cont'd)

$$\begin{aligned}
 & \text{3-6. } \overset{(7, \text{ p. } 97)}{80 \frac{\text{gal}}{\text{min}}} \times \frac{1440 \text{ min}}{\text{day}} \times 3785 \frac{\text{ml}}{\text{gal}} \times \overset{(6, \text{ p. } 31)}{3.5 \times 10^{-7} \frac{\mu\text{Ci}}{\text{ml}}} \times \frac{\text{Ci}}{10^6 \mu\text{Ci}} \times \frac{\text{g } ^{226}\text{Ra}}{0.99 \text{ Ci}} \times \frac{\text{kg}}{10^3 \text{ g}} = \\
 & 1.54 \times 10^{-7} \frac{\text{kg } ^{226}\text{Ra}}{\text{day}} \quad \therefore \quad \frac{1.54 \times 10^{-7} \text{ kg } ^{226}\text{Ra/day}}{2722 \text{ kg U/day}} = 5.66 \times 10^{-11} \frac{\text{kg } ^{226}\text{Ra}}{\text{kg U (input)}}
 \end{aligned}$$

4-19-77

3-7. Radon-222 (38, p. 5-14)

$$5.46 \times 10^5 \frac{\mu\text{Ci}}{\text{day}} \times \frac{6.46 \times 10^{-6} \text{ g}}{\text{Ci}} \times \frac{\text{Ci}}{10^6 \mu\text{Ci}} \times \frac{\text{kg}}{10^3 \text{ g}} = 3.53 \times 10^{-9}$$

$$\text{RF} = \frac{3.53 \times 10^{-9} \text{ kg Rn } ^{222}}{2722 \text{ kg U}} = 1.3 \times 10^{-12} \frac{\text{kg Rn } ^{222}}{\text{kg U}}$$

REFERENCE CALCULATIONS: Milling Facility (cont'd)

3-8 Rock dust (39)

Particulate emissions; 3-year average (1975-77)

Crusher	7.1×10^3 grams/day
Fine Orebin	1.5×10^2
Leach	6.9×10^1
Sample Room	2.7×10^2
Yellowcake Dryer	7.6×10^2
TOTAL	8.4×10^3 grams/day

$$8.4 \times 10^3 \frac{\text{grams}}{\text{day}} \times \frac{\text{kg}}{10^3 \text{ gr}} = 8.4 \text{ kg/day}$$

$$\text{RF} = \frac{8.4}{2722} \frac{\text{kg particulate}}{\text{kg U}} = 3.09 \times 10^{-3} \frac{\text{kg particulate}}{\text{kg U}}$$

A.29

(6, p.41)

$$3-9. [285 \text{ (leaching)} + 175 \text{ (boilers)}] \frac{\text{lbs SO}_2}{\text{yr}} \times \frac{.4536 \text{ kg}}{\text{lb}} \times \frac{\text{yr}}{365 \text{ days}} = 5.72 \times 10^{-1} \frac{\text{kg SO}_2}{\text{day}}$$

$$\frac{5.72 \times 10^{-1} \text{ kg SO}_2/\text{day}}{2722 \text{ kg U/day}} = \frac{2.10 \times 10^{-4} \text{ kg SO}_2}{\text{kg U (input)}}$$

REFERENCE CALCULATIONS: Milling Facility (cont'd)

$$3-10. \quad 365 \frac{\text{lbs kerosene}}{\text{yr}} \times \frac{.4536 \text{ kg}}{1 \text{ lb}} \times \frac{\text{yr}}{365 \text{ days}} = 4.54 \times 10^{-1} \frac{\text{kg kerosene}}{\text{day}}$$

$$\therefore \frac{4.54 \times 10^{-1} \text{ kg kerosene/day}}{2722 \text{ kg U/day}} = 1.67 \times 10^{-4} \frac{\text{kg kerosene}}{\text{kg U (input)}}$$

$$3-11. \quad 1750 \frac{\text{lbs particulate (from boilers)}}{\text{yr}} \times \frac{.4536 \text{ kg}}{1 \text{ lb}} \times \frac{\text{yr}}{365 \text{ days}} = 2.17 \frac{\text{kg particulate}}{\text{day}}$$

$$\therefore \frac{2.17 \text{ kg particulate/day}}{2722 \text{ kg U/day}} = 7.97 \times 10^{-4} \frac{\text{kg particulate}}{\text{kg U (input)}}$$

$$3-12. \quad 35,000 \frac{\text{lbs NO}_x}{\text{yr}} \times \frac{.4536 \text{ kg}}{1 \text{ lb}} \times \frac{\text{yr}}{365 \text{ days}} = 4.35 \times 10^1 \frac{\text{kg NO}_x}{\text{day}}$$

$$\therefore \frac{4.35 \times 10^1 \text{ kg NO}_x/\text{day}}{2722 \text{ kg U/day}} = 1.60 \times 10^{-2} \frac{\text{kg NO}_x}{\text{kg U (input)}}$$

$$3-13. \quad 7,000 \frac{\text{lbs hydrocarbons}}{\text{yr}} \times \frac{.4536 \text{ kg}}{1 \text{ lb}} \times \frac{\text{yr}}{365 \text{ days}} = 8.70 \frac{\text{kg hydrocarbons}}{\text{day}}$$

REFERENCE CALCULATIONS: Milling Facility (cont'd)

$$\therefore \frac{8.70 \text{ kg hydrocarbons/day}}{2722 \text{ kg U/day}} = 3.20 \times 10^{-3} \frac{\text{kg hydrocarbons}}{\text{kg U (input)}}$$

(6, p. 41)

$$3-14. \frac{10,500 \text{ lbs organic acids}}{\text{yr}} \times \frac{.4536 \text{ kg}}{1 \text{ lb}} \times \frac{\text{yr}}{365 \text{ days}} = 1.30 \times 10^1 \frac{\text{kg org. acids}}{\text{day}}$$

$$\therefore \frac{1.30 \times 10^1 \text{ kg organic acids/day}}{2722 \text{ kg U/day}} = 4.78 \times 10^{-3} \frac{\text{kg organic acids}}{\text{kg U (input)}}$$

(6, p. 41)

$$3-15. \frac{1752 \text{ lbs aldehydes}}{\text{yr}} \times \frac{.4536 \text{ kg}}{1 \text{ lb}} \times \frac{\text{yr}}{365 \text{ days}} = 2.18 \frac{\text{kg aldehydes}}{\text{day}}$$

$$\therefore \frac{2.18 \text{ kg aldehydes/day}}{2722 \text{ kg U/day}} = 8.01 \times 10^{-4} \frac{\text{kg aldehydes}}{\text{kg U (input)}}$$

(8, p. 173) (7, p. 97)

$$3-16. \frac{0.5 \text{ g Ca}}{\text{liter}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{80 \text{ gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{\text{kg}}{10^3 \text{ g}} = 2.18 \times 10^2 \frac{\text{kg Ca}}{\text{day}}$$

$$\therefore \frac{2.18 \times 10^2 \text{ kg Ca/day}}{2722 \text{ kg U/day}} = 8.01 \times 10^{-2} \frac{\text{kg Ca}}{\text{kg U (input)}}$$

(8, p. 173) (7, p. 97)

$$3-17. \frac{1 \text{ g Fe}}{\text{liter}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{80 \text{ gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{\text{kg}}{10^3 \text{ g}} = 4.36 \times 10^2 \frac{\text{kg Fe}}{\text{day}}$$

REFERENCE CALCULATIONS: Milling Facility (cont'd)

$$\therefore \frac{4.36 \times 10^2 \text{ kg Fe/day}}{2722 \text{ kg U/day}} = 1.60 \times 10^{-1} \frac{\text{kg Fe}}{\text{kg U (input)}}$$

$$3-18. \quad \frac{(8, \text{ p. } 173)}{2 \text{ g Al}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{(7, \text{ p. } 97)}{80 \text{ gal}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{\text{kg}}{10^3 \text{ g}} = 8.72 \times 10^2 \frac{\text{kg Al}}{\text{day}}$$

$$\therefore \frac{8.72 \times 10^2 \text{ kg Al/day}}{2722 \text{ kg U/day}} = 3.20 \times 10^{-1} \frac{\text{kg Al}}{\text{kg U (input)}}$$

$$3-19. \quad \text{Assuming } \frac{.5 \text{ g NH}_3}{\text{liter}} \text{ from (8, p. 173) release is the same as in ref. calc. 3-16 as for Ca.}$$

$$3-20. \quad \frac{(8, \text{ p. } 173)}{0.2 \text{ g Na}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{(7, \text{ p. } 97)}{80 \text{ gal}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{\text{kg}}{10^3 \text{ g}} = 8.72 \times 10^1 \frac{\text{kg Na}}{\text{day}}$$

$$\therefore \frac{8.72 \times 10^1 \text{ kg Na/day}}{2722 \text{ kg U/day}} = 3.20 \times 10^{-2} \frac{\text{kg Na}}{\text{kg U (input)}}$$

$$3-21. \quad \frac{(8, \text{ p. } 173)}{2 \times 10^{-4} \text{ g As}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{(7, \text{ p. } 97)}{80 \text{ gal}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{\text{kg}}{10^3 \text{ g}} = 8.72 \times 10^{-2} \frac{\text{kg As}}{\text{day}}$$

$$\therefore \frac{8.72 \times 10^{-2} \text{ kg As/day}}{2722 \text{ kg U/day}} = 3.20 \times 10^{-5} \frac{\text{kg As}}{\text{kg U (input)}}$$

REFERENCE CALCULATIONS: Milling Facility (cont'd)

$$3-22. \quad \begin{matrix} (8, \text{ p. } 173) \\ 5 \times 10^{-3} \frac{\text{g F}}{\text{liter}} \end{matrix} \times \begin{matrix} (7, \text{ p. } 97) \\ \frac{3.785 \text{ liter}}{\text{gal}} \end{matrix} \times \frac{80 \text{ gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{\text{kg}}{10^3 \text{ g}} = 2.18 \frac{\text{kg F}}{\text{day}}$$

$$\therefore \frac{2.18 \text{ kg F/day}}{2722 \text{ kg U/day}} = 8.01 \times 10^{-4} \frac{\text{kg F}}{\text{kg U (input)}}$$

$$3-23. \quad \begin{matrix} (8, \text{ p. } 173) \\ 1 \times 10^{-4} \frac{\text{g V}}{\text{liter}} \end{matrix} \times \begin{matrix} (7, \text{ p. } 97) \\ \frac{3.785 \text{ liter}}{\text{gal}} \end{matrix} \times \frac{80 \text{ gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{\text{kg}}{10^3 \text{ g}} = 4.36 \times 10^{-2} \frac{\text{kg V}}{\text{day}}$$

$$\therefore \frac{4.36 \times 10^{-2} \text{ kg V/day}}{2722 \text{ kg U/day}} = 1.60 \times 10^{-5} \frac{\text{kg V}}{\text{kg U (input)}}$$

$$3-24. \quad \begin{matrix} (8, \text{ p. } 173) \\ 3 \times 10^1 \frac{\text{g SO}_4}{\text{liter}} \end{matrix} \times \begin{matrix} (7, \text{ p. } 97) \\ \frac{3.785 \text{ liter}}{\text{gal}} \end{matrix} \times \frac{80 \text{ gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{\text{kg}}{10^3 \text{ g}} = 1.31 \times 10^4 \frac{\text{kg SO}_4}{\text{day}}$$

$$\therefore \frac{1.31 \times 10^4 \text{ kg SO}_4/\text{day}}{2722 \text{ kg U/day}} = 4.81 \frac{\text{kg SO}_4}{\text{kg U (input)}}$$

$$\therefore \frac{1.31 \times 10^2 \text{ kg Cl/day}}{2722 \text{ kg U/day}} = 4.81 \times 10^{-2} \frac{\text{kg Cl}}{\text{kg U (input)}}$$

$$3-25. \quad \begin{matrix} (8, \text{ p. } 173) \\ 3 \times 10^{-1} \frac{\text{g Cl}}{\text{liter}} \end{matrix} \times \begin{matrix} (7, \text{ p. } 97) \\ \frac{3.785 \text{ liter}}{\text{gal}} \end{matrix} \times \frac{80 \text{ gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{\text{kg}}{10^3 \text{ g}} = 1.31 \times 10^2 \frac{\text{kg Cl}}{\text{day}}$$

REFERENCE CALCULATIONS: Milling Facility (cont'd)

(from ref. calc. 3-1) (4, p. B-35)

$$3-26. \quad 2.48 \times 10^{-4} \frac{\text{kg U}}{\text{kg U (input)}} \times 99.2830\% \text{ } ^{238}\text{U in nat'l U} = 2.46 \times 10^{-4} \frac{\text{kg } ^{238}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 3-1) (4, p. B-35)

$$2.48 \times 10^{-4} \frac{\text{kg U}}{\text{kg U (input)}} \times 0.7110\% \text{ } ^{235}\text{U in nat'l U} = 1.76 \times 10^{-6} \frac{\text{kg } ^{235}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 3-1) (4, p. B-35)

$$2.48 \times 10^{-4} \frac{\text{kg U}}{\text{kg U (input)}} \times 0.0054\% \text{ } ^{234}\text{U in nat'l U} = 1.36 \times 10^{-8} \frac{\text{kg } ^{234}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 3-2) (4, p. B-35)

$$3-27. \quad 3.04 \times 10^{-4} \frac{\text{kg U}}{\text{kg U (input)}} \times 99.2830\% \text{ } ^{238}\text{U in nat'l U} = 3.02 \times 10^{-4} \frac{\text{kg } ^{238}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 3-2) (4, p. B-35)

$$3.04 \times 10^{-4} \frac{\text{kg U}}{\text{kg U (input)}} \times 0.7110\% \text{ } ^{235}\text{U in nat'l U} = 2.16 \times 10^{-6} \frac{\text{kg } ^{235}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 3-2) (4, p. B-35)

$$3.04 \times 10^{-4} \frac{\text{kg U}}{\text{kg U (input)}} \times 0.0054\% \text{ } ^{234}\text{U in nat'l U} = 1.64 \times 10^{-8} \frac{\text{kg } ^{234}\text{U}}{\text{kg U (input)}}$$

(6, p. 41)

$$3-28. \quad 3500 \frac{\text{lbs NH}_3}{\text{yr}} \text{ (from boilers)} \times \frac{.4536 \text{ kg}}{1 \text{ lb}} \times \frac{\text{yr}}{365 \text{ days}} = 4.35 \frac{\text{kg NH}_3}{\text{day}}$$

$$\therefore \frac{4.35 \text{ kg NH}_3/\text{day}}{2722 \text{ kg U/day}} = 1.60 \times 10^{-3} \frac{\text{kg NH}_3 \text{ (from boilers)}}{\text{kg U (input)}}$$

CONVERSION FACILITY CHEMICAL RELEASE FACTOR ^{Kg/Kg U (INPUT)}

F-4-21-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium (natural)	4×10^{-6}	2	4-1	1×10^{-3}	2	4-8
Thorium - 230						
Radium - 226						
Nitrogen Oxides (NO _x)	2×10^{-2}	2	4-2			
Nitric Acid (HNO ₃)						
Hydrogen Fluoride (HF)	3×10^{-4}	2	4-3			
Fluorine (F ₂)	1×10^{-5}	2	4-4			
Hydrogen (H ₂)						
Hexane	1.7×10^{-2}	3	4-5			
Sulfur Oxides (SO _x)	5×10^{-3}	2	4-6			
Hydrogen Sulfide (H ₂ S)						
Nonradioactive						
Particulate	7×10^{-4}	2	4-7			
Carbon Monoxide (CO)	7×10^{-4}	2	4-7			
Hydrocarbons	1×10^{-4}	2	4-7			
Nitrate (NO ₃)				7×10^{-4}	2	4-8
Fluoride (F)				4×10^{-4}	2	4-8
Calcium (Ca)				7×10^{-3}	2	4-8
Sulfate (SO ₄)				8×10^{-3}	2	4-8

CONVERSION FACILITY RADIONUCLIDE RELEASE FACTOR Kg/Kg U (INPUT)						F-4-21-77
Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium (natural)						
*Uranium - 238	3.49×10^{-6}	2	4-9	1.06×10^{-3}	2	4-10
*Uranium - 235	2.50×10^{-8}	2	4-9	7.61×10^{-6}	2	4-10
*Uranium - 234	1.90×10^{-10}	2	4-9	5.78×10^{-8}	2	4-10
*Thorium - 230						
*Radium - 226						

*Has Data Base In Computer Model

REFERENCE CALCULATIONS: CONVERSION FACILITY (365 Operating Days/yr)

4-1. U input to the conversion facility:

$$\frac{10,000 \text{ short tons U}}{\text{yr}} \times \frac{907.2 \text{ kg}}{\text{short ton}} \times \frac{\text{yr}}{365 \text{ days}} = 2.485 \times 10^4 \frac{\text{kg U}}{\text{day}}$$

U airborne output from the conversion facility:

Sampled preparation room air exhaust and HF scrubber

A. (9, p. 24)
 $(1.34 \times 10^{-4} + 2.5 \times 10^{-3}) \frac{\text{metric tons U}}{\text{month}} \times \frac{10^3 \text{ kg}}{\text{metric ton}} \times \frac{12 \text{ months/yr}}{365 \text{ days/yr}} \times = 8.66 \times 10^{-2} \frac{\text{kg U}}{\text{day}}$

UO₃ dust collector exhaust

B. (10, p. 61) (assumed linear scaleup
(from 2312 s.t. U/yr → 10,000 s.t. U/yr))

$$(2 \times 10^{-6} \frac{\text{metric tons U}}{\text{month}} \times \frac{10^3 \text{ kg}}{\text{metric ton}} \times \frac{12 \text{ months/yr}}{365 \text{ days/yr}} \times \frac{4.33}{1} = 2.85 \times 10^{-4} \frac{\text{kg U}}{\text{day}}$$

Reduction off-gas to plant stack

C. (from ref. (calc. 4-1)) (assumed amt. released to eff. control) (assumed SMF 80% eff.) (assumed bag filter 99% eff.)

$$2.485 \times 10^4 \frac{\text{kg U}}{\text{day}} \times .001\% \times 20\% \times 1\% = 4.97 \times 10^{-4} \frac{\text{kg U}}{\text{day}}$$

$$\therefore \frac{(8.66 \times 10^{-2} + 2.85 \times 10^{-4} + 4.97 \times 10^{-4}) \text{ kg U/day}}{2.485 \times 10^4 \text{ kg U/day}} = 3.52 \times 10^{-6} \frac{\text{kg U}}{\text{kg U (input)}}$$

4-2. Assuming 5.8 metric tons NO_x/month (11, p. III-8) for burning 65 million cubic feet of natural gas per month in stoichiometric air (9, p. 24) then:

REFERENCE CALCULATIONS: Conversion Facility (cont'd)

(see
above) (9, p.24)

$$[5.8 + 12.1 \text{ (from absorber tail gas)}] \frac{\text{metric tons NO}_x}{\text{month}} \times \frac{12 \text{ months}}{365 \text{ days}} \times \frac{10^3 \text{ kg}}{\text{metric ton}} = 5.88 \times 10^2 \frac{\text{kg NO}_x}{\text{day}}$$

$$\therefore \frac{5.88 \times 10^2 \text{ kg NO}_x/\text{day}}{2.485 \times 10^4 \text{ kg U/day}} = \frac{2.37 \times 10^{-2} \text{ kg NO}_x}{\text{kg U (input)}}$$

4-3. (from ref. calc. 4-1) (amount of orig. U as UF₄
assumed to be on exit filters)

$$\text{A. } 2.485 \times 10^4 \frac{\text{kg U}}{\text{day}} \times \frac{314 \text{ kg UF}_4}{238 \text{ kg U}} \times 5 \times 10^{-4} \times \frac{80 \text{ kg HF}}{314 \text{ kg U}} \times$$

(assuming NaOH scrubbing
is 95% efficient)

$$.05 = 2.09 \times 10^{-1} \frac{\text{kg HF}}{\text{day}} \quad (\text{from miscellaneous digester and associated effluent treatment})$$

(9, p. 24)

$$\text{B. } (0.123 + 0.040 + 0.032) \frac{\text{metric ton HF}}{\text{month}} \times \frac{10^3 \text{ kg}}{\text{metric ton}} \times \frac{12 \text{ months}}{365 \text{ days}} = 6.41 \frac{\text{kg HF}}{\text{day}} \quad (\text{from HF scrubber, F}_2 \text{ emergency vent, F}_2 \text{ rework})$$

$$\therefore \frac{(2.09 \times 10^{-1} + 6.41) \text{ kg HF/day}}{2.485 \times 10^4 \text{ kg U/day}} = \frac{2.66 \times 10^{-4} \text{ kg HF}}{\text{kg U (input)}}$$

REFERENCE CALCULATIONS: Conversion Facility (cont'd)

4-4. $\frac{(9, \text{p.24})}{0.011 \text{ metric ton } F_2}{\text{month}} \times \frac{10^3 \text{ kg}}{\text{metric ton}} \times \frac{12 \text{ months}}{365 \text{ days}} = 3.62 \times 10^{-1} \frac{\text{kg } F_2}{\text{day}}$

$$\therefore \frac{3.62 \times 10^{-1} \text{ kg } F_2/\text{day}}{2.485 \times 10^4 \text{ kg U/day}} = \frac{1.46 \times 10^{-5} \text{ kg } F_2}{\text{kg U (input)}}$$

(see above) $\frac{(12, \text{p.3})}{2500 \frac{\text{gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \text{ liters}}{\text{gal}} \times 0.74 \frac{\text{mg } F}{\text{liter}} \times \frac{\text{kg}}{10^6 \text{ mg}}} = 1.01 \times 10^1 \frac{\text{kg } F}{\text{day}}$

$$\therefore \frac{1.01 \times 10^1 \text{ kg } F/\text{day}}{2.485 \times 10^4 \text{ kg U/day}} = \frac{4.06 \times 10^{-4} \text{ kg } F}{\text{kg U (input)}}$$

(see above) $\frac{(12, \text{p.3})}{2500 \frac{\text{gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times 12.13 \frac{\text{mg Ca}}{\text{liter}} \times \frac{\text{kg}}{10^6 \text{ mg}}} = 1.65 \times 10^2 \frac{\text{kg Ca}}{\text{day}}$

$$\therefore \frac{1.65 \times 10^2 \text{ kg Ca/day}}{2.485 \times 10^4 \text{ kg U/day}} = \frac{6.65 \times 10^{-3} \text{ kg Ca}}{\text{kg U (input)}}$$

4-5. Hexane Release Factor

$$\frac{9.5 \text{ gal hexane}}{\text{MTU}} \times 3.785 \frac{\text{L}}{\text{gal}} \times \frac{0.66 \text{ kg}}{\text{L}} \times \frac{5}{7} \times 0.98 \times \frac{\text{MTU}}{1000 \text{ kg}} = 1.66 \times 10^{-2} \frac{\text{kg hexane}}{\text{kg U}}$$

(scale up) fraction
air release

REFERENCE CALCULATIONS: Conversion Facility (cont'd)

- 4-6. Assuming 65 lbs SO_x/month (8, p. V-10) for burning 65 million cubic feet of natural gas per month in stoichiometric air (9, p.24) then:

$$\left[\left(\frac{\text{(see above)} \quad 65 \text{ lbs SO}_x}{\text{month}} \times \frac{.4536 \text{ kg}}{1 \text{ lb}} \right) + \left(\frac{\text{(9, p.24)} \quad 4.10 \text{ metric tons SO}_x}{\text{month}} \times \frac{10^3 \text{ kg}}{\text{metric ton}} \right) \right] \times \frac{12 \text{ months}}{365 \text{ days}} = 1.36 \times 10^2 \frac{\text{kg SO}_x}{\text{day}}$$

$$\therefore \frac{1.36 \times 10^2 \text{ kg SO}_x/\text{day}}{2.485 \times 10^4 \text{ kg U/day}} = \frac{5.46 \times 10^{-3} \text{ kg SO}_x}{\text{kg U (input)}}$$

- 4-7. Basis for the following numbers is the use of 65 million cubic feet of natural gas per month and EPA emission factors (1, p. 1.4-2).

$$\therefore \frac{18 \text{ kg particulate/day}}{2.485 \times 10^4 \text{ kg U/day}} = \frac{7.24 \times 10^{-4} \text{ kg particulate}}{\text{kg U (input)}}$$

$$\therefore \frac{17 \text{ kg CO/day}}{2.485 \times 10^4 \text{ kg U/day}} = \frac{6.84 \times 10^{-4} \text{ kg CO}}{\text{kg U (input)}}$$

$$\therefore \frac{3 \text{ kg hydrocarbons/day}}{2.485 \times 10^4 \text{ kg U/day}} = \frac{1.21 \times 10^{-4} \text{ kg hydrocarbons}}{\text{kg U (input)}}$$

- 4-8. Assuming the liquid effluents leave the facility in a 2,500 gal/min stream (12, p.3) and included the concentrations of chemicals given in (12, p.3) then:

$$\frac{\text{(see above)} \quad 2500 \text{ gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{\text{(12, p.3)} \quad 1.95 \text{ mg U}}{\text{liter}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 2.66 \times 10^1 \frac{\text{kg U}}{\text{day}}$$

REFERENCE CALCULATIONS: Conversion Facility (cont'd)

$$\therefore \frac{2.66 \times 10^1 \text{ kg U/day}}{2.485 \times 10^4 \text{ kg U/day}} = \frac{1.07 \times 10^{-3} \text{ kg U (in liquid effluent)}}{\text{kg U (input)}}$$

$$\begin{array}{l} \text{(see above)} \\ 2500 \frac{\text{gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{1.31 \text{ mg NO}_3}{\text{liter}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.79 \times 10^1 \frac{\text{kg NO}_3}{\text{day}} \end{array} \quad (12, \text{ p.3})$$

$$\therefore \frac{1.79 \times 10^1 \text{ kg NO}_3/\text{day}}{2.485 \times 10^4 \text{ kg U/day}} = \frac{7.18 \times 10^{-4} \text{ kg NO}_3}{\text{kg U (input)}}$$

$$\begin{array}{l} \text{(see above)} \\ 2500 \frac{\text{gal}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{14.9 \text{ mg SO}_4}{\text{liter}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 2.03 \times 10^2 \frac{\text{kg SO}_4}{\text{day}} \end{array} \quad (12, \text{ p.3})$$

$$\therefore \frac{2.03 \times 10^2 \text{ kg SO}_4/\text{day}}{2.485 \times 10^4 \text{ kg U/day}} = \frac{8.17 \times 10^{-3} \text{ kg SO}_4}{\text{kg U (input)}}$$

4-21-77

$$\begin{array}{l} \text{(from ref. calc. 4-1)} \\ 4-9. \quad \frac{3.52 \times 10^{-6} \text{ kg U}}{\text{kg U (input)}} \times 99.2830\% \text{ } ^{238}\text{U in nat'l U} = 3.49 \times 10^{-6} \frac{\text{kg } ^{238}\text{U}}{\text{kg U (input)}} \end{array} \quad (4, \text{ p. B-35})$$

$$\begin{array}{l} \text{(from ref. calc. 4-1)} \\ 3.52 \times 10^{-6} \frac{\text{kg U}}{\text{kg U (input)}} \times 0.7110\% \text{ } ^{235}\text{U in nat'l U} = 2.50 \times 10^{-8} \frac{\text{kg } ^{235}\text{U}}{\text{kg U (input)}} \end{array} \quad (4, \text{ p. B-35})$$

REFERENCE CALCULATIONS: Conversion Facility (cont'd)

(from ref. calc. 4-1) (4, p. B-35)

$$\frac{3.52 \times 10^{-6} \text{ kg U}}{\text{kg U (input)}} \times 0.0054\% \text{ } ^{234}\text{U in nat'l U} = 1.90 \times 10^{-10} \frac{\text{kg } ^{234}\text{U}}{\text{kg U (input)}}$$

4-10. (from ref. calc. 4-8) (4, p. B-35)

$$\frac{1.07 \times 10^{-3} \text{ kg U}}{\text{kg U (input)}} \times 99.2830\% \text{ } ^{238}\text{U in nat'l U} = 1.06 \times 10^{-3} \frac{\text{kg } ^{238}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 4-8) (4, p. B-35)

$$\frac{1.07 \times 10^{-3} \text{ kg U}}{\text{kg U (input)}} \times 0.7110\% \text{ } ^{235}\text{U in nat'l U} = 7.61 \times 10^{-6} \frac{\text{kg } ^{235}\text{U}}{\text{kg U (input)}}$$

(from ref. calc. 4-8) (4, p. B-35)

$$\frac{1.07 \times 10^{-3} \text{ kg U}}{\text{kg U (input)}} \times 0.0054\% \text{ } ^{234}\text{U in nat'l U} = 5.78 \times 10^{-8} \frac{\text{kg } ^{234}\text{U}}{\text{kg U (input)}}$$

DIFFUSION ENRICHMENT CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)

F-9-20-78

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium	1×10^{-5}	1	5-1	7×10^{-5}	1	5-2
Thorium - 234				1×10^{-13}	1	5-3
Hydrogen Fluoride (HF)	1×10^{-3}	1	5-4			
Freon	6×10^{-3}	1	5-5			
Ammonia (NH_3)	2×10^{-4}	1	5-6			
Nitrogen Oxides (NO_x)	3×10^{-1}	1	5-7			
Nonradioactive						
Particulate	2×10^{-2}	1	5-8			
Sulfur Oxides (SO_x)	3×10^{-1}	1	5-9			
Carbon Monoxide (CO)	4×10^{-2}	1	5-10			
Hydrocarbons	7×10^{-3}	1	5-11			
Ozone (O_3)	2×10^{-5}	1	5-12			
Chloroethene	1×10^{-3}	1	5-13			
Trichlorethylene	2×10^{-2}	1	5-14			
Acetone	6×10^{-4}	1	5-15			
Xylol (xylene)	8×10^{-5}	1	5-16			
Kerosene	5×10^{-4}	1	5-17			
Fluorine (F_2)						
Chlorine (Cl_2)				9×10^{-4}	1	5-24
Nitrate (NO_3)				2×10^{-2}	1	5-18

DIFFUSION ENRICHMENT (cont'd) CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT) F-9-20-78

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Aluminum (Al)				1×10^{-4}	1	5-19
Fluoride (F)				2×10^{-4}	1	5-20
Tributyl Phosphate				3×10^{-5}	1	5-21
Varsol				9×10^{-5}	1	5-22
Phosphate (PO_4)				2×10^{-3}	1	5-23
Chloride (Cl)						
Chromium (Cr)				1×10^{-4}	1	5-25
Zinc (Zn)				1×10^{-3}	1	5-26
Sulfate (SO_4)						
Sulfuric Acid (H_2SO_4)	x					
Boric Acid (H_3BO_3)	x					
Nickel Sulfate ($NiSO_4$)	x					
Nickel Chloride ($NiCl_2$)	x					
Helium (He)	x					
Hydrogen (H_2)	x					
Nitrogen (N_2)	x					
Argon (Ar)	x					
Calcium (Ca)				x		
Sodium (Na)				x		
Sulfite (SO_3)				x		

DIFFUSION ENRICHMENT (cont'd)			CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)			F-9-20-78
Air Borne			Liquid			
Material Released	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Iron (Fe)				x		
Boron (B)				x		
Nickel (Ni)				x		
Magnesium (Mg)				x		
Molybdenum (Mo)				x		
Silver (Ag)				x		
Manganese (Mn)				x		

x Indicates Most Likely Form Of Effluent

DIFFUSION ENRICHMENT RADIONUCLIDE RELEASE FACTOR Kg/Kg U (INPUT) F-9-20-78

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium						
*Uranium - 238	9.22×10^{-6}	1	5-27	6.47×10^{-5}	1	5-28
*Uranium - 235	3.37×10^{-7}	1	5-27	5.15×10^{-7}	1	5-28
*Uranium - 234	1.52×10^{-13}	1	5-27	4.33×10^{-9}	1	5-28
Thorium - 234				1×10^{-13}		5-3

*Has Data Base In Computer Model

REFERENCE CALCULATIONS: DIFFUSION ENRICHMENT FACILITY (365 Operating Days/yr)

4-28-77

- 5-1. Enriched U (3.2% ²³⁵U) output from diffusion enrichment facility based on 0.25% tails and 8.75x 10⁶ SWU/year:

(13, p. 40 and p. 41)

$$8.75 \times 10^6 \frac{\text{kg SWU}}{\text{yr}} \times \frac{\text{kg U product}}{4.2 \text{ kg SWU}} \times \frac{\text{yr}}{365 \text{ days}} = 5707.76 \frac{\text{kg 3.2\% } ^{235}\text{U product}}{\text{day}}$$

U airborne output from the diffusion enrichment facility: (assume just natural U input)

(14, p. 2.3-50 and 2.3-140) (30, #31)

(14, p. 2.3-50 and 2.3-140) (30, #28)

$$\left[\left(6.4 \times 10^{-3} \frac{\text{Ci } ^{238}\text{U}}{\text{yr}} \times \frac{\text{g } ^{238}\text{U}}{3.33 \times 10^{-7} \text{ Ci } ^{238}\text{U}} \right) + \left(1.5 \times 10^{-3} \frac{\text{Ci } ^{235}\text{U}}{\text{yr}} \times \frac{\text{g } ^{235}\text{U}}{2.14 \times 10^{-6} \text{ Ci } ^{235}\text{U}} \right) + \right.$$

(14, p. 2.3-50 and 2.3-140) (30, #27)

$$\left. \left(3.9 \times 10^{-2} \frac{\text{Ci } ^{234}\text{U}}{\text{yr}} \times \frac{\text{g } ^{234}\text{U}}{6.1 \times 10^{-3} \text{ Ci } ^{234}\text{U}} \right) \right] \times \frac{\text{yr}}{365 \text{ days}} \times \frac{\text{kg}}{10^3 \text{ g}} = 5.46 \times 10^{-2} \frac{\text{kg U}}{\text{day}}$$

$$\therefore \frac{5.46 \times 10^{-2} \text{ kg U/day}}{5708 \text{ kg U/day}} = 9.56 \times 10^{-6} \frac{\text{kg U (airborne)}}{\text{kg U (product)}}$$

- 5-2. Assume only natural U input to diffusion enrichment facility.

(15, p. A-259)

$$300 \frac{\text{lbs U}}{\text{yr}} \times \frac{0.4536 \text{ kg}}{1 \text{ lb}} \times \frac{\text{yr}}{365 \text{ days}} = 3.73 \times 10^{-1} \frac{\text{kg U (liquid)}}{\text{day}}$$

REFERENCE CALCULATIONS: Diffusion Enrichment Facility (cont'd)

$$\therefore \frac{3.73 \times 10^{-1} \text{ kg U/day}}{5708 \text{ kg U/day}} = 6.53 \times 10^{-5} \frac{\text{kg U (liquid)}}{\text{kg U (product)}}$$

(15, p. A-259)

$$5-3. \quad 5 \frac{\text{Ci } ^{234}\text{Th}}{\text{yr}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{\text{g } ^{234}\text{Th}}{2.32 \times 10^4 \text{ Ci } ^{234}\text{Th}} \times \frac{\text{kg}}{10^3 \text{ g}} = 5.90 \times 10^{-10} \frac{\text{kg } ^{234}\text{Th}}{\text{day}}$$

$$\therefore \frac{5.90 \times 10^{-10} \text{ kg } ^{234}\text{Th/day}}{5708 \text{ kg U/day}} = 1.03 \times 10^{-13} \frac{\text{kg } ^{234}\text{Th}}{\text{kg U (product)}}$$

(14, p. 3.3-10)

$$5-4. \quad 7.56 \times 10^4 \frac{\mu\text{g HF}}{\text{sec}} \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^9 \mu\text{g}} = 6.53 \frac{\text{kg HF}}{\text{day}}$$

$$\therefore \frac{6.53 \text{ kg HF/day}}{5708 \text{ kg U/day}} = 1.14 \times 10^{-3} \frac{\text{kg HF}}{\text{kg U (product)}}$$

(16, p. 11)

$$5-5. \quad 2,260 \frac{\text{lbs Freon}}{\text{month}} \times \frac{12 \text{ months}}{365 \text{ days}} \times \frac{\text{kg}}{2.205 \text{ lbs}} = 3.37 \times 10^1 \frac{\text{kg Freon}}{\text{day}}$$

$$\therefore \frac{3.37 \times 10^1 \text{ kg Freon/day}}{5708 \text{ kg U/day}} = 5.90 \times 10^{-3} \frac{\text{kg Freon}}{\text{kg U (product)}}$$

REFERENCE CALCULATIONS: Diffusion Enrichment Facility (cont'd)

$$5-6. \frac{322 \text{ kg NH}_3}{\text{yr}} \times \frac{\text{yr}}{365 \text{ days}} = 8.82 \times 10^{-1} \frac{\text{kg NH}_3}{\text{day}} \quad (15, \text{pA-154})$$

$$\therefore \frac{8.82 \times 10^{-1} \text{ kg NH}_3/\text{day}}{5708 \text{ kg U/day}} = 1.55 \times 10^{-4} \frac{\text{kg NH}_3}{\text{kg U (product)}}$$

$$5.7 \left(\frac{5600 \text{ lb}}{\text{yr}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{0.4536 \text{ kg}}{\text{lb}} \right) \quad (\text{calcination}) (19, \text{pA-85})$$

(welding) (19, pA-128)

$$+ \left(\frac{1.66 \times 10^7 \text{ } \mu\text{g NO}_x}{\text{sec}} \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^9 \text{ } \mu\text{g}} \right) + \left(\frac{[1632 + (3650 \times \frac{1040}{920})] \text{ kg}}{\text{yr}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{1 \text{ PPM NO}_x}{6.05 \text{ PPM}} \right) \quad (\text{steam plant}) (14, \text{p.3.3-10})$$

$$+ \left(\frac{2 \text{ gal}}{\text{day-vehicle}} \times 250 \text{ vehicles} \times \frac{10 \text{ miles}}{\text{gal}} \times 4.7 \frac{\text{gNO}_x}{\text{mile}} \times \frac{\text{kg}}{10^3 \text{ g}} \right) \quad \begin{matrix} (14, \text{p.2.3-163}) & (14, \text{p.2.3-163}) & (\text{assumed}) & (1, \text{p3.1.1-6(1976)}) \\ & & (\text{no ref}) & \end{matrix}$$

$$\therefore \frac{1.47 \times 10^3 \text{ NO}_x/\text{day}}{5708 \text{ kg U/day}} = 2.58 \times 10^{-1} \frac{\text{kg NO}_x}{\text{kg U (product)}}$$

$$5-8. \left[\left(\frac{1.24 \times 10^4 \text{ } \mu\text{g particulate}}{\text{sec}} + 9.98 \times 10^5 \frac{\text{ } \mu\text{g particulate}}{\text{sec}} \right) \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^9 \text{ } \mu\text{g}} + \right. \quad \begin{matrix} (\text{D\&R incinerator}) \\ (14, \text{p.3.3-10}) \end{matrix} \quad \begin{matrix} (\text{steam plant}) \\ (14, \text{p.3.3-10}) \end{matrix}$$

REFERENCE CALCULATIONS: Diffusion Enrichment Facility (cont'd)

$$\begin{aligned}
 & \left(\frac{5 \text{ MT Al (smelted)}}{\text{yr}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{0.95 \text{ kg particulate}}{\text{MT Al (smelted)}} \right) + \\
 & \left(\frac{2 \text{ gal}}{\text{day-vehicle}} \times 250 \text{ vehicles} \times \frac{10 \text{ miles}}{\text{gal}} \times (0.38 + 0.20) \frac{\text{g particulate}}{\text{mile}} \times \frac{\text{kg}}{10^3 \text{ g}} \right) \Bigg] = \\
 & 9.02 \times 10^1 \frac{\text{kg particulate}}{\text{day}}
 \end{aligned}$$

$$\therefore \frac{9.02 \times 10^1 \text{ kg particulate/day}}{5708 \text{ kg U/day}} = 1.58 \times 10^{-2} \frac{\text{kg particulate}}{\text{kg U (product)}}$$

5-9.
$$\begin{aligned}
 & \left[\left(1.45 \times 10^2 \frac{\mu\text{g SO}_x}{\text{sec}} + 2.08 \times 10^7 \frac{\mu\text{g SO}_x}{\text{sec}} \right) \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^9 \mu\text{g}} + \right. \\
 & \left. \left(\frac{2 \text{ gal}}{\text{day-vehicle}} \times 250 \text{ vehicles} \times \frac{10 \text{ miles}}{\text{gal}} \times \frac{0.20 \text{ g SO}_x}{\text{mile}} \times \frac{\text{kg}}{10^3 \text{ g}} \right) \right] = 1.80 \times 10^3 \frac{\text{kg SO}_x}{\text{day}} \\
 & \therefore \frac{1.80 \times 10^3 \text{ kg SO}_x/\text{day}}{5708 \text{ kg U/day}} = 3.15 \times 10^{-1} \frac{\text{kg SO}_x}{\text{kg U (product)}}
 \end{aligned}$$

REFERENCE CALCULATIONS: Diffusion Enrichment Facility (cont'd)

$$5-10. \left[\begin{array}{l} \text{(steam plant)} \\ \text{(14,p.3.3-10)} \\ 3.33 \times 10^5 \frac{\mu\text{g CO}}{\text{sec}} \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^9 \mu\text{g}} \end{array} \right] + \left(\frac{\text{(welding)(19,pA-128)} \left(1632 + \left(3650 \times \frac{1040}{920} \right) \text{kg} \right)}{\text{yr}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{5 \text{ PPM CO}}{6.05 \text{ PPM}} \right) +$$

$$\left(\frac{\text{(14,p.2.3-163)} \left(\frac{2 \text{ gal}}{\text{day-vehicle}} \times 250 \text{ vehicles} \times \frac{\text{(assumed)} \left(\frac{10 \text{ miles}}{\text{gal}} \times \frac{42 \text{ g CO}}{\text{mile}} \times \frac{\text{(no ref.)} \left(\frac{\text{kg}}{10^3 \text{ g}} \right)}{\text{day}} \right)}{\text{day}} \right)}{5708 \text{ kg U/day}} = 2.52 \times 10^2 \frac{\text{kg CO}}{\text{day}} \right)$$

$$\therefore \frac{2.52 \times 10^2 \text{ kg CO/day}}{5708 \text{ kg U/day}} = 4.41 \times 10^{-2} \frac{\text{kg CO}}{\text{kg U (product)}}$$

$$5-11. \left[\begin{array}{l} \text{(steam plant)} \\ \text{(14,p.3.3-10)} \\ 1.68 \times 10^5 \frac{\mu\text{g H}_x\text{C}_y/\text{day}}{\text{mile}} \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^9 \mu\text{g}} \end{array} \right] + \left(\frac{\text{(14,p.2.3-163)} \left(\frac{2 \text{ gal}}{\text{day-vehicle}} \times 250 \text{ vehicles} \times \right. \right.$$

$$\left. \frac{\text{(assumed)} \left(\frac{10 \text{ miles}}{\text{gal}} \times (4.2 + 1.3) \frac{\text{g H}_x\text{C}_y}{\text{mile}} \times \frac{\text{(no ref.)} \left(\frac{\text{kg}}{10^3 \text{ g}} \right)}{\text{day}} \right)}{\text{day}} \right) = 4.29 \times 10^1 \frac{\text{kg H}_x\text{C}_y}{\text{day}}$$

$$\therefore \frac{4.20 \times 10^1 \text{ kg H}_x\text{C}_y/\text{day}}{5708 \text{ kg U/day}} = 7.36 \times 10^{-3} \frac{\text{kg H}_x\text{C}_y}{\text{kg U (product)}}$$

REFERENCE CALCULATIONS: Diffusion Enrichment Facility (cont'd)

5-12.
$$\left(\begin{array}{c} \text{(welding)} \\ \text{(19,pA-128)} \end{array} \right) \left(1632 + \left(3650 \times \frac{1040}{920} \right) \right) \frac{\text{kg}}{\text{yr}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{0.05 \text{ PPM } O_3}{6.05 \text{ PPM}} = 1.30 \times 10^{-1} \frac{\text{kg } O_3}{\text{day}}$$

$$\therefore \frac{1.30 \times 10^{-1} \text{ kg } O_3/\text{day}}{5708 \text{ kg U/day}} = 2.28 \times 10^{-5} \frac{\text{kg } O_3}{\text{kg U (product)}}$$

5-13. Assume that Chlorothene is perchloroethylene ($Cl_2C=CCl_2$) with a density of 1.6 g/ml (4,p.C-292)

(see above)

A.52

$$\begin{array}{c} \text{(19,pA-128)} \\ \text{350 gal chlorothene} \end{array} \frac{\text{yr}}{\text{yr}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{10^3 \text{ ml}}{\text{liter}} \times \frac{1.6 \text{ g}}{\text{ml}} \times \frac{\text{kg}}{10^3 \text{ g}} = 5.81 \frac{\text{kg chlorothene}}{\text{day}}$$

$$\therefore \frac{5.81 \text{ kg chlorothene/day}}{5708 \text{ kg U/day}} = 1.02 \times 10^{-3} \frac{\text{kg chlorothene}}{\text{kg U (product)}}$$

5-14.
$$\begin{array}{c} \text{(19,p.A-128)} \\ \text{(7500 + 850)} \end{array} \frac{\text{gal trichloroethylene}}{\text{yr}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{10^3 \text{ ml}}{\text{liter}} \times$$

(assumed)

(4,p.C-292)

$$\frac{1.5 \text{ g}}{\text{ml}} \times \frac{\text{kg}}{10^3 \text{ g}} = 1.30 \times 10^2 \frac{\text{kg trichloroethylene}}{\text{day}}$$

REFERENCE CALCULATIONS: Diffusion Enrichment Facility (cont'd)

$$\therefore \frac{1.30 \times 10^2 \text{ kg trichloroethylene/day}}{5708 \text{ kg U/day}} = 2.28 \times 10^{-2} \frac{\text{kg trichloroethylene}}{\text{kg U (product)}}$$

(19,pA-128) (assumed) (4,p.C-455)

$$5-15. \frac{400 \text{ gal acetone}}{\text{yr}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{10^3 \text{ ml}}{\text{liter}} \times \frac{0.79 \text{ g}}{\text{ml}} \times \frac{\text{kg}}{10^3 \text{ g}} = 3.28 \frac{\text{kg acetone}}{\text{day}}$$

$$\therefore \frac{3.28 \text{ kg acetone/day}}{5708 \text{ kg U/day}} = 5.75 \times 10^{-4} \frac{\text{kg acetone}}{\text{kg U (product)}}$$

(19,p.A-128) (assumed) (4,p.C-155)

$$5-16. \frac{50 \text{ gal xylene}}{\text{yr}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{10^3 \text{ ml}}{\text{liter}} \times \frac{0.87 \text{ g}}{\text{ml}} \times \frac{\text{kg}}{10^3 \text{ g}} = 4.51 \times 10^{-1} \frac{\text{kg xylene}}{\text{day}}$$

$$\therefore \frac{4.51 \times 10^{-1} \text{ kg xylene/day}}{5708 \text{ kg U/day}} = 7.90 \times 10^{-5} \frac{\text{kg xylene}}{\text{kg U (product)}}$$

(19,pA-128) (assumed(no ref.))

$$5-17. \frac{400 \text{ gal kerosene}}{\text{yr}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{3.785 \text{ liter}}{\text{gal}} \times \frac{10^3 \text{ ml}}{\text{liter}} \times \frac{0.7 \text{ g}}{\text{ml}} \times \frac{\text{kg}}{10^3 \text{ g}} = 2.90 \frac{\text{kg kerosene}}{\text{day}}$$

$$\therefore \frac{2.90 \text{ kg kerosene/day}}{5708 \text{ kg U/day}} = 5.08 \times 10^{-4} \frac{\text{kg kerosene}}{\text{kg U (product)}}$$

REFERENCE CALCULATIONS: Diffusion Enrichment Facility (cont'd)

(14,p.2.3-146)

$$5-18. \quad 5.3 \frac{\text{mg NO}_3}{\text{liter}} \times 1.71 \times 10^7 \frac{\text{liters}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 9.06 \times 10^1 \frac{\text{kg NO}_3}{\text{day}}$$

$$\therefore \frac{9.06 \times 10^1 \text{ kg NO}_3/\text{day}}{5708 \text{ kg U/day}} = 1.59 \times 10^{-2} \frac{\text{kg NO}_3}{\text{kg U (product)}}$$

(14, p.2.3-146)

$$5-19. \quad 0.04 \frac{\text{mg Al}}{\text{liter}} \times 1.71 \times 10^7 \frac{\text{liters}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 6.84 \times 10^{-1} \frac{\text{kg Al}}{\text{day}}$$

$$\therefore \frac{6.84 \times 10^{-1} \text{ kg Al/day}}{5708 \text{ kg U/day}} = 1.20 \times 10^{-4} \frac{\text{kg Al}}{\text{kg U (product)}}$$

(14,p.2.3-146)

$$5-20. \quad 0.07 \frac{\text{mg F}}{\text{liter}} \times 1.71 \times 10^7 \frac{\text{liters}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.20 \frac{\text{kg F}}{\text{day}}$$

$$\therefore \frac{1.20 \text{ kg F/day}}{5708 \text{ kg U/day}} = 2.10 \times 10^{-4} \frac{\text{kg F}}{\text{kg U (product)}}$$

(14,p.2.3-146)

$$5-21. \quad 0.01 \frac{\text{mg tributylphosphate}}{\text{liter}} \times 1.71 \times 10^7 \frac{\text{liters}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.71 \times 10^{-1} \frac{\text{kg TBP}}{\text{day}}$$

REFERENCE CALCULATIONS: Diffusion Enrichment Facility (cont'd)

$$\therefore \frac{1.71 \times 10^{-1} \text{ kg tributylphosphate/day}}{5708 \text{ kg U/day}} = 3.00 \times 10^{-5} \frac{\text{kg TBP}}{\text{kg U (product)}}$$

(14,p.2.3-146)

$$5-22. \quad 0.03 \frac{\text{mg varsol}}{\text{liter}} \times 1.71 \times 10^7 \frac{\text{liters}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 5.13 \times 10^{-1} \frac{\text{kg varsol}}{\text{day}}$$

$$\therefore \frac{5.13 \times 10^{-1} \text{ kg varsol/day}}{5708 \text{ kg U/day}} = 8.99 \times 10^{-5} \frac{\text{kg varsol}}{\text{kg U (product)}}$$

A.55

(14,p.2.3-146)

$$5-23. \quad 0.70 \frac{\text{mg PO}_4}{\text{liter}} \times 1.71 \times 10^7 \frac{\text{liters}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.20 \times 10^1 \frac{\text{kg PO}_4}{\text{day}}$$

$$\therefore \frac{1.20 \times 10^1 \text{ kg PO}_4/\text{day}}{5708 \text{ kg U/day}} = 2.10 \times 10^{-3} \frac{\text{kg PO}_4}{\text{kg U (product)}}$$

(14,p.2.3-146)

$$5-24. \quad 0.285 \frac{\text{mg Cl}_2}{\text{liter}} \times 1.71 \times 10^7 \frac{\text{liters}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 4.87 \frac{\text{kg Cl}_2}{\text{day}}$$

$$\therefore \frac{4.87 \text{ kg Cl}_2/\text{day}}{5708 \text{ kg U/day}} = 8.53 \times 10^{-4} \frac{\text{kg Cl}_2}{\text{kg U (product)}}$$

REFERENCE CALCULATIONS: Diffusion Enrichment Facility (cont'd)

5-02-77

(14,p.2.3-146)

$$5-25. \quad 0.047 \frac{\text{mg Cr}}{\text{liter}} \times 1.71 \times 10^7 \frac{\text{liters}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 8.04 \times 10^{-1} \frac{\text{kg Cr}}{\text{day}}$$

$$\therefore \frac{8.04 \times 10^{-1} \text{ kg Cr/day}}{5708 \text{ kg U/day}} = 1.41 \times 10^{-4} \frac{\text{kg Cr}}{\text{kg U (product)}}$$

(14,p.2.3-146)

$$5-26. \quad 0.475 \frac{\text{mg Zn}}{\text{liter}} \times 1.71 \times 10^7 \frac{\text{liters}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 8.12 \frac{\text{kg Zn}}{\text{day}}$$

$$\therefore \frac{8.12 \text{ kg Zn/day}}{5708 \text{ kg U/day}} = 1.42 \times 10^{-3} \frac{\text{kg Zn}}{\text{kg U (product)}}$$

5-27. Assuming the same ratio of ^{238}U : ^{235}U : ^{234}U as is indicated in (14, p.2.3-50 and p.2.3-140) then:

(from ref.calc. 5-1)

(inferred from ref.calc.5-1)

$$\therefore \frac{9.56 \times 10^{-6} \text{ kg U (airborne)}}{\text{kg U (prod-output)}} \times \frac{1.92 \times 10^4 \text{ g } ^{238}\text{U/yr}}{1.99 \times 10^4 \text{ g U(235)/yr}} = \frac{9.22 \times 10^{-6} \text{ kg } ^{238}\text{U (air)}}{\text{kg U (product)}}$$

REFERENCE CALCULATIONS: Diffusion Enrichment Facility (cont'd)

$$\begin{array}{l} \text{(from ref.calc. 5-1)} \qquad \qquad \text{(inferred from ref.calc.5-1)} \\ \therefore 9.56 \times 10^{-6} \frac{\text{kg U(airborne)}}{\text{kg U(prod.-output)}} \times \frac{7.01 \times 10^2 \text{ g }^{235}\text{U/yr}}{1.99 \times 10^4 \text{ g U(235)/yr}} = \frac{3.37 \times 10^{-7} \text{ kg }^{235}\text{U(air)}}{\text{kg U (product)}} \end{array}$$

$$\begin{array}{l} \text{(from ref.calc.5-1)} \qquad \qquad \text{(inferred from ref.calc.5-1)} \\ \therefore 9.56 \times 10^{-6} \frac{\text{kg U(airborne)}}{\text{kg U(prod.-output)}} \times \frac{3.17 \times 10^{-4} \text{ g }^{234}\text{U/yr}}{1.99 \times 10^4 \text{ g U(235)/yr}} = \frac{1.52 \times 10^{-13} \text{ kg }^{234}\text{U(air)}}{\text{kg U (product)}} \end{array}$$

5-28. Assuming the same ratio of ^{238}U : ^{235}U : ^{234}U as is indicated in (14, p.2.3-141) then:

$$\begin{array}{l} \text{(from ref.calc.5-2)} \qquad \qquad \text{(inferred from 14, p.2.3-141)} \\ \therefore 6.53 \times 10^{-5} \frac{\text{kg U(liquid)}}{\text{kg U(prod.-output)}} \times \frac{3.48 \times 10^3 \text{ g }^{238}\text{U/yr}}{3.51 \times 10^3 \text{ g U(235)/yr}} = \frac{6.47 \times 10^{-5} \text{ kg }^{238}\text{U}}{\text{kg U (product)}} \end{array}$$

$$\begin{array}{l} \text{(from ref.calc. 5-2)} \qquad \qquad \text{(inferred from 14, p.2.3-141)} \\ \therefore 6.53 \times 10^{-5} \frac{\text{kg U(liquid)}}{\text{kg U(prod.-output)}} \times \frac{2.77 \times 10^1 \text{ g }^{235}\text{U/yr}}{3.51 \times 10^3 \text{ g U(235)/yr}} = \frac{5.15 \times 10^{-7} \text{ kg }^{235}\text{U}}{\text{kg U (product)}} \end{array}$$

$$\begin{array}{l} \text{(from ref.calc.5-2)} \qquad \qquad \text{(inferred from 14,p.2.3-141)} \\ \therefore 6.53 \times 10^{-5} \frac{\text{kg U(liquid)}}{\text{kg U(prod.-output)}} \times \frac{2.33 \times 10^{-1} \text{ g }^{234}\text{U/yr}}{3.51 \times 10^3 \text{ g U(235)/yr}} = \frac{4.33 \times 10^{-9} \text{ kg }^{234}\text{U}}{\text{kg U (product)}} \end{array}$$

UO ₂ FUEL FABRICATION CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)				F-4-25-77		
Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium (enriched 3.2%)	1×10^{-6}	2	6-1	1×10^{-7}	2	6-2
Thorium - 234						
Protactinium - 234						
Hydrogen Fluoride (HF)	1×10^{-4}	2	6-4			
Ammonium Fluoride (NH ₄ F)	1×10^{-4}	2	6-5			
Ammonia (NH ₃)	2×10^{-1}	2	6-6	2×10^{-3}	2	6-22
Nitrogen Oxides (NO _x)	2×10^{-3}	1	6-7			
Nitric Acid (HNO ₃)	5×10^{-3}	1	6-8			
Hydrogen (H ₂)						
Helium (He)						
Hydrocarbons	1×10^{-6}	2	6-9			
Sulfur Oxides (SO _x)	2×10^{-7}	2	6-9			
Nonradioactive						
Particulate	7×10^{-6}	2	6-9			
Carbon Monoxide (CO)	7×10^{-6}	2	6-9			
Sulfuric Acid (H ₂ SO ₄)						
Boric Acid (H ₃ BO ₃)						
Nickel Sulfate (NiSO ₄)						
Nickel Chloride (NiCl ₂)						
Silver (Ag)				6×10^{-5}	2	6-10
Iron (Fe)				3×10^{-4}	2	6-11
Sodium (Na)				2×10^{-2}	2	6-12

UO₂ FUEL FABRICATION (cont'd) CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)

F-4-25-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Calcium (Ca)				4×10^{-1}	2	6-13
Magnesium (Mg)				9×10^{-4}	2	6-14
Manganese (Mn)				2×10^{-5}	2	6-15
Molybdenum (Mo)				7×10^{-5}	2	6-16
Nickel (Ni)				2×10^{-4}	2	6-17
Boron (B)				3×10^{-4}	2	6-18
Chloride (Cl)				2×10^{-2}	2	6-19
Phosphorus (P)				5×10^{-4}	2	6-20
Nitrogen (KJELDAHL)				9×10^{-2}	2	2-21
Fluoride (F)				3×10^{-3}	2	2-23
Sulfate (SO ₄)				3×10^{-2}	2	2-24
Sulfite (SO ₃)				4×10^{-4}	2	2-25
Sulfide (S)						
Phenols						
Oils and Grease				1×10^{-3}	2	2-26
Hardness as CaCO ₃				2×10^{-1}	2	6-27
Acetone	x					
Nitrogen	x					
Argon	x					
Zinc (Zn)				x		

UO₂ FUEL FABRICATION RADIONUCLIDE RELEASE FACTOR Kg/Kg U (INPUT)

F-4-25-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium (enriched 3.2%)						
*Uranium - 238	1.13×10^{-6}	2	6-28	1.15×10^{-7}	2	6-29
*Uranium - 235	3.74×10^{-8}	2	6-28	3.81×10^{-9}	2	6-29
*Uranium - 234	1.79×10^{-10}	2	6-28	1.82×10^{-11}	2	6-29
*Thorium - 234						
*Protactinium - 234						

* Has Data Base In Computer Model

REFERENCE CALCULATIONS: UO₂ FUEL FABRICATION FACILITY (365 Operating Days/yr)

6-1. U input to the UO₂ fuel fabrication facility:

(assumed from reference 18)

$$4404 \frac{\text{kg U}}{\text{day}} \text{ (enriched to 3.2\% } ^{235}\text{U)}$$

U airborne output from the UO₂ fuel fabrication facility (from reference 18):

$$5.14 \times 10^{-3} \frac{\text{kg U}}{\text{day}} \cdot \frac{5.14 \times 10^{-3} \text{ kg U/day}}{4404 \text{ kg U/day}} = 1.17 \times 10^{-6} \frac{\text{kg U (air)}}{\text{kg U (input)}}$$

(From reference 18 pages 3.3-14 and 4.8-13:)

$$6-2. \frac{5.26 \times 10^{-4} \text{ kg U/day}}{4404 \text{ kg U/day}} = 1.19 \times 10^{-7} \frac{\text{kg U (liquid)}}{\text{kg U (input)}}$$

(18, p.3.3-10)

(18, p.3.3-10)

(assumed scaleup from 400 MT to 1600 MT only increases F release by 1/5*)

$$6-3. \quad 0.36 \frac{\text{mgF}}{\text{m}^3} \times \frac{\text{m}^3}{10^6 \text{ m}^3} \times 6.0 \times 10^{10} \frac{\text{ml}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} \times \frac{7}{5} = 7.26 \times 10^{-1} \frac{\text{kg F}}{\text{day}}$$

* Phone call from Roger E. Fischer, Radiological & Environmental Engineer for Westinghouse Nuclear Fuel Division, Columbia, South Carolina, on April 15, 1977 provided the information that their planned scale-up from 400 MTU/year to 1600 MTU/year would not increase the Fluorine to the environment by the apparent 4 to 1 but only by the ratio of 7 to 5 due to easier design of valve activator packings, etc., for the larger equipment.

REFERENCE CALCULATIONS: UO_2 Fuel Fabrication Facility (cont'd)

(from ref. (calc. 6-3) (See Note)

$$6-4. \quad 7.26 \times 10^{-1} \frac{\text{kg F}}{\text{day}} \times \frac{\text{kg-mole F}}{19 \text{ kg F}} \times \frac{2/3 \text{ kg-mole HF}}{1 \text{ kg-mole F}} \times \frac{20 \text{ kg HF}}{\text{kg-mole HF}} = 5.09 \times 10^{-1} \frac{\text{kg HF}}{\text{day}}$$

$$\therefore \frac{5.09 \times 10^{-1} \text{ kg HF/day}}{4404 \text{ kg U/day}} = 1.16 \times 10^{-4} \frac{\text{kg HF}}{\text{kg U(input)}}$$

(from ref. (calc. 6-3) (See Note)

$$6-5. \quad 7.26 \times 10^{-1} \frac{\text{kg F}}{\text{day}} \times \frac{\text{kg-mole F}}{19 \text{ kg F}} \times \frac{1/3 \text{ kg-mole NH}_4\text{F}}{1 \text{ kg-mole F}} \times \frac{36 \text{ kg NH}_4\text{F}}{\text{kg-mole NH}_4\text{F}} = 4.59 \times 10^{-1} \frac{\text{kg NH}_4\text{F}}{\text{day}}$$

$$\therefore \frac{4.59 \times 10^{-1} \text{ kg NH}_4\text{F/day}}{4404 \text{ kg U/day}} = 1.04 \times 10^{-4} \frac{\text{kg NH}_4\text{F}}{\text{kg U(input)}}$$

(18, p.3.3-10) (18, p.3.3-10)

$$6-6. \quad 390 \frac{\text{mg NH}_3}{\text{m}^3} \times \frac{\text{m}^3}{10^6 \text{ m}^3} \times 6.0 \times 10^{10} \frac{\text{m}^3}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} \times \frac{7}{5}^* = 7.86 \times 10^2 \frac{\text{kg NH}_3}{\text{day}}$$

$$\therefore \frac{7.86 \times 10^2 \text{ kg NH}_3/\text{day}}{4404 \text{ kg U/day}} = 1.79 \times 10^{-1} \frac{\text{kg NH}_3}{\text{kg U(input)}}$$

* assumed scaleup from 400 MT/day to 1600 MT/day only increases release by a ratio of $\frac{7}{5}$ (see calculation 6-3)

REFERENCE CALCULATIONS: UO_2 Fuel Fabrication Facility (cont'd)

4-22-77

(See Note)

$$6-7. \quad \frac{10 \text{ kg } NO_x/\text{day}}{4404 \text{ kg U/day}} = \frac{2.27 \times 10^{-3} \text{ kg } NO_x}{\text{kg U(input)}}$$

(See Note)

$$6-8. \quad \frac{24 \text{ kg } HNO_3/\text{day}}{4404 \text{ kg U/day}} = \frac{5.45 \times 10^{-3} \text{ kg } HNO_3}{\text{kg U(input)}}$$

6-9. Basis for the following numbers is the use of $1.4 \times 10^6 \text{ ft}^3$ natural gas per year at 1600 Mtu/yr capacity (18, p.3.2-13, 4.3-1) and EPA emission factors (1, p.1.4-2) - industrial boiler.

$$\therefore \frac{5 \times 10^{-3} \text{ kg hydrocarbons/day}}{4404 \text{ kg U/day}} = \frac{1.14 \times 10^{-6} \text{ kg hydrocarbons}}{\text{kg U(input)}}$$

$$\therefore \frac{1 \times 10^{-3} \text{ kg } SO_x/\text{day}}{4404 \text{ kg U/day}} = \frac{2.27 \times 10^{-7} \text{ kg } SO_x}{\text{kg U(input)}}$$

$$\therefore \frac{3 \times 10^{-2} \text{ kg particulate/day}}{4404 \text{ kg U/day}} = \frac{6.81 \times 10^{-6} \text{ kg particulate}}{\text{kg U(input)}}$$

$$\therefore \frac{3 \times 10^{-2} \text{ kg CO/day}}{4404 \text{ kg U/day}} = \frac{6.81 \times 10^{-6} \text{ kg CO}}{\text{kg U(input)}}$$

REFERENCE CALCULATIONS: UO_2 Fuel Fabrication Facility (cont'd)

(See Note)

$$6-10. \frac{0.25 \text{ kg Ag/day}}{4404 \text{ kg U/day}} = 5.68 \times 10^{-5} \frac{\text{kg Ag}}{\text{kg U(input)}}$$

(See Note)

$$6-11. \frac{1.53 \text{ kg Fe/day}}{4404 \text{ kg U/day}} = 3.47 \times 10^{-4} \frac{\text{kg Fe}}{\text{kg U(input)}}$$

(See Note)

$$6-12. \frac{102 \text{ kg Na/day}}{4404 \text{ kg U/day}} = 2.32 \times 10^{-2} \frac{\text{kg Na}}{\text{kg U(input)}}$$

(See Note)

$$6-13. \frac{1692 \text{ kg Ca/day}}{4404 \text{ kg U/day}} = 3.84 \times 10^{-1} \frac{\text{kg Ca}}{\text{kg U(input)}}$$

(See Note)

$$6-14. \frac{3.92 \text{ kg Mg/day}}{4404 \text{ kg U/day}} = 8.90 \times 10^{-4} \frac{\text{kg Mg}}{\text{kg U(input)}}$$

(See Note)

$$6-15. \frac{0.073 \text{ kg Mn/day}}{4404 \text{ kg U/day}} = 1.66 \times 10^{-5} \frac{\text{kg Mn}}{\text{kg U(input)}}$$

REFERENCE CALCULATIONS: UO_2 Fuel Fabrication Facility (cont'd)

$$6-16. \frac{\text{(See Note)}}{4404 \text{ kg U/day}} = 7.49 \times 10^{-5} \frac{\text{kg Mo}}{\text{kg U(input)}}$$

$$6-17. \frac{\text{(See Note)}}{4404 \text{ kg U/day}} = 1.59 \times 10^{-4} \frac{\text{kg Ni}}{\text{kg U(input)}}$$

$$6-18. \frac{\text{(See Note)}}{4404 \text{ kg U/day}} = 2.79 \times 10^{-4} \frac{\text{kg B}}{\text{kg U(input)}}$$

$$6-19. \frac{\text{(See Note)}}{4404 \text{ kg U/day}} = 1.75 \times 10^{-2} \frac{\text{kg Cl}}{\text{kg U(input)}}$$

$$6-20. \frac{\text{(See Note)}}{4404 \text{ kg U/day}} = 4.61 \times 10^{-4} \frac{\text{kg P}}{\text{kg U(input)}}$$

$$6-21. \frac{\text{(See Note)}}{4404 \text{ kg U/day}} = 8.81 \times 10^{-2} \frac{\text{kg N}}{\text{kg U(input)}}$$

REFERENCE CALCULATIONS: UO_2 Fuel Fabrication Facility (cont'd)

6-22. $\frac{\text{(See Note)} \quad 6.83 \text{ kg NH}_3/\text{day}}{4404 \text{ kg U/day}} = \frac{1.55 \times 10^{-3} \text{ kg NH}_3}{\text{kg U(input)}}$

6-23. $\frac{\text{(See Note)} \quad 11.34 \text{ kg F/day}}{4404 \text{ kg U/day}} = \frac{2.57 \times 10^{-3} \text{ kg F}}{\text{kg U(input)}}$

6-24. $\frac{\text{(See Note)} \quad 129 \text{ kg SO}_4/\text{day}}{4404 \text{ kg U/day}} = \frac{2.93 \times 10^{-2} \text{ kg SO}_4}{\text{kg U(input)}}$

6-25. $\frac{\text{(See Note)} \quad 1.67 \text{ kg SO}_3/\text{day}}{4404 \text{ kg U/day}} = \frac{3.79 \times 10^{-4} \text{ kg SO}_3}{\text{kg U(input)}}$

6-26. $\frac{\text{(See Note)} \quad 5.67 \text{ kg oil and grease/day}}{4404 \text{ kg U/day}} = \frac{1.29 \times 10^{-3} \text{ kg oil and grease}}{\text{kg U(input)}}$

6-27. $\frac{\text{(See Note)} \quad 730.4 \text{ kg Ca CO}_3/\text{day}}{4404 \text{ kg U/day}} = \frac{1.66 \times 10^{-1} \text{ kg Ca CO}_3}{\text{kg U(input)}}$

A.66

REFERENCE CALCULATIONS: UO_2 Fuel Fabrication Facility (cont'd)

6-28. $(\text{from ref.calc. 6-1})$
 $1.17 \times 10^{-6} \frac{\text{kg U}}{\text{kg U(input)}} \times \frac{(4, \text{p.B-35})}{[99.9994\% - (3.2\% + (0.0054\% \times 2.84))]} \frac{(20)}{=} 1.13 \times 10^{-6} \frac{\text{kg } ^{238}\text{U}}{\text{kg U(input)}}$

$(\text{from ref.calc. 6-1})$
 $1.17 \times 10^{-6} \frac{\text{kg U}}{\text{kg U(input)}} \times 3.2\% = 3.74 \times 10^{-8} \frac{\text{kg } ^{235}\text{U}}{\text{kg U(input)}}$

$(\text{from ref.calc. 6-1})$
 $1.17 \times 10^{-6} \frac{\text{kg U}}{\text{kg U(input)}} \times \frac{(4, \text{p.B-35})}{(0.0054\% \times 2.84)} \frac{(20)}{=} 1.79 \times 10^{-10} \frac{\text{kg } ^{234}\text{U}}{\text{kg U(input)}}$

6-29. $(\text{from ref.calc. 6-2})$
 $1.19 \times 10^{-7} \frac{\text{kg U}}{\text{kg U(input)}} \times \frac{(4, \text{p.B-35})}{[99.9994\% - (3.2\% + (0.0054\% \times 2.84))]} \frac{(20)}{=} 1.15 \times 10^{-7} \frac{\text{kg } ^{238}\text{U}}{\text{kg U(input)}}$

$(\text{from ref.calc. 6-2})$
 $1.19 \times 10^{-7} \frac{\text{kg U}}{\text{kg U(input)}} \times 3.2\% = 3.81 \times 10^{-9} \frac{\text{kg } ^{235}\text{U}}{\text{kg U(input)}}$

$(\text{from ref.calc. 6-2})$
 $1.19 \times 10^{-7} \frac{\text{kg U}}{\text{kg U(input)}} \times \frac{(4, \text{p.B-35})}{(0.0054\% \times 2.84)} \frac{(20)}{=} 1.82 \times 10^{-11} \frac{\text{kg } ^{234}\text{U}}{\text{kg U(input)}}$

NOTE: Many of the references used in this section were obtained through use of the references and other extensively footnoted data contained in the 800 pages of: "Description and Analysis of Reference Fuel Fabrication Facilities for LWR UO_2 and UO_2 -- PuO_2 Fuels" prepared by Wendell J. Bailey, Battelle Pacific Northwest Laboratories. Unfortunately, it has not as yet been released for publication, and therefore cannot be used as a direct reference.

MOX FUEL FABRICATION CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)

F-4-26-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium (enriched 3.2%)	1×10^{-11}	2	7-1	2×10^{-10}	1	7-2
Plutonium	7×10^{-13}	2	7-3	7×10^{-12}	1	7-4
Hydrogen (H ₂)	9×10^{-3}	2	7-5			
Helium (He)						
Nitrogen (N ₂)	2	2	7-6			
Sulfur Oxide (SO _x)	1×10^{-5}	2	7-7			
Nitrogen Dioxide (NO ₂)	1×10^{-4}	2	7-8			
Hydrocarbon	1×10^{-3}	1	7-9			
Phosphate (PO ₄)				9×10^{-5}	2	7-10
Nitrate (NO ₃)				3×10^{-3}	2	7-11
Sodium (Na)				1×10^{-3}	2	7-12
Chloride (Cl)				2×10^{-5}	2	7-13
Sulfate (SO ₄)				7×10^{-5}	2	7-14

MOX FUEL FABRICATION RADIONUCLIDE RELEASE FACTOR Kg/Kg U (INPUT)						F-4-26-77
Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Uranium (enriched 3.2%)						
*Uranium - 238	1.42×10^{-11}	2	7-15	1.52×10^{-10}	1	7-15
*Uranium - 235	4.70×10^{-13}	2	7-15	5.02×10^{-12}	1	7-15
*Uranium - 234	2.25×10^{-15}	2	7-15	2.40×10^{-14}	1	7-15
Plutonium						
*Plutonium - 242	6.25×10^{-14}	2	7-16	6.66×10^{-13}	1	7-16
*Plutonium - 241	1.11×10^{-13}	2	7-16	1.18×10^{-12}	1	7-16
*Plutonium - 240	1.87×10^{-13}	2	7-16	2.00×10^{-12}	1	7-16
*Plutonium - 239	3.16×10^{-13}	2	7-16	3.37×10^{-12}	1	7-16
*Plutonium - 238	1.74×10^{-14}	2	7-16	1.85×10^{-13}	1	7-16

* Has Data Base In Computer Model

REFERENCE CALCULATIONS: MOX FUEL FABRICATION FACILITY (365 Operating Days/yr)

4-26-77

7-1. U input to MOX fuel fabrication facility:

(See Note)

$$930 \frac{\text{kg U(enriched to 3.2\% } ^{235}\text{U)}}{\text{day}}$$

U airborne output from the MOX fuel fabrication facility:

(See Note)

$$\frac{1.37 \times 10^{-8} \text{ kg U/day}}{930 \text{ kg U/day}} = 1.47 \times 10^{-11} \frac{\text{kg U(airborne)}}{\text{kg U(input)}}$$

(See Note)

$$7-2. \frac{1.46 \times 10^{-7} \text{ kg U/day}}{930 \text{ kg U/day}} = 1.57 \times 10^{-10} \frac{\text{kg U(liquid)}}{\text{kg U(input)}}$$

(See Note)

$$7-3. \frac{6.45 \times 10^{-10} \text{ kg Pu/day}}{930 \text{ kg U/day}} = 6.94 \times 10^{-13} \frac{\text{kg Pu (airborne)}}{\text{kg U(input)}}$$

(See Note)

$$7-4. \frac{6.88 \times 10^{-9} \text{ kg Pu/day}}{930 \text{ kg U/day}} = 7.40 \times 10^{-12} \frac{\text{kg Pu(liquid)}}{\text{kg U(input)}}$$

REFERENCE CALCULATIONS: MOX Fuel Fabrication Facility (cont'd)

(See Note)

$$7-5. \frac{8.3553 \text{ kg H}_2/\text{day}}{930 \text{ kg U/day}} = \frac{8.98 \times 10^{-3} \text{ kg H}_2}{\text{kg U(input)}}$$

(See Note)

$$7-6. \frac{1821 \text{ kg N}_2/\text{day}}{930 \text{ kg U/day}} = \frac{1.96 \text{ kg N}_2}{\text{kg U(input)}}$$

(See Note)

$$7-7. \frac{0.011 \text{ kg SO}_3/\text{day}}{930 \text{ kg U/day}} = \frac{1.18 \times 10^{-5} \text{ kg SO}_3}{\text{kg U(input)}}$$

(See Note)

$$7-8. \frac{0.104 \text{ kg NO}_2/\text{day}}{930 \text{ kg U/day}} = \frac{1.12 \times 10^{-4} \text{ kg NO}_2}{\text{kg U(input)}}$$

7-9. Assuming all the die lubricant used in the presses is driven off in the sintering furnaces as hydrocarbons then:

$$400 \text{ metric tons (U \& PU)} \times \frac{\sim 270 \text{ MOX}}{\sim 238 \text{ (U \& PU)}} \times \frac{10^3 \text{ kg}}{\text{metric ton}} \times \frac{\text{yr}}{365 \text{ days}} \times \frac{\text{(See Note)}}{0.1\% \text{ die lubricant}} =$$

REFERENCE CALCULATIONS: MOX Fuel Fabrication Facility (cont'd)

1.24 $\frac{\text{kg hydrocarbons}}{\text{day}}$

$$\therefore \frac{1.24 \text{ kg hydrocarbons/day}}{930 \text{ kg U/day}} = 1.34 \times 10^{-3} \frac{\text{kg hydrocarbons}}{\text{kg U(input)}}$$

(assumed
(21, p.3.5-4))

$$7-10. \frac{0.18 \text{ lbs PO}_4^{-3}}{\text{day}} \times \frac{\text{kg}}{2.205 \text{ lbs}} = \frac{8.16 \times 10^{-2} \text{ kg PO}_4^{-3}}{\text{day}}$$

$$\therefore \frac{8.16 \times 10^{-2} \text{ kg PO}_4^{-3}/\text{day}}{930 \text{ kg U/day}} = \frac{8.78 \times 10^{-5} \text{ kg PO}_4^{-3}}{\text{kg U(input)}}$$

Airborne Pu:

$$\begin{array}{l} \text{(from ref.calc. 7-3)} \\ 6.94 \times 10^{-13} \frac{\text{kg Pu}}{\text{kg U(input)}} \end{array} \times \begin{array}{l} \text{(see} \\ \text{(above)} \\ 0.09 \end{array} = 6.25 \times 10^{-14} \frac{\text{kg } ^{242}\text{Pu}}{\text{kg U(input)}}$$

$$\begin{array}{l} \text{(from ref.calc. 7-3)} \\ 6.94 \times 10^{-13} \frac{\text{kg Pu}}{\text{kg U(input)}} \end{array} \times \begin{array}{l} \text{(see} \\ \text{(above)} \\ 0.16 \end{array} = 1.11 \times 10^{-13} \frac{\text{kg } ^{241}\text{Pu}}{\text{kg U(input)}}$$

REFERENCE CALCULATIONS: MOX Fuel Fabrication Facility (cont'd)

$$\begin{array}{l} \text{(from ref.calc. 7-3)} \\ 6.94 \times 10^{-13} \frac{\text{kg Pu}}{\text{kg U(input)}} \end{array} \times \begin{array}{l} \text{(see} \\ \text{(above)} \\ 0.27 \end{array} = 1.87 \times 10^{-13} \frac{\text{kg } ^{240}\text{Pu}}{\text{kg U(input)}}$$

$$\begin{array}{l} \text{(from ref.calc. 7-3)} \\ 6.94 \times 10^{-13} \frac{\text{kg Pu}}{\text{kg U(input)}} \end{array} \times \begin{array}{l} \text{(see} \\ \text{(above)} \\ 0.455 \end{array} = 3.16 \times 10^{-13} \frac{\text{kg } ^{239}\text{Pu}}{\text{kg U(input)}}$$

$$\begin{array}{l} \text{(from ref.calc. 7-3)} \\ 6.94 \times 10^{-13} \frac{\text{kg Pu}}{\text{kg U(input)}} \end{array} \times \begin{array}{l} \text{(see} \\ \text{(above)} \\ 0.025 \end{array} = 1.74 \times 10^{-14} \frac{\text{kg } ^{238}\text{Pu}}{\text{kg U(input)}}$$

Liquid Pu:

$$\begin{array}{l} \text{(from ref.calc. 7-4)} \\ 7.40 \times 10^{-12} \frac{\text{kg Pu}}{\text{kg U(input)}} \end{array} \times \begin{array}{l} \text{(see} \\ \text{(above)} \\ 0.09 \end{array} = 6.66 \times 10^{-13} \frac{\text{kg } ^{242}\text{Pu}}{\text{kg U(input)}}$$

$$\begin{aligned} 7-11. & \left[\left(\begin{array}{l} \text{(assumed} \\ \text{(21, p.3.5-4)} \\ 8.5 \text{ lbs NaNO}_3 \end{array} \right) \times \frac{\text{kg}}{\text{day}} \times \frac{62 \text{ kg NO}_3}{2.205 \text{ lbs} \times 85 \text{ kg NaNO}_3} \right) + \left(\begin{array}{l} \text{(assumed} \\ \text{(21, p.3.5-4)} \\ 0.06 \text{ lbs HNO}_3 \end{array} \right) \times \frac{\text{kg}}{\text{day}} \times \frac{62 \text{ kg NO}_3}{2.205 \text{ lbs} \times 63 \text{ kg HNO}_3} \right)] \\ & = \frac{2.84 \text{ kg NO}_3}{\text{day}} \therefore \frac{2.84 \text{ kg NO}_3/\text{day}}{930 \text{ kg U/day}} = 3.05 \times 10^{-3} \frac{\text{kg NO}_3}{\text{kg U(input)}} \end{aligned}$$

REFERENCE CALCULATIONS: MOX Fuel Fabrication Facility (cont'd)

$$7-12. \left[\left(\frac{\text{(assumed)} \\ (21, \text{p.3.5-4}) \\ 8.5 \text{ lbs NaNO}_3}{\text{day}} \times \frac{\text{kg}}{2.205 \text{ lbs}} \times \frac{23 \text{ kg Na}}{85 \text{ kg NaNO}_3} \right) + \left(\frac{\text{(assumed)} \\ (21, \text{p.3.5-4}) \\ 1.23 \text{ lbs NaOH}}{\text{day}} \times \frac{\text{kg}}{2.205 \text{ lbs}} \times \frac{23 \text{ kg Na}}{40 \text{ kg NaOH}} \right) \right] =$$

$$\frac{1.36 \text{ kg Na}}{\text{day}} \therefore \frac{1.36 \text{ kg Na/day}}{930 \text{ kg U/day}} = 1.47 \times 10^{-3} \frac{\text{kg Na}}{\text{kg U(input)}}$$

$$7-13. \frac{\text{(assumed)} \\ (21, \text{p.3.5-4}) \\ 0.04 \text{ lbs HCl}}{\text{day}} \times \frac{\text{kg}}{2.205 \text{ lbs}} \times \frac{35.5 \text{ kg Cl}}{36.5 \text{ kg HCl}} = 1.76 \times 10^{-2} \frac{\text{kg Cl}}{\text{day}}$$

$$\therefore \frac{1.76 \times 10^{-2} \text{ kg Cl/day}}{930 \text{ kg U/day}} = 1.90 \times 10^{-5} \frac{\text{kg Cl}}{\text{kg U(input)}}$$

$$7-14. \frac{\text{(assumed)} \\ (21, \text{p.3.5-4}) \\ 0.14 \text{ lbs H}_2\text{SO}_4}{\text{day}} \times \frac{\text{kg}}{2.205 \text{ lbs}} \times \frac{96 \text{ kg SO}_4}{98 \text{ kg H}_2\text{SO}_4} = 6.22 \times 10^{-2} \frac{\text{kg SO}_4}{\text{day}}$$

$$\therefore \frac{6.22 \times 10^{-2} \text{ kg SO}_4/\text{day}}{930 \text{ kg U/day}} = 6.69 \times 10^{-5} \frac{\text{kg SO}_4}{\text{kg U(input)}}$$

REFERENCE CALCULATIONS: MOX Fuel Fabrication Facility (cont'd)

- 7-15. Assuming isotopic compositions for uranium of 96.7841% ^{238}U , 3.2% ^{235}U , and 0.0153% ^{234}U as calculated in ref. calc. 6-28, 6-29 then:

Airborne U:

$$\begin{array}{l} \text{(from ref. calc. 7-1)} \quad \quad \quad \text{(see} \\ 1.47 \times 10^{-11} \frac{\text{kg U(airborne)}}{\text{kg U(input)}} \times \text{(above)} \\ \quad \quad \quad \times .967841 = 1.42 \times 10^{-11} \frac{\text{kg } ^{238}\text{U}}{\text{kg U(input)}} \end{array}$$

$$\begin{array}{l} \text{(from ref. calc. 7-1)} \quad \quad \quad \text{(see} \\ 1.47 \times 10^{-11} \frac{\text{kg U(airborne)}}{\text{kg U(input)}} \times \text{(above)} \\ \quad \quad \quad \times 0.032 = 4.70 \times 10^{-13} \frac{\text{kg } ^{235}\text{U}}{\text{kg U(input)}} \end{array}$$

$$\begin{array}{l} \text{(from ref. calc. 7-1)} \\ 1.47 \times 10^{-11} \frac{\text{kg U(airborne)}}{\text{kg U(input)}} \times \text{(see above)} \\ \quad \quad \quad \times 0.000153 = 2.25 \times 10^{-15} \frac{\text{kg } ^{234}\text{U}}{\text{kg U(input)}} \end{array}$$

Liquid U:

$$\begin{array}{l} \text{(from ref. calc. 7-2)} \quad \quad \quad \text{(see above)} \\ 1.57 \times 10^{-10} \frac{\text{kg U(liquid)}}{\text{kg U(input)}} \times \text{(see above)} \\ \quad \quad \quad \times .967841 = 1.52 \times 10^{-10} \frac{\text{kg } ^{238}\text{U}}{\text{kg U(input)}} \end{array}$$

$$\begin{array}{l} \text{(from ref. calc. 7-2)} \quad \quad \quad \text{(see} \\ 1.57 \times 10^{-10} \frac{\text{kg U(liquid)}}{\text{kg U(input)}} \times \text{(above)} \\ \quad \quad \quad \times 0.032 = 5.02 \times 10^{-12} \frac{\text{kg } ^{235}\text{U}}{\text{kg U(input)}} \end{array}$$

REFERENCE CALCULATIONS: MOX Fuel Fabrication Facility (cont'd)

(from ref.calc. 7-2)

$$1.57 \times 10^{-10} \frac{\text{kg U(liquid)}}{\text{kg U(input)}} \times \frac{(\text{see above})}{0.000153} = 2.40 \times 10^{-14} \frac{\text{kg } ^{234}\text{U}}{\text{kg U(input)}}$$

7-16. Assuming isotopic compositions for plutonium of 9% ^{242}Pu , 16% ^{241}Pu , 27% ^{240}Pu , 45.5% ^{239}Pu ,
(See Note)
2.5% ^{238}Pu from them:

$$\begin{array}{l} \text{(from ref.calc. 7-4)} \\ 7.40 \times 10^{-12} \frac{\text{kg Pu}}{\text{kg U(input)}} \end{array} \times \begin{array}{l} \text{(see} \\ \text{above)} \\ 0.16 \end{array} = 1.18 \times 10^{-12} \frac{\text{kg } ^{241}\text{Pu}}{\text{kg U(input)}}$$

$$\begin{array}{l} \text{(from ref.calc. 7-4)} \\ 7.40 \times 10^{-12} \frac{\text{kg Pu}}{\text{kg U(input)}} \end{array} \times \begin{array}{l} \text{(see} \\ \text{above)} \\ 0.27 \end{array} = 2.00 \times 10^{-12} \frac{\text{kg } ^{240}\text{Pu}}{\text{kg U(input)}}$$

$$\begin{array}{l} \text{(from ref.calc. 7-4)} \\ 7.40 \times 10^{-12} \frac{\text{kg Pu}}{\text{kg U(input)}} \end{array} \times \begin{array}{l} \text{(see} \\ \text{above)} \\ 0.455 \end{array} = 3.37 \times 10^{-12} \frac{\text{kg } ^{239}\text{Pu}}{\text{kg U(input)}}$$

$$\begin{array}{l} \text{(from ref.calc. 7-4)} \\ 7.40 \times 10^{-12} \frac{\text{kg Pu}}{\text{kg U(input)}} \end{array} \times \begin{array}{l} \text{(see} \\ \text{above)} \\ 0.025 \end{array} = 1.85 \times 10^{-13} \frac{\text{kg } ^{238}\text{Pu}}{\text{kg U(input)}}$$

NOTE: Many of the references used in this section were obtained through use of the references and other extensively footnoted data contained in the 800 pages of: "Description and Analysis of Reference Fuel Fabrication Facilities for LWR UO_2 and UO_2 -- PuO_2 Fuels" prepared by Wendell J. Bailey, Battelle Pacific Northwest Laboratories. Unfortunately, it has not as yet been released for publication, and therefore cannot be used as a direct reference.

PWR REACTOR CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Argon	2.0×10^{-14}	2	8-2			
Krypton	5.9×10^{-8}	2	8-51			
Xenon	7.8×10^{-10}	2	8-52			
Rubidium	1.9×10^{-17}	2	8-53	1.6×10^{-16}	2	8-69
Cesium	7.0×10^{-13}	2	8-54	4.3×10^{-11}	2	8-70
Bromine	6.2×10^{-19}	2	8-55	2.4×10^{-18}	2	8-67
Iodine	5.4×10^{-15}	2	8-56	3.3×10^{-13}	2	8-68
Chromium	1.5×10^{-16}	2	8-9	3.3×10^{-15}	2	8-32
Manganese	1.8×10^{-15}	2	8-10	8.9×10^{-15}	2	8-33
Iron	4.7×10^{-15}	2	8-57	1.1×10^{-13}	2	8-71
Cobalt	2.3×10^{-14}	2	8-58	5.3×10^{-13}	2	8-72
Strontium	1.3×10^{-15}	2	8-59	1.3×10^{-14}	2	8-73
Yttrium	5.8×10^{-16}	2	8-60	1.3×10^{-14}	2	8-74
Zirconium	2.2×10^{-17}	2	8-15	1.8×10^{-15}	2	8-38
Niobium	9.9×10^{-18}	2	8-16	1.2×10^{-15}	2	8-39
Molybdenum	6.0×10^{-15}	2	8-17	1.1×10^{-13}	2	8-40
Technetium	4.8×10^{-16}	2	8-18			
Ruthenium	3.0×10^{-17}	2	8-61	7.8×10^{-16}	2	8-75
Rhodium	1.2×10^{-20}	2	8-62	2.3×10^{-19}	2	8-76
Silver				1.8×10^{-15}	2	8-43
Tellurium	1.1×10^{-15}	2	8-63	2.4×10^{-14}	2	8-77
Barium	2.2×10^{-17}	2	8-64	4.6×10^{-16}	2	8-78

PWR REACTOR (cont'd) CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Lanthanum	2.0×10^{-18}	2	8-23	5.2×10^{-17}	2	8-46
Cerium	9.4×10^{-17}	2	8-65	3.2×10^{-14}	2	8-79
Praseodymium	5.2×10^{-18}	2	8-66	1.2×10^{-16}	2	8-80
Neptunium	3.5×10^{-17}	2	8-26	5.8×10^{-16}	2	8-49
Tritium	1.0×10^{-9}	2	8-27	3.5×10^{-9}	2	8-50
Sulfate (SO ₄)				7×10^1	2	8-81
Volatile Amines				9×10^{-4}	2	8-82
Boron (B)				6×10^{-3}	2	8-83
Sodium (Na)				7	2	8-84
Sulfite (SO ₃)				7×10^{-5}	2	8-85
Orthophosphate				2×10^{-2}	2	8-87
Alum						
Sulfuric Acid (H ₂ SO ₄)	x					
Chlorine (Cl ₂)	x			x		
Carbon Monoxide (CO)	x					
Nitrogen Oxide (NO _x)	x					
Sulfur Oxide (SO _x)	x					
Aldehyde	x					
Nonradioactive						
Particulate	x					

PWR REACTOR (cont'd) CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Hydrocarbon	x					
Chloride				x		
Oil and Grease				x		

PWR REACTOR RADIONUCLIDE RELEASE FACTORS			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	
Air Borne			Liquid			
Material Released	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Argon - 41	1.0	2	8-86-1			
Krypton						
Krypton - 83M	4.8×10^{-7}	2	8-86-2			
Krypton - 85M	7.7×10^{-7}	2	8-86-3			
Krypton - 85	2.0×10^{-3}	2	8-86-4			
Krypton - 87	2.2×10^{-7}	2	8-86-5			
Krypton - 88	5.1×10^{-7}	2	8-86-6			
Krypton - 89	9.9×10^{-9}	2	8-86-7			
Xenon						
Xenon - 131M	1.4×10^{-3}	2	8-86-8			
Xenon - 133M	1.6×10^{-5}	2	8-86-9			
Xenon - 133	7.9×10^{-5}	2	8-86-10			
Xenon - 135M	3.8×10^{-8}	2	8-86-11			
Xenon - 135	1.4×10^{-6}	2	8-86-12			
Xenon - 137	7.4×10^{-9}	2	8-86-13			
Xenon - 138	3.7×10^{-8}	2	8-86-14			
Rubidium						
Rubidium - 86	1.4×10^{-9}	2	8-86-15	2.8×10^{-8}	2	8-86-77
Rubidium - 88	2.4×10^{-9}	2	8-86-16	3.0×10^{-11}	2	8-86-78

PWR REACTOR RADIONUCLIDE RELEASE FACTORS			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	
Air Borne			Liquid			
Material Released	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Cesium						
Cesium - 134	2.2×10^{-10}	2	8-86-17	1.8×10^{-8}	2	8-86-79
Cesium - 136	1.7×10^{-9}	2	8-86-18	3.5×10^{-8}	2	8-86-80
Cesium - 137	5.9×10^{-10}	2	8-86-19	3.2×10^{-8}	2	8-86-81
Bromine						
Bromine - 83	1.5×10^{-10}	2	8-86-20	6.4×10^{-10}	2	8-86-68
Bromine - 84	3.0×10^{-11}	2	8-86-21	8.4×10^{-12}	2	8-86-69
Bromine - 85	3.3×10^{-12}	2	8-86-22	5.2×10^{-15}	2	8-86-70
Iodine						
Iodine - 130	1.2×10^{-10}	2	8-86-23	2.9×10^{-9}	2	8-86-71
Iodine - 131	6.9×10^{-10}	2	8-86-24	4.4×10^{-8}	2	8-86-72
Iodine - 132	1.6×10^{-10}	2	8-86-25	3.4×10^{-9}	2	8-86-73
Iodine - 133	4.2×10^{-10}	2	8-86-26	1.7×10^{-8}	2	8-86-74
Iodine - 134	4.6×10^{-11}	2	8-86-27	3.7×10^{-11}	2	8-86-75
Iodine - 135	2.5×10^{-10}	2	8-86-28	3.4×10^{-9}	2	8-86-76
Chromium - 51	5.6×10^{-8}	2	8-86-29	1.2×10^{-6}	2	8-86-82
Manganese - 54	1.8×10^{-6}	2	8-86-30	8.7×10^{-6}	2	8-86-83
Iron						
Iron - 55	2.7×10^{-7}	2	8-86-31	6.2×10^{-6}	2	8-86-84
Iron - 59	1.8×10^{-6}	2	8-86-32	4.8×10^{-5}	2	8-86-85

PWR REACTOR RADIONUCLIDE RELEASE FACTORS			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	
Air Borne			Liquid			
Material Released	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Cobalt						
Cobalt - 58	1.1×10^{-6}	2	8-86-33	4.5×10^{-5}	2	8-86-86
Cobalt - 60	3.7×10^{-5}	2	8-86-34	8.1×10^{-4}	2	8-86-87
Strontium						
Stronium - 89	1.5×10^{-12}	2	8-86-35	7.7×10^{-11}	2	8-86-88
Stronium - 90	2.4×10^{-12}	2	8-86-36	2.1×10^{-11}	2	8-86-89
Stronium - 91	4.7×10^{-12}	2	8-86-37	2.8×10^{-11}	2	8-86-90
Yttrium						
Yttrium - 90	1.4×10^{-12}	2	8-86-38	3.1×10^{-11}	2	8-86-91
Yttrium - 91M	4.7×10^{-12}	2	8-86-39	3.0×10^{-11}	2	8-86-92
Yttrium - 91	1.5×10^{-11}	2	8-86-40	3.5×10^{-10}	2	8-86-93
Yttrium - 93	7.4×10^{-13}	2	8-86-41	4.9×10^{-13}	2	8-86-94
Zirconium - 95	3.4×10^{-13}	2	8-86-42	2.7×10^{-11}	2	8-86-95
Niobium - 95	2.8×10^{-13}	2	8-86-43	3.5×10^{-11}	2	8-86-96
Molybdenum - 99	1.9×10^{-9}	2	8-86-44	3.6×10^{-8}	2	8-86-97
Technetium - 99M	1.9×10^{-9}	2	8-86-45			
Ruthenium						
Ruthenium - 103	2.6×10^{-13}	2	8-86-46	8.1×10^{-12}	2	8-86-98
Ruthenium - 106	1.2×10^{-13}	2	8-86-47	2.9×10^{-12}	2	8-86-99

PWR REACTOR RADIONUCLIDE RELEASE FACTORS				kg Effluent kg Contained	OR	Ci Effluent Ci Contained	
Air Borne				Liquid			
Material Released	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.	
Rhodium							
Rhodium - 103M	2.6×10^{-13}	2	8-86-48	5.9×10^{-12}	2	8-86-100	
Rhodium - 106	1.0×10^{-11}	2	8-86-49	6.0×10^{-11}	2	8-86-101	
Silver - 110M				2.3×10^{-9}	2	8-86-102	
Tellurium							
Tellurium - 125M	6.0×10^{-11}	2	8-86-50	1.5×10^{-9}	2	8-86-103	
Tellurium - 127M	1.2×10^{-10}	2	8-86-51	3.1×10^{-9}	2	8-86-104	
Tellurium - 127	8.1×10^{-11}	2	8-86-52	9.7×10^{-10}	2	8-86-105	
Tellurium - 129M	1.6×10^{-10}	2	8-86-53	3.9×10^{-9}	2	8-86-106	
Tellurium - 129	3.2×10^{-11}	2	8-86-54	4.3×10^{-10}	2	8-86-107	
Tellurium - 131M	1.4×10^{-10}	2	8-86-55	1.7×10^{-9}	2	8-86-108	
Tellurium - 131	9.6×10^{-12}	2	8-86-56	5.5×10^{-11}	2	8-86-109	
Tellurium - 132	1.6×10^{-10}	2	8-86-57	2.9×10^{-9}	2	8-86-110	
Barium							
Barium - 137M	5.2×10^{-15}	2	8-86-58	1.6×10^{-17}	2	8-86-111	
Barium - 140	1.1×10^{-12}	2	8-86-59	2.4×10^{-11}	2	8-86-112	
Lanthanum - 140	7.4×10^{-13}	2	8-86-60	2.0×10^{-11}	2	8-86-113	

PWR REACTOR RADIONUCLIDE RELEASE FACTORS			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	
Air Borne			Liquid			
Material Released	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Cerium						
Cerium - 141	3.7×10^{-13}	2	8-86-61	8.1×10^{-12}	2	8-86-114
Cerium - 143	2.2×10^{-13}	2	8-86-62	3.1×10^{-12}	2	8-86-115
Cerium - 144	2.2×10^{-13}	2	8-86-63	9.2×10^{-11}	2	8-86-116
Praseodymium						
Praseodymium - 143	2.9×10^{-13}	2	8-86-64	6.9×10^{-12}	2	8-86-117
Praseodymium - 144	2.2×10^{-13}	2	8-86-65	4.9×10^{-12}	2	8-86-118
Neptunium - 239	4.5×10^{-13}	2	8-86-66	7.6×10^{-12}	2	8-86-119
Tritium (H-3)	2.0×10^{-2}	2	8-86-67	7.1×10^{-2}	2	8-86-120
Carbon - 14						

REFERENCE CALCULATIONS: PWR REACTOR (290 Operating Days/year)

10-1-78

8-1. U input to the PWR reactor assuming 1/3 of the fuel is changed out every year:

(22, p. 11-2) (see above)

$$101,033 \text{ kg UO}_2 \times \frac{238 \text{ U}}{270 \text{ UO}_2} \times \frac{1/3}{1 \text{ year}} \times \frac{\text{year}}{290 \text{ operating days}} = 102 \frac{\text{kg U}}{\text{day}}$$

Reference calculations through use the following format for calculation of numbers:

$$\frac{\text{A Ci radionuclide}}{\text{year}} \times \frac{\text{year}}{290 \text{ op. days}} \times \frac{\text{g radionuclide}}{\text{B Ci radionuclide}} \times \frac{\text{kg}}{10^3 \text{ g}} = \frac{\text{C kg radionuclide}}{\text{operating days}}$$

Note: All A values in reference calculations 8-2 through 8-27 are from reference 32, table 11.3-3;
all A values in reference calculations 8-28 through 8-50 are from reference 32, table 11.2-12.
All B values in reference calculations 8-51 through 8-87 are from reference 24.

8-2. Argon 41:

$$A = 2.5 \times 10^1 \quad B = \overset{(\#71)}{4.18 \times 10^7} \quad C = 2.06 \times 10^{-12} \quad D = 2.02 \times 10^{-14}$$

8-3. Krypton 83M:

$$A = 8.26 \times 10^{-1} \quad B = \overset{(\#1)}{2.03 \times 10^7} \quad C = 1.40 \times 10^{-13} \quad D = 1.38 \times 10^{-15}$$

Krypton 85M:

$$A = 4.17 \quad B = \overset{(\#2)}{8.40 \times 10^6} \quad C = 1.71 \times 10^{-12} \quad D = 1.68 \times 10^{-14}$$

Krypton 85:

$$A = 6.80 \times 10^2 \quad B = \overset{(\#3)}{3.91 \times 10^2} \quad C = 6.00 \times 10^{-6} \quad D = 5.88 \times 10^{-8}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

Krypton 87:

$$\begin{array}{llll} A = 2.29 & B = \overset{(\#4)}{2.84 \times 10^7} & C = 2.78 \times 10^{-13} & D = 2.73 \times 10^{-15} \end{array}$$

Krypton 88:

$$\begin{array}{llll} A = 7.81 & B = \overset{(\#5)}{1.27 \times 10^7} & C = 2.12 \times 10^{-12} & D = 2.08 \times 10^{-14} \end{array}$$

Krypton 89:

$$\begin{array}{llll} A = 1.89 \times 10^{-1} & B = \overset{(\#6)}{6.60 \times 10^8} & C = 9.87 \times 10^{-16} & D = 9.68 \times 10^{-18} \end{array}$$

8-4. Xenon 131M:

$$\begin{array}{llll} A = 2.89 \times 10^2 & B = \overset{(\#7)}{8.45 \times 10^4} & C = 1.18 \times 10^{-8} & D = 1.16 \times 10^{-10} \end{array}$$

Xenon 133M:

$$\begin{array}{llll} A = 1.76 \times 10^1 & B = \overset{(\#8)}{4.35 \times 10^5} & C = 1.40 \times 10^{-10} & D = 1.37 \times 10^{-12} \end{array}$$

Xenon 133:

$$\begin{array}{llll} A = 3.66 \times 10^3 & B = \overset{(\#9)}{1.86 \times 10^5} & C = 6.79 \times 10^{-8} & D = 6.65 \times 10^{-10} \end{array}$$

Xenon 135M:

$$\begin{array}{llll} A = 4.73 \times 10^{-1} & B = \overset{(\#10)}{8.93 \times 10^7} & C = 1.83 \times 10^{-14} & D = 1.79 \times 10^{-16} \end{array}$$

Xenon 135:

$$\begin{array}{llll} A = 1.56 \times 10^1 & B = \overset{(\#11)}{2.52 \times 10^6} & C = 2.13 \times 10^{-11} & D = 2.09 \times 10^{-13} \end{array}$$

Xenon 137:

$$\begin{array}{llll} A = 3.36 \times 10^{-1} & B = \overset{(\#12)}{3.52 \times 10^8} & C = 3.29 \times 10^{-15} & D = 3.23 \times 10^{-17} \end{array}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

Xenon 138:

$$\begin{array}{llll} A = 1.61 & B = \begin{matrix} (\#13) \\ 8.02 \times 10^7 \end{matrix} & C = 6.92 \times 10^{-14} & D = 6.79 \times 10^{-16} \end{array}$$

8-5. Rubidium 86:

$$\begin{array}{llll} A = 1.96 \times 10^{-5} & B = \begin{matrix} (\#19) \\ 8.14 \times 10^4 \end{matrix} & C = 8.30 \times 10^{-16} & D = 8.14 \times 10^{-18} \end{array}$$

Rubidium 88:

$$\begin{array}{llll} A = 3.73 \times 10^{-2} & B = \begin{matrix} (\#20) \\ 1.20 \times 10^8 \end{matrix} & C = 1.07 \times 10^{-15} & D = 1.05 \times 10^{-17} \end{array}$$

8-6. Cesium 134:

$$\begin{array}{llll} A = 1.62 \times 10^{-3} & B = \begin{matrix} (\#51) \\ 1.3 \times 10^3 \end{matrix} & C = 4.30 \times 10^{-12} & D = 4.21 \times 10^{-14} \end{array}$$

Cesium 136:

$$\begin{array}{llll} A = 2.95 \times 10^{-3} & B = \begin{matrix} (\#52) \\ 7.39 \times 10^4 \end{matrix} & C = 1.38 \times 10^{-13} & D = 1.35 \times 10^{-15} \end{array}$$

Cesium 137:

$$\begin{array}{llll} A = 1.67 \times 10^{-3} & B = \begin{matrix} (\#53) \\ 8.64 \times 10^1 \end{matrix} & C = 6.67 \times 10^{-11} & D = 6.53 \times 10^{-13} \end{array}$$

8-7. Bromine 83:

$$\begin{array}{llll} A = 2.56 \times 10^{-4} & B = \begin{matrix} (\#84) \\ 1.57 \times 10^7 \end{matrix} & C = 5.62 \times 10^{-17} & D = 5.51 \times 10^{-19} \end{array}$$

Bromine 84:

$$\begin{array}{llll} A = 1.33 \times 10^{-4} & B = \begin{matrix} (\#85) \\ 7.04 \times 10^7 \end{matrix} & C = 6.51 \times 10^{-18} & D = 6.39 \times 10^{-20} \end{array}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

Bromine 85:

$$A = 1.58 \times 10^{-5} \quad B = \frac{(\#99)}{7.37 \times 10^8} \quad C = 7.39 \times 10^{-20} \quad D = 7.25 \times 10^{-22}$$

8-8. Iodine 130:

$$A = 1.16 \times 10^{-4} \quad B = \frac{(\#14)}{1.96 \times 10^6} \quad C = 2.04 \times 10^{-16} \quad D = 2.00 \times 10^{-18}$$

Iodine 131:

$$A = 1.72 \times 10^{-2} \quad B = \frac{(\#15)}{1.24 \times 10^5} \quad C = 4.78 \times 10^{-13} \quad D = 4.69 \times 10^{-15}$$

Iodine 132:

$$A = 5.59 \times 10^{-3} \quad B = \frac{(\#16)}{1.03 \times 10^7} \quad C = 1.87 \times 10^{-15} \quad D = 1.83 \times 10^{-17}$$

Iodine 133:

$$A = 1.94 \times 10^{-2} \quad B = \frac{(\#17)}{1.13 \times 10^6} \quad C = 5.92 \times 10^{-14} \quad D = 5.80 \times 10^{-16}$$

Iodine 134:

$$A = 2.44 \times 10^{-3} \quad B = \frac{(\#94)}{2.70 \times 10^7} \quad C = 3.12 \times 10^{-16} \quad D = 3.06 \times 10^{-18}$$

Iodine 135:

$$A = 1.03 \times 10^{-2} \quad B = \frac{(\#18)}{3.47 \times 10^6} \quad C = 1.02 \times 10^{-14} \quad D = 1.00 \times 10^{-16}$$

8-9. Chromium 51:

$$A = 4.18 \times 10^{-4} \quad B = \frac{(\#64)}{9.21 \times 10} \quad C = 1.57 \times 10^{-14} \quad D = 1.53 \times 10^{-16}$$

8-10. Manganese 54:

$$A = 4.24 \times 10^{-4} \quad B = \frac{(\#65)}{7.98 \times 10^3} \quad C = 1.83 \times 10^{-13} \quad D = 1.80 \times 10^{-15}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

8-11. Iron 55:

$$A = 3.35 \times 10^{-4} \quad B = \frac{(\#66)}{2.50 \times 10^3} \quad C = 4.62 \times 10^{-13} \quad D = 4.53 \times 10^{-15}$$

Iron 59:

$$A = 1.77 \times 10^{-4} \quad B = \frac{(\#67)}{4.91 \times 10^4} \quad C = 1.24 \times 10^{-14} \quad D = 1.22 \times 10^{-16}$$

8-12. Cobalt 58:

$$A = 1.91 \times 10^{-3} \quad B = \frac{(\#68)}{3.16 \times 10^4} \quad C = 2.08 \times 10^{-13} \quad D = 2.04 \times 10^{-15}$$

Cobalt 60:

$$A = 6.86 \times 10^{-4} \quad B = \frac{(\#69)}{1.13 \times 10^3} \quad C = 2.09 \times 10^{-12} \quad D = 2.05 \times 10^{-14}$$

8-13. Strontium 89:

$$A = 3.21 \times 10^{-5} \quad B = \frac{(\#21)}{2.82 \times 10^4} \quad C = 3.93 \times 10^{-15} \quad D = 3.85 \times 10^{-17}$$

Strontium 90:

$$A = 5.47 \times 10^{-6} \quad B = \frac{(\#22)}{1.42 \times 10^2} \quad C = 1.33 \times 10^{-13} \quad D = 1.30 \times 10^{-15}$$

Strontium 91:

$$A = 1.23 \times 10^{-4} \quad B = \frac{(\#23)}{3.56 \times 10^6} \quad C = 1.19 \times 10^{-16} \quad D = 1.17 \times 10^{-18}$$

8-14. Yttrium 90:

$$A = 3.35 \times 10^6 \quad B = \frac{(\#24)}{5.44 \times 10^5} \quad C = 2.12 \times 10^{17} \quad D = 2.08 \times 10^{-19}$$

Yttrium 91M:

$$A = 7.25 \times 10^{-5} \quad B = \frac{(\#25)}{4.13 \times 10^7} \quad C = 6.05 \times 10^{-18} \quad D = 5.93 \times 10^{-20}$$

Yttrium 91:

$$A = 4.18 \times 10^{-4} \quad B = \frac{(\#26)}{2.44 \times 10^4} \quad C = 5.91 \times 10^{-14} \quad D = 5.79 \times 10^{-16}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

Yttrium 93:

$$A = 2.42 \times 10^{-5} \quad B = \frac{(\#27)}{3.31 \times 10^6} \quad C = 2.52 \times 10^{-17} \quad D = 2.47 \times 10^{-19}$$

8-15. Zirconium 95:

$$A = 1.36 \times 10^{-5} \quad B = \frac{(\#28)}{2.12 \times 10^4} \quad C = 2.21 \times 10^{-15} \quad D = 2.17 \times 10^{-17}$$

8-16. Niobium 95:

$$A = 1.15 \times 10^{-5} \quad B = \frac{(\#30)}{3.91 \times 10^4} \quad C = 1.01 \times 10^{-15} \quad D = 9.94 \times 10^{-18}$$

8-17. Molybdenum 99:

$$A = 8.46 \times 10^{-2} \quad B = \frac{(\#33)}{4.75 \times 10^5} \quad C = 6.14 \times 10^{-13} \quad D = 6.02 \times 10^{-15}$$

8-18. Technetium 99M:

$$A = 7.46 \times 10^{-2} \quad B = \frac{(\#34)}{5.28 \times 10^6} \quad C = 4.87 \times 10^{-14} \quad D = 4.78 \times 10^{-16}$$

8-19. Ruthenium 103:

$$A = 9.17 \times 10^{-6} \quad B = \frac{(\#35)}{3.20 \times 10^4} \quad C = 9.88 \times 10^{-16} \quad D = 9.69 \times 10^{-18}$$

Ruthenium 106:

$$A = 1.97 \times 10^{-6} \quad B = \frac{(\#36)}{3.36 \times 10^3} \quad C = 2.02 \times 10^{-15} \quad D = 1.98 \times 10^{-17}$$

8-20. Rhodium 103M:

$$A = 9.12 \times 10^{-6} \quad B = \frac{(\#37)}{3.20 \times 10^7} \quad C = 9.83 \times 10^{-19} \quad D = 9.63 \times 10^{-21}$$

Rhodium 106:

$$A = 2.26 \times 10^{-4} \quad B = \frac{(\#39)}{3.55 \times 10^9} \quad C = 2.20 \times 10^{-19} \quad D = 2.15 \times 10^{-21}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

8-21. Tellurium 125M:

$$A = 5.62 \times 10^{-6} \quad B = \begin{matrix} (\#43) \\ 1.80 \times 10^4 \end{matrix} \quad C = 1.08 \times 10^{-15} \quad D = 1.06 \times 10^{-17}$$

Tellurium 127M:

$$A = 5.56 \times 10^{-5} \quad B = \begin{matrix} (\#44) \\ 9.44 \times 10^3 \end{matrix} \quad C = 2.03 \times 10^{-14} \quad D = 1.99 \times 10^{-16}$$

Tellurium 127:

$$A = 1.67 \times 10^{-4} \quad B = \begin{matrix} (\#45) \\ 2.63 \times 10^6 \end{matrix} \quad C = 2.19 \times 10^{-16} \quad D = 2.15 \times 10^{-18}$$

Tellurium 129M:

$$A = 2.70 \times 10^{-4} \quad B = \begin{matrix} (\#46) \\ 2.98 \times 10^4 \end{matrix} \quad C = 3.12 \times 10^{-14} \quad D = 3.06 \times 10^{-16}$$

Tellurium 129:

$$A = 3.13 \times 10^{-4} \quad B = \begin{matrix} (\#47) \\ 2.11 \times 10^7 \end{matrix} \quad C = 5.12 \times 10^{-17} \quad D = 5.01 \times 10^{-19}$$

Tellurium 131M:

$$A = 5.02 \times 10^{-4} \quad B = \begin{matrix} (\#48) \\ 7.98 \times 10^5 \end{matrix} \quad C = 2.17 \times 10^{-15} \quad D = 2.13 \times 10^{-17}$$

Tellurium 131:

$$A = 2.10 \times 10^{-4} \quad B = \begin{matrix} (\#49) \\ 5.74 \times 10^7 \end{matrix} \quad C = 1.26 \times 10^{-17} \quad D = 1.24 \times 10^{-19}$$

Tellurium 132:

$$A = 5.32 \times 10^{-3} \quad B = \begin{matrix} (\#50) \\ 3.05 \times 10^5 \end{matrix} \quad C = 6.01 \times 10^{-14} \quad D = 5.90 \times 10^{-16}$$

8-22. Barium 137M:

$$A = 3.56 \times 10^{-3} \quad B = \begin{matrix} (\#54) \\ 5.38 \times 10^8 \end{matrix} \quad C = 2.28 \times 10^{-17} \quad D = 2.24 \times 10^{-19}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

Barium 140:

$$A = 4.63 \times 10^{-5} \quad B = \frac{(\#55)}{7.29 \times 10^4} \quad C = 2.19 \times 10^{-15} \quad D = 2.15 \times 10^{-17}$$

8-23. Lanthanum 140:

$$A = 3.22 \times 10^{-5} \quad B = \frac{(\#56)}{5.57 \times 10^5} \quad C = 1.99 \times 10^{-16} \quad D = 1.95 \times 10^{-18}$$

8-24. Cerium 141:

$$A = 1.46 \times 10^{-5} \quad B = \frac{(\#57)}{2.81 \times 10^4} \quad C = 1.79 \times 10^{-15} \quad D = 1.76 \times 10^{-17}$$

Cerium 143:

$$A = 7.72 \times 10^{-6} \quad B = \frac{(\#58)}{6.64 \times 10^5} \quad C = 4.01 \times 10^{-17} \quad D = 3.93 \times 10^{-19}$$

Cerium 144:

$$A = 7.18 \times 10^{-6} \quad B = \frac{(\#59)}{3.18 \times 10^3} \quad C = 7.79 \times 10^{-15} \quad D = 7.63 \times 10^{-17}$$

8-25. Praseodymium 143:

$$A = 1.02 \times 10^{-5} \quad B = \frac{(\#60)}{6.67 \times 10^4} \quad C = 5.27 \times 10^{-16} \quad D = 5.17 \times 10^{-18}$$

Praseodymium 144:

$$A = 7.22 \times 10^{-6} \quad B = \frac{(\#61)}{7.55 \times 10^7} \quad C = 3.30 \times 10^{-19} \quad D = 3.23 \times 10^{-21}$$

8-26. Neptunium 239:

$$A = 2.39 \times 10^{-4} \quad B = \frac{(\#83)}{2.33 \times 10^5} \quad C = 3.54 \times 10^{-15} \quad D = 3.47 \times 10^{-17}$$

8-27. Tritium (H3):

$$A = 2.87 \times 10^2 \quad B = \frac{(\#70)}{9.73 \times 10^3} \quad C = 1.02 \times 10^{-7} \quad D = 9.97 \times 10^{-10}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

8-28. Bromine 83:

$$A = 1.1 \times 10^{-3} \quad B = \frac{(\#84)}{1.57 \times 10^7} \quad C = 2.42 \times 10^{-16} \quad D = 2.37 \times 10^{-18}$$

Bromine 84:

$$A = 3.7 \times 10^{-5} \quad B = \frac{(\#85)}{7.04 \times 10^7} \quad C = 1.81 \times 10^{-18} \quad D = 1.78 \times 10^{-20}$$

Bromine 85:

$$A = 2.5 \times 10^{-8} \quad B = \frac{(\#99)}{7.37 \times 10^8} \quad C = 1.17 \times 10^{-22} \quad D = 1.15 \times 10^{-24}$$

8-29. Iodine 130:

$$A = 2.8 \times 10^{-3} \quad B = \frac{(\#14)}{1.96 \times 10^6} \quad C = 4.93 \times 10^{-15} \quad D = 4.83 \times 10^{-17}$$

Iodine 131:

$$A = 1.1 \quad B = \frac{(\#15)}{1.24 \times 10^5} \quad C = 3.06 \times 10^{-11} \quad D = 3.00 \times 10^{-13}$$

Iodine 132:

$$A = 1.2 \times 10^{-1} \quad B = \frac{(\#16)}{1.03 \times 10^7} \quad C = 4.02 \times 10^{-14} \quad D = 3.94 \times 10^{-16}$$

Iodine 133:

$$A = 7.9 \times 10^{-1} \quad B = \frac{(\#17)}{1.13 \times 10^6} \quad C = 2.41 \times 10^{-12} \quad D = 2.36 \times 10^{-14}$$

Iodine 134:

$$A = 2.0 \times 10^{-3} \quad B = \frac{(\#94)}{2.70 \times 10^7} \quad C = 2.55 \times 10^{-16} \quad D = 2.50 \times 10^{-18}$$

Iodine 135:

$$A = 1.4 \times 10^{-1} \quad B = \frac{(\#18)}{3.47 \times 10^6} \quad C = 1.39 \times 10^{-13} \quad D = 1.36 \times 10^{-15}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

8-30. Rubidium 86:

$$A = 3.9 \times 10^{-4} \quad B = \overset{(\#19)}{8.14 \times 10^4} \quad C = 1.65 \times 10^{-14} \quad D = 1.62 \times 10^{-16}$$

Rubidium 88:

$$A = 4.5E-4 \quad B = \overset{(\#20)}{1.20 \times 10^8} \quad C = 1.29 \times 10^{-17} \quad D = 1.27 \times 10^{-19}$$

8-31. Cesium 134:

$$A = 1.3 \times 10^{-1} \quad B = \overset{(\#51)}{1.30 \times 10^3} \quad C = 3.45 \times 10^{-10} \quad D = 3.38 \times 10^{-12}$$

Cesium 136:

$$A = 6.2 \times 10^{-2} \quad B = \overset{(\#52)}{7.39 \times 10^4} \quad C = 2.89 \times 10^{-12} \quad D = 2.84 \times 10^{-14}$$

Cesium 137:

$$A = 1.0 \times 10^{-1} \quad B = \overset{(\#53)}{8.64 \times 10^1} \quad C = 3.99 \times 10^{-9} \quad D = 3.91 \times 10^{-11}$$

8-32. Chromium 51:

$$A = 9.0 \times 10^{-3} \quad B = \overset{(\#64)}{9.21 \times 10^4} \quad C = 3.37 \times 10^{-13} \quad D = 3.30 \times 10^{-15}$$

8-33. Manganese 54:

$$A = 2.1 \times 10^{-3} \quad B = \overset{(\#65)}{7.98 \times 10^3} \quad C = 9.07 \times 10^{-13} \quad D = 8.90 \times 10^{-15}$$

8-34. Iron 55:

$$A = 7.6 \times 10^{-3} \quad B = \overset{(\#66)}{2.50 \times 10^3} \quad C = 1.05 \times 10^{-11} \quad D = 1.03 \times 10^{-13}$$

Iron 59:

$$A = 4.6 \times 10^{-3} \quad B = \overset{(\#67)}{4.91 \times 10^4} \quad C = 3.23 \times 10^{-13} \quad D = 3.17 \times 10^{-15}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

8-35. Cobalt 58:

$$A = 7.6 \times 10^{-2} \quad B = \begin{matrix} (\#68) \\ 3.16 \times 10^4 \end{matrix} \quad C = 8.29 \times 10^{-12} \quad D = 8.13 \times 10^{-14}$$

Cobalt 60:

$$A = 1.5 \times 10^{-2} \quad B = \begin{matrix} (\#69) \\ 1.13 \times 10^3 \end{matrix} \quad C = 4.58 \times 10^{-11} \quad D = 4.49 \times 10^{-13}$$

8-36. Strontium 89:

$$A = 1.6 \times 10^{-3} \quad B = \begin{matrix} (\#21) \\ 2.82 \times 10^4 \end{matrix} \quad C = 1.96 \times 10^{-13} \quad D = 1.92 \times 10^{-15}$$

Strontium 90:

$$A = 4.7 \times 10^{-5} \quad B = \begin{matrix} (\#22) \\ 1.42 \times 10^2 \end{matrix} \quad C = 1.14 \times 10^{-12} \quad D = 1.12 \times 10^{-14}$$

Strontium 91:

$$A = 7.2 \times 10^{-4} \quad B = \begin{matrix} (\#23) \\ 3.56 \times 10^6 \end{matrix} \quad C = 6.97 \times 10^{-16} \quad D = 6.84 \times 10^{-18}$$

8-37. Yttrium 90:

$$A = 7.4 \times 10^{-5} \quad B = \begin{matrix} (\#24) \\ 5.44 \times 10^5 \end{matrix} \quad C = 4.69 \times 10^{-16} \quad D = 4.60 \times 10^{-18}$$

Yttrium 91M:

$$A = 4.6 \times 10^{-4} \quad B = \begin{matrix} (\#25) \\ 4.13 \times 10^7 \end{matrix} \quad C = 3.84 \times 10^{-17} \quad D = 3.77 \times 10^{-19}$$

Yttrium 91:

$$A = 9.7 \times 10^{-3} \quad B = \begin{matrix} (\#26) \\ 2.44 \times 10^4 \end{matrix} \quad C = 1.37 \times 10^{-12} \quad D = 1.34 \times 10^{-14}$$

Yttrium 93:

$$A = 1.6 \times 10^{-4} \quad B = \begin{matrix} (\#27) \\ 3.31 \times 10^6 \end{matrix} \quad C = 1.67 \times 10^{-16} \quad D = 1.63 \times 10^{-19}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

8-38. Zirconium 95:

$$A = 1.1 \times 10^{-3} \quad B = \frac{(\#28)}{2.12 \times 10^4} \quad C = 1.79 \times 10^{-13} \quad D = 1.75 \times 10^{-15}$$

8-39. Niobium 95:

$$A = 1.4 \times 10^{-3} \quad B = \frac{(\#30)}{3.91 \times 10^4} \quad C = 1.23 \times 10^{-13} \quad D = 1.21 \times 10^{-15}$$

8-40. Molybdenum 99:

$$A = 1.6 \quad B = \frac{(\#33)}{4.75 \times 10^5} \quad C = 1.16 \times 10^{-11} \quad D = 1.14 \times 10^{-13}$$

8-41. Ruthenium 103:

$$A = 2.9 \times 10^{-4} \quad B = \frac{(\#35)}{3.20 \times 10^4} \quad C = 3.13 \times 10^{-14} \quad D = 3.06 \times 10^{-16}$$

Ruthenium 106:

$$A = 4.7 \times 10^{-5} \quad B = \frac{(\#36)}{3.36 \times 10^3} \quad C = 4.82 \times 10^{-14} \quad D = 4.73 \times 10^{-16}$$

8-42. Rhodium 103M:

$$A = 2.1 \times 10^{-4} \quad B = \frac{(\#37)}{3.20 \times 10^7} \quad C = 2.26 \times 10^{-17} \quad D = 2.22 \times 10^{-19}$$

Rhodium 106:

$$A = 1.3 \times 10^{-3} \quad B = \frac{(\#39)}{3.55 \times 10^9} \quad C = 1.26 \times 10^{-18} \quad D = 1.24 \times 10^{-20}$$

8-43. Silver 110M:

$$A = 2.5 \times 10^{-4} \quad B = \frac{(\#100)}{4.69 \times 10^3} \quad C = 1.84 \times 10^{-13} \quad D = 1.80 \times 10^{-15}$$

8-44. Tellurium 125M:

$$A = 1.4 \times 10^{-4} \quad B = \frac{(\#43)}{1.80 \times 10^4} \quad C = 2.68 \times 10^{-14} \quad D = 2.63 \times 10^{-16}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

Tellurium 127M:

$$A = 1.4 \times 10^{-3} \quad B = \frac{(\#44)}{9.44 \times 10^3} \quad C = 5.11 \times 10^{-13} \quad D = 5.01 \times 10^{-15}$$

Tellurium 127:

$$A = 2.0 \times 10^{-3} \quad B = \frac{(\#45)}{2.63 \times 10^6} \quad C = 2.62 \times 10^{-15} \quad D = 2.57 \times 10^{-17}$$

Tellurium 129M:

$$A = 6.4 \times 10^{-3} \quad B = \frac{(\#46)}{2.98 \times 10^4} \quad C = 7.41 \times 10^{-13} \quad D = 7.26 \times 10^{-15}$$

Tellurium 129:

$$A = 4.2 \times 10^{-3} \quad B = \frac{(\#47)}{2.11 \times 10^7} \quad C = 6.86 \times 10^{-16} \quad D = 6.73 \times 10^{-18}$$

Tellurium 131M:

$$A = 6.4 \times 10^{-3} \quad B = \frac{(\#48)}{7.98 \times 10^5} \quad C = 2.77 \times 10^{-14} \quad D = 2.71 \times 10^{-16}$$

Tellurium 131:

$$A = 1.2 \times 10^{-3} \quad B = \frac{(\#49)}{5.74 \times 10^7} \quad C = 7.21 \times 10^{-17} \quad D = 7.07 \times 10^{-19}$$

Tellurium 132:

$$A = 9.9 \times 10^{-2} \quad B = \frac{(\#50)}{3.05 \times 10^5} \quad C = 1.12 \times 10^{-12} \quad D = 1.10 \times 10^{-14}$$

8-45. Barium 137M:

$$A = 1.1 \times 10^{-5} \quad B = \frac{(\#54)}{5.38 \times 10^8} \quad C = 7.05 \times 10^{-20} \quad D = 6.91 \times 10^{-22}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

Barium 140:

$$A = 1.0 \times 10^{-3} \quad B = \frac{(\#55)}{7.29 \times 10^4} \quad C = 4.73 \times 10^{-14} \quad D = 4.64 \times 10^{-16}$$

8-46. Lanthanum 140:

$$A = 8.5 \times 10^{-4} \quad B = \frac{(\#56)}{5.57 \times 10^5} \quad C = 5.26 \times 10^{-15} \quad D = 5.16 \times 10^{-17}$$

8-47. Cerium 141:

$$A = 3.2 \times 10^{-4} \quad B = \frac{(\#57)}{2.81 \times 10^4} \quad C = 3.93 \times 10^{-14} \quad D = 3.85 \times 10^{-16}$$

Cerium 143:

$$A = 1.1 \times 10^{-4} \quad B = \frac{(\#58)}{6.64 \times 10^5} \quad C = 5.71 \times 10^{-16} \quad D = 5.60 \times 10^{-18}$$

Cerium 144:

$$A = 3.0 \times 10^{-3} \quad B = \frac{(\#59)}{3.18 \times 10^3} \quad C = 3.25 \times 10^{-12} \quad D = 3.19 \times 10^{-14}$$

8-48. Praseodymium 143:

$$A = 2.4 \times 10^{-4} \quad B = \frac{(\#60)}{6.67 \times 10^4} \quad C = 1.24 \times 10^{-14} \quad D = 1.22 \times 10^{-16}$$

Praseodymium 144:

$$A = 1.6 \times 10^{-4} \quad B = \frac{(\#61)}{7.55 \times 10^7} \quad C = 7.31 \times 10^{-18} \quad D = 7.16 \times 10^{-20}$$

8-49. Neptunium 239:

$$A = 4.0 \times 10^{-3} \quad B = \frac{(\#83)}{2.33 \times 10^5} \quad C = 5.92 \times 10^{-14} \quad D = 5.80 \times 10^{-16}$$

8-50. Tritium (H3):

$$A = 1010 \quad B = 9.73 \times 10^3 \quad C = 3.58 \times 10^{-7} \quad D = 3.51 \times 10^{-9}$$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

- 8-51. Summation of D values in ref. calc. 8-3 = $\frac{5.88 \times 10^{-8} \text{ kg krypton}}{\text{kg U(reactor input)}}$
- 8-52. Summation of D values in ref. calc. 8-4 = $\frac{7.83 \times 10^{-10} \text{ kg xenon}}{\text{kg U(reactor input)}}$
- 8-53. Summation of D values in ref. calc. 8-5 = $\frac{1.86 \times 10^{-17} \text{ kg rubidium}}{\text{kg U(reactor input)}}$
- 8-54. Summation of D values in ref. calc. 8-6 = $\frac{6.96 \times 10^{-13} \text{ kg cesium}}{\text{kg U(reactor input)}}$
- 8-55. Summation of D values in ref. calc. 8-7 = $\frac{6.16 \times 10^{-19} \text{ kg bromine}}{\text{kg U(reactor input)}}$
- 8-56. Summation of D values in ref. calc. 8-8 = $\frac{5.39 \times 10^{-15} \text{ kg iodine}}{\text{kg U(reactor input)}}$
- 8-57. Summation of D values in ref. calc. 8-11 = $\frac{4.65 \times 10^{-15} \text{ kg iron}}{\text{kg U(reactor input)}}$
- 8-58. Summation of D values in ref. calc. 8-12 = $\frac{2.25 \times 10^{-14} \text{ kg cobalt}}{\text{kg U(reactor input)}}$
- 8-59. Summation of D values in ref. calc. 8-13 = $\frac{1.34 \times 10^{-15} \text{ kg strontium}}{\text{kg U(reactor input)}}$
- 8-60. Summation of D values in ref. calc. 8-14 = $\frac{5.80 \times 10^{-16} \text{ kg yttrium}}{\text{kg U(reactor input)}}$
- 8-61. Summation of D values in ref. calc. 8-19 = $\frac{2.95 \times 10^{-17} \text{ kg ruthenium}}{\text{kg U(reactor input)}}$
- 8-62. Summation of D values in ref. calc. 8-20 = $\frac{1.18 \times 10^{-20} \text{ kg rhodium}}{\text{kg U(reactor input)}}$
- 8-63. Summation of D values in ref. calc. 8-21 = $\frac{1.13 \times 10^{-15} \text{ kg tellurium}}{\text{kg U(reactor input)}}$
- 8-64. Summation of D values in ref. calc. 8-22 = $\frac{2.17 \times 10^{-17} \text{ kg barium}}{\text{kg U(reactor input)}}$
- 8-65. Summation of D values in ref. calc. 8-24 = $\frac{9.43 \times 10^{-17} \text{ kg cerium}}{\text{kg U(reactor input)}}$

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

- 8-66. Summation of D values in ref. calc. 8-25 = $\frac{5.17 \times 10^{-18}}{\text{kg U(reactor input)}}$ kg praseodymium
- 8-67. Summation of D values in ref. calc. 8-28 = $\frac{2.39 \times 10^{-18}}{\text{kg U(reactor input)}}$ kg bromine
- 8-68. Summation of D values in ref. calc. 8-29 = $\frac{3.25 \times 10^{-13}}{\text{kg U(reactor input)}}$ kg iodine
- 8-69. Summation of D values in ref. calc. 8-30 = $\frac{1.62 \times 10^{-16}}{\text{kg U(reactor input)}}$ kg rubidium
- 8-70. Summation of D values in ref. calc. 8-31 = $\frac{4.25 \times 10^{-11}}{\text{kg U(reactor input)}}$ kg cesium
- 8-71. Summation of D values in ref. calc. 8-34 = $\frac{1.06 \times 10^{-13}}{\text{kg U(reactor input)}}$ kg iron
- 8-72. Summation of D values in ref. calc. 8-35 = $\frac{5.30 \times 10^{-13}}{\text{kg U(reactor input)}}$ kg cobalt
- 8-73. Summation of D values in ref. calc. 8-36 = $\frac{1.31 \times 10^{-14}}{\text{kg U(reactor input)}}$ kg strontium
- 8-74. Summation of D values in ref. calc. 8-37 = $\frac{1.34 \times 10^{-14}}{\text{kg U(reactor input)}}$ kg yttrium
- 8-75. Summation of D values in ref. calc. 8-41 = $\frac{7.79 \times 10^{-16}}{\text{kg U(reactor input)}}$ kg ruthenium
- 8-76. Summation of D values in ref. calc. 8-42 = $\frac{2.34 \times 10^{-19}}{\text{kg U(reactor input)}}$ kg rhodium
- 8-77. Summation of D values in ref. calc. 8-44 = $\frac{2.38 \times 10^{-14}}{\text{kg U(reactor input)}}$ kg tellurium
- 8-78. Summation of D values in ref. calc. 8-45 = $\frac{4.64 \times 10^{-16}}{\text{kg U(reactor input)}}$ kg barium
- 8-79. Summation of D values in ref. calc. 8-47 = $\frac{3.23 \times 10^{-14}}{\text{kg U(reactor input)}}$ kg cerium
- 8-80. Summation of D values in ref. calc. 8-48 = $\frac{1.22 \times 10^{-16}}{\text{kg U(reactor input)}}$ kg praseodymium

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

$$8-81. \frac{\begin{matrix} \text{(assumed} \\ \text{(23, p. III-47)} \\ 14,945 \text{ lb } \text{H}_2\text{SO}_4 \\ \text{day} \end{matrix}}{\text{day}} \times \frac{\text{kg}}{2.205 \text{ lb}} \times \frac{96 \text{ kg SO}_4}{98 \text{ kg H}_2\text{SO}_4} = 6.64 \times 10^3 \frac{\text{kg SO}_4}{\text{day}}$$

$$\therefore \frac{6.64 \times 10^3 \text{ kg SO}_4/\text{day}}{102 \text{ kg U/day}} = \frac{6.51 \times 10^1 \text{ kg SO}_4}{\text{kg U}(\text{reactor input})}$$

$$8-82. \frac{\begin{matrix} \text{(assumed} \\ \text{(23, P. III-47)} \\ 0.2 \text{ lb volatile amines} \\ \text{day} \end{matrix}}{\text{day}} \times \frac{\text{kg}}{2.205 \text{ lb}} = 9.07 \times 10^{-2} \frac{\text{kg volatile amine}}{\text{day}}$$

$$\therefore \frac{9.07 \times 10^{-2} \text{ kg volatile amine/day}}{102 \text{ kg U/day}} = \frac{8.89 \times 10^{-4} \text{ kg volatile amine}}{\text{kg U}(\text{reactor input})}$$

$$8-83. \frac{\begin{matrix} \text{(assumed} \\ \text{(23, p. III-47)} \\ 8.05 \text{ lb } \text{H}_3\text{BO}_3 \\ \text{day} \end{matrix}}{\text{day}} \times \frac{\text{kg}}{2.205 \text{ lb}} \times \frac{11 \text{ kg B}}{62 \text{ kg H}_3\text{BO}_3} = 6.48 \times 10^{-1} \frac{\text{kg B}}{\text{day}}$$

$$\therefore \frac{6.48 \times 10^{-1} \text{ kg B/day}}{102 \text{ kg U/day}} = \frac{6.35 \times 10^{-3} \text{ kg B}}{\text{kg U}(\text{reactor input})}$$

$$8-84. \left[\left(\frac{\text{(assumed)} \\ \text{(23, p.III-47)} \\ 2700 \text{ lb NaOH}}{\text{day}} \times \frac{\text{kg}}{2.205 \text{ lb}} \times \frac{23 \text{ kg Na}}{40 \text{ kg NaOH}} \right) + \left(\frac{\text{(assumed)} \\ \text{(23, p.III-47)} \\ 0.02 \text{ lbs NaHSO}_3}{\text{day}} \times \frac{\text{kg}}{2.205 \text{ lb}} \times \frac{23 \text{ kg Na}}{104 \text{ kg NaHSO}_3} \right) \right] =$$

$$7.04 \times 10^2 \frac{\text{kg Na}}{\text{day}} \quad \therefore \quad \frac{7.04 \times 10^2 \text{ kg Na/day}}{102 \text{ kg U/day}} = \frac{6.90 \text{ kg Na}}{\text{kg U (reactor input)}}$$

$$8-85. \frac{\text{(assumed)} \\ \text{(23, p.III-47)} \\ 0.02 \text{ lb NaHSO}_3}{\text{day}} \times \frac{\text{kg}}{2.205 \text{ lb}} \times \frac{80 \text{ kg SO}_3}{104 \text{ kg NaHSO}_3} = \frac{6.98 \times 10^{-3} \text{ kg SO}_3}{\text{day}}$$

$$\therefore \frac{6.98 \times 10^{-3} \text{ kg SO}_3/\text{day}}{102 \text{ kg U/day}} = \frac{6.84 \times 10^{-5} \text{ kg SO}_3}{\text{kg U (reactor input)}}$$

86. Calculation of the release factors in the table below is based on the following equation:

$$\frac{D \text{ kg radionuclide}}{\text{kg U (reactor input)}} \times \frac{1}{\frac{\text{GA gram-atoms radionuclide}}{\text{kg U (reactor input)}}} \times$$

$$\frac{10^3 \text{ grams}}{\text{kg}} \times \frac{1}{\text{gram atomic weight of radionuclide}} =$$

$$\frac{\text{RF kg radionuclide (effluent)}}{\text{kg radionuclide (contained)}}$$

Note: D values come from reference calculations 8-2 through 8-50.

GA values come from ORIGEN code, chain 5 (for PWR at equilibrium).

RF values are the release factors.

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

	<u>Isotope</u>	<u>D</u>	<u>GA</u>	<u>RF</u>
1)	Argon-41	2.02E-14	4.38E-16	1.0
2)	Krypton-83M	1.38E-15	3.46E-8	4.8E-7
3)	Krypton-85M	1.68E-14	2.58E-7	7.7E-7
4)	Krypton-85	5.88E-8	3.38E-4	2.0E-3
5)	Krypton-87	2.73E-15	1.43E-7	2.2E-7
6)	Krypton-88	2.08E-14	4.62E-7	5.1E-7
7)	Krypton-89	9.68E-18	1.10E-8	9.9E-9
8)	Xenon-131M	1.16E-10	6.15E-7	1.4E-3
9)	Xenon-133M	1.37E-12	6.57E-7	1.6E-5
10)	Xenon-133	6.65E-10	6.32E-5	7.9E-5
11)	Xenon-135M	1.79E-16	3.48E-8	3.8E-8
12)	Xenon-135	2.09E-13	1.08E-6	1.4E-6
13)	Xenon-137	3.23E-17	3.17E-8	7.4E-9
14)	Xenon-138	6.79E-16	1.33E-7	3.7E-8
15)	Rubidium-86	8.14E-18	6.65E-8	1.4E-9
16)	Rubidium-88	1.05E-17	4.89E-8	2.4E-9
17)	Cesium-134	4.21E-14	1.41E-3	2.2E-10
18)	Cesium-136	1.35E-15	6.00E-6	1.7E-9
19)	Cesium-137	6.53E-13	9.06E-3	5.9E-10
20)	Bromine-83	5.51E-19	4.49E-8	1.5E-10

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

Isotope	D	GA	RF
21) Bromine-84	6.39E-20	2.51E-8	3.0E-11
22) Bromine-85	7.25E-22	2.61E-9	3.3E-12
23) Iodine-130	2.00E-18	1.27E-7	1.2E-10
24) Iodine-131	4.69E-15	5.19E-5	6.9E-10
25) Iodine-132	1.83E-17	8.79E-7	1.6E-10
26) Iodine-133	5.80E-16	1.05E-5	4.2E-10
27) Iodine-134	3.06E-18	5.00E-17	4.6E-11
28) Iodine-135	1.00E-16	2.96E-6	2.5E-10
29) Chromium-51	1.53E-16	5.39E-8	5.6E-8
30) Manganese-54	1.80E-15	1.90E-8	1.8E-6
31) Iron-55	4.53E-15	3.04E-17	2.7E-7
32) Iron-59	1.22E-16	1.12E-9	1.8E-6
33) Cobalt-58	2.04E-15	3.12E-8	1.1E-6
34) Cobalt-60	2.05E-14	9.29E-9	3.7E-5
35) Strontium-89	3.85E-17	2.82E-4	1.5E-12
36) Strontium-90	1.30E-15	6.03E-3	2.4E-12
37) Strontium-91	1.17E-18	2.73E-6	4.7E-12
38) Yttrium-90	2.08E-19	1.63E-6	1.4E-12
39) Yttrium-91M	5.93E-20	1.39E-7	4.7E-12
40) Yttrium-91	5.79E-16	4.19E-4	1.5E-11
41) Yttrium-93	2.47E-19	3.59E-6	7.4E-13

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

	<u>Isotope</u>	<u>D</u>	<u>GA</u>	<u>RF</u>
42)	Zirconium-95	2.17E-17	6.74E-4	3.4E-13
43)	Niobium-95	9.94E-18	3.69E-4	2.8E-13
44)	Molybdenum-99	6.02E-15	3.19E-5	1.9E-9
45)	Technetium-99M	4.78E-16	2.49E-6	1.9E-9
46)	Ruthenium-103	9.69E-18	3.65E-4	2.6E-13
47)	Ruthenium-106	1.98E-17	1.55E-3	1.2E-13
48)	Rhodium-103M	9.63E-21	3.65E-7	2.6E-13
49)	Rhodium-106	2.15E-21	1.95E-9	1.0E-11
50)	Tellurium-125M	1.06E-17	1.41E-6	6.0E-11
51)	Tellurium-127M	1.99E-16	1.26E-5	1.2E-10
52)	Tellurium-127	2.15E-18	2.09E-7	8.1E-11
53)	Tellurium-129M	3.06E-16	1.45E-5	1.6E-10
54)	Tellurium-129	5.01E-19	1.20E-7	3.2E-11
55)	Tellurium-131M	2.13E-17	1.20E-6	1.4E-10
56)	Tellurium-131	1.24E-19	9.82E-8	9.6E-12
57)	Tellurium-132	5.90E-16	2.88E-5	1.6E-10
58)	Barium-137M	2.24E-19	3.17E-4	5.2E-15
59)	Barium-140	2.15E-17	1.39E-4	1.1E-12
60)	Lanthanum-140	1.95E-18	1.87E-5	7.4E-13
61)	Cerium-141	1.76E-17	3.38E-4	3.7E-13
62)	Cerium-143	3.93E-19	1.25E-5	2.2E-13
63)	Cerium-144	7.63E-17	2.40E-3	2.2E-13
64)	Praseodymium-143	5.17E-18	1.24E-4	2.9E-13

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

	Isotope	D	GA	RF
65)	Praseodymium-144	3.23E-21	1.02E-7	2.2E-13
66)	Neptunium-239	3.47E-17	3.20E-4	4.5E-13
67)	Tritium(H-3)	9.97E-10	1.64E-5	2.0E-2
68)	Bromine-83	2.37E-18	4.49E-8	6.4E-10
69)	Bromine-84	1.78E-20	2.51E-8	8.4E-12
70)	Bromine-85	1.15E-24	2.61E-9	5.2E-15
71)	Iodine-130	4.83E-17	1.27E-7	2.9E-9
72)	Iodine-131	3.00E-13	5.19E-5	4.4E-8
73)	Iodine-132	3.94E-16	8.79E-7	3.4E-9
74)	Iodine-133	2.36E-14	1.05E-5	1.7E-8
75)	Iodine-134	2.50E-18	5.00E-7	3.7E-11
76)	Iodine-135	1.36E-15	2.96E-6	3.4E-9
77)	Rubidium-86	1.62E-16	6.65E-8	2.8E-8
78)	Rubidium-88	1.27E-19	4.89E-8	3.0E-11
79)	Cesium-134	3.38E-12	1.41E-3	1.8E-8
80)	Cesium-136	2.84E-14	6.00E-6	3.5E-8
81)	Cesium-137	3.91E-11	9.06E-3	3.2E-8
82)	Chromium-51	3.30E-15	5.39E-8	1.2E-6
83)	Manganese-54	8.90E-15	1.90E-8	8.7E-6
84)	Iron-55	1.03E-13	3.04E-7	6.2E-6
85)	Iron-59	3.17E-15	1.12E-9	4.8E-5
86)	Cobalt-58	8.13E-14	3.12E-8	4.5E-5
87)	Cobalt-60	4.49E-13	9.29E-9	8.1E-4
88)	Strontium-89	1.92E-15	2.82E-4	7.7E-11

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

Isotope	D	GA	RF
89) Strontium-90	1.12E-14	6.03E-3	2.1E-11
90) Strontium-91	6.84E-18	2.73E-16	2.8E-11
91) Yttrium-90	4.60E-18	1.63E-6	3.1E-11
92) Yttrium-91M	3.77E-19	1.39E-7	3.0E-11
93) Yttrium-91	1.34E-14	4.19E-4	3.5E-10
94) Yttrium-93	1.63E-19	3.59E-6	4.9E-13
95) Zirconium-95	1.75E-15	6.74E-4	2.7E-11
96) Niobium-95	1.21E-15	3.68E-4	3.5E-11
97) Molybdenum-99	1.14E-13	3.19E-5	3.6E-8
98) Ruthenium-103	3.06E-16	3.65E-4	8.1E-12
99) Ruthenium-106	4.73E-16	1.55E-3	2.9E-12
100) Rhodium-103M	2.22E-19	3.65E-7	5.9E-12
101) Rhodium-106	1.24E-20	1.95E-9	6.0E-11
102) Silver-110M	1.80E-15	7.12E-6	2.3E-9
103) Tellurium-125M	2.63E-16	1.41E-6	1.5E-9
104) Tellurium-127M	5.01E-15	1.26E-5	3.1E-9
105) Tellurium-127	2.57E-17	2.09E-7	9.7E-10
106) Tellurium-129M	7.26E-15	1.45E-5	3.9E-9
107) Tellurium-129	6.73E-18	1.20E-7	4.3E-10
108) Tellurium-131M	2.71E-16	1.20E-6	1.7E-9
109) Tellurium-131	7.07E-19	9.82E-8	5.5E-11
110) Tellurium-132	1.10E-14	2.88E-5	2.9E-9

REFERENCE CALCULATIONS: PWR Reactor (cont'd)

	<u>Isotope</u>	<u>D</u>	<u>GA</u>	<u>RF</u>
111)	Barium-137M	6.9E-22	3.17E-4	1.6E-17
112)	Barium-140	4.64E-16	1.39E-4	2.4E-11
113)	Lanthanum-140	5.16E-17	1.87E-5	2.0E-11
114)	Cerium-141	3.85E-16	3.38E-4	8.1E-12
115)	Cerium-143	5.60E-18	1.25E-5	3.1E-12
116)	Cerium-144	3.19E-14	2.40E-3	9.2E-11
117)	Praseodymium-143	1.22E-16	1.24E-4	6.9E-12
118)	Praseodymium-144	7.16E-20	1.02E-7	4.9E-12
119)	Neptunium-239	5.80E-16	3.20E-4	7.6E-12
120)	Tritium (H-3)	3.51E-9	1.64E-5	7.1E-2

8-87. $\frac{5 \text{ lb orthophosphate}}{\text{day}} \times \frac{\text{kg}}{2,205 \text{ lb}} = \frac{2.27 \text{ kg orthophosphate}}{\text{day}}$

$\therefore \frac{2.27 \text{ kg orthophosphate/day}}{102 \text{ kg U/day}} = 2.22 \times 10^{-2} \frac{\text{kg orthophosphate}}{\text{kg U (reactor input)}}$

BWR REACTOR CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)

F-5-16-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Calcium (Ca)				2×10^1	2	9-47
Magnesium (Mg)				4	2	9-48
Sodium (Na)				2	2	9-49
Bicarbonate (HCO_3)				2×10^1	2	9-50
Sulfate (SO_4)				4×10^1	2	9-51
Chloride (Cl)				8×10^{-1}	2	9-52
Nitrate (NO_3)				2×10^{-1}	2	9-53
Phosphate (PO_4)				1×10^{-2}	2	9-54
Chlorine (Cl_2)				8×10^{-3}	1	9-55

BWR REACTOR RADIONUCLIDE RELEASE FACTOR			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	F-5-16-77
Air Borne			Liquid			
Material Released	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Argon						
*Argon - 41	1	1	9-56-1			
Krypton						
Krypton - 83M	1×10^{-6}	2	9-56-2			
Krypton - 85M	3×10^{-5}	2	9-56-3			
Krypton - 85	1×10^{-3}	2	9-56-4			
Krypton - 87	4×10^{-5}	2	9-56-5			
Krypton - 88	3×10^{-5}	2	9-56-6			
Krypton - 89	1×10^{-7}	2	9-56-7			
Xenon						
Xenon - 131M	5×10^{-5}	2	9-56-8			
Xenon - 133M	2×10^{-6}	2	9-56-9			
Xenon - 133	1×10^{-4}	2	9-56-10			
Xenon - 135M	1×10^{-4}	2	9-56-11			
Xenon - 135	2×10^{-4}	2	9-56-12			
Xenon - 137	4×10^{-8}	2	9-56-13			
Xenon - 138	6×10^{-5}	2	9-56-14			

BWR REACTOR RADIONUCLIDE RELEASE FACTOR			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	F-5-16-77	
Air Borne			Liquid				
Material Released	Factor	Reliability	Ref. Calc.		Factor	Reliability	Ref. Calc.
Iodine							
Iodine - 131	4×10^8	2	9-56-15		6×10^{-11}	2	9-56-75
Iodine - 132					2×10^{-11}	2	9-56-76
Iodine - 133	7×10^{-8}	2	9-56-16		8×10^{-11}	2	9-56-77
Iodine - 134					6×10^{-12}	2	9-56-78
Iodine - 135					4×10^{-11}	2	9-56-79
Chromium							
Chromium - 51	3×10^{-6}	2	9-56-17		2×10^{-7}	2	9-56-36
Manganese							
Manganese - 54	3×10^{-5}	2	9-56-18		7×10^{-8}	2	9-56-37
Manganese - 56					2×10^{-7}	2	9-56-38
Iron							
Iron - 55					2×10^{-7}	2	9-56-39
Iron - 59	2×10^{-5}	2	9-56-19		8×10^{-8}	2	9-56-40
Cobalt							
Cobalt - 58	1×10^{-6}	2	9-56-20		3×10^{-8}	2	9-56-41
Cobalt - 60	1×10^{-3}	1	9-56-21		6×10^{-6}	2	9-56-42
Zinc							
Zinc - 65	5×10^{-3}	1	9-56-22		7×10^{-5}	2	9-56-45
Zinc - 69M					0	1	9-56-46
Zinc - 69					0	1	9-56-47

BWR REACTOR RADIONUCLIDE RELEASE FACTOR			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	F-5-16-77	
Air Borne			Liquid				
Material Released	Factor	Reliability	Ref. Calc.		Factor	Reliability	Ref. Calc.
Strontium							
Strontium - 89	6×10^{-10}	2	9-56-23		2×10^{-12}	2	9-56-53
Strontium - 90	2×10^{-11}	2	9-56-24				
Strontium - 91					2×10^{-11}	2	9-56-54
Strontium - 92					1×10^{-11}	2	9-56-55
Zirconium							
Zirconium - 95	2×10^{-11}	2	9-56-25				
Antimony							
Antimony - 124	7×10^{-8}	2	9-56-26				
Cesium							
Cesium - 134	1×10^{-9}	2	9-56-27		2×10^{-10}	2	9-56-80
Cesium - 136	4×10^{-10}	2	9-56-28		6×10^{-10}	2	9-56-81
Cesium - 137	3×10^{-9}	2	9-56-29		9×10^{-10}	2	9-56-82
Cesium - 138					4×10^{-11}	2	9-56-83
Barium							
Barium - 137M					9×10^{-10}	2	9-56-84
Barium - 139					3×10^{-12}	2	9-56-85
Barium - 140	5×10^{-10}	2	9-56-30		3×10^{-12}	2	9-56-86

BWR REACTOR RADIONUCLIDE RELEASE FACTOR			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	F-5-16-77
Air Borne			Liquid			
Material Released	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Cerium						
Cerium - 141	4×10^{-11}	2	9-56-31	2×10^{-13}	2	9-56-90
Cerium - 143				2×10^{-13}	2	9-56-91
Tritium	7×10^{-3}	2	9-56-32	1×10^{-3}	2	9-56-93
Carbon						
Carbon - 14				1	1	9-56-33
Sodium						
Sodium - 24				5×10^{-5}	2	9-56-34
Phosphorus						
Phosphorus - 32				2×10^{-6}	2	9-56-35
Nickel						
Nickel - 65				6×10^{-8}	2	9-56-43
Copper						
Copper - 64				2×10^{-6}	2	9-56-44
Wolfram						
Wolfram - 187				9×10^{-9}	2	9-56-48
Neptunium						
Neptunium - 239				3×10^{-12}	2	9-56-49

BWR REACTOR RADIONUCLIDE RELEASE FACTOR			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	F-5-16-77	
Air Borne			Liquid				
Material Released	Factor	Reliability	Ref. Calc.		Factor	Reliability	Ref. Calc.
Bromine							
Bromine - 83					5×10^{-11}	2	9-56-50
Bromine - 84					2×10^{-12}	2	9-56-51
Rubidium							
Rubidium - 89					2×10^{-12}	2	9-56-52
Yttrium							
Yttrium - 91M					2×10^{-11}	2	9-56-56
Yttrium - 91					6×10^{-13}	2	9-56-57
Yttrium - 92					2×10^{-11}	2	9-56-58
Yttrium - 93					2×10^{-11}	2	9-56-59
Niobium							
Niobium - 98					2×10^{-11}	2	9-56-60
Molybdenum							
Molybdenum - 99					1×10^{-11}	2	9-56-61
Technetium							
Technetium - 99M					5×10^{-11}	2	9-56-62
Technetium - 101					1×10^{-13}	2	9-56-63
Technetium - 104					4×10^{-13}	2	9-56-64

BWR REACTOR RADIONUCLIDE RELEASE FACTOR			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	F-5-16-77	
Air Borne			Ref. Calc.			Liquid	
Material Released	Factor	Reliability			Factor	Reliability	Ref. Calc.
Ruthenium							
Ruthenium - 103					2×10^{-13}	2	9-56-65
Ruthenium - 105					5×10^{-12}	2	9-56-66
Rhodium							
Rhodium - 103M					2×10^{-13}	2	9-56-67
Rhodium - 105M					5×10^{-12}	2	9-56-68
Rhodium - 105					2×10^{-12}	2	9-56-69
Tellurium							
Tellurium - 129M					7×10^{-12}	2	9-56-70
Tellurium - 129					7×10^{-13}	2	9-56-71
Tellurium - 131M					6×10^{-12}	2	9-56-72
Tellurium - 131					2×10^{-13}	2	9-56-73
Tellurium - 132					6×10^{-14}	2	9-56-74
Lanthanum							
Lanthanum - 140					6×10^{-13}	2	9-56-87
Lanthanum - 141					1×10^{-12}	2	9-56-88
Lanthanum - 142					2×10^{-12}	2	9-56-89
Praseodymium							
Praseodymium - 143					3×10^{-13}	2	9-56-92

REFERENCE CALCULATIONS: BWR REACTOR (292 Operating Days/yr)
5-10-77

9-1. U input to the BWR reactor assuming 1/5 of the fuel is changed out every year:

$$\begin{array}{l} (25, \text{ p. 11-45}) \quad \quad \quad (\text{see above}) \\ 139,344 \text{ kg UO}_2 \times \frac{238 \text{ U}}{270 \text{ UO}_2} \times \frac{1/5}{1} \times \frac{\text{year}}{292 \text{ operating days}} = 84 \frac{\text{kg U}}{\text{day}} \end{array}$$

Reference calculations 9-2 through 9-46 use the following format for calculation of numbers:

$$\frac{A \text{ Ci radionuclide}}{\text{yr}} \times \frac{\text{yr}}{292 \text{ op. days}} \times \frac{g \text{ radionuclide}}{B \text{ Ci radionuclide}} \times \frac{\text{kg}}{10^3 \text{ g}} = \frac{C \text{ kg radionuclide}}{\text{operating days}}$$

$$\frac{C \text{ kg radionuclide/operating day}}{84 \text{ kg U/operating day}} = \frac{D \text{ kg radionuclide}}{\text{kg U(reactor input)}}$$

Note: Primary coolant activity based on an 0.80 plant load factor and a noble gas release rate of $10^5 \mu \text{ Ci/sec}$ after a 30-minute decay.

All A values in reference calculations 9-3 through 9-18 are from reference 33, tables 11.3-7 and 11.3-9;
all A values in reference calculations 9-19 through 9-46 are from reference 33, tables 11.2-7 and 11.2-9.

All B values in reference calculations 9-2 through 9-46 are from reference 24.

9-2. Argon 41: (assumed) (#71)

$$A = 2.5 \times 10^1 \quad B = 4.18 \times 10^7 \quad C = 2.05 \times 10^{-12} \quad D = 2.44 \times 10^{-14}$$

9.3. Krypton 83M: (#1)

$$A = 1.0 \quad B = 2.03 \times 10^7 \quad C = 1.69 \times 10^{13} \quad D = 2.01 \times 10^{-14}$$

Krypton 85M: (#2)

$$A = 7.6 \times 10^1 \quad B = 8.40 \times 10^6 \quad C = 3.10 \times 10^{-11} \quad D = 3.69 \times 10^{-13}$$

REFERENCE CALCULATIONS: BWR REACTOR (cont'd)

Krypton 85:

$$A = 2.7 \times 10^2 \quad B = \begin{matrix} (\#3) \\ 3.91 \times 10^2 \end{matrix} \quad C = 2.36 \times 10^{-6} \quad D = 2.82 \times 10^{-8}$$

Krypton 87:

$$A = 2.0 \times 10^2 \quad B = \begin{matrix} (\#4) \\ 2.84 \times 10^7 \end{matrix} \quad C = 2.41 \times 10^{-11} \quad D = 2.87 \times 10^{-13}$$

Krypton 88:

$$A = 2.4 \times 10^2 \quad B = \begin{matrix} (\#5) \\ 1.27 \times 10^7 \end{matrix} \quad C = 6.47 \times 10^{-11} \quad D = 7.70 \times 10^{-13}$$

Krypton 89:

$$A = 1.0 \quad B = \begin{matrix} (\#6) \\ 6.60 \times 10^8 \end{matrix} \quad C = 5.19 \times 10^{-15} \quad D = 6.18 \times 10^{-17}$$

9-4. Xenon 131M:

$$A = 5.0 \quad B = \begin{matrix} (\#7) \\ 8.45 \times 10^4 \end{matrix} \quad C = 2.03 \times 10^{-10} \quad D = 2.41 \times 10^{-12}$$

Xenon 133M:

$$A = 1.0 \quad B = \begin{matrix} (\#8) \\ 4.35 \times 10^5 \end{matrix} \quad C = 7.87 \times 10^{-12} \quad D = 9.37 \times 10^{-14}$$

Xenon 133:

$$A = 2.7 \times 10^3 \quad B = \begin{matrix} (\#9) \\ 1.86 \times 10^5 \end{matrix} \quad C = 4.97 \times 10^{-8} \quad D = 5.92 \times 10^{-10}$$

Xenon 135M:

$$A = 7.4 \times 10^2 \quad B = \begin{matrix} (\#10) \\ 8.93 \times 10^7 \end{matrix} \quad C = 2.84 \times 10^{-11} \quad D = 3.38 \times 10^{-13}$$

Xenon 135:

$$A = 1.1 \times 10^3 \quad B = \begin{matrix} (\#11) \\ 2.52 \times 10^6 \end{matrix} \quad C = 1.49 \times 10^{-9} \quad D = 1.77 \times 10^{-11}$$

Xenon 137:

$$A = 1.0 \quad B = \begin{matrix} (\#12) \\ 3.52 \times 10^8 \end{matrix} \quad C = 9.73 \times 10^{-15} \quad D = 1.16 \times 10^{-16}$$

Xenon 138:

$$A = 1.4 \times 10^3 \quad B = \begin{matrix} (\#13) \\ 8.02 \times 10^7 \end{matrix} \quad C = 5.98 \times 10^{-11} \quad D = 7.12 \times 10^{-13}$$

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

9-5. Iodine 131:				
A = 4.6×10^{-1}	B = 1.24×10^5	C = 1.27×10^{-11}	D = 1.51×10^{-13}	(#15)
Iodine 133:				
A = 1.7	B = 1.13×10^6	C = 5.15×10^{-12}	D = 6.13×10^{-14}	(#17)
9-6. Chromium 51:				
A = 1.3×10^{-2}	B = 9.21×10^4	C = 4.83×10^{-13}	D = 5.75×10^{-15}	(#64)
9-7. Manganese 54:				
A = 4.1×10^{-3}	B = 7.98×10^3	C = 1.76×10^{-12}	D = 2.10×10^{-14}	(#65)
9-8. Iron 59:				
A = 1.1×10^{-3}	B = 4.91×10^4	C = 7.67×10^{-14}	D = 9.13×10^{-16}	(#67)
9-9. Cobalt 58:				
A = 1.3×10^{-3}	B = 3.16×10^4	C = 1.41×10^{-13}	D = 1.68×10^{-15}	(#68)
Cobalt 60:				
A = 1.3×10^{-2}	B = 1.13×10^3	C = 3.94×10^{-11}	D = 4.69×10^{-13}	(#69)
9-10. Zinc 65:				
A = 2.2×10^{-3}	B = 8.25×10^3	C = 9.13×10^{-13}	D = 1.09×10^{-14}	(#72)
9-11. Strontium 89:				
A = 6.1×10^{-3}	B = 2.82×10^4	C = 7.41×10^{-13}	D = 8.82×10^{-15}	(#21)
Strontium 90:				
A = 2.8×10^{-5}	B = 1.42×10^2	C = 6.75×10^{-13}	D = 8.04×10^{-15}	(#22)

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

9-12. Zirconium 95:

$$A = 5.0 \times 10^{-4} \quad B = \begin{matrix} (\#28) \\ 2.12 \times 10^4 \end{matrix} \quad C = 8.08 \times 10^{-14} \quad D = 9.62 \times 10^{-16}$$

9-13. Antimony 124:

$$A = 5.0 \times 10^{-4} \quad B = \begin{matrix} (\#73) \\ 1.75 \times 10^4 \end{matrix} \quad C = 9.78 \times 10^{-14} \quad D = 1.16 \times 10^{-15}$$

9-14. Cesium 134:

$$A = 4.4 \times 10^{-3} \quad B = \begin{matrix} (\#51) \\ 1.30 \times 10^3 \end{matrix} \quad C = 1.16 \times 10^{-11} \quad D = 1.38 \times 10^{-13}$$

Cesium 136:

$$A = 3.6 \times 10^{-4} \quad B = \begin{matrix} (\#52) \\ 7.39 \times 10^4 \end{matrix} \quad C = 1.67 \times 10^{-14} \quad D = 1.99 \times 10^{-16}$$

Cesium 137:

$$A = 6.3 \times 10^{-3} \quad B = \begin{matrix} (\#53) \\ 8.64 \times 10^1 \end{matrix} \quad C = 2.50 \times 10^{-10} \quad D = 2.98 \times 10^{-12}$$

9-15. Barium 140:

$$A = 1.1 \times 10^{-2} \quad B = \begin{matrix} (\#55) \\ 7.29 \times 10^4 \end{matrix} \quad C = 5.17 \times 10^{-13} \quad D = 6.15 \times 10^{-15}$$

9-16. Cerium 141:

$$A = 7.6 \times 10^{-4} \quad B = \begin{matrix} (\#57) \\ 2.81 \times 10^4 \end{matrix} \quad C = 9.26 \times 10^{-14} \quad D = 1.10 \times 10^{-15}$$

9-17. Tritium:

$$A = 6.8 \times 10^1 \quad B = \begin{matrix} (\#70) \\ 9.73 \times 10^3 \end{matrix} \quad C = 2.39 \times 10^{-8} \quad D = 2.85 \times 10^{-10}$$

9-18. Carbon 14:

$$A = 9.5 \quad B = \begin{matrix} (\#74) \\ 4.46 \end{matrix} \quad C = 7.29 \times 10^{-6} \quad D = 8.68 \times 10^{-8}$$

9-19. Sodium 24:

$$A = 7.5 \times 10^{-4} \quad B = \begin{matrix} (\#75) \\ 8.71 \times 10^6 \end{matrix} \quad C = 2.95 \times 10^{-16} \quad D = 3.51 \times 10^{-18}$$

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

9-20. Phosphorus 32:

$$A = 3.0 \times 10^{-5} \quad B = \begin{matrix} (\#76) \\ 2.85 \times 10^5 \end{matrix} \quad C = 3.60 \times 10^{-16} \quad D = 4.29 \times 10^{-18}$$

9-21. Chromium 51:

$$A = 7.7 \times 10^{-4} \quad B = \begin{matrix} (\#64) \\ 9.21 \times 10^4 \end{matrix} \quad C = 2.86 \times 10^{-14} \quad D = 3.40 \times 10^{-16}$$

9-22. Manganese 54:

$$A = 9.1 \times 10^{-6} \quad B = \begin{matrix} (\#65) \\ 7.98 \times 10^3 \end{matrix} \quad C = 3.91 \times 10^{-15} \quad D = 4.65 \times 10^{-17}$$

Manganese 56:

$$A = 8.1 \times 10^{-4} \quad B = \begin{matrix} (\#77) \\ 2.17 \times 10^7 \end{matrix} \quad C = 1.28 \times 10^{-16} \quad D = 1.52 \times 10^{-18}$$

9-23. Iron 55:

$$A = 1.6 \times 10^{-4} \quad B = \begin{matrix} (\#66) \\ 2.50 \times 10^3 \end{matrix} \quad C = 2.19 \times 10^{-13} \quad D = 2.61 \times 10^{-15}$$

Iron 59:

$$A = 4.6 \times 10^{-6} \quad B = \begin{matrix} (\#67) \\ 4.91 \times 10^4 \end{matrix} \quad C = 3.21 \times 10^{-16} \quad D = 3.82 \times 10^{-18}$$

9-24. Cobalt 58:

$$A = 3.1 \times 10^{-5} \quad B = \begin{matrix} (\#68) \\ 3.16 \times 10^4 \end{matrix} \quad C = 3.36 \times 10^{-15} \quad D = 4.00 \times 10^{-17}$$

Cobalt 60:

$$A = 6.3 \times 10^{-5} \quad B = \begin{matrix} (\#69) \\ 1.13 \times 10^3 \end{matrix} \quad C = 1.91 \times 10^{-13} \quad D = 2.27 \times 10^{-15}$$

9-25. Nickel 65:

$$A = 4.6 \times 10^{-6} \quad B = \begin{matrix} (\#78) \\ 1.91 \times 10^7 \end{matrix} \quad C = 8.25 \times 10^{-19} \quad D = 9.82 \times 10^{-21}$$

9-26. Copper 64:

$$A = 2.3 \times 10^{-3} \quad B = \begin{matrix} (\#79) \\ 3.80 \times 10^6 \end{matrix} \quad C = 2.07 \times 10^{-15} \quad D = 2.46 \times 10^{-17}$$

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

9-27. Zinc 65:

$$A = 3.1 \times 10^{-5} \quad B = \begin{matrix} (\#72) \\ 8.25 \times 10^3 \end{matrix} \quad C = 1.29 \times 10^{-14} \quad D = 1.54 \times 10^{-16}$$

Zinc 69M:

$$A = 1.6 \times 10^{-4} \quad B = \begin{matrix} (\#80) \\ 3.27 \times 10^6 \end{matrix} \quad C = 1.68 \times 10^{-16} \quad D = 2.00 \times 10^{-18}$$

Zinc 69:

$$A = 1.7 \times 10^{-4} \quad B = \begin{matrix} (\#81) \\ 4.70 \times 10^7 \end{matrix} \quad C = 1.24 \times 10^{-17} \quad D = 1.48 \times 10^{-19}$$

9-28. Wolfram 187:

$$A = 3.1 \times 10^{-5} \quad B = \begin{matrix} (\#82) \\ 6.99 \times 10^5 \end{matrix} \quad C = 1.52 \times 10^{-16} \quad D = 1.81 \times 10^{-18}$$

9-29. Neptunium 239:

$$A = 9.0 \times 10^{-4} \quad B = \begin{matrix} (\#83) \\ 2.33 \times 10^5 \end{matrix} \quad C = 1.32 \times 10^{-14} \quad D = 1.57 \times 10^{-16}$$

9-30. Bromine 83:

$$A = 4.2 \times 10^{-5} \quad B = \begin{matrix} (\#84) \\ 1.57 \times 10^7 \end{matrix} \quad C = 9.16 \times 10^{-18} \quad D = 1.09 \times 10^{-19}$$

Bromine 84:

$$A = 3.4 \times 10^{-6} \quad B = \begin{matrix} (\#85) \\ 7.04 \times 10^7 \end{matrix} \quad C = 1.65 \times 10^{-19} \quad D = 1.96 \times 10^{-21}$$

9-31. Rubidium 89:

$$A = 2.4 \times 10^{-5} \quad B = \begin{matrix} (\#86) \\ 1.37 \times 10^8 \end{matrix} \quad C = 6.00 \times 10^{-19} \quad D = 7.14 \times 10^{-21}$$

9-32. Strontium 89:

$$A = 1.6 \times 10^{-5} \quad B = \begin{matrix} (\#21) \\ 2.82 \times 10^4 \end{matrix} \quad C = 1.94 \times 10^{-15} \quad D = 2.31 \times 10^{-17}$$

Strontium 91:

$$A = 2.5 \times 10^{-4} \quad B = \begin{matrix} (\#23) \\ 3.56 \times 10^6 \end{matrix} \quad C = 2.40 \times 10^{-16} \quad D = 2.86 \times 10^{-18}$$

Strontium 92:

$$A = 1.7 \times 10^{-4} \quad B = \begin{matrix} (\#87) \\ 1.26 \times 10^7 \end{matrix} \quad C = 4.62 \times 10^{-17} \quad D = 5.50 \times 10^{-19}$$

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

9-33. Yttrium 91M:

$$A = 1.6 \times 10^{-4} \quad B = \begin{matrix} (\#25) \\ 4.13 \times 10^7 \end{matrix} \quad C = 1.33 \times 10^{-17} \quad D = 1.58 \times 10^{-19}$$

Yttrium 91:

$$A = 8.0 \times 10^{-6} \quad B = \begin{matrix} (\#26) \\ 2.44 \times 10^4 \end{matrix} \quad C = 1.12 \times 10^{-15} \quad D = 1.34 \times 10^{-17}$$

Yttrium 92:

$$A = 3.6 \times 10^{-4} \quad B = \begin{matrix} (\#88) \\ 9.65 \times 10^6 \end{matrix} \quad C = 1.28 \times 10^{-16} \quad D = 1.52 \times 10^{-18}$$

Yttrium 93:

$$A = 2.6 \times 10^{-4} \quad B = \begin{matrix} (\#27) \\ 3.31 \times 10^6 \end{matrix} \quad C = 2.69 \times 10^{-16} \quad D = 3.20 \times 10^{-18}$$

9-34 Niobium 98:

$$A = 9.1 \times 10^{-6} \quad B = \begin{matrix} (\#89) \\ 3.76 \times 10^7 \end{matrix} \quad C = 8.29 \times 10^{-19} \quad D = 9.87 \times 10^{-21}$$

9-35. Molybdenum 99:

$$A = 2.7 \times 10^{-4} \quad B = \begin{matrix} (\#33) \\ 4.75 \times 10^5 \end{matrix} \quad C = 1.95 \times 10^{-15} \quad D = 2.32 \times 10^{-17}$$

9-36. Technetium 99M:

$$A = 1.0 \times 10^{-3} \quad B = \begin{matrix} (\#34) \\ 5.28 \times 10^6 \end{matrix} \quad C = 6.49 \times 10^{-16} \quad D = 7.73 \times 10^{-18}$$

Technetium 101:

$$A = 2.3 \times 10^{-6} \quad B = \begin{matrix} (\#90) \\ 1.33 \times 10^8 \end{matrix} \quad C = 5.92 \times 10^{-20} \quad D = 7.05 \times 10^{-22}$$

Technetium 104:

$$A = 6.8 \times 10^{-6} \quad B = \begin{matrix} (\#91) \\ 1.00 \times 10^8 \end{matrix} \quad C = 2.33 \times 10^{-19} \quad D = 2.77 \times 10^{-21}$$

9-37. Ruthenium 103:

$$A = 3.4 \times 10^{-6} \quad B = \begin{matrix} (\#35) \\ 3.20 \times 10^4 \end{matrix} \quad C = 3.64 \times 10^{-16} \quad D = 4.33 \times 10^{-18}$$

Ruthenium 105:

$$A = 6.3 \times 10^{-5} \quad B = \begin{matrix} (\#92) \\ 6.72 \times 10^6 \end{matrix} \quad C = 3.21 \times 10^{-17} \quad D = 3.82 \times 10^{-19}$$

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

9-38. Rhodium 103M:

$$A = 3.4 \times 10^{-6} \quad B = \begin{matrix} (\#37) \\ 3.20 \times 10^7 \end{matrix} \quad C = 3.64 \times 10^{-19} \quad D = 4.33 \times 10^{-21}$$

Rhodium 105M:

$$A = 6.4 \times 10^{-5} \quad B = \begin{matrix} (\#93) \\ 2.39 \times 10^9 \end{matrix} \quad C = 9.17 \times 10^{-20} \quad D = 1.09 \times 10^{-21}$$

Rhodium 105:

$$A = 2.1 \times 10^{-5} \quad B = \begin{matrix} (\#38) \\ 8.32 \times 10^5 \end{matrix} \quad C = 8.64 \times 10^{-17} \quad D = 1.03 \times 10^{-18}$$

9-39. Tellurium 129M:

$$A = 5.7 \times 10^{-6} \quad B = \begin{matrix} (\#46) \\ 2.98 \times 10^4 \end{matrix} \quad C = 6.55 \times 10^{-16} \quad D = 7.80 \times 10^{-18}$$

Tellurium 129:

$$A = 3.4 \times 10^{-6} \quad B = \begin{matrix} (\#47) \\ 2.11 \times 10^7 \end{matrix} \quad C = 5.52 \times 10^{-19} \quad D = 6.57 \times 10^{-21}$$

Tellurium 131M:

$$A = 1.1 \times 10^{-5} \quad B = \begin{matrix} (\#48) \\ 7.98 \times 10^5 \end{matrix} \quad C = 4.72 \times 10^{-17} \quad D = 5.62 \times 10^{-19}$$

Tellurium 131:

$$A = 2.3 \times 10^{-6} \quad B = \begin{matrix} (\#49) \\ 5.74 \times 10^7 \end{matrix} \quad C = 1.37 \times 10^{-19} \quad D = 1.63 \times 10^{-21}$$

Tellurium 132:

$$A = 1.1 \times 10^{-6} \quad B = \begin{matrix} (\#50) \\ 3.05 \times 10^5 \end{matrix} \quad C = 1.24 \times 10^{-17} \quad D = 1.48 \times 10^{-19}$$

9-40. Iodine 131:

$$A = 7.3 \times 10^{-4} \quad B = \begin{matrix} (\#15) \\ 1.24 \times 10^5 \end{matrix} \quad C = 2.02 \times 10^{-14} \quad D = 2.40 \times 10^{-16}$$

Iodine 132:

$$A = 3.9 \times 10^{-4} \quad B = \begin{matrix} (\#16) \\ 1.03 \times 10^7 \end{matrix} \quad C = 1.30 \times 10^{-16} \quad D = 1.55 \times 10^{-18}$$

Iodine 133:

$$A = 1.9 \times 10^{-3} \quad B = \begin{matrix} (\#17) \\ 1.13 \times 10^6 \end{matrix} \quad C = 5.76 \times 10^{-15} \quad D = 6.86 \times 10^{-17}$$

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

Iodine 134:

$$A = 1.6 \times 10^{-4} \quad B = \begin{matrix} (\#94) \\ 2.70 \times 10^7 \end{matrix} \quad C = 2.03 \times 10^{-17} \quad D = 2.42 \times 10^{-19}$$

Iodine 135:

$$A = 9.0 \times 10^{-4} \quad B = \begin{matrix} (\#18) \\ 3.47 \times 10^6 \end{matrix} \quad C = 8.88 \times 10^{-16} \quad D = 1.06 \times 10^{-17}$$

9-41. Cesium 134:

$$A = 8.5 \times 10^{-4} \quad B = \begin{matrix} (\#51) \\ 1.30 \times 10^3 \end{matrix} \quad C = 2.24 \times 10^{-12} \quad D = 2.67 \times 10^{-14}$$

Cesium 136:

$$A = 5.4 \times 10^{-4} \quad B = \begin{matrix} (\#52) \\ 7.39 \times 10^4 \end{matrix} \quad C = 2.50 \times 10^{-14} \quad D = 2.98 \times 10^{-16}$$

Cesium 137:

$$A = 2.0 \times 10^{-3} \quad B = \begin{matrix} (\#53) \\ 8.64 \times 10^1 \end{matrix} \quad C = 7.93 \times 10^{-11} \quad D = 9.44 \times 10^{-13}$$

Cesium 138:

$$A = 8.3 \times 10^{-4} \quad B = \begin{matrix} (\#95) \\ 4.23 \times 10^7 \end{matrix} \quad C = 6.72 \times 10^{-17} \quad D = 8.00 \times 10^{-19}$$

9-42. Barium 137M:

$$A = 1.8 \times 10^{-3} \quad B = \begin{matrix} (\#54) \\ 5.38 \times 10^8 \end{matrix} \quad C = 1.15 \times 10^{-17} \quad D = 1.37 \times 10^{-19}$$

Barium 139:

$$A = 6.0 \times 10^{-5} \quad B = \begin{matrix} (\#96) \\ 1.63 \times 10^7 \end{matrix} \quad C = 1.26 \times 10^{-17} \quad D = 1.50 \times 10^{-19}$$

Barium 140:

$$A = 6.0 \times 10^{-5} \quad B = \begin{matrix} (\#55) \\ 7.29 \times 10^4 \end{matrix} \quad C = 2.82 \times 10^{-15} \quad D = 3.36 \times 10^{-17}$$

9-43. Lanthanum 140:

$$A = 1.3 \times 10^{-5} \quad B = \begin{matrix} (\#56) \\ 5.57 \times 10^5 \end{matrix} \quad C = 7.99 \times 10^{-17} \quad D = 9.51 \times 10^{-19}$$

Lanthanum 141:

$$A = 1.9 \times 10^{-5} \quad B = \begin{matrix} (\#97) \\ 5.70 \times 10^6 \end{matrix} \quad C = 1.14 \times 10^{-17} \quad D = 1.36 \times 10^{-19}$$

Lanthanum 142:

$$A = 4.1 \times 10^{-5} \quad B = \begin{matrix} (\#98) \\ 1.44 \times 10^7 \end{matrix} \quad C = 9.75 \times 10^{-18} \quad D = 1.16 \times 10^{-19}$$

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

9-44. Cerium 141:

$$A = 4.6 \times 10^{-6} \quad B = \begin{matrix} (\#57) \\ 2.81 \times 10^4 \end{matrix} \quad C = 5.61 \times 10^{-16} \quad D = 6.68 \times 10^{-18}$$

Cerium 143:

$$A = 3.4 \times 10^{-6} \quad B = \begin{matrix} (\#58) \\ 6.64 \times 10^5 \end{matrix} \quad C = 1.75 \times 10^{-17} \quad D = 2.08 \times 10^{-19}$$

9-45. Praseodymium 143:

$$A = 5.7 \times 10^{-6} \quad B = \begin{matrix} (\#60) \\ 6.67 \times 10^4 \end{matrix} \quad C = 2.93 \times 10^{-16} \quad D = 3.49 \times 10^{-18}$$

9-46. Tritium:

$$A = 1.2 \times 10^1 \quad B = \begin{matrix} (\#70) \\ 9.73 \times 10^3 \end{matrix} \quad C = 4.22 \times 10^{-9} \quad D = 5.03 \times 10^{-11}$$

5-16-77

$$\begin{matrix} (26, \text{TABLE 3.6-1}) & (25, \text{p. 11-53}) \\ 9-47. \frac{116 \text{ mg Ca(ppm)}}{\text{liter}} \times \frac{1.41 \times 10^7 \text{ liters}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.64 \times 10^3 \frac{\text{kg Ca}}{\text{day}} \end{matrix}$$

$$\therefore \frac{1.64 \times 10^3 \text{ kg Ca/day}}{84 \text{ kg U/day}} = 1.95 \times 10^1 \frac{\text{kg Ca}}{\text{kg U(reactor input)}}$$

$$\begin{matrix} (26, \text{TABLE 3.6-1}) & (25, \text{p. 11-53}) \\ 9-48. \frac{21 \text{ mg Mg(ppm)}}{\text{liter}} \times \frac{1.41 \times 10^7 \text{ liters}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 2.96 \times 10^2 \frac{\text{kg Mg}}{\text{day}} \end{matrix}$$

$$\therefore \frac{2.96 \times 10^2 \text{ kg Mg/day}}{84 \text{ kg U/day}} = 3.52 \frac{\text{kg Mg}}{\text{kg U(reactor input)}}$$

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

$$9-49. \frac{(26, \text{TABLE 3.6-1})}{12 \text{ mg Na(ppm)}} \times \frac{(25, \text{p. 11-53})}{1.41 \times 10^7 \text{ liters}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.69 \times 10^2 \frac{\text{kg Na}}{\text{day}}$$

$$\therefore \frac{1.69 \times 10^2 \text{ kg Na/day}}{84 \text{ kg U/day}} = \frac{2.01 \text{ kg Na}}{\text{kg U(reactor input)}}$$

$$9-50. \frac{(26, \text{TABLE 3.6-1})}{92 \text{ mg HCO}_3(\text{ppm})} \times \frac{(25, \text{p. 11-53})}{1.41 \times 10^7 \text{ liters}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.30 \times 10^3 \frac{\text{kg HCO}_3}{\text{day}}$$

$$\therefore \frac{1.30 \times 10^3 \text{ HCO}_3/\text{day}}{84 \text{ kg U/day}} = \frac{1.55 \times 10^1 \text{ kg HCO}_3}{\text{kg U(reactor input)}}$$

$$9-51. \frac{(26, \text{TABLE 3.6-1})}{236 \text{ mg SO}_4(\text{ppm})} \times \frac{(25, \text{p. 11-53})}{1.41 \times 10^7 \text{ liters}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 3.33 \times 10^3 \frac{\text{kg SO}_4}{\text{day}}$$

$$\therefore \frac{3.33 \times 10^3 \text{ kg SO}_4/\text{day}}{84 \text{ kg U/day}} = \frac{3.96 \times 10^1 \text{ kg SO}_4}{\text{kg U(reactor input)}}$$

$$9-52. \frac{(26, \text{TABLE 3.6-1})}{5 \text{ mg Cl(ppm)}} \times \frac{(25, \text{p. 11-53})}{1.41 \times 10^7 \text{ liters}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 7.05 \times 10^1 \frac{\text{kg Cl}}{\text{day}}$$

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

$$\therefore \frac{7.05 \times 10^1 \text{ kg Cl/day}}{84 \text{ kg U/day}} = \frac{8.39 \times 10^{-1} \text{ kg Cl}}{\text{kg U}(\text{reactor input})}$$

9-53. $\frac{(26, \text{TABLE 3.6-1})}{1.24 \text{ mg NO}_3(\text{ppm})} \times \frac{(25, \text{p. 11-53})}{1.41 \times 10^7 \text{ liters/day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = \frac{1.75 \times 10^1 \text{ kg NO}_3}{\text{day}}$

$$\therefore \frac{1.75 \times 10^1 \text{ kg NO}_3/\text{day}}{84 \text{ kg U/day}} = \frac{2.08 \times 10^{-1} \text{ kg NO}_3}{\text{kg U}(\text{reactor input})}$$

9-54. $\frac{(26, \text{TABLE 3.6-1})}{0.06 \text{ mg PO}_4(\text{ppm})} \times \frac{(25, \text{p. 11-53})}{1.41 \times 10^7 \text{ liters/day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = \frac{8.46 \times 10^{-1} \text{ kg PO}_4}{\text{day}}$

$$\therefore \frac{8.46 \times 10^{-1} \text{ kg PO}_4/\text{day}}{84 \text{ kg U/day}} = \frac{1.01 \times 10^{-2} \text{ kg PO}_4}{\text{kg U}(\text{reactor input})}$$

9-55. $\frac{(25, \text{p. 11-53})}{0.05 \text{ mg Cl}_2} \times \frac{1.41 \times 10^7 \text{ liters/day}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = \frac{7.05 \times 10^{-1} \text{ kg Cl}_2}{\text{day}}$

$$\therefore \frac{7.05 \times 10^{-1} \text{ kg Cl}_2/\text{day}}{84 \text{ kg U/day}} = \frac{8.39 \times 10^{-3} \text{ kg Cl}_2}{\text{kg U}(\text{reactor input})}$$

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

5-27-77

9-56 Calculation of the release factors in the table below is based on the following equation:

$$\frac{D \text{ kg radionuclide}}{\text{kg U(reactor input)}} \times \frac{1}{\frac{GA \text{ gram-atoms radionuclide}}{\text{kg U(reactor input)}}} \times$$

$$\frac{10^3 \text{ grams}}{\text{kg}} \times \frac{1}{\text{gram atomic weight of radionuclide}} =$$

$$\frac{RF \text{ kg radionuclide (effluent)}}{\text{kg radionuclide (contained)}}$$

Note: D values come from reference calculations 9-2 through 9-46.

GA values come from ORIGEN code, chain 11 (for BWR at equilibrium).

RF values are the release factors.

<u>Isotope</u>	<u>D</u>	<u>GA</u>	<u>RF</u>
1) Argon-41	2.44E-14	2.59E-16	Assumed to be 1
2) Krypton-83m	2.01E-15	2.13E-8	1.1E-6
3) Krypton-85M	3.69E-13	1.58E-7	2.7E-5
4) Krypton-85	2.82E-8	2.67E-4	1.2E-3
5) Krypton-87	2.87E-13	8.80E-8	3.7E-5

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

<u>Isotope</u>	<u>D</u>	<u>GA</u>	<u>RF</u>
6) Krypton-88	7.70E-13	2.83E-7	3.1E-5
7) Krypton-89	6.18E-17	6.75E-9	1.0E-7
8) Xenon-131M	2.41E-12	3.78E-7	4.9E-5
9) Xenon-133M	9.37E-14	4.03E-7	1.7E-6
10) Xenon-133	5.92E-10	3.89E-5	1.1E-4
11) Xenon-135M	3.38E-13	2.14E-8	1.2E-4
12) Xenon-135	1.77E-11	7.84E-7	1.7E-4
13) Xenon-137	1.16E-16	1.95E-8	4.3E-8
14) Xenon-138	7.12E-13	8.17E-8	6.3E-5
15) Iodine-131	1.51E-13	3.19E-5	3.6E-8
16) Iodine-133	6.13E-14	6.45E-6	7.1E-8
17) Chromium-51	5.75E-15	4.31E-8	2.6E-6
18) Manganese-54	2.10E-14	1.22E-8	3.2E-5
19) Iron-59	9.13E-16	8.04E-10	1.9E-5
20) Cobalt-58	1.68E-15	2.01E-8	1.4E-6
21) Cobalt-60	4.69E-13	6.27E-9	1.2E-3
22) Zinc-65	1.09E-14	3.18E-11	5.3E-3
23) Strontium-89	8.82E-15	1.71E-4	5.8E-10
24) Strontium-90	8.04E-15	4.88E-3	1.8E-11
25) Zirconium-95	9.62E-16	4.11E-4	2.5E-11
26) Antimony-124	1.16E-15	1.37E-7	6.8E-8

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

<u>Isotope</u>	<u>D</u>	<u>GA</u>	<u>RF</u>
27) Cesium-134	1.38E-13	8.67E-4	1.2E-9
28) Cesium-136	1.99E-16	3.52E-6	4.2E-10
29) Cesium-137	2.98E-12	7.32E-3	3.0E-9
30) Barium-140	6.15E-15	8.52E-5	5.2E-10
31) Cerium-141	1.10E-15	2.04E-4	3.8E-11
32) Tritium	2.85E-10	1.3E-5	7.3E-3
33) Carbon-14	8.68E-8	4.61E-6	Assumed to be 1
34) Sodium-24	3.51E-18	2.73E-12	5.4E-5
35) Phosphorus-32	4.29E-18	8.81E-11	1.5E-6
36) Chromium-51	3.40E-16	4.31E-8	1.5E-7
37) Manganese-54	4.65E-17	1.22E-8	7.1E-8
38) Manganese-56	1.52E-18	1.63E-10	1.7E-7
39) Iron-55	2.61E-15	2.92E-7	1.6E-7
40) Iron-59	3.82E-18	8.04E-10	8.1E-8
41) Cobalt-58	4.00E-17	2.01E-8	3.4E-8
42) Cobalt-60	2.27E-15	6.27E-9	6.0E-6
43) Nickel-65	9.82E-21	2.39E-12	6.3E-8
44) Copper-64	2.46E-17	1.68E-10	2.3E-6
45) Zinc-65	1.54E-16	3.18E-11	7.5E-5
46) Zinc-69M	2.00E-18	-0-	0.0

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

<u>Isotope</u>	<u>D</u>	<u>GA</u>	<u>RF</u>
47) Zinc-69	1.48E-19	-0-	0.0
48) Wolfram-187	1.81E-18	1.05E-9	9.2E-9
49) Neptunium-239	1.57E-16	1.99E-4	3.3E-12
50) Bromine-83	1.09E-19	2.76E-8	4.8E-11
51) Bromine-84	1.96E-21	1.54E-8	1.5E-12
52) Rubidium-89	7.14E-21	3.26E-8	2.5E-12
53) Stronium-89	2.31E-17	1.71E-4	1.5E-12
54) Stronium-91	2.86E-18	1.68E-6	1.9E-11
55) Stronium-92	5.50E-19	4.72E-7	1.3E-11
56) Yttrium-91M	1.58E-19	8.53E-8	2.0E-11
57) Yttrium-91	1.34E-17	2.54E-4	5.8E-13
58) Yttrium-92	1.52E-18	6.92E-7	2.4E-11
59) Yttrium-93	3.20E-18	2.21E-6	1.6E-11
60) Niobium-98	9.87E-21	5.75E-9	1.8E-11
61) Molybdenum-99	2.32E-17	1.96E-5	1.2E-11
62) Technetium-99M	7.73E-18	1.53E-6	5.1E-11
63) Technetium-101	7.05E-22	6.30E-8	1.1E-13
64) Technetium-104	2.77E-21	6.64E-8	4.0E-13
65) Ruthenium-103	4.33E-18	2.23E-4	1.9E-13
66) Ruthenium-105	3.82E-19	8.03E-7	4.5E-12
67) Rhodium-103M	4.33E-21	2.23E-7	1.9E-13
68) Rhodium-105M	1.09E-21	2.26E-9	4.6E-12

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

<u>Isotope</u>	<u>D</u>	<u>GA</u>	<u>RF</u>
69) Rhodium-105	1.03E-18	5.20E-6	1.9E-12
70) Tellurium-129M	7.80E-18	8.83E-6	6.8E-12
71) Tellurium-129	6.57E-21	7.34E-8	6.9E-13
72) Tellurium-131M	5.62E-19	7.39E-7	5.8E-12
73) Tellurium-131	1.63E-21	6.03E-8	2.1E-13
74) Tellurium-132	1.48E-19	1.77E-5	6.3E-14

5-31-77

75) Iodine-131	2.40E-16	3.19E-5	5.7E-11
76) Iodine-132	1.55E-18	5.40E-7	2.2E-11
77) Iodine-133	6.86E-17	6.45E-6	8.0E-11
78) Iodine-134	2.42E-19	3.07E-7	5.9E-12
79) Iodine-135	1.06E-17	1.82E-6	4.3E-11
80) Cesium-134	2.67E-14	8.67E-4	2.3E-10
81) Cesium-136	2.98E-16	3.52E-6	6.2E-10
82) Cesium-137	9.44E-13	7.32E-3	9.4E-10
83) Cesium-138	8.00E-19	1.56E-7	3.7E-11

REFERENCE CALCULATIONS: BWR Reactor (cont'd)

<u>Isotope</u>	<u>D</u>	<u>GA</u>	<u>RF</u>
84) Barium-137M	1.37E-19	1.11E-9	9.0E-10
85) Barium-139	1.50E-19	4.00E-7	2.7E-12
86) Barium-140	3.36E-17	8.52E-5	2.8E-12
87) Lanthanum-140	9.51E-19	1.15E-5	5.9E-13
88) Lanthanum-141	1.36E-19	1.02E-6	9.5E-13
89) Lanthanum-142	1.16E-19	3.88E-7	2.1E-12
90) Cerium-141	6.68E-18	2.04E-4	2.3E-13
91) Cerium-143	2.08E-19	7.70E-6	1.9E-13
92) Praseodymium-143	3.49E-18	7.63E-5	3.2E-13
93) Tritium	5.03E-11	1.3E-5	1.3E-3

REPROCESSING CHEMICAL RELEASE FACTOR ^{kg/kg U} (INPUT)						F-5-18-77
Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Nitrogen Oxides (NO _x)	4 X 10 ⁻¹	2	10-2			
Hydrogen Fluoride (HF)	1 X 10 ⁻³	2	10-3			
Hydrogen Sulfide (H ₂ S)	4 X 10 ⁻³	2	10-4			
Carbon Monoxide (CO)	1 X 10 ⁻²	2	10-5			
Hydrogen (H ₂)	2 X 10 ⁻²	2	10-6			
Nonradioactive						
Particulates	2 X 10 ⁻²	2	10-7			
Ammonia (NH ₃)	2 X 10 ⁻⁴	2	10-8			
Sulfur Oxides (SO _x)	8 X 10 ⁻²	2	10-10			
Hydrocarbons	2 X 10 ⁻³	2	10-9			
Carbon Dioxide (CO ₂)				1 X 10 ⁻¹	2	10-11
Calcium (Ca)				3 X 10 ⁻³	2	10-12
Iron (Fe)				1 X 10 ⁻³	2	10-13
Magnesium (Mg)				1 X 10 ⁻³	2	10-14
Nitrate (NO ₃)				2 X 10 ⁻³	2	10-15
Phosphorus-Ortho				1 X 10 ⁻⁴	2	10-16
Potassium (K)				4 X 10 ⁻²	2	10-17
Sulfate (SO ₄)				8 X 10 ⁻³	2	10-18
Sulfite (SO ₃)				1 X 10 ⁻⁴	2	10-19

REPROCESSING (cont'd) CHEMICAL RELEASE FACTOR Kg/Kg U (INPUT)

F-5-18-77

Material Released	Air Borne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Dodecane	x					
Tributyl Phosphate	x					
Oxalic Acid	x					
Nitrate Acid	x					
Sulfuric Acid	x					
Nitrogen	x					
Fluorine	x					
Fluorocarbon	x					
Phosphoric Acid	x					
Acrolein				x		

x Indicates Most Likely Form Of Effluent

REPROCESSING RADIONUCLIDE RELEASE FACTOR			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	F-5-26-77
Air Borne			Liquid			
Material Released	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Tritium	7×10^{-1}	2	10-35-01			
Krypton						
Krypton - 85	1.0	2	10-35-02			
Strontium						
Strontium - 89	2×10^{-9}	2	10-35-03			
Strontium - 90	2×10^{-9}	2	10-35-04			
Yttrium						
Yttrium - 90	2×10^{-9}	2	10-35-05			
Yttrium - 91	2×10^{-9}	2	10-35-06			
Zirconium						
Zirconium - 95	3×10^{-9}	2	10-35-07			
Niobium						
Niobium - 95	3×10^{-9}	2	10-35-08			
Ruthenium						
Ruthenium - 103	3×10^{-9}	2	10-35-09			
Ruthenium - 106	3×10^{-9}	2	10-35-10			
Iodine						
Iodine - 129	9×10^{-4}	2	10-35-33			
Iodine - 131	9×10^{-4}	2	10-35-33			
Cesium						
Cesium - 134	2×10^{-9}	2	10-35-11			
Cesium - 137	2×10^{-9}	2	10-35-12			

REPROCESSING RADIONUCLIDE RELEASE FACTOR			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	F-5-26-77
Air Borne			Liquid			
Material Released	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Cerium						
Cerium - 141	3×10^{-9}	2	10-35-13			
Cerium - 144	3×10^{-9}	2	10-35-14			
Promethium						
Promethium - 147	3×10^{-9}	2	10-35-15			
Uranium						
Uranium - 232	2×10^{-5}	2	10-35-16			
Uranium - 233	2×10^{-5}	2	10-35-17			
Uranium - 234	2×10^{-5}	2	10-35-18			
Uranium - 235	2×10^{-5}	2	10-35-19			
Uranium - 236	2×10^{-5}	2	10-35-20			
Uranium - 237	2×10^{-5}	2	10-35-21			
Uranium - 238	2×10^{-5}	2	10-35-22			
Plutonium						
Plutonium - 238	1×10^{-9}	2	10-35-23			
Plutonium - 239	1×10^{-9}	2	10-35-24			
Plutonium - 240	1×10^{-9}	2	10-35-25			
Plutonium - 241	1×10^{-9}	2	10-35-26			
Plutonium - 242	1×10^{-9}	2	10-35-27			

REPROCESSING RADIONUCLIDE RELEASE FACTOR			kg Effluent kg Contained	OR	Ci Effluent Ci Contained	F-5-26-77	
Air Borne			Liquid				
Material Released	Factor	Reliability	Ref. Calc.		Factor	Reliability	Ref. Calc.
Americium							
Americium - 241	2×10^{-9}	2	10-35-28				
Americium - 242	2×10^{-9}	2	10-35-29				
Curium							
Curium - 242	6×10^{-9}	2	10-35-30				
Curium - 243	6×10^{-9}	2	10-35-31				
Curium - 244	6×10^{-9}	2	10-35-32				

REFERENCE CALCULATIONS: REPROCESSING FACILITY (300 Operating Days/yr)

5-23-77

10-1. U input to reprocessing facility:

$$\frac{5 \text{ metric tons U (depleted 0.84\% } ^{235}\text{U)}}{\text{day}} \times \frac{10^3 \text{ kg}}{\text{metric ton}} = \frac{5000 \text{ kg U}^*}{\text{day}}$$

Note: (1) SF indicates main separations facility.
 (2) UF₆F indicates UF₆ facility.
 (3) PPF indicates plutonium product facility.

* "Input" to a reprocessing plant is a complex concept, since various fuel assemblies have received different exposures. This 5000 kg U/day is really the weight of U as charged into a reactor. The spent fuel breaks down into U, Pu and fission products as shown on Table 12-6, page 12-50, Section 12.

10-2.
$$\left[\begin{array}{c} \text{(assumed UF}_6\text{F)} \\ \text{(28, p.67)} \\ \text{(4 X 24) mg NO}_x \\ \text{sec} \end{array} + \begin{array}{c} \text{(assumed UF}_6\text{F)} \\ \text{(28, p.68)} \\ \text{249 mg NO}_x \\ \text{sec} \end{array} + \begin{array}{c} \text{(assumed SF)} \\ \text{(28, App. VI p.13)} \\ \text{22,836 mg NO}_x \\ \text{sec} \end{array} + \begin{array}{c} \text{(assumed PPF)} \\ \text{(29, p. III-5)} \\ \text{500 mg NO}_x \\ \text{sec} \end{array} \right] \times$$

$$\frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = \frac{2.05 \times 10^3 \text{ kg NO}_x}{\text{day}}$$

$$\therefore \frac{2.05 \times 10^3 \text{ kg NO}_x/\text{day}}{5000 \text{ kg U/day}} = \frac{4.10 \times 10^{-1} \text{ kg NO}_x}{\text{kg U (facility input)}}$$

10-3.
$$\left[\begin{array}{c} \text{(assumed UF}_6\text{F)} \\ \text{(28, p.67)} \\ \text{46.3 mg HF} \\ \text{sec} \end{array} + \begin{array}{c} \text{(assumed UF}_6\text{F)} \\ \text{(28, p.68)} \\ \text{29 mg HF} \\ \text{sec} \end{array} \right] \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = \frac{6.51 \text{ kg HF}}{\text{day}}$$

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

$$\therefore \frac{6.51 \text{ kg HF/day}}{5000 \text{ kg U/day}} = 1.30 \times 10^{-3} \frac{\text{kg HF}}{\text{kg U(facility input)}}$$

(assumed UF_6F)

10-4. $\frac{249 \text{ mg H}_2\text{S}}{\text{sec}} \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 2.15 \times 10^1 \frac{\text{kg H}_2\text{S}}{\text{day}}$

$$\therefore \frac{2.15 \times 10^1 \text{ kg H}_2\text{S/day}}{5000 \text{ kg U/day}} = 4.30 \times 10^{-3} \frac{\text{kg H}_2\text{S}}{\text{kg U(facility input)}}$$

10-5. $\left[\begin{array}{l} \text{(assumed UF}_6\text{F)} \\ \text{(28, p.67)} \\ (4 \times 4.8) \frac{\text{mg CO}}{\text{sec}} \end{array} + \begin{array}{l} \text{(assumed SF)} \\ \text{(28, APP.VI, p.13)} \\ 452 \frac{\text{mg CO}}{\text{sec}} \end{array} + \begin{array}{l} \text{(assumed PPF)} \\ \text{(29, p.III-5)} \\ 300 \frac{\text{mg CO}}{\text{sec}} \end{array} \right] \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 6.66 \times 10^1 \frac{\text{kg CO}}{\text{day}}$

$$\therefore \frac{6.66 \times 10^1 \text{ kg CO/day}}{5000 \text{ kg U/day}} = 1.33 \times 10^{-2} \frac{\text{kg CO}}{\text{kg U(facility input)}}$$

10-6. $\left[\begin{array}{l} \text{(assumed UF}_6\text{F)} \\ \text{(28, p.67)} \\ 530 \frac{\text{mg H}_2}{\text{sec}} \end{array} + \begin{array}{l} \text{(assumed UF}_6\text{F)} \\ \text{(28, p.68)} \\ 500 \frac{\text{mg H}_2}{\text{sec}} \end{array} \right] \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 8.90 \times 10^1 \frac{\text{kg H}_2}{\text{day}}$

$$\therefore \frac{8.90 \times 10^1 \text{ kg H}_2/\text{day}}{5000 \text{ kg U/day}} = 1.78 \times 10^{-2} \frac{\text{kg H}_2}{\text{kg U(facility input)}}$$

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

10-7. Assuming natural gas is used for heating and using EPA emission factors:

$$\begin{array}{l} \text{(from ref.calc. 10-5)} \quad \text{(assumed industrial boiler)} \\ \text{(1, p.1.4-2)} \\ 6.66 \times 10^1 \frac{\text{kg CO}}{\text{day}} \times \frac{290 \text{ nonradioactive particulate}}{270 \text{ CO}} = 7.15 \times 10^1 \frac{\text{kg nonradioactive particulate}}{\text{day}} \end{array}$$

$$\begin{array}{l} \text{(assumed)} \\ \text{(28, p.67)} \\ \left(91 \frac{\text{mg nonradioactive particulate}}{\text{sec}} \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} \right) + 7.15 \times 10^1 \frac{\text{kg nonradioactive particulate}}{\text{day}} = \end{array}$$

$$7.94 \times 10^1 \frac{\text{kg nonradioactive particulate}}{\text{day}}$$

$$\therefore \frac{7.94 \times 10^1 \text{ kg nonradioactive particulate/day}}{5000 \text{ kg U/day}} = 1.59 \times 10^{-2} \frac{\text{kg nonradioactive particulate}}{\text{kg U(facility input)}}$$

(assumed UF₆F)
(28, p.68)

$$10-8. \quad \frac{13 \text{ mg NH}_3}{\text{sec}} \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = \frac{1.12 \text{ kg NH}_3}{\text{day}}$$

$$\therefore \frac{1.12 \text{ kg NH}_3/\text{day}}{5000 \text{ kg U/day}} = \frac{2.24 \times 10^{-4} \text{ kg NH}_3}{\text{kg U(facility input)}}$$

10-9. Assuming natural gas is used for heating and using EPA emission factors:

(from ref.calc. 10-5)

$$6.66 \times 10^1 \frac{\text{kg CO}}{\text{day}} \times \frac{48 \text{ hydrocarbons}}{270 \text{ CO}} = 1.18 \times 10^1 \frac{\text{kg hydrocarbons}}{\text{day}}$$

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

$$\therefore \frac{1.18 \times 10^1 \text{ kg hydrocarbons/day}}{5000 \text{ kg U/day}} = \frac{2.36 \times 10^{-3} \text{ kg hydrocarbons}}{\text{kg U(facility input)}}$$

$$10-10. \left(\frac{\substack{\text{(assumed SF)} \\ \text{(28, APP.VI,p.13)}}{4007 \text{ mg SO}_2}}{\text{sec}} + \frac{\substack{\text{(assumed PPF)} \\ \text{(29, p.III-5)}}{500 \text{ mg SO}_2}}{\text{sec}} \right) \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 3.89 \times 10^2 \frac{\text{kg SO}_2}{\text{day}}$$

$$\therefore \frac{3.89 \times 10^2 \text{ kg SO}_2/\text{day}}{5000 \text{ kg U/day}} = \frac{7.78 \times 10^{-2} \text{ kg SO}_2}{\text{kg U(facility input)}}$$

5-24-77

$$10-11. \frac{\substack{\text{(assumed)} \\ \text{(27,p.III-22)}}{40 \text{ mg CO}_2(\text{ppm})}}{\ell} \times \frac{\substack{\text{(assumed)} \\ \text{(27,p.III-19)}}{(2311 + 40) \text{ gal}}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \ell}{\text{gal}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 5.12 \times 10^2 \frac{\text{kg CO}_2}{\text{day}}$$

$$\therefore \frac{5.13 \times 10^2 \text{ kg CO}_2/\text{day}}{5000 \text{ kg U/day}} = \frac{1.03 \times 10^{-1} \text{ kg CO}_2}{\text{kg U(facility input)}}$$

$$10-12. \frac{\substack{\text{(assumed)} \\ \text{(27,p.III-22)}}{1 \text{ mg Ca(ppm)}}}{\ell} \times \frac{\substack{\text{(assumed)} \\ \text{(27,p.III-19)}}{(2311 + 40) \text{ gal}}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \ell}{\text{gal}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.28 \times 10^1 \frac{\text{kg Ca}}{\text{day}}$$

$$\therefore \frac{1.28 \times 10^1 \text{ kg Ca/day}}{5000 \text{ kg U/day}} = \frac{2.56 \times 10^{-3} \text{ kg Ca}}{\text{kg U(facility input)}}$$

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

$$10-13. \frac{\begin{matrix} \text{(assumed)} \\ \text{(27,p.III-22)} \\ 0.5 \text{ mg Fe(ppm)} \\ \ell \end{matrix}}{\ell} \times \frac{\begin{matrix} \text{(assumed)} \\ \text{(27,p.III-19)} \\ (2311 + 40) \text{ gal} \\ \text{min} \end{matrix}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \ell}{\text{gal}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 6.41 \frac{\text{kg Fe}}{\text{day}}$$

$$\therefore \frac{6.41 \text{ kg Fe/day}}{5000 \text{ kg U/day}} = 1.28 \times 10^{-3} \frac{\text{kg Fe}}{\text{kg U(facility input)}}$$

10-14. Value for Magnesium is the same as for Iron in reference calculation 10-13.

$$10-15. \frac{\begin{matrix} \text{(assumed)} \\ \text{(27,p.III-22)} \\ 0.7 \text{ mg NO}_3 \text{ (ppm)} \\ \ell \end{matrix}}{\ell} \times \frac{\begin{matrix} \text{(assumed)} \\ \text{(27,p.III-19)} \\ (2311 + 40) \text{ gal} \\ \text{min} \end{matrix}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \ell}{\text{gal}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 8.97 \frac{\text{kg NO}_3}{\text{day}}$$

$$\therefore \frac{8.97 \text{ kg NO}_3/\text{day}}{5000 \text{ kg U/day}} = 1.79 \times 10^{-3} \frac{\text{kg NO}_3}{\text{kg U(facility input)}}$$

$$10-16. \frac{\begin{matrix} \text{(assumed)} \\ \text{(27,p.III-22)} \\ 0.04 \text{ mg P-ortho(ppm)} \\ \ell \end{matrix}}{\ell} \times \frac{\begin{matrix} \text{(assumed)} \\ \text{(27,p.III-19)} \\ (2311 + 40) \text{ gal} \\ \text{min} \end{matrix}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \ell}{\text{gal}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 5.13 \times 10^{-1} \frac{\text{kg P-ortho}}{\text{day}}$$

$$\therefore \frac{5.13 \times 10^{-1} \text{ kg P-ortho/day}}{5000 \text{ kg U/day}} = 1.03 \times 10^{-4} \frac{\text{kg P-ortho}}{\text{kg U(facility input)}}$$

$$10-17. \frac{\begin{matrix} \text{(assumed)} \\ \text{(27,p.III-22)} \\ 15 \text{ mg K(ppm)} \\ \ell \end{matrix}}{\ell} \times \frac{\begin{matrix} \text{(assumed)} \\ \text{(27,p.III-19)} \\ (2311 + 40) \text{ gal} \\ \text{min} \end{matrix}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \ell}{\text{gal}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.92 \times 10^2 \frac{\text{kg K}}{\text{day}}$$

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

$$\therefore \frac{1.92 \times 10^2 \text{ kg K/day}}{5000 \text{ kg U/day}} = 3.84 \times 10^{-2} \frac{\text{kg K}}{\text{kg U(facility input)}}$$

10-18. $\frac{\begin{matrix} \text{(assumed)} \\ \text{(27,p.III-22)} \\ 3 \text{ mg SO}_4 \text{ (ppm)} \\ \ell \end{matrix}}{\ell} \times \frac{\begin{matrix} \text{(assumed)} \\ \text{(27,p.III-19)} \\ (2311 + 40) \text{ gal} \\ \text{min} \end{matrix}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \ell}{\text{gal}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 3.84 \times 10^1 \frac{\text{kg SO}_4}{\text{day}}$

$$\therefore \frac{3.84 \times 10^1 \text{ kg SO}_4/\text{day}}{5000 \text{ kg U/day}} = 7.68 \times 10^{-3} \frac{\text{kg SO}_4}{\text{kg U(facility input)}}$$

10-19. $\frac{\begin{matrix} \text{(assumed)} \\ \text{(27,p.III-22)} \\ 0.05 \text{ mg SO}_3 \text{ (ppm)} \\ \ell \end{matrix}}{\ell} \times \frac{\begin{matrix} \text{(assumed)} \\ \text{(27,p.III-19)} \\ (2311 + 40) \text{ gal} \\ \text{min} \end{matrix}}{\text{min}} \times \frac{1440 \text{ min}}{\text{day}} \times \frac{3.785 \ell}{\text{gal}} \times \frac{\text{kg}}{10^6 \text{ mg}} = 6.41 \times 10^{-1} \frac{\text{kg SO}_3}{\text{day}}$

$$\therefore \frac{6.41 \times 10^{-1} \text{ kg SO}_3/\text{day}}{5000 \text{ kg U/day}} = 1.28 \times 10^{-4} \frac{\text{kg SO}_3}{\text{kg U(facility input)}}$$

Reference calculations 10-20 through 10-33 use the following format for calculation of numbers:

$$\frac{\underline{A} \text{ Ci radionuclide}}{\text{sec}} \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\underline{g} \text{ radionuclide}}{\underline{B} \text{ Ci radionuclide}} \times \frac{\text{kg}}{10^3 \text{ g}} = \frac{\underline{C} \text{ kg radionuclide}}{\text{operating day}}$$

$$\frac{\underline{C} \text{ kg radionuclide/operating day}}{5000 \text{ kg U/operating day}} = \frac{\underline{D} \text{ kg radionuclide}}{\text{kg U(facility input)}}$$

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

10-20. Tritium:

$$\begin{array}{llll} (28, \text{App. VI, p. 9 SF}) & (30, \#1) & & \\ A = 1.8 \times 10^{-2} & B = 9.73 \times 10^3 & C = 1.60 \times 10^{-4} & D = 3.20 \times 10^{-8} \end{array}$$

10-21. Krypton 85:

$$\begin{array}{llll} (28, \text{App. VI, p. 9 SF}) & (30, \#3) & & \\ A = 4.3 \times 10^{-1} & B = 3.91 \times 10^2 & C = 9.50 \times 10^{-2} & D = 1.90 \times 10^{-5} \end{array}$$

10-22. Strontium 89:

$$\begin{array}{llll} (28, \text{App. VI, p. 9 SF}) & (30, \#4) & & \\ A = 7.6 \times 10^{-9} & B = 2.82 \times 10^4 & C = 2.33 \times 10^{-11} & D = 4.66 \times 10^{-15} \end{array}$$

Strontium 90:

$$\begin{array}{llll} (28, \text{App. VI, p. 9, 10, 11 SF}) & (30, \#5) & & \\ A = (8.8 \times 10^{-9} + 5 \times 10^{-11} + 3 \times 10^{-16}) & B = 1.42 \times 10^2 & & \\ & C = 5.38 \times 10^{-9} & D = 1.08 \times 10^{-12} \end{array}$$

10-23. Yttrium 90:

$$\begin{array}{llll} (28, \text{App. VI, p. 9 SF}) & (30, \#6) & & \\ A = 8.8 \times 10^{-9} & B = 5.44 \times 10^5 & C = 1.40 \times 10^{-12} & D = 2.80 \times 10^{-16} \end{array}$$

Yttrium 91:

$$\begin{array}{llll} (28, \text{App. VI, p. 9 SF}) & (30, \#7) & & \\ A = 1.6 \times 10^{-8} & B = 2.44 \times 10^4 & C = 5.67 \times 10^{-11} & D = 1.13 \times 10^{-14} \end{array}$$

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

10-24. Zirconium 95:

$$A = \left[\frac{(28, \text{App. VI, p. 9 SF})}{2.8 \times 10^{-8} \frac{\text{Ci}}{\text{sec}}} + \left(\frac{(28, \text{p. 70 UF}_6\text{F})}{1.1 \times 10^{-3} \frac{\text{Ci}}{\text{yr}} + 1.5 \times 10^{-5} \frac{\text{Ci}}{\text{yr}} + 4.8 \times 10^{-4} \frac{\text{Ci}}{\text{yr}}} \right) \times \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}} \right]$$

$$B = \frac{(30, \#8)}{2.12 \times 10^4} \quad C = 1.14 \times 10^{-10} \quad D = 2.28 \times 10^{-14}$$

10-25. Niobium 95:

$$A = \frac{(28, \text{App. VI, p. 9 SF})}{5.3 \times 10^{-8}} \quad B = \frac{(30, \#9)}{3.91 \times 10^4} \quad C = 1.17 \times 10^{-10} \quad D = 2.34 \times 10^{-14}$$

10-26. Ruthenium 103:

$$A = \frac{(28, \text{App. VI, p. 9 SF})}{8.4 \times 10^{-9}} \quad B = \frac{(30, \#10)}{3.20 \times 10^4} \quad C = 2.27 \times 10^{-11} \quad D = 4.54 \times 10^{-15}$$

Ruthenium 106:

$$A = \left[\frac{(28, \text{App. VI, p. 9 SF})}{5.0 \times 10^{-8} \frac{\text{Ci}}{\text{sec}}} + \left(\frac{(28, \text{p. 70 UF}_6\text{F})}{3.2 \times 10^{-3} \frac{\text{Ci}}{\text{yr}} + 4.5 \times 10^{-5} \frac{\text{Ci}}{\text{yr}} + 1.4 \times 10^{-3} \frac{\text{Ci}}{\text{yr}}} \right) \times \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}} \right]$$

$$B = \frac{(30, \#11)}{3.36 \times 10^3} \quad C = 1.29 \times 10^{-9} \quad D = 2.58 \times 10^{-13}$$

10-27. Cesium 134:

$$A = (1.9 \times 10^{-8} + 1 \times 10^{-10} + 6 \times 10^{-16}) \quad B = \frac{(30, \#18)}{1.3 \times 10^3}$$

$$C = 1.27 \times 10^{-9} \quad D = 2.54 \times 10^{-13}$$

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

Cesium 137:

$$\begin{array}{l} (28, \text{App. VI, p. 9, 10, 11 SF}) \\ A = (1.2 \times 10^{-8} + 6 \times 10^{-11} + 4 \times 10^{-16}) \quad B = \frac{(30, \#19)}{8.64 \times 10^1} \quad C = 1.21 \times 10^{-8} \quad D = 2.42 \times 10^{-12} \end{array}$$

10-28. Cerium 141:

$$\begin{array}{l} (28, \text{App. VI, p. 9 SF}) \\ A = 5.5 \times 10^{-9} \quad B = \frac{(30, \#20)}{2.81 \times 10^4} \quad C = 1.69 \times 10^{-11} \quad D = 3.38 \times 10^{-15} \end{array}$$

Cerium 144:

$$\begin{array}{l} (28, \text{App. VI, p. 9 SF}) \\ A = 8.4 \times 10^{-8} \quad B = \frac{(30, \#21)}{3.18 \times 10^3} \quad C = 2.28 \times 10^{-9} \quad D = 4.56 \times 10^{-13} \end{array}$$

10-29. Promethium 147:

$$\begin{array}{l} (28, \text{App. VI, p. 9 SF}) \\ A = 1.5 \times 10^{-8} \quad B = \frac{(30, \#22)}{9.74 \times 10^2} \quad C = 1.33 \times 10^{-9} \quad D = 2.66 \times 10^{-13} \end{array}$$

10-30. Uranium 232:

$$\begin{array}{l} (28, \text{p. 70 UF}_6\text{F}) \\ A = \left[1.2 \times 10^{-4} \frac{\text{Ci}}{\text{yr}} + 2.8 \times 10^{-9} \frac{\text{Ci}}{\text{yr}} + 5.6 \times 10^{-5} \frac{\text{Ci}}{\text{yr}} \right] \times \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}} \\ B = \frac{(30, \#25)}{2.10 \times 10^1} \quad C = 2.79 \times 10^{-11} \quad D = 5.58 \times 10^{-15} \end{array}$$

Uranium 233:

$$\begin{array}{l} (28, \text{p. 70 UF}_6\text{F}) \\ A = \left[3.5 \times 10^{-7} \frac{\text{Ci}}{\text{yr}} + 7.8 \times 10^{-12} \frac{\text{Ci}}{\text{yr}} + 1.6 \times 10^{-7} \frac{\text{Ci}}{\text{yr}} \right] \times \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}} \end{array}$$

A.147

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

5-25-77

$$B = \frac{(30, \#26)}{9.48 \times 10^{-3}} \quad C = 1.79 \times 10^{-10} \quad D = 3.58 \times 10^{-14}$$

Uranium 234:

$$A = \left[\frac{(28, \text{App. VI, p. 9 SF})}{7.0 \times 10^{-14} \frac{\text{Ci}}{\text{yr}}} + \left(\frac{(28, \text{p. 70 UF}_6\text{F})}{3.2 \times 10^{-4} \frac{\text{Ci}}{\text{yr}} + 7.2 \times 10^{-9} \frac{\text{Ci}}{\text{yr}} + 1.4 \times 10^{-4} \frac{\text{Ci}}{\text{yr}}} \right) \times \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}} \right]$$

$$B = \frac{(30, \#27)}{6.19 \times 10^{-3}} \quad C = 2.49 \times 10^{-7} \quad D = 4.98 \times 10^{-11}$$

Uranium 235:

$$A = \left[\frac{(28, \text{App. VI, p. 9 SF})}{7.0 \times 10^{-16} \frac{\text{Ci}}{\text{yr}}} + \left(\frac{(28, \text{p. 70 UF}_6\text{F})}{3.6 \times 10^{-6} \frac{\text{Ci}}{\text{yr}} + 8.2 \times 10^{-11} \frac{\text{Ci}}{\text{yr}} + 1.6 \times 10^{-5} \frac{\text{Ci}}{\text{yr}}} \right) \times \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}} \right]$$

$$B = \frac{(30, \#28)}{2.14 \times 10^{-6}} \quad C = 3.06 \times 10^{-5} \quad D = 6.12 \times 10^{-9}$$

Uranium 236:

$$A = \left[\frac{(28, \text{p. 70 UF}_6\text{F})}{5.5 \times 10^{-3} \frac{\text{Ci}}{\text{yr}} + 1.2 \times 10^{-7} \frac{\text{Ci}}{\text{yr}} + 2.5 \times 10^{-3} \frac{\text{Ci}}{\text{yr}}} \right] \times \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}}$$

$$B = \frac{(30, \#29)}{6.35 \times 10^{-5}} \quad C = 4.20 \times 10^{-4} \quad D = 8.40 \times 10^{-8}$$

Uranium 237:

$$A = \left[\frac{(28, \text{p. 70 UF}_6\text{F})}{6.3 \times 10^{-2} \frac{\text{Ci}}{\text{yr}} + 1.4 \times 10^{-6} \frac{\text{Ci}}{\text{yr}} + 2.9 \times 10^{-2} \frac{\text{Ci}}{\text{yr}}} \right] \times \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}}$$

$$B = \frac{(30, \#30)}{8.17 \times 10^4} \quad C = 3.75 \times 10^{-12} \quad D = 7.50 \times 10^{-16}$$

A.148

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

Uranium 238:

$$A = \left[\begin{array}{c} (28, \text{App. VI, p. 9 SF}) \\ 2.0 \times 10^{-14} \frac{\text{Ci}}{\text{yr}} + \left(6.6 \times 10^{-3} \frac{\text{Ci}}{\text{yr}} + 1.5 \times 10^{-7} \frac{\text{Ci}}{\text{yr}} + 3.0 \times 10^{-3} \frac{\text{Ci}}{\text{yr}} \right) \times \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}} \end{array} \right]$$

$$B = \begin{array}{c} (30, \#31) \\ 3.33 \times 10^{-7} \end{array} \quad C = 9.61 \times 10^{-2} \quad D = 1.92 \times 10^{-5}$$

10-31. The basis for plutonium calculations for the plutonium product facility is the isotopic distribution as follows from reference 31, p. 10-13:

plutonium-238	2.5%
plutonium-239	50.0%
plutonium-240	25.0%
plutonium-241	15.0%
plutonium-242	7.5%

and the release rate of 1.55×10^{-13} grams of plutonium per second (Ref. 31, p. 10-12).

Plutonium 238:

$$A = \left[\begin{array}{c} (28, \text{App. VI, p. 9, 10, 11 SF}) \\ \left(1.3 \times 10^{-10} \frac{\text{Ci}}{\text{sec}} + 4 \times 10^{-11} \frac{\text{Ci}}{\text{sec}} + 1 \times 10^{-15} \frac{\text{Ci}}{\text{sec}} \right) + \left(\begin{array}{c} (28, \text{p. 70 UF}_6\text{F}) \\ 9.1 \times 10^{-5} \frac{\text{Ci}}{\text{yr}} + 5.2 \times 10^{-7} \frac{\text{Ci}}{\text{yr}} + \end{array} \right. \\ \left. 4.1 \times 10^{-5} \frac{\text{Ci}}{\text{yr}} \right) \times \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}} + \left(\begin{array}{c} (\text{see above PPF}) \\ 1.55 \times 10^{-13} \frac{\text{g}}{\text{sec}} \times 0.025 \times \end{array} \right. \\ \left. \begin{array}{c} (30, \#32) \\ 1.75 \times 10^1 \frac{\text{Ci}}{\text{g}} \end{array} \right) \end{array} \right]$$

$$B = \begin{array}{c} (30, \#32) \\ 1.75 \times 10^1 \end{array} \quad C = 8.65 \times 10^{-10} \quad D = 1.73 \times 10^{-13}$$

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

Plutonium 239:

$$A = \left[\begin{array}{l} \text{(28, App. Vi, p.9, 10, 11 SF)} \\ \left(1.2 \times 10^{-11} \frac{\text{Ci}}{\text{sec}} + 4 \times 10^{-12} \frac{\text{Ci}}{\text{sec}} + 1 \times 10^{-16} \frac{\text{Ci}}{\text{sec}} \right) + \left(6.6 \times 10^{-6} \frac{\text{Ci}}{\text{yr}} + 3.7 \times 10^{-8} \frac{\text{Ci}}{\text{yr}} + \right. \\ \left. 3.0 \times 10^{-6} \frac{\text{Ci}}{\text{yr}} \right) \times \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}} + \left(\begin{array}{l} \text{(see above PPF)} \\ 1.55 \times 10^{-13} \frac{\text{g}}{\text{sec}} \end{array} \times \begin{array}{l} \text{(30, #33)} \\ 0.5 \times 6.14 \times 10^{-2} \frac{\text{Ci}}{\text{yr}} \end{array} \right) \end{array} \right]$$

$$B = 6.14 \times 10^{-2} \quad C = 2.30 \times 10^{-8} \quad D = 4.60 \times 10^{-12}$$

Plutonium 240:

$$A = \left[\begin{array}{l} \text{(28, App. VI, p.9, 10, 11 SF)} \\ \left(2.1 \times 10^{-11} \frac{\text{Ci}}{\text{sec}} + 6 \times 10^{-12} \frac{\text{Ci}}{\text{sec}} + 2 \times 10^{-16} \frac{\text{Ci}}{\text{sec}} \right) + \left(1.2 \times 10^{-5} \frac{\text{Ci}}{\text{yr}} + 6.8 \times 10^{-8} \frac{\text{Ci}}{\text{yr}} + \right. \\ \left. 5.5 \times 10^{-6} \frac{\text{Ci}}{\text{yr}} \right) \times \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}} + \left(\begin{array}{l} \text{(see above PPF)} \\ 1.55 \times 10^{-13} \frac{\text{g}}{\text{sec}} \end{array} \times \begin{array}{l} \text{(30, #34)} \\ 0.25 \times 2.27 \times 10^{-1} \frac{\text{Ci}}{\text{g}} \end{array} \right) \end{array} \right]$$

$$B = 2.27 \times 10^{-1} \quad C = 1.05 \times 10^{-8} \quad D = 2.10 \times 10^{-12}$$

Plutonium 241:

$$A = \left[\begin{array}{l} \text{(28, App. VI, p.9, 10, 11 SF)} \\ \left(5.5 \times 10^{-9} \frac{\text{Ci}}{\text{sec}} + 2 \times 10^{-9} \frac{\text{Ci}}{\text{sec}} + 5 \times 10^{-14} \frac{\text{Ci}}{\text{sec}} \right) + \left(3.2 \times 10^{-3} \frac{\text{Ci}}{\text{yr}} + 1.8 \times 10^{-5} \frac{\text{Ci}}{\text{yr}} + \right. \end{array} \right]$$

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

$$1.4 \times 10^{-3} \frac{\text{Ci}}{\text{yr}} \left(\frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}} + \left(\overset{\text{(see above PPF)}}{1.55 \times 10^{-13} \frac{\text{g}}{\text{sec}}} \times 0.15 \times \overset{\text{(30, \#35)}}{1.13 \times 10^2 \frac{\text{Ci}}{\text{g}}} \right) \right]$$

$$B = \overset{\text{(30, \#35)}}{1.13 \times 10^2} \quad C = 5.87 \times 10^{-9} \quad D = 1.17 \times 10^{-12}$$

Plutonium 242:

$$A = \left[\overset{\text{(28, App. VI, p. 9 SF)}}{1.1 \times 10^{-13} \frac{\text{Ci}}{\text{sec}}} + \left(\overset{\text{(28, p. 70 UF}_6\text{F)}}{5.6 \times 10^{-8} \frac{\text{Ci}}{\text{yr}}} + 3.4 \times 10^{-10} \frac{\text{Ci}}{\text{yr}} + 2.8 \times 10^{-8} \frac{\text{Ci}}{\text{yr}} \right) \times \right. \\ \left. \frac{\text{yr}}{300 \text{ days}} \times \frac{\text{day}}{86,400 \text{ sec}} + \left(\overset{\text{(see above PPF)}}{1.55 \times 10^{-13} \frac{\text{g}}{\text{sec}}} \times 0.075 \times \overset{\text{(30, \#36)}}{3.90 \times 10^{-3} \frac{\text{Ci}}{\text{g}}} \right) \right]$$

$$B = \overset{\text{(30, \#36)}}{3.90 \times 10^{-3}} \quad C = 2.51 \times 10^{-9} \quad D = 5.02 \times 10^{-13}$$

10-32. Americium 241:

$$A = \left[\overset{\text{(28, App. VI, p. 9, 10, 11 SF)}}{3.2 \times 10^{-11} \frac{\text{Ci}}{\text{sec}}} + 2 \times 10^{-13} \frac{\text{Ci}}{\text{sec}} + 3 \times 10^{-16} \frac{\text{Ci}}{\text{sec}} \right]$$

$$B = \overset{\text{(30, \#37)}}{3.24} \quad C = 8.59 \times 10^{-10} \quad D = 1.72 \times 10^{-13}$$

Americium 242:

$$A = 6.3 \times 10^{-13} \quad B = \overset{\text{(28, App. VI, p. 9 SF)}}{8.1 \times 10^5} \quad C = 6.72 \times 10^{-17} \quad D = 1.34 \times 10^{-20}$$

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

10-33. Curium 242:

$$A = \left[\left(3.7 \times 10^{-9} \frac{\text{Ci}}{\text{sec}} + 2 \times 10^{-11} \frac{\text{Ci}}{\text{sec}} + 1 \times 10^{-16} \frac{\text{Ci}}{\text{sec}} \right) \right]$$

$$B = \frac{(30, \#40)}{3.31 \times 10^3} \quad C = 9.71 \times 10^{-11} \quad D = 1.94 \times 10^{-14}$$

Curium 243:

$$A = \frac{(28, \text{App. VI, p. 9 SF})}{2.5 \times 10^{-12}} \quad B = \frac{(30, \#41)}{4.60 \times 10^1} \quad C = 4.70 \times 10^{-12} \quad D = 9.40 \times 10^{-16}$$

Curium 244:

$$A = \left[\left(3.9 \times 10^{-10} \frac{\text{Ci}}{\text{sec}} + 2 \times 10^{-12} \frac{\text{Ci}}{\text{sec}} + 1 \times 10^{-17} \frac{\text{Ci}}{\text{sec}} \right) \right]$$

$$B = \frac{(30, \#42)}{8.33 \times 10^1} \quad C = 4.07 \times 10^{-10} \quad D = 8.14 \times 10^{-14}$$

10-34. Iodine - Derived from Iodine 129 because of its long radioactive half life.

$$A = \frac{(27, \text{p III-11})}{1.5 \times 10^{-9}} \quad B = \frac{(30, \#16)}{1.63 \times 10^{-4}} \quad C = 7.95 \times 10^{-4} \quad D = 1.59 \times 10^{-7}$$

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

5-31-77

10-35. Calculation of the release factors in the table below is based on the following equation:

$$\frac{D \text{ kg radionuclide}}{\text{kg U(reprocessing input)}} \times \frac{1}{\frac{G \text{ gram radionuclide}}{\text{metric ton U(reactor input)}}} \times \frac{10^3 \text{ grams radionuclide}}{\text{kg radionuclide}} \times \frac{10^3 \text{ kg U}}{\text{metric ton U}} \times \frac{.965 \text{ U(reprocessing input)}}{1.000 \text{ U(reactor input)}} = \frac{\text{RF kg radionuclide (effluent)}}{\text{kg radionuclide (contained)}}$$

Note: D values come from reference calculations 10-20 through 10-33.

G values come from ORIGEN code, chain 10(180 days cooling time).

RF values are the release factors.

Isotope	D	G	RF	Averaged RF
1) Tritium	3.20E-8	4.52E-2	6.83E-1	6.83E-1
2) Krypton-85	1.90E-5	2.44E+1	7.51E-1	1.0
3) Strontium-89	4.66E-15	1.93	2.33E-9	2.27E-9
4) Strontium-90	1.08E-12	4.73E+2	2.20E-9	
5) Yttrium-90	2.80E-16	1.23E-1	2.20E-9	2.50E-9
6) Yttrium-91	1.13E-14	3.91	2.79E-9	
7) Zirconium-95	2.28E-14	8.17	2.69E-9	2.69E-9
8) Niobium-95	2.34E-14	8.57	2.63E-9	2.63E-9

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

Isotope	D	G	RF	Averaged RF
9) Ruthenium-103	4.54E-15	1.34	3.27E-9	2.88E-9
10) Ruthenium-106	2.58E-13	9.99E+1	2.49E-9	
11) Cesium-134	2.54E-13	1.28E+2	1.91E-9	2.04E-9
12) Cesium-137	2.42E-12	1.08E+3	2.16E-9	
13) Cerium-141	3.38E-15	8.41E-1	3.88E-9	3.11E-9
14) Cerium-144	4.56E-13	1.89E+2	2.33E-9	
15) Promethium-147	2.66E-13	9.72E+1	2.64E-9	2.64E-9
16) Uranium-232	5.58E-15	1.98E-4	2.72E-5	2.08E-5
17) Uranium-233	3.58E-14	2.45E-3	1.41E-5	
18) Uranium-234	4.98E-11	2.49	1.93E-5	
19) Uranium-235	6.12E-9	7.62E+3	7.75E-7	
20) Uranium-236	8.40E-8	3.52E+3	2.30E-5	
21) Uranium-237	7.50E-16	3.40E-5	2.13E-5	
22) Uranium-238	1.92E-5	9.45E+5	1.96E-5	
23) Plutonium-238	1.73E-13	1.23E+2	1.36E-9	1.10E-9
24) Plutonium-239	4.60E-12	4.75E+3	9.35E-10	
25) Plutonium-240	2.10E-12	2.06E+3	9.84E-10	
26) Plutonium-241	1.17E-12	1.10E+3	1.03E-9	
27) Plutonium-242	5.02E-13	4.14E+2	1.17E-9	1.93E-9
28) Americium-241	1.72E-13	5.71E+1	2.91E-9	
29) Americium-242	1.34E-20	1.35E-5	9.58E-10	6.32E-9
30) Curium-242	1.94E-14	5.05	3.71E-9	
31) Curium-243	9.40E-16	8.71E-2	1.04E-8	
32) Curium-244	8.14E-14	1.62E+1	4.85E-9	
33) Iodine-129	1.59E-17	1.70E+2	8.88E-4	

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

5-02-77

REFERENCE 24

	<u>Half-life</u>	<u>Ci/g</u>
1. Krypton-83M	1.86h	2.03E+7
2. Krypton-85M	4.39h (4.4)	8.40E+6
3. Krypton-85	10.76y	3.91E+2
4. Krypton-87	76m	2.84E+7
5. Krypton-88	2.80h	1.27E+7
6. Krypton-89	3.2m	6.60E+8
7. Xenon-131M	11.8d (12)	8.45E+4
8. Xenon-133M	2.26d (2.3)	4.35E+5
9. Xenon-133	5.27d	1.86E+5
10. Xenon-135M	15.6m (16)	8.93E+7
11. Xenon-135	9.2h	2.52E+6
12. Xenon-137	3.9m (4.2)	3.52E+8
13. Xenon-138	17m	8.02E+7
14. Iodine-130	12.3h (12)	1.96E+6
15. Iodine-131	8.070d (8.05)	1.24E+5
16. Iodine-132	2.3h	1.03E+7
17. Iodine-133	20.9h (21)	1.13E+6
18. Iodine-135	6.7h	3.47E+6

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

REFERENCE 24 (cont'd)

	<u>Half-life</u>	<u>Ci/g</u>
19. Rubidium-86	18.66d (18.7)	8.14E+4
20. Rubidium-88	17.8m (18)	1.20E+8
21. Strontium-89	52d (50.6)	2.82E+4
22. Strontium-90	28.1y (28.8)	1.42E+2
23. Strontium-91	9.67h (9.7)	3.56E+6
24. Yttrium-90	64h (64.2)	5.44E+5
25. Yttrium-91M	50m	4.13E+7
26. Yttrium-91	58.8d (59)	2.44E+4
27. Yttrium-93	10.2h (10.1)	3.31E+6
28. Zirconium-95	65d	2.12E+4
29. Zirconium-97	17h	1.90E+6
30. Niobium-95	35.15d (35)	3.91E+4
31. Niobium-97M	1.0m	1.94E+9
32. Niobium-97	72m	2.69E+7
33. Molybdenum-99	66.69h (67)	4.75E+5
34. Technitium-99M	6.0h	5.28E+6
35. Ruthenium-103	39.6d (40)	3.20E+4
36. Ruthenium-106	367d (1 yr)	3.36E+3
37. Rhodium-103M	(57m)	3.20E+7
38. Rhodium-105	35.9h (36)	8.32E+5
39. Rhodium-106	30s	3.55E+9

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

REFERENCE 24 (cont'd)

	<u>Half-life</u>	<u>Ci/g</u>
40. Tin-125	9.4d (9.62)	1.11E+5
41. Antimony-125	2.7y	1.06E+3
42. Antimony-127	93h (3.9d)	2.65E+5
43. Tellurium-125M	58d	1.80E+4
44. Tellurium-127M	109d (105)	9.44E+3
45. Tellurium-127	9.4h (9.3)	2.63E+6
46. Tellurium-129M	34d	2.98E+4
47. Tellurium-129	69m (67)	2.11E+7
48. Tellurium-131M	30h (1.2d)	7.98E+5
49. Tellurium-131	25m	5.74E+7
50. Tellurium-132	78h	3.05E+5
51. Cesium-134	2.05y (2.1)	1.30E+3
52. Cesium-136	13d	7.39E+4
53. Cesium-137	30.23y (30)	8.64E+1
54. Barium-137M	2.55m (2.6)	5.38E+8
55. Barium-140	12.8d	7.29E+4
56. Lanthanum-140	40.22h (40.2)	5.57E+5
57. Cerium-141	33d (32.5)	2.81E+4
58. Cerium-143	33h	6.64E+5
59. Cerium-144	284.9d (285)	3.18E+3
60. Praseodymium-143	13.7d	6.67E+4

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

REFERENCE 24 (cont'd)

	<u>Half-life</u>	<u>Ci/g</u>
61. Praseodymium-144	17.3m	7.55E+7
62. Neodymium-147	11.1d	8.01E+4
63. Promethium-147	2.5y (2.6)	9.74E+2
64. Chromium-51	27.8d	9.21E+4
65. Manganese-54	303d (312)	7.98E+3
66. Iron-55	2.6y (2.4)	2.50E+3
67. Iron-59	45.1d (45)	4.91E+4
68. Cobalt-58	71.3d (71)	3.16E+4
69. Cobalt-60	5.26y (5.24)	1.13E+3
70. Tritium	12.26y	9.73E+3
71. Argon-41	1.83h	4.18E+7
72. Zinc-65	243.6d	8.25E+3
73. Antimony-124	60.3d	1.75E+4
74. Carbon-14	5730y	4.46
75. Sodium-24	15.0h	8.71E+6
76. Phosphorus-32	14.3d	2.85E+5
77. Manganese-56	2.576h	2.17E+7
78. Nickel-65	2.521h	1.91E+7
79. Copper-64	12.9h	3.80E+6
80. Zinc-69M	13.9h	3.27E+6

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

REFERENCE 24 (cont'd)

	<u>Half-life</u>	<u>Ci/g</u>
81. Zinc-69	58m	4.70E+7
82. Wolfram-187	24h	6.99E+5
83. Neptunium-239	2.35d	2.33E+5
84. Bromine-83	2.41h	1.57E+7
85. Bromine-84	31.8m	7.04E+7
86. Rubidium-89	15.4m	1.37E+8
87. Strontium-92	2.71h	1.26E+7
88. Yttrium-92	3.53h	9.65E+6
89. Niobium-98	51m	3.76E+7
90. Technitium-101	14m	1.33E+8
91. Technitium-104	18m	1.00E+8
92. Ruthenium-105	4.44h	6.72E+6
93. Rhodium-105M	45s	2.39E+9
94. Iodine-134	52m	2.70E+7
95. Cesium-138	32.2m	4.23E+7
96. Barium-139	82.9m	1.63E+7
97. Lanthanum-141	3.9h	5.70E+6
98. Lanthanum-142	92m	1.44E+7

() Chart of Nuclides (1969)

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

5-19-77

REFERENCE 30

	<u>Half-life</u>	<u>Ci/g</u>
1. Hydrogen-3	12.26y	9.73E+3
2. Carbon-14	5730y	4.46
3. Krypton-85	10.76y	3.91E+2
4. Strontium-89	52d	2.82E+4
5. Strontium-90	28.1y	1.42E+2
6. Yttrium-90	64h	5.44E+5
7. Yttrium-91	58.8d	2.44E+4
8. Zirconium-95	65d	2.12E+4
9. Niobium-95	35.15d	3.91E+4
10. Ruthenium-103	39.6d	3.20E+4
11. Ruthenium-106	367d	3.36E+3
12. Silver-110M	253d	4.69E+3
13. Antimony-125	2.7y	1.06E+3
14. Tellurium-127M	109d	9.44E+3
15. Tellurium-129M	34d	2.98E+4
16. Iodine-129	1.7 X 10E+7y	1.63E-4
17. Iodine-131	8.070d	1.24E+5
18. Cesium-134	2.05y	1.30E+3
19. Cesium-137	30.23y	8.64E+1

REFERENCE CALCULATIONS: Reprocessing Facility (cont'd)

REFERENCE 30 (cont'd)

	<u>Half-life</u>	<u>Ci/g</u>
20. Cerium-141	33d	2.81E+4
21. Cerium-144	284.9d	3.18E+3
22. Promethium-147	2.5y	9.74E+2
23. Europium-154	16y	1.45E+2
24. Europium-155	1.81y	1.28E+3
25. Uranium-232	73.6y	2.10E+1
26. Uranium-233	1.62 X 10E+5y	9.48E-3
27. Uranium-234	2.47 X 10E+5y	6.19E-3
28. Uranium-235	7.1 X 10E+8y	2.14E-6
29. Uranium-236	2.39 X 10+7y	6.35E-5
30. Uranium-237	6.75d	8.17E+4
31. Uranium-238	4.51 X 10E+9y	3.33E-7
32. Plutonium-238	86y	1.75E+1
33. Plutonium-239	2.44 X 10E+4y	6.14E-2
34. Plutonium-240	6580y	2.27E-1
35. Plutonium-241	13.2y	1.13E+2
36. Plutonium-242	3.79 X 10E+5y	3.90E-3
37. Americium-241	458y	3.24
38. Americium-242	16.0h	8.10E+5
39. Americium-243	7.37 X 10E+3y	2.00E-1
40. Curium-242	163d	3.31E+3
41. Curium-243	32y	4.60E+1
42. Curium-244	17.6y	8.33E+1

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17. Environmental Survey of the Uranium Fuel Cycle, U.S.A.E.C., WASH-1248, April 1974.
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21. Recycle Fuels Plant, Environmental Report, Westinghouse Nuclear Fuel Division, July 1973 (no document number assigned).
22. From Section 11A of this report.
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25. & 26. Final Safety Analysis Report, WNP-2, Washington Public Power Supply System, U.S. NRC Docket No. 50-397.
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**EFFLUENT
RELEASE
FACTORS: B**

APPENDIX B

ADDITIONAL DERIVATIONS OF EFFLUENT RELEASE FACTORS FOR THE REFERENCE FUEL CYCLE FACILITIES

M. H. Arndt, J. K. Young

Appendix B contains the derivations of radioactive carbon-14 release factors for the reference boiling water reactor, pressurized water reactor and reprocessing facilities.

A release factor is defined in units of kilograms released per kilogram of heavy metal processed for each chemical species. The release factors are assigned a reliability rating of 1, 2, or 3 based on the following assumptions:

1. A reasonable but unsubstantiated guess
2. Calculated or based on laboratory measurement
3. Based on some plant experience

The reference plants studied were:

<u>Facility</u>	<u>Page Number of Summary Table</u>
Surface Mine	B-2
Underground Mine	B-8
Acid Leach Mill	B-17
Aqueous Conversion	B-26
Gaseous Diffusion Enrichment	B-34
Uranium Fuel Fabrication	B-30
Pressurized Water Reactor	B-39
Boiling Water Reactor	B-47
Fuel Reprocessing	B-53

The summary tables present the release factor, the reliability rating and the number of the reference calculation for individual chemicals released from the facility. These release factors supplement those found in Appendix A.

TABLE B-1. Surface Mine - Chemical Release Factors
kg/kgU (input)

<u>Material Released</u>	<u>Airborne</u>			<u>Liquid</u>		
	<u>Factor</u>	<u>Reliability</u>	<u>Ref. Calc.</u>	<u>Factor</u>	<u>Reliability</u>	<u>Ref. Calc.</u>
Thorium-230						
Hydrogen Sulfide						
Chloride						
Sulfate						
Arsenic				4×10^{-5}	1	B.1.2.1
Selenium				2×10^{-5}	1	B.1.2.2
Ammonia				3×10^{-4}	1	B.1.2.3
Kjeldahl Nitrogen				8×10^{-4}	1	B.1.2.4
Nitrate				1×10^{-4}	1	B.2.2.5
Phosphorus				6×10^{-4}	1	B.1.2.6
Fluoride				4×10^{-4}	1	B.1.2.7
Aluminum				4×10^{-4}	1	B.1.2.8
Beryllium				8×10^{-6}	1	B.1.2.9
Calcium				8×10^{-2}	1	B.1.2.10
Magnesium				3×10^{-2}	1	B.1.2.11
Titanium				7×10^{-4}	1	B.1.2.12
Molybdenum				7×10^{-4}	1	B.1.2.13
Vanadium				1×10^{-3}	1	B.1.2.14
Iron				6×10^{-3}	1	B.1.2.15
Lead				1×10^{-4}	1	B.1.2.16
Zinc				2×10^{-5}	1	B.1.2.17

B.1 SURFACE MINE CALCULATIONS

B.1.1 ASSUMPTIONS

The largest liquid waste stream from open pit mining operations is the mine drainage water. The mine water discharge for a similar model mine with a capacity of 960 MT U_3O_8 /yr is about 1500 gpm (Reference 4, pp. A-9). The capacity of the ENFORM model mine is 2337 MT U_3O_8 /yr. therefore the following scale-up is utilized to assume a reasonable mine-water discharge rate for calculations.

$$1500 \text{ gal/min} \times 1440 \text{ min/day} \times \frac{2337 \text{ MT } U_3O_8/\text{yr}}{960 \text{ MT } U_3O_8/\text{yr}} = 5.26 \times 10^6 \text{ gal/day}$$

The mine drainage water is pumped from the mine to keep the mine dry while ore is being extracted. Only part of this water becomes surface run-off (arbitrarily assumed 25%) while the bulk recycles through natural seepage and evaporation (Reference 4, pp. A-9).

$$5.26 \times 10^6 \text{ gal/day} \times .25 = 1.31 \times 10^6 \text{ gal/day}$$

Therefore, only 1.31×10^6 gpd of the mine drainage stream is assumed an effluent.

Reference 5 data will be used for surface mine calculations (see page B-9 for explanation).

B.1.2 LIQUID RELEASES

B.1.2.1 Arsenic

(4, pp. A-10)

$$.05 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.31 \times 10^6 \text{ gal/day} = .25 \text{ kg As/day}$$

$$\therefore \frac{.25 \text{ kg As/day}}{6350 \text{ kg U/day}} = 4 \times 10^{-5} \frac{\text{kg As}}{\text{kg U (input)}}$$

B.1.2.2 Selenium

(4, p. A-10)

$$.02 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.31 \times 10^6 \text{ gal/day} = .10 \text{ kg Se/day}$$

$$\therefore \frac{.10 \text{ kg Se/day}}{6350 \text{ kg U/day}} = 1.6 \times 10^{-5} \frac{\text{kg Se}}{\text{kg U (input)}}$$

B.1.2.3 Ammonia

(4, p. A-12)

$$\frac{.22 + 1.33 + 1.51}{3} \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.31 \times 10^6 \text{ gal/day}$$

$$= 5.08 \text{ kg NH}_3/\text{day}$$

$$\therefore \frac{5.08 \text{ kg NH}_3/\text{day}}{6350 \text{ kg U/day}} = 8.0 \times 10^{-4} \frac{\text{kg NH}_3}{\text{kg U}}$$

B.1.2.4 Kjeldahl Nitrogen

(4, p. A-12)

$$\frac{.22 + 1.33 + 1.42}{3} \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.31 \times 10^6 \text{ gal/day}$$

$$= 4.9 \text{ kg N/day}$$

$$\therefore \frac{4.9 \text{ kg N/day}}{6350 \text{ kg U/day}} = 7.8 \times 10^{-4} \frac{\text{kg N}}{\text{kg U}}$$

B.1.2.5 Nitrate

(4, p. A-12)

$$\frac{.01 + .002 + .53}{3} \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.31 \times 10^6 \text{ gal/day}$$

$$= 0.90 \text{ kg NO}_3/\text{day}$$

$$\therefore \frac{0.90 \text{ kg NO}_3/\text{day}}{6350 \text{ kg U/day}} = 1.4 \times 10^{-4} \frac{\text{kg NO}_3}{\text{kg U}}$$

B.1.2.6 Phosphorus

(4, p. A-12)

$$\begin{aligned} & \left(\frac{.05 + .07 + 2.3}{3} \right) \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.31 \times 10^6 \text{ gal/day} \\ & = 4.0 \text{ kg PO}_4\text{/day} \\ & \therefore \frac{4.0 \text{ kg PO}_4\text{/day}}{6350 \text{ kg U/day}} = 6.3 \times 10^{-4} \frac{\text{kg PO}_4}{\text{kg U}} \end{aligned}$$

B.1.2.7 Fluoride

(5, p. 336)

$$\begin{aligned} & .45 \text{ mg/l} \times 1.31 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 2.24 \text{ kg Fluoride/day} \\ & \therefore \frac{2.24 \text{ kg Fluoride/day}}{6350 \text{ kg U/day}} = 3.5 \times 10^{-4} \frac{\text{kg Fluoride}}{\text{kg U}} \end{aligned}$$

B.1.2.8 Aluminum

(Same as Fluoride)

B.1.2.9 Beryllium

(5, p. 336)

$$\begin{aligned} & .01 \text{ mg/l} \times 1.31 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = .05 \text{ kg Be/day} \\ & \therefore \frac{.05 \text{ kg Be/day}}{6350 \text{ kg U/day}} = 7.81 \times 10^{-6} \frac{\text{kg Be}}{\text{kg U}} \end{aligned}$$

B.1.2.10 Calcium

(5, p. 336)

$$\begin{aligned} & \left(\frac{90 + 120}{2} \right) \text{ mg/l} \times 1.31 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 522 \text{ kg Ca/day} \\ & \therefore \frac{522 \text{ kg Ca/day}}{6350 \text{ kg U/day}} = .082 \frac{\text{kg Ca}}{\text{kg U}} \end{aligned}$$

B.1.2.11 Magnesium

(5, p. 336)

$$40 \text{ mg/l} \times 1.31 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 199.0 \text{ kg Mg/day}$$

$$\therefore \frac{199.0 \text{ kg Mg/day}}{6350 \text{ kg U/day}} = .031 \frac{\text{kg Mg}}{\text{kg U}}$$

B.1.2.12 Titanium

(5, p. 336)

$$.95 \text{ mg/l} \times 1.31 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 4.7 \text{ kg Ti/day}$$

$$\therefore \frac{4.7 \text{ kg Ti/day}}{6350 \text{ kg U/day}} = 7.4 \times 10^{-4} \frac{\text{kg Ti}}{\text{kg U}}$$

B.1.2.13 Molybdenum

(5, p. 336)

$$.85 \text{ mg/l} \times 1.31 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 4.2 \text{ kg Mo/day}$$

$$\therefore \frac{4.2 \text{ kg Mo/day}}{6350 \text{ kg U/day}} = 6.7 \times 10^{-4} \frac{\text{kg Mo}}{\text{kg U}}$$

B.1.2.14 Vanadium

(5, p. 336)^(a)

$$1.3 \text{ mg/l} \times 1.31 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 6.5 \text{ kg V/day}$$

$$\therefore \frac{6.5 \text{ kg V/day}}{6350 \text{ kg U/day}} = 1 \times 10^{-3} \frac{\text{kg V}}{\text{kg U}}$$

(a) 0.5 to 2.1 mg/l; assumed average of 1.3

B.1.2.15 Iron

(5, p. 337)

$$7.6 \text{ mg/l} \times 1.31 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 37.8 \text{ kg Fe/day}$$

$$\therefore \frac{37.8 \text{ kg Fe/day}}{6350 \text{ kg U/day}} = 6 \times 10^{-3} \frac{\text{kg Fe}}{\text{kg U}}$$

B.1.2.16 Lead

(5, p. 337)

$$.14 \text{ mg/l} \times 1.31 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 0.70 \text{ kg Pb/day}$$

$$\therefore \frac{0.70 \text{ kg Pb/day}}{6350 \text{ kg U/day}} = 1.10 \times 10^{-4} \frac{\text{kg Pb}}{\text{kg U}}$$

B.1.2.17 Zinc

(5, p. 337)

$$.025 \text{ mg/l} \times 1.31 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 0.12 \text{ kg Zn/day}$$

$$\therefore \frac{0.12 \text{ kg Zn/day}}{6350 \text{ kg U/day}} = 1.96 \times 10^{-5} \frac{\text{kg Zn}}{\text{kg U}}$$

TABLE B-2. Underground Mine - Chemical Release Factors
kg/kgU (input)

Material Released	Airborne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Hydrogen Sulfide						
Thorium-230						
Benzo(a)pyrene	7×10^{-8}	2	B.2.2.1			
Beryllium	1×10^{-6}	2	B.2.2.2	1×10^{-5}	1	B.2.3.16
Cadmium	2×10^{-6}	2	B.2.2.3			
Sulfur	5×10^{-4}	2	B.2.2.4			
Zinc	2×10^{-5}	2	B.2.2.5	3×10^{-5}	1	B.2.3.8
Lead	2×10^{-5}	2	B.2.2.6	2×10^{-4}	1	B.2.3.22
Copper				1×10^{-4}	1	B.2.3.1
Silica				2×10^{-2}	1	B.2.3.2
Fluoride				1×10^{-3}	1	B.2.3.3
Iron				2×10^{-4}	1	B.2.3.4
Chloride				2	1	B.2.3.5
Magnesium				2×10^{-2}	1	B.2.3.6
Calcium				4×10^{-2}	1	B.2.3.7
Phosphate				2×10^{-4}	1	B.2.3.9
Nitrate				1×10^{-2}	1	B.2.3.10
Sulfates				3×10^{-1}	1	B.2.3.11
Sodium				1	1	B.2.3.12
Ammonia				1×10^{-3}	1	B.2.3.13
Kjeldahl Nitrogen				5×10^{-2}	1	B.2.3.14
Aluminum				5×10^{-4}	1	B.2.3.15
Titanium				1×10^{-3}	1	B.2.3.17
Arsenic				2×10^{-5}	1	B.2.3.18
Molybdenum				9×10^{-4}	1	B.2.3.19
Vanadium				1×10^{-3}	1	B.2.3.20
Manganese				3×10^{-4}	1	B.2.3.21

B.2 UNDERGROUND MINE CALCULATIONS

B.2.1 ASSUMPTIONS

The following values were previously calculated in Appendix A⁽¹⁾ and will be used extensively in the subsequent calculations.

<u>Value</u>	<u>Calc.</u>
6351 kg U(input)/day	2-1 ⁽¹⁾
1.87×10^6 gal mine water to surface runoff/day	2-7 ⁽¹⁾

Fresh air enters the seven mines at a total rate of 6.26×10^{10} L/day. It is assumed that air also discharges at this rate. At the average elevation of 2134 m (7000 ft), this air discharge would weigh about 6.22×10^7 kg day (see calculation B.1.3.23, Appendix B).

The Rio Algon Uranium Mine reported the liquid discharge concentrations used for calculations B.1.3.1 to B.1.3.12. This water was discharged from the ventilation shaft. Release factors are calculated assuming concentrations are also the same for water discharged from the production shaft.

Reference 5 makes no distinction between underground and surface mine waste water because choice of mine is determined by factors other than chemical characteristics of the deposits. In lieu of this reasoning, data from Reference 5 is used for release factor calculations B.1.3.15 to B.1.3.22 since data specific to underground mine water is not available for these elements. (When a range of concentrations is given, the median is used for calculation.)

Several other elemental airborne effluents, in addition to those calculated in this report, are present in the mine-air discharge. However, it is assumed that these particles are considered in the release factor for rock dust.⁽¹⁾ Beryllium and cadmium (Calculations B.1.2.2, B.1.2.3) are considered separately from rock dust because of their toxicity.

B.2.2 AIRBORNE RELEASES

B.2.2.1 Benzo(a)pyrene - results from incomplete combustion of diesel fuel

(2, p. 4-6)

$$62 \frac{\mu\text{g BaP}}{\text{gal fuel}} \times 7000 \text{ gal fuel/day} \times \frac{\text{kg}}{10^9 \mu\text{g}} = 4.34 \times 10^{-4} \text{ kg BaP/day}$$
$$\therefore \frac{4.34 \times 10^{-4} \text{ kg BaP/day}}{6351 \text{ kg U/day}} = 6.8 \times 10^{-8} \frac{\text{kg BaP}}{\text{kg U (input)}}$$

B.2.2.2 Beryllium - Beryllium and cadmium will be considered separately from rock dust because of their toxicity.

(2, p. 5-42)

$$\frac{100 \text{ ng}}{\text{m}^3} \times 6.26 \times 10^7 \text{ m}^3/\text{day} \times \frac{\text{kg}}{10^{12} \text{ ng}} = 6.3 \times 10^{-3} \text{ Kg Be/day}$$
$$\therefore \frac{6.3 \times 10^{-3} \text{ kg Be/day}}{6351 \text{ kg U/day}} = 9.9 \times 10^{-7} \frac{\text{kg Be}}{\text{kg U (input)}}$$

B.2.2.3 Cadmium

(2, p. 5-42)

$$\frac{200 \text{ ng}}{\text{m}^3} \times 6.26 \times 10^7 \text{ m}^3/\text{day} \times \frac{\text{kg}}{10^{12} \text{ ng}} = .0125 \text{ kg Cd/day}$$
$$\therefore \frac{.0125 \text{ kg Cd/day}}{6351 \text{ kg U/day}} = 1.97 \times 10^{-6} \frac{\text{kg Cd}}{\text{kg U (input)}}$$

B.2.2.4 Sulfur - from blasting, fuses probable source

(2, p. 5-41)

$$6.26 \times 10^7 \text{ m}^3/\text{day} \times \frac{50 \mu\text{g}}{\text{m}^3} \times \frac{\text{kg}}{10^9 \mu\text{g}} = 3.13 \text{ kg S/day}$$
$$\therefore \frac{3.13 \text{ kg S/day}}{6351 \text{ kg U/day}} = 4.9 \times 10^{-4} \frac{\text{kg S}}{\text{kg U (input)}}$$

B.2.2.5 Zinc - blasting, blasting caps source

(2, p. 5-41)

$$\frac{2 \text{ } \mu\text{g}}{\text{m}^3} \times 6.26 \times 10^7 \text{ m}^3/\text{day} \times \frac{\text{kg}}{10^9 \text{ } \mu\text{g}} = .125 \text{ kg Zn/day}$$

$$\therefore \frac{.125 \text{ kg Zn/day}}{6351 \text{ kg U/day}} = 1.97 \times 10^{-5} \frac{\text{kg Zn}}{\text{kg U (input)}}$$

B.2.2.6 Lead - blasting, blasting caps source

See Calculation B.2.2.5 for Zinc.

B.2.3 LIQUID RELEASES

B.2.3.1 Copper

(3, p. 38)

$$.1 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day} = .71 \text{ kg Cu/day}$$

$$\therefore \frac{.71 \text{ kg Cu/day}}{6351 \text{ kg U/day}} = 1.1 \times 10^{-4} \frac{\text{kg Cu}}{\text{kg U (input)}}$$

B.2.3.2 Silica

(3, p. 38)

$$14.2 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day}$$

$$= 1.0 \times 10^2 \text{ kg silica/day}$$

$$\therefore \frac{1 \times 10^2 \text{ kg silica/day}}{6351 \text{ kg U/day}} = 1.6 \times 10^{-2} \frac{\text{kg silica}}{\text{kg U (input)}}$$

B.2.3.3 Fluoride

(3, p.38)

$$1.28 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day}$$

$$= 9.06 \text{ kg fluoride/day}$$

$$\therefore \frac{9.06 \text{ kg fluoride/day}}{6351 \text{ kg U/day}} = 1.4 \times 10^{-3} \frac{\text{kg fluoride}}{\text{kg U (input)}}$$

B.2.3.4 Iron

(3, p. 38)

$$.16 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day} = 1.13 \text{ kg Fe/day}$$

$$\therefore \frac{1.13 \text{ kg Fe/day}}{6351 \text{ kg U/day}} = 1.78 \times 10^{-4} \frac{\text{kg Fe}}{\text{kg U (input)}}$$

B.2.3.5 Chloride

(3, p. 38)

$$1597 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day}$$

$$= 1.13 \times 10^4 \text{ kg chloride/day}$$

$$\therefore \frac{1.13 \times 10^4 \text{ kg chloride day}}{6351 \text{ kg U/day}} = 1.78$$

B.2.3.6 Magnesium

(3, p. 38)

$$17.2 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day}$$

$$= 1.22 \times 10^2 \text{ kg Mg/day}$$

$$\therefore \frac{1.22 \times 10^2 \text{ kg Mg/day}}{6351 \text{ kg U/day}} = \frac{1.9 \times 10^{-2} \text{ kg Mg}}{\text{kg U (input)}}$$

B.2.3.7 Calcium

(3, p. 38)

$$37.8 \text{ mg Ca/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day} = 268 \text{ kg Ca/day}$$

$$\therefore \frac{268 \text{ kg Ca/day}}{6351 \text{ kg U/day}} = 4.2 \times 10^{-2} \frac{\text{kg Ca}}{\text{kg U (input)}}$$

B.2.3.8 Zinc

(3, p. 38)

$$.03 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day} = .21 \text{ kg Zn/day}$$

$$\therefore \frac{.21 \text{ kg Zn/day}}{6351 \text{ kg U/day}} = 3.3 \times 10^{-5} \frac{\text{kg Zn}}{\text{kg U (input)}}$$

B.2.3.9 Phosphate

(3, p. 38)

$$.2 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day} = 1.4 \text{ kg PO}_4\text{/day}$$

$$\therefore \frac{1.4 \text{ kg PO}_4\text{/day}}{6351 \text{ kg U/day}} = 2.20 \times 10^{-4} \frac{\text{kg PO}_4}{\text{kg U (input)}}$$

B.2.3.10 Nitrates

(3, p. 38)

$$9.5 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day} = 67.2 \text{ kg NO}_3\text{/day}$$

$$\therefore \frac{67.2 \text{ kg NO}_3\text{/day}}{6351 \text{ kg U/day}} = 1.0 \times 10^{-2} \frac{\text{kg NO}_3}{\text{kg U (input)}}$$

B.2.3.11 Sulfates

(3, p. 38)

$$309 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day}$$

$$= 2.19 \times 10^3 \text{ kg SO}_4\text{/day}$$

$$\therefore \frac{2.19 \times 10^3 \text{ kg SO}_4\text{/day}}{6351 \text{ kg U/day}} = 3.4 \times 10^{-1} \frac{\text{kg SO}_4}{\text{kg U (input)}}$$

B.2.3.12 Sodium

(3. p. 30)

$$1335 \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day} = 9.4 \times 10^3 \text{ kg Na/day}$$
$$\therefore \frac{9.4 \times 10^3 \text{ kg Na/day}}{6351 \text{ kg U/day}} = 1.5 \frac{\text{kg Na}}{\text{kg U (input)}}$$

B.2.3.13 Ammonia

(4. p. A-13)

$$\frac{.15 + .10 + .10 + 3.3}{4}^{(a)} \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day} = 6.5 \text{ kg NH}_3/\text{day}$$
$$\therefore \frac{6.5 \text{ kg NH}_3/\text{day}}{6351 \text{ kg U/day}} = 1.0 \times 10^{-3} \frac{\text{kg NH}_3}{\text{kg U (input)}}$$

B.2.3.14 Kjeldahl Nitrogen

(4, p. A-13)

$$\frac{.55 + 145 + .3 + 21.8}{4}^{(a)} \text{ mg/l} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} \times 1.87 \times 10^6 \text{ gal/day} = 3 \times 10^2 \text{ kg N/day}$$
$$\therefore \frac{300 \text{ kg N/day}}{6351 \text{ kg U/day}} = 4.7 \times 10^{-2} \frac{\text{kg N}}{\text{kg U (input)}}$$

B.2.3.15 Aluminum

(5, p. 336)

$$.45 \text{ mg/l} \times 1.87 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 3.18 \text{ kg Al/day}$$
$$\therefore \frac{3.18 \text{ kg Al/day}}{6351 \text{ kg U/day}} = 5.0 \times 10^{-4} \frac{\text{kg Al}}{\text{kg U}}$$

(a) Concentration data from 4 mines in Colorado.

B.2.3.16 Beryllium

(5, p. 336)

$$.01 \text{ mg/l} \times 1.87 \times 10^6 \text{ gal/day} \times \frac{\text{kg}}{10^6 \text{ mg}} \times 3.785 \text{ l/gal} = .07 \text{ kg Be/day}$$

$$\therefore \frac{.07 \text{ kg Be/day}}{6351 \text{ kg U/day}} = 1.1 \times 10^{-5} \frac{\text{kg Be}}{\text{kg U}}$$

B.2.3.17 Titanium

(5, p. 336)

$$.95 \text{ mg/l} \times 1.87 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 6.72 \text{ kg Ti/day}$$

$$\therefore \frac{6.72 \text{ kg Ti/day}}{6351 \text{ kg U/day}} = 1.1 \times 10^{-3} \frac{\text{kg Ti}}{\text{kg U}}$$

B.2.3.18 Arsenic

(5, p. 336)

$$.02 \text{ mg/l} \times 1.87 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = .14 \text{ kg As/day}$$

$$\therefore \frac{.14 \text{ kg As/day}}{6351 \text{ kg U/day}} = 2.2 \times 10^{-5} \frac{\text{kg As}}{\text{kg U}}$$

B.2.3.19 Molybdenum

(5, p. 336)

$$.85 \text{ mg/l} \times 1.87 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 6.02 \text{ kg Mo/day}$$

$$\therefore \frac{6.02 \text{ kg Mo/day}}{6351 \text{ kg U/day}} = 9.5 \times 10^{-4} \frac{\text{kg Mo}}{\text{kg U}}$$

B.2.3.20 Vanadium

(6, p. 11)

$$1.3 \text{ mg/l} \times 1.87 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 9.2 \text{ kg V/day}$$

$$\therefore \frac{9.2 \text{ kg V/day}}{6351 \text{ kg U/day}} = 1.4 \times 10^{-3} \frac{\text{kg V}}{\text{kg U (input)}}$$

B.2.3.21 Manganese

(5, p. 336)

$$.25 \text{ mg/l} \times 1.87 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.77 \text{ kg Mn/day}$$

$$\therefore \frac{1.77 \text{ kg Mn/day}}{6351 \text{ kg U/day}} = 2.8 \times 10^{-4} \frac{\text{kg Mn}}{\text{kg U (input)}}$$

B.2.3.22 Lead

From Appendix A, page 11, water discharged to surface is estimated at $1.87 \times 10^6 \frac{\text{gal}}{\text{day}}$ and reference 5, p. 337:

$$.2 \text{ mg/l} \times 1.87 \times 10^6 \text{ gal/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.42 \text{ kg Pb/day}$$

$$\therefore \frac{1.42 \text{ kg Pb/day}}{6351 \text{ kg U/day}} = 2.23 \times 10^{-4} \frac{\text{kg Pb}}{\text{kg U}}$$

B.2.3.23 Fresh Air

Fresh air is pumped through all work areas of the mines so that surplus oxygen is available to the miners and radioactive and chemical pollutants are maintained within safe limits. Walter I. Enderlin, at PNL, obtained from Kerr-McGee's Ambrosia Lake, New Mexico facilities an average of 206,000 CFM of fresh air for each of the seven mines at average elevation 2134 meters or 7000 feet:

$$0.206 \times 10^6 \text{ CFM} \times 28.32 \frac{\text{l}}{\text{CF}} \times 1440 \frac{\text{minutes}}{\text{day}} \times 7 \text{ mines} = 5.88 \times 10^{10} \frac{\text{l}}{\text{day}} \text{ fresh air}$$

Our reference underground facility is assumed to be 6-1/2% larger than the Ambrosia Lake mines so that the contained uranium produced in the mined ore is the same quantity as that produced from the reference surface mine. This makes all effluents directly comparable. Since:

$$1.065 \times 5.88 \times 10^{10} \frac{\text{l}}{\text{day}} = 6.26 \times 10^{10} \frac{\text{l}}{\text{day}} \text{ fresh air}$$

Density ratio for air from page 1530, Marks' Handbook, Fourth Edition, 1941 at 6000 feet = 0.8358, 8000 feet = 0.7859,

the interpolated value for 7000 feet = 0.81085;

The weight of air at sea level, 760 mm Hg, 15°C (59°F) = $1.2256 \frac{\text{g}}{\text{L}}$ (from page 470, Standard Handbook for Electrical Engineers, Seventh Edition, 1941)

then $6.26 \times 10^{10} \frac{\text{L}}{\text{day}}$ fresh air $\times 1.2256 \frac{\text{g}}{\text{L}} \times 0.81085 = 6.22 \times 10^{10} \frac{\text{g}}{\text{day}}$

or $6.22 \times 10^7 \frac{\text{kg}}{\text{day}}$ of fresh air.

TABLE B-3. Acid Leach Mill Chemical Release Factors kg/kg U (input)

Material Released	Airborne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Tertiary Amine				1×10^{-3}	2	B.3.3.1
Isodecanol				2×10^{-3}	2	B.3.3.2
Kerosene	9×10^{-2}	2	B.3.3.3			
Beryllium				1×10^{-5}	2	B.3.3.4
Chromium				9×10^{-4}	2	B.3.3.5
Molybdenum				1×10^{-3}	2	B.3.3.6
Copper				3×10^{-4}	2	B.3.3.7
Nickel				2×10^{-4}	2	B.3.3.8
Lead				2×10^{-4}	2	B.3.3.9
Zinc				5×10^{-4}	2	B.3.3.10
Titanium				1×10^{-3}	2	B.3.3.11
Sulfide				4×10^{-5}	2	B.3.3.12
Cyanide				8×10^{-7}	2	B.3.3.13
Silver				8×10^{-7}	2	B.3.3.14
Manganese				2×10^{-2}	2	B.3.3.15
Magnesium				9×10^{-2}	2	B.3.3.16
Selenium				0	2	B.3.3.17
Sulfuric Acid	neg ^(a)	2		8×10^{-2}	1	B.3.3.18
Arsine	0	1				
Stibine	0	1				
Hydrogen Sulfide	neg ^(a)	1				

(a) negligible

B.3 ACID LEACH MILL CALCULATIONS

B.3.1 ASSUMPTIONS

The following values will be used extensively in the succeeding calculations:

	<u>From Appendix A</u>
2722 kg U (input)/day	Calculation A.3-1
80 gal/min pond flow out	Calculation A.3-2
500 gal/min overflow into pond	Calculation A.3-2

The reference facility has a tailings pond behind a dam which receives all liquid effluents from the mill. It is amply large so that:^(a)

1. Effluents totaling 500 gpm can flow into it 24 hours per day, 365 days per year.
2. Sufficient extra capacity is available to receive the 500 gpm during sub-zero weather which may last several months.
3. Allowance is made for buildup of sludges on the bottom of the pond; sludge will occupy more space with the passage of time.

It is expected that there will initially be a maximum seepage of 80 gpm of tailing solution into the sides of the tailing basin.^(10 p. 37) It is also expected that sludges, etc., will gradually seal off the seepage, so that after about five years there will be no seepage. Mill operations will try to maintain 7 or 8 feet of "freeboard" at all times so that the dam will never be overtopped.

According to Reference 5 p. 165, in a general analysis of raw waste water, the only distinction that must be made is between mills using acid leaching of ore and mills using alkaline leaching of ore. "While other differences between ores and processes can have an effect on waste water characteristics, they are not believed to justify further subcategorization."⁽⁵⁾ Therefore the data on

(a) Information supplied by process engineers at Highland Uranium Mill near Casper, Wyoming.

mill wastes presented in this report, despite the fact that it is not specific to the ENFORM model, is assumed to be applicable for release factor calculations. (See Calculations B.3.3.1 to B.3.3.15.)

B.3.2 AIRBORNE RELEASES

The leach tank vent system releases small amounts of sulfur dioxide, sulfuric acid fumes (SO_3), and possibly hydrogen sulfide. According to the Department of Energy^(4, p. B-10) and their Grand Junction office⁽⁸⁾, the concentration of these gases is very low. In the case of the sulfur oxides, the amount released in the leach tank vents is negligible in comparison with the oxides released as combustion products, therefore they are neglected. Hydrogen sulfide has been detected only in the leaching of high sulfide ore. Since most uranium ore in the United States contains little, if any, sulfur,⁽⁸⁾ hydrogen sulfide is also neglected.

Arsine (AsH_3) and stibine (SbH_3) have also been cited as possible effluents from the leach tank vents in the milling of ores containing arsenic and antimony.⁽¹¹⁾ Both compounds result from reduction in an acid solution of other antimony or arsenic compounds in uranium ore. Since both gases are unstable towards heat (leach tank temperature approximately 95°F), the compounds (if formed) probably decompose and will be neglected in our study. If future evidence indicates the existence of arsine and stibine, re-examination of these gases may be necessary.

B.3.3 LIQUID RELEASES

From Reference 6 p. 192, we learn that "Most reagents used in present commercial operations are relatively stable and have low volatility." We therefore assume no tertiary amine or isodecanol in the gaseous effluents. "Entrainment losses usually result from the presence of very finely dispersed organic in the aqueous phase, often due either to excessive intensity in mixing, or to insufficient capacity in the settlers and incomplete phase separation...." We therefore are assuming both the tertiary amine and isodecanol as being contained in the liquid effluents only.

B.3.3.1 Tertiary Amine (NR₃)

ECT document "6.0 Uranium Milling", derives an input of 2722 kg U/day:

$$2722 \text{ kg U/day} \times 93.5\% \text{ recovered} \times \frac{842.082 \text{ atomic wt. U}_3\text{O}_8}{714.087 \text{ atomic wt. } ^3\text{U}}$$

$$= 3001 \text{ kg U}_3\text{O}_8 \text{ produced/day}$$

(6, p. 192)

$$\frac{.008 \text{ kg NR}_3}{\text{kg U}_3\text{O}_8 \text{ produced}} \times 3001 \text{ kg U}_3\text{O}_8 \text{ produced/day} = 24.0 \text{ kg NR}_3/\text{day}$$

$$24.0 \text{ kg NR}_3/\text{day} \times \frac{80 \text{ gal/min}}{500 \text{ gal/min}} = 3.84 \text{ kg NR}_3/\text{day}$$

$$\therefore \frac{3.84 \text{ kg NR}_3/\text{day}}{2722 \text{ kg U/day}} = 1.41 \times 10^{-3} \frac{\text{kg NR}_3}{\text{kg U (input)}}$$

B.3.3.2 Isodecanol (a long-chain alcohol)

From engineers at the Highland Mill we learned that their organic solvent is composed of the following:

2% isodecanol

3% Tertiary amine

95% kerosene

According to R. C. Merritt^(6 p. 192), "the loss of isodecanol will be nearly twice as great in proportion to its concentration in the solvent as the loss of amine."

From the foregoing tertiary amine calculation we have 24.0 kg of NR₃/day:

$$24.0 \text{ kg NR}_3 \times \frac{2\%}{3\%} \times 2 \text{ (double the loss of NR}_3\text{)} = 32.0 \text{ kg/day loss of isodecanol}$$

$$32.0 \text{ kg isodecanol/day} \times \frac{80 \text{ gpm}}{500 \text{ gpm}} = 5.12 \text{ kg isodecanol/day released to the environment}$$

$$\frac{5.12 \text{ kg isodecanol/day released}}{2722 \text{ kg U/day}} = 1.88 \times 10^{-3} \frac{\text{kg isodecanol}}{\text{kg U (input)}} \text{ release factor}$$

B.3.3.3 Kerosene

Reference 1 calculated an airborne release factor of $2 \times 10^{-4} \frac{\text{kg kerosene}}{\text{kg U input}}$. This is for the uranium acid leach mill itself, vented through the roof stack. There is a liquid release which originates from the two bleed streams shown on Figure 7.2, page 7-5 of Section 7. This liquid release is unusual in that the kerosene discarded as part of these waste streams flows out to the tailings pond where it floats on top of the water and approximately 100% of it eventually becomes an airborne release. In warm or cold weather the Kerosene floats on the water and gradually evaporates. In extremely cold weather the raffinate bleed streams flow onto the top of the ice, and again, the kerosene component gradually evaporates. Although this kerosene in the bleed streams is initially a liquid effluent, it is eventually an airborne effluent released to the environment.

Reference 8 says about 0.1 liter of kerosene is lost to the bleed stream (Figure 7.2) per 1,000 liters of aqueous solution circulated in the solvent extraction step.

The specific gravity of kerosene is assumed to be 0.82.

Reference 6, page 137, assumes one gram U_3O_8 needs one liter of aqueous feed, or 1000 ℓ per kg of U_3O_8 .

The ratio of the weights of U_3O_8 to U is $\frac{.18}{.15}$.

2722 kg U/day $\times$ 0.95 U
in ore is soluble and reaches solvent extraction step $\times \frac{0.18 \text{g } \text{U}_3\text{O}_8}{0.15 \text{g U}}$
 $\times \frac{1000 \ell \text{ aqueous solvent circulated}}{\text{kg } \text{U}_3\text{O}_8} \times \frac{0.1 \text{ liter lost of bleeds}}{1000 \ell \text{ aqueous circulated}} \times \frac{0.82 \text{ kg}}{\ell} \text{ density}$
= 254 kg/day kerosene list as part of liquid effluent to tailings ponds,
approximately 100% of which eventually becomes an airborne effluent.
 $\therefore \frac{254 \text{ kg kerosene/day}}{2722 \text{ kg U/day}} = 9.3 \times 10^{-2} \frac{\text{kg kerosene (airborne)}}{\text{kg U (input)}}$

B.3.3.4 Beryllium

(5,p. 336)

$.08 \text{ mg}/\ell \times 80 \text{ gal}/\text{min} \times 1440 \text{ min}/\text{day} \times 3.785 \ell/\text{gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = .035 \text{ kg}$

$\text{Be}/\text{day} \therefore \frac{.035 \text{ kg Be}/\text{day}}{2722 \text{ kg U}/\text{day}} = 1.3 \times 10^{-5} \frac{\text{kg Be}}{\text{kg U}}$

B.3.3.5 Chromium

(5, p. 336)

$$\left(\frac{2 + 9}{2}\right) \text{ mg/l} \times 80 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}}$$
$$= 2.398 \text{ kg Cr/day}$$

$$\therefore \frac{2.398 \text{ kg Cr/day}}{2722 \text{ kg U/day}} = 8.8 \times 10^{-4} \frac{\text{kg Cr}}{\text{kg U (input)}}$$

B.3.3.6 Molybdenum

(5, p. 336)

$$\left(\frac{.3 + 16}{2}\right) \text{ mg/l} \times 80 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}}$$
$$= 3.5 \text{ kg Mo/day}$$

$$\therefore \frac{3.5 \text{ kg Mo/day}}{2722 \text{ kg U/day}} = 1.3 \times 10^{-3} \frac{\text{kg Mo}}{\text{kg U (input)}}$$

B.3.3.9 Copper

(5, p. 337)

$$\left(\frac{.7 + 3}{2}\right) \text{ mg/l} \times 80 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}}$$
$$= .807 \text{ kg Cu/day}$$

$$\therefore \frac{.807 \text{ kg Cu/day}}{2722 \text{ kg U/day}} = 3 \times 10^{-4} \frac{\text{kg Cu}}{\text{kg U (input)}}$$

B.3.3.8 Nickel

(5, p. 337)

$$1.4 \text{ mg/l} \times 80 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = .610 \text{ kg Ni/day}$$

$$\therefore \frac{.610 \text{ kg Ni/day}}{2722 \text{ kg U/day}} = 2.2 \times 10^{-4} \frac{\text{kg Ni}}{\text{kg U (input)}}$$

B.3.3.9 Lead

(5, p. 337)

$$\left(\frac{.8 + 2}{2}\right) \text{ mg/l} \times 80 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} \\ = .610 \text{ kg Pb/day}$$

$$\therefore \frac{.610 \text{ kg Pb/day}}{2722 \text{ kg U/day}} = 2.2 \times 10^{-4} \frac{\text{kg Pb}}{\text{kg U (input)}}$$

B.3.3.10 Zinc

(5, p. 337)

$$3 \text{ mg/l} \times 80 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.30 \text{ kg Zn/day}$$

$$\therefore \frac{1.30 \text{ kg Zn/day}}{2722 \text{ kg U/day}} = 4.8 \times 10^{-4} \frac{\text{kg Zn}}{\text{kg U (input)}}$$

B.3.3.11 Titanium

(5, p. 336)

$$7 \text{ mg/l} \times 80 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 3.052 \text{ kg Ti/day}$$

$$\therefore \frac{3.052 \text{ kg Ti/day}}{2722 \text{ kg U/day}} = 1.12 \times 10^{-3} \frac{\text{kg Ti}}{\text{kg U (input)}}$$

B.3.3.12 Sulfide

(5, p. 336)

$$\left(\frac{0 + .5}{2}\right) \text{ mg/l} \times 80 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} \\ = .109 \text{ kg S}^{-2}/\text{day}$$

$$\therefore \frac{.109 \text{ kg S}^{-2}/\text{day}}{2722 \text{ kg U/day}} = 4 \times 10^{-5} \frac{\text{kg S}^{-2}}{\text{kg U (input)}}$$

B.3.3.13 Cyanide

(5, p. 336)

$$\left(\frac{0 + .01}{2}\right) \text{ mg/l} \times 80 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}}$$

$$= .002 \text{ kg Cn/day}$$

$$\therefore \frac{.002 \text{ kg Cn/day}}{2722 \text{ kg U/day}} = 8 \times 10^{-7} \frac{\text{kg Cn}}{\text{kg U (input)}}$$

B.3.3.14 Silver

(5, p. 337)

$$\left(\frac{0 + .01}{2}\right) \text{ mg/l} \times 80 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}}$$

$$= .002 \text{ kg Ag/day}$$

$$\therefore \frac{.002 \text{ kg Ag/day}}{2722 \text{ kg U/day}} = 8 \times 10^{-7} \frac{\text{kg Ag}}{\text{kg U (input)}}$$

B.3.3.15 Manganese

(5, p. 337)

$$\left(\frac{100 + 210}{2}\right) \text{ mg/l} \times 80 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}}$$

$$= 67.5 \text{ kg Mn/day}$$

$$\therefore \frac{67.5 \text{ kg Mn/day}}{2722 \text{ kg U/day}} = .025 \frac{\text{kg Mn}}{\text{kg U (input)}}$$

B.3.3.16 Magnesium

(5, p. 336)

$$550 \text{ mg/l} \times 80 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 240 \text{ kg Mg/day}$$

$$\therefore \frac{240 \text{ kg Mg/day}}{2722 \text{ kg U/day}} = .088 \frac{\text{kg Mg}}{\text{kg U (input)}}$$

B.3.3.17 Selenium

According to Reference 6, selenium is leached from ores in the alkaline circuit. Therefore, the release factor in an acid circuit is assumed zero.

B.3.3.18 Sulfuric Acid

The pH of the tailings solution⁽⁹⁾ provides a good estimate of the sulfuric acid content of the tailings pond.

(9, p. 173)

$$\text{pH} = 2 - -\log [\text{H}^+]$$

$$[\text{H}^+] = 10^{-2}\text{M}$$

Since one mole of H_2SO_4 results in 2 moles of free H^+ ion, the concentration of H_2SO_4 is half the concentration of the H^+ ion:

$$\frac{10^{-2}\text{M}}{2} \text{H}_2\text{SO}_4/\ell \times .098 \text{ kg H}_2\text{SO}_4/\text{mole} = 4.9 \times 10^{-4} \text{ kg H}_2\text{SO}_4/\ell$$

$$4.9 \times 10^{-4} \text{ kg H}_2\text{SO}_4/\ell \times 80 \text{ gal/min} \times 3.785 \ell/\text{gal} \times 1440 \text{ min./day} \\ = 214 \text{ kg H}_2\text{SO}_4/\text{day}$$

$$\therefore \frac{214 \text{ kg H}_2\text{SO}_4/\text{day}}{2722 \text{ kg U/day}} = .08 \frac{\text{kg H}_2\text{SO}_4}{\text{kg U}}$$

TABLE B-4. Aqueous Conversion - Chemical Release
Factor kg/kg U^3 (input)

<u>Material Released</u>	<u>Airborne</u>			<u>Liquid</u>		
	<u>Factor</u>	<u>Reliability</u>	<u>Ref. Calc.</u>	<u>Factor</u>	<u>Reliability</u>	<u>Ref. Calc.</u>
Chloride				3×10^{-2}	2	B.4.3.1
Aluminum				2×10^{-4}	2	B.4.3.2
Barium				7×10^{-5}	2	B.4.3.3
Copper				5×10^{-5}	2	B.4.3.4
Iron				5×10^{-4}	2	B.4.3.5
Sodium				2×10^{-2}	2	B.4.3.6
Zinc				2×10^{-5}	2	B.4.3.7
Hydrogen Sulfide	0	2				
Ammonia				0	2	
Nitric Acid	0	2		0	2	
Thorium-230						

B.4 URANIUM PURIFICATION AND CONVERSION

B.4.1 ASSUMPTIONS

The model plant produces the following two major liquid waste streams: 1) the solvent extraction circuit raffinate and 2) the waste hydrogen fluoride scrubber product. Only the latter fluoride stream is considered an effluent because part of it is discharged to the environment.

The fluoride stream consists of several smaller streams which combine prior to treatment. The resulting stream is then neutralized with slaked lime to a pH of 12 and routed to the fluoride sludge pond where the bulk of excess lime and calcium fluoride precipitate settle out. The overflow from the sludge pond is now treated with sulfuric acid to a pH of 7, and the resulting solution is fed to a clarifying pond. Overflow from this clarifying pond is combined with "clean" waste water and sewage lagoon overflow and discharged from the facility to the receiving river at a rate of 2500 gal/min. (13, p.13) Liquid effluents are calculated assuming the analyses of these discharge streams at the Kerr-McGee, Sequoyah facility are representative of the ENFORM model plant.

The uranium input to this facility, calculated in Appendix A, (1, calc. 4-1) is assumed to be 2.485×10^4 kg U/day.

B.4.2 AIRBORNE RELEASES

Nitric Acid

Process off gases are treated to recover gaseous nitric acid which is then returned for reuse to the process. (14, p. III-7) Any liquid nitric acid that is released is neutralized and impounded in storage ponds. (12, p. III-9)

Hydrogen Sulfide

Hydrogen sulfide, released from the reduction tower, is burned in air to water vapor and sulfur oxide and discharged to the plant stack. Theoretically, then, no hydrogen sulfide is released to the atmosphere. (12, p. III-7)

Ammonia

Ammonia released from the conversion process is also retained in storage ponds. (15, p. 27)

B.4.3 LIQUID RELEASES

B.4.3.1 Chloride

(14, p. V-5)

$$50 \text{ mg/l} \times 2500 \text{ gal/min} \times 3.785 \text{ l/gal} \times 1440 \text{ min/day} \times \frac{\text{kg}}{10^6 \text{ mg}} \\ = 681.3 \text{ kg Chloride/day}$$

$$\therefore \frac{681.3 \text{ kg Chloride/day}}{2.485 \times 10^4 \text{ kg U/day}} = .027 \frac{\text{kg Chloride}}{\text{kg U}}$$

B.4.3.2 Aluminum

(14, p. V-5)

$$.40 \text{ mg/l} \times 2500 \text{ gal/min} \times 3.785 \text{ l/gal} \times 1440 \text{ min/day} \times \frac{\text{kg}}{10^6 \text{ mg}} \\ = 5.45 \text{ kg Al/day}$$

$$\therefore \frac{5.45 \text{ kg Al/day}}{2.485 \times 10^4 \text{ kg U/day}} = 2.2 \times 10^{-4} \frac{\text{kg Al}}{\text{kg U}}$$

B.4.3.3 Barium

(14, p. V-5)

$$.125 \text{ mg/l} \times 2500 \text{ gal/min} \times 3.785 \text{ l/gal} \times 1440 \text{ min/day} \times \frac{\text{kg}}{10^6 \text{ mg}} \\ = 1.7 \text{ kg Ba/day}$$

$$\therefore \frac{1.7 \text{ kg Ba/day}}{2.485 \times 10^4 \text{ kg U/day}} = 6.85 \times 10^{-5} \frac{\text{kg Ba}}{\text{kg U}}$$

B.4.3.4 Copper

(14, p. V-5)

$$.09 \text{ mg/l} \times 2500 \text{ gal/min} \times 3.785 \text{ l/gal} \times 1440 \text{ min/day} \times \frac{\text{kg}}{10^6 \text{ mg}} \\ = 1.2 \text{ kg Cu/day}$$

$$\therefore \frac{1.2 \text{ kg Cu/day}}{2.485 \times 10^4 \text{ kg U/day}} = 4.9 \times 10^{-5} \frac{\text{kg Cu}}{\text{kg U}}$$

B.4.3.5 Iron

(14, p. V-5)

$$1 \text{ mg/l} \times 2500 \text{ gal/min} \times 3.785 \text{ l/gal} \times 1440 \text{ min/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 13.6 \text{ kg Fe/day}$$

$$\therefore \frac{13.6 \text{ kg Fe/day}}{2.485 \times 10^4 \text{ kg U/day}} = 5.5 \times 10^{-4} \frac{\text{kg Fe}}{\text{kg U}}$$

B.4.3.6 Sodium

(14, p. V-5)

$$35 \text{ mg/l} \times 2500 \text{ gal/min} \times 3.785 \text{ l/gal} \times 1440 \text{ min/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 476.9 \text{ Na/day}$$

$$\therefore \frac{476.9 \text{ kg Na/day}}{2.485 \times 10^4 \text{ kg U/day}} = .019 \frac{\text{kg Na}}{\text{kg U}}$$

B.4.3.7 Zinc

(14, p. V-5)

$$.04 \text{ mg/l} \times 2500 \text{ gal/min} \times 3.785 \text{ l/gal} \times 1440 \text{ min/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = .55 \text{ kg Zn/day}$$

$$\therefore \frac{.55 \text{ kg Zn/day}}{2.485 \times 10^4 \text{ kg U/day}} = 2.2 \times 10^{-5} \frac{\text{kg Zn}}{\text{kg U}}$$

TABLE B-5. Gaseous Diffusion Plant Chemical Release
Factors kg/kg U (produced)

<u>Material Released</u>	<u>Airborne</u>			<u>Liquid</u>		
	<u>Factor</u>	<u>Reliability</u>	<u>Ref. Calc.</u>	<u>Factor</u>	<u>Reliability</u>	<u>Ref. Calc.</u>
Nitric Acid	?					
Boric Acid	?					
Nickel Sulfate	?					
Nickel Chloride	?					
Hydrogen Fluoride	1×10^{-3}	2	5.2.1			
Ammonia				3×10^{-3}	2	5.3.1
Cadmium				1×10^{-5}	2	5.3.2
Calcium				9×10^{-2}	2	5.3.3
Chloride				1×10^{-1}	2	5.3.4
Copper				2×10^{-4}	2	5.3.5
Iron				6×10^{-3}	2	5.3.6
Nickel				6×10^{-4}	2	5.3.7
Sodium				1×10^{-1}	2	5.3.8
Sulfate				9×10^{-2}	2	5.3.9
Sulfites				1×10^{-4}	1	5.3.10
Boron				1×10^{-4}	1	5.3.10
Magnesium				1×10^{-4}	1	5.3.10
Molybdenum				1×10^{-4}	1	5.3.10
Silver				1×10^{-4}	1	5.3.10
Manganese				1×10^{-4}	1	5.3.10

B.5. GASEOUS DIFFUSION ENRICHMENT

B.5.1 ASSUMPTIONS

The following values are assumed from calculations by Tom Powers.⁽¹⁾

<u>Value</u>	<u>Calculation</u>
5708 kg U/product/day	5-1
1.71×10^7 ℓ liquid effluent stream/day	5-18

The concentrations in the effluent stream utilized for liquid release calculations are derived from the Oak Ridge GDP. However, the values are also assumed to be representative of the Portsmouth GDP (16, p. D-12) and therefore the ENFORM model GDP.

B.5.2 AIRBORNE RELEASES

B.5.2.1 Hydrogen Fluoride (gas)

(17, p. 2.3-145)

$$2.4 \text{ MT/yr} \times 1000 \text{ kg/MT} \times 1 \text{ yr}/365 \text{ day} = 6.6 \text{ kg/day}$$

$$\therefore \frac{6.6 \text{ kg/day}}{5708 \text{ kg U/day}} = 1.2 \times 10^{-3} \frac{\text{kg HF}}{\text{kg U}}$$

Airborne effluents include nitric acid, boric acid, nickel sulfate, and nickel chloride. Due to insufficient data, no release factors are calculated for these.

B.5.3 LIQUID RELEASES

B.5.3.1 Ammonia

(16, p. D-19)

$$1 \text{ mg}/\ell \text{ NH}_4^+ \times 1.71 \times 10^7 \ell/\text{day} \times \frac{1}{10^{-6} \text{ mg/kg}} = 17.1 \text{ kg NH}_4^+/\text{day}$$

$$\therefore \frac{17.1 \text{ kg NH}_3/\text{day}}{5708 \text{ kg U/day}} = 3.00 \times 10^{-3} \frac{\text{kg NH}_3}{\text{kg U (product)}}$$

B.5.3.2 Cadmium

(16, p. D-19)

$$.004 \text{ mg/l} \times 1.71 \times 10^7 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = .0684 \text{ kg Cd/day}$$

$$\therefore \frac{.0684 \text{ kg Cd/day}}{5708 \text{ kg U/day}} = 1.20 \times 10^{-5} \frac{\text{kg Cd}}{\text{kg U (product)}}$$

B.5.3.3 Calcium

(16, p. D-19)

$$30 \text{ mg/l} \times 1.71 \times 10^7 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 513 \text{ kg Ca/day}$$

$$\therefore \frac{513 \text{ kg Ca/day}}{5708 \text{ kg U/day}} = 9 \times 10^{-2} \frac{\text{kg Ca}}{\text{kg U (product)}}$$

B.5.3.4 Chloride

(16, p. D-19)

$$45 \text{ mg/l} \times 1.71 \times 10^7 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 7.69.5 \text{ kg Chloride/day}$$

$$\therefore \frac{769.5 \text{ kg Chloride/day}}{5708 \text{ kg U/day}} = .13 \frac{\text{kg Chloride}}{\text{kg U}}$$

B.5.3.5 Copper

(16, D-19)

$$.07 \text{ mg/l} \times 1.71 \times 10^7 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.2 \text{ kg Cu/day}$$

$$\therefore \frac{1.2 \text{ kg Cu}}{5708 \text{ kg U}} = 2.1 \times 10^{-4} \frac{\text{kg Cu}}{\text{kg U}}$$

B.5.3.6 Iron

(16, p. D-19)

$$2 \text{ mg Fe/l} \times 1.71 \times 10^7 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 34.2 \text{ kg Fe/day}$$

$$\therefore \frac{34.2 \text{ kg Fe/day}}{5708 \text{ kg U/day}} = 6.0 \times 10^{-3} \frac{\text{kg Fe}}{\text{kg U}}$$

B.5.3.7 Nickel

(16, p. D-19)

$$.2 \text{ mg/l} \times 1.71 \times 10^7 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 3.42 \text{ kg Ni/day}$$

$$\therefore \frac{3.42 \text{ kg Ni/day}}{5708 \text{ kg U/day}} = 6.0 \times 10^{-4} \frac{\text{kg Ni}}{\text{kg U}}$$

B.5.3.8 Sodium

(16, p. D-19)

$$45 \text{ mg/l} \times 1.71 \times 10^7 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 769.5 \text{ kg Na/day}$$

$$\therefore \frac{769.5 \text{ kg Na/day}}{5708 \text{ kg U/day}} = .13 \frac{\text{kg Na}}{\text{kg U}}$$

B.5.3.9 Sulfate

Same as calculation B.5.3.3 for calcium.

B.5.3.10 Other Liquid Effluents

No data has been found to determine release factors for the remaining liquid effluents. Assuming the constituents all result from impurities in the uranium ore, they will be present in the enrichment tailings in low concentration. Therefore, a concentration of .05 ppm shall be assumed, resulting in the following release factor for each of the following: sulfites, boron, magnesium, molybdenum, silver, and manganese.

$$.05 \text{ mg/l} \times 1.71 \times 10^7 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = .855 \text{ kg/day}$$

$$\therefore \frac{.855 \text{ kg/day}}{5708 \text{ kg U/day}} = 1.5 \times 10^{-4} \frac{\text{kg}}{\text{kg U}}$$

TABLE B-6. Fuel Fabrication Chemical Release
Factors kg/kg U (input)

<u>Material Released</u>	<u>Airborne</u>			<u>Liquid</u>		
	<u>Factor</u>	<u>Reliability</u>	<u>Ref. Calc.</u>	<u>Factor</u>	<u>Reliability</u>	<u>Ref. Calc.</u>
Chromium						
Zirconium	5×10^{-3}	1	6.2.1			
Nitric Acid	5×10^{-3}	1	6.2.2			
Xylol	1×10^{-3}	1	6.2.3			
Butanol	1×10^{-3}	1	6.2.4			
Methyl Butyl Ketone	9×10^{-4}	1	6.2.5			
Glycol Ethyl Ether	7×10^{-4}	1	6.2.6			
Isopropyl Alcohol	5×10^{-3}	1	6.2.7			
Nickel Sulfate	?					
Nickel Chloride	?					
Sulfuric Acid	?					
Boric Acid	?					
Acetone	?					
Zinc	?					
Copper				1×10^{-5}	1	6.3.1
Nitrate				8×10^{-3}	2	6.3.2

B.6. FUEL FABRICATION

B.6.1 ASSUMPTIONS

The following value was assumed in Appendix A:

4404 kg U (input - enriched to 3.2%)/day
(the plant output is 1600 MTM/year or 4.38 MTM/day)

The chemical effluent information for calculations 6.2.1 to 6.2.7 and 6.3.1 was reported for the General Electric Fuel Fabrication facility.⁽¹⁹⁾ It is assumed to be representative of the ENFORM model. Reference 19 lists effluent quantities for the cladding plant and two supporting facilities. The calculations below are adjusted for just the cladding plant.

B.6.2 AIRBORNE RELEASES

B.6.2.1 Zirconium (air)

(Appendix C, Table C-1)

$$\frac{5.43 \text{ kg Zr}}{\text{MTU}} \times \frac{\text{MT}}{1000 \text{ kg}} = 5.43 \times 10^{-3} \frac{\text{kg Zr}}{\text{kg U}}$$

B.6.2.2 Nitric Acid (air)

(Appendix C, Table C-1)

$$\frac{5.48 \text{ kg HNO}_3}{\text{MTU}} \times \frac{\text{MT}}{1000 \text{ kg}} = 5.48 \times 10^{-3} \frac{\text{kg HNO}_3}{\text{kg U}}$$

B.6.2.3 Xylo1 (air)

(Appendix C, Table C-1)

$$3.83 \text{ kg/MTU} \times \frac{\text{MT}}{1000 \text{ kg}} \times \frac{1}{3}^{(a)} = 1.28 \times 10^{-3} \frac{\text{kg Xylo1}}{\text{kg U}}$$

B.6.2.4 Butanol (air)

(Appendix C, Table C-1)

$$4.38 \text{ kg/MTU} \times \frac{\text{MT}}{1000 \text{ kg}} \times \frac{1}{3}^{(a)} = 1.46 \times 10^{-3} \frac{\text{kg Butanol}}{\text{kg U}}$$

^(a) Assumed portion for cladding plant

B.6.2.5 Methyl Butyl Ketone (air)

(Appendix C, Table C-1)

$$2.74 \text{ kg/MTU} \times \frac{\text{MT}}{1000 \text{ kg}} \times \frac{1}{3}^{(a)} = 9.13 \times 10^{-4} \frac{\text{kg Methyl Butyl Ketone}}{\text{kg U}}$$

B.6.2.6 Glycol Ethyl Ether (air)

(Appendix C, Table C-1)

$$2.19 \text{ kg/MTU} \times \frac{\text{MT}}{1000 \text{ kg}} \times \frac{1}{3}^{(a)} = 7.30 \times 10^{-4} \frac{\text{kg Glycol Ethyl Ether}}{\text{kg U}}$$

B.6.2.7 Isopropyl Alcohol (air)

(Appendix C, Table C-1)

$$13.7 \text{ kg/MTU} \times \frac{\text{MT}}{1000 \text{ kg}} \times \frac{1}{3}^{(a)} = 4.57 \times 10^{-3} \frac{\text{kg Isopropyl Alcohol}}{\text{kg U}}$$

B.6.2.8 No release factors were computed for the following, as data were not available.

Nickel sulfate (air)

Nickel chloride (air)

Sulfuric acid (air)

Boric acid (air)

Acetone

Zinc

B.6.3 LIQUID RELEASES

B.6.3.1 Copper

(Appendix C, Table C-2)

$$.011 \text{ kg/MTU} \times \frac{\text{MT}}{1000 \text{ kg}} = 1.1 \times 10^{-5} \frac{\text{kg Cu}}{\text{kg U}}$$

B.6.3.2 Nitrates

(20, p. 9)

$$81 \text{ lb NO}_3/\text{day} \times .4536 \text{ kg/lb} = 36.7 \text{ kg NO}_3/\text{day}$$

$$\therefore \frac{36.7 \text{ kg NO}_3/\text{day}}{4404 \text{ kg U/day}} = 8.3 \times 10^{-3} \frac{\text{kg NO}_3}{\text{kg U}}$$

TABLE B-7. Pressurized Water Reactor Chemical Release Factors kg/kg U (input)

Material Released	Chemical Release Factors kg/kg U (input)					
	Airborne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Chlorine				5×10^{-3}	2	7.3.1
Phosphates				2×10^{-2}	2	7.3.2
Lithium				4×10^{-3}	2	7.3.3
Sulfur Oxides	3×10^{-3}	1	7.2.11			
Nitrogen Oxides	8×10^{-3}	1	7.2.14			
Particulates	1×10^{-3}	1	7.2.10			
Carbon Monoxide	4×10^{-4}	1	7.2.12			
Aldehydes	2×10^{-4}	1	7.2.15			
Hydrocarbons	3×10^{-4}	1	7.2.13			
Sulfuric Acid	?					
Calcium	1	2	7.2.1			
Magnesium	1×10^{-1}	2	7.2.2			
Sodium	2×10^{-1}	2	7.2.3			
Chloride	2×10^{-1}	2	7.2.4			
Sulfate	2	2	7.2.5			
Bicarbonate	8×10^{-2}	2	7.2.6			
Silica	3×10^{-1}	2	7.2.7			
Potassium	2×10^{-2}	2	7.2.8			
<u>Radionuclide Release Factor, kg Released/kg Radionuclide (input)</u>						
Carbon 14	0.30	2	7.4			

B.7 PRESSURIZED WATER REACTOR

B.7 ASSUMPTIONS

The capacity of the model plant, 102 kg U (input) per day, was previously calculated in Appendix A⁽¹⁾ and is used extensively for PWR release factor calculations.

Waste heat from the Trojan plant is dissipated to the atmosphere by means of a single large natural draft cooling tower. A small portion of the circulating water will be lost from the cooling tower in the form of small droplets or drift. Average drift for a natural draft cooling tower is approximately 116 gpm. However, Trojan utilizes a drift eliminator which reduces cooling tower drift to about 43 gpm.^(21, p. III-5) The 43 gpm drift is of the same composition as the circulating water containing ≈ 1800 ppm dissolved solids.^(21, p. III-15) This drift is assumed an airborne effluent. (See calculations 7.2.1 to 7.2.8.)

B.7.2 AIRBORNE EFFLUENTS

B.7.2.1 Calcium

(21, p. III-48)

$$600 \text{ mg/l} \times 43 \text{ gal/min} \times 3.785 \text{ l/gal} \times 1440 \text{ min/day} \times \frac{\text{kg}}{10^6 \text{ mg}} \\ = 140.6 \text{ kg Ca/day}$$

$$\therefore \frac{140.6 \text{ kg Ca/day}}{102 \text{ kg U/day}} = 1.38 \frac{\text{kg Ca}}{\text{kg U (input)}}$$

B.7.2.2 Magnesium

(21, p. III-48)

$$60 \text{ mg/l} \times 43 \text{ gal/min} \times 3.785 \text{ l/gal} \times 1440 \text{ min/day} \times \frac{\text{kg}}{10^6 \text{ mg}} \\ = 14.06 \text{ kg Mg/day}$$

$$\therefore \frac{14.06 \text{ kg Mg/day}}{102 \text{ kg U/day}} = .138 \frac{\text{kg Mg}}{\text{kg U (input)}}$$

B.7.2.3 Sodium

(21, p. III-48)

$$75 \text{ mg/l} \times 43 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 17.6 \text{ kg Na/day}$$

$$\therefore \frac{17.6 \text{ kg Na/day}}{102 \text{ kg U/day}} = .172 \frac{\text{kg Na}}{\text{kg U}}$$

B.7.2.4 Chloride

(21, p. III-48)

$$70 \text{ mg/l} \times 43 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 16.4 \text{ kg}$$

$$\therefore \frac{16.4 \text{ kg Cl/day}}{102 \text{ kg U/day}} = .161 \frac{\text{kg Cl}}{\text{kg U}}$$

B.7.2.5 Sulfate

(21, p. III-48)

$$800 \text{ mg/l} \times 43 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 187 \text{ kg SO}_4/\text{day}$$

$$\therefore \frac{187 \text{ kg SO}_4/\text{day}}{102 \text{ kg U/day}} = 1.8 \frac{\text{kg SO}_4}{\text{kg U}}$$

B.7.2.6 Bicarbonate

(21, p. III-48)

$$35 \text{ mg/l} \times 43 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 8.2 \text{ kg HCO}_3/\text{day}$$

$$\therefore \frac{8.2 \text{ kg HCO}_3/\text{day}}{102 \text{ kg U/day}} = .08 \frac{\text{kg HCO}_3}{\text{kg U}}$$

B.7.2.7 Silica

(21, p. III-48)

$$150 \text{ mg/l} \times 43 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}}$$

$$= 35.16 \text{ kg Silica/day}$$

$$\therefore \frac{35.16 \text{ kg Silica/day}}{102 \text{ kg U/day}} = .345 \frac{\text{kg Silica}}{\text{kg U}}$$

B.7.2.8 Potassium

(21, p. III-48)

$$10 \text{ mg/l} \times 43 \text{ gal/min} \times 1440 \text{ min/day} \times 3.785 \text{ l/gal} \times \frac{\text{kg}}{10^6 \text{ mg}} = 2.3 \text{ kg K/day}$$

$$\therefore \frac{2.3 \text{ kg k/day}}{102 \text{ kg U/day}} = .023 \frac{\text{kg K}}{\text{kg U}}$$

B.7.2.9 Combustion Products

As a source of auxiliary electric power required for emergency power generation, two diesel electric sets are available on site. Each set is operated at least once a month for one hour as a part of regular maintenance. These sets would be activated for power generation in the unlikely event that power is not available from transmission lines. These diesels burn about 4.5 gpm of No. 2 fuel oil per engine. (22, p.3.8-1)

$$\begin{aligned} & (22, \text{p. 3.8-1}) \\ & \frac{4.5 \text{ gal fuel oil/min}}{\text{engine}} \times 2 \text{ diesel engines} \times 60 \text{ min/hr} \times \frac{1 \text{ hr}}{\text{mo}} \times 3.785 \text{ l/gal} \\ & = 2044 \text{ l/mo No. 2 fuel oil} \end{aligned}$$

To keep the calculations in terms consistent with the use (monthly rather than daily) of the diesel sets, the uranium input shall be converted to a monthly basis also.

$$102 \text{ kg U/day} \times 290 \text{ operating days/yr}^{(1)} \times 1 \text{ yr/12 mo} = 2465 \text{ kg U/mo}$$

This will be used for the following calculations.

B.7.2.10 Particulates

(23, p, 1.3-2)

$$2044 \text{ l fuel/mo} \times 1.8 \text{ kg/1000 l} = 3.68 \text{ kg/mo}$$

$$\therefore \frac{3.68 \text{ kg/mo}}{2465 \text{ kg U/mo}} = 1.5 \times 10^{-3} \frac{\text{kg Particulates}}{\text{kg U}}$$

B. 7.2.11 Sulfur Oxides

(S = 22% sulfur by weight)⁽²⁴⁾

$$2044 \text{ g fuel/mo} \times \frac{17.25 \text{ kg SO}_x}{1000 \text{ g}} \times .22 = 7.76 \text{ kg SO}_x/\text{mo}$$

$$\therefore \frac{7.76 \text{ kg SO}_x/\text{mo}}{2465 \text{ kg U/mo}} = 3 \times 10^{-3} \frac{\text{kg SO}_x}{\text{kg U}}$$

B. 7.2.12 Carbon Monoxide

$$2044 \text{ g fuel/mo} \times \frac{.5 \text{ kg CO}}{1000 \text{ g}} = 1.022 \text{ kg CO/mo}$$

$$\therefore \frac{1.022 \text{ kg CO/mo}}{2465 \text{ kg U/mo}} = 4.15 \times 10^{-4} \frac{\text{kg CO}}{\text{kg U}}$$

B. 7.2.13 Hydrocarbons

$$2044 \text{ g fuel/mo} \times \frac{.35 \text{ kg C}_x\text{H}_x}{1000 \text{ g}} = .72 \text{ kg C}_x\text{H}_x/\text{mo}$$

$$\therefore \frac{.72 \text{ kg C}_x\text{H}_x/\text{mo}}{2465 \text{ kg U/mo}} = 2.9 \times 10^{-4} \frac{\text{kg Hydrocarbons}}{\text{kg U}}$$

B. 7.2.14 Nitrogen Oxides

$$2044 \text{ g fuel/mo} \times \frac{9.6 \text{ kg NO}_x}{1000 \text{ g}} = 19.6 \text{ kg NO}_x/\text{mo}$$

$$\therefore \frac{19.6 \text{ kg NO}_x/\text{mo}}{2465 \text{ kg U/mo}} = 7.96 \times 10^{-3} \frac{\text{kg NO}_x}{\text{kg U}}$$

B. 7.2.15 Aldehydes

$$2044 \text{ g fuel/mo} \times \frac{.25 \text{ kg CH}_2\text{O}}{1000 \text{ g}} = .511 \text{ kg CH}_2\text{O/mo}$$

$$\therefore \frac{.511 \text{ kg CH}_2\text{O/mo}}{2465 \text{ kg U/mo}} = 2.1 \times 10^{-4}$$

B.7.3 LIQUID RELEASES

B.7.3.1 Chlorine

(21, p. III-46)

$$.01 \text{ mg/l} \times 4.75 \times 10^7 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = .475 \text{ kg Cl/day}$$

$$\therefore \frac{.475 \text{ kg Cl/day}}{102 \text{ kg U/day}} = 4.7 \times 10^{-3} \frac{\text{kg Cl}}{\text{kg U}}$$

B.7.3.2 Phosphates

(21, Table III-8)

$$5 \text{ lb PO}_4\text{/day} \times \text{kg}/2.205 \text{ lb} = 2.3 \text{ kg PO}_4\text{/day}$$

$$\therefore \frac{2.3 \text{ kg PO}_4\text{/day}}{102 \text{ kg U/day}} = 2.2 \times 10^{-2} \frac{\text{kg PO}_4}{\text{kg U}}$$

B.7.3.3 Lithium

(21, p. III-51)

$$.009 \text{ mg/l} \times 4.75 \times 10^7 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = .4275 \text{ kg Li/day}$$

$$\therefore \frac{.4275 \text{ kg Li/day}}{102 \text{ kg U/day}} = 4.2 \times 10^{-3} \frac{\text{kg Li}}{\text{kg U}}$$

B.7.4 Carbon 14

Much of the ^{14}C is generated within the liquid coolant and some may be entrained in the blowdown as fine bubbles or dissolved in the liquid releases, so that it starts out as a liquid release. "Leakers" among the fuel rods either in the reactor core or in the storage basin tend to release part of the ^{14}C generated within the fuel. This also starts out entrained as a liquid release but is eventually released to the environment as an airborne release. A release factor of 0.30 was calculated as follows:

From Appendix A, reference calculation 8-1:

$$101,033 \text{ kg UO}_2 \times \frac{238}{270} \times \frac{1}{3} \times \frac{1}{290} \text{ operating days} = 102 \text{ kg U per day}$$

The activity value is obtained from Reference 18, page B-58, with the exception that we are using the NRC figure of 8 Ci per year for the $^{17}\text{O}(n,\alpha)^{14}\text{C}$ reaction in the coolant. We find no basis for deviating from 0.09 Ci per year as calculated by the SAI study for the $^{14}\text{N}(n,p)^{14}\text{C}$ reaction in the PWR coolant:

PWR Fuel $^{17}\text{O}(n,\alpha)^{14}\text{C}$	4.1
PWR Fuel $^{14}\text{N}(n,p)^{14}\text{C}$	17.3
PWR Coolant $^{17}\text{O}(n,\alpha)^{14}\text{C}$	8.0
PWR Coolant $^{14}\text{N}(n,p)^{14}\text{C}$	<u>0.09</u>
Total annual production ^{14}C in Ci/GWe-year	29.49

A 1250 MWe reactor at 80% capacity factor produces 1,000 MWe-year/ year or one GWe-year. Therefore, Ci/GW-year is the same as Ci per operating year for a 1250 MWe reactor at 80%. The reference facility assumes only 79.45% plant capacity factor or 290 days operation. Adjusting for this:

$$29.49 \text{ Ci/year} \times \frac{79.45}{80.0} = 29.29 \text{ Ci/year}$$

Utilizing the specific activity of ^{14}C of 4.46 Ci/gram:

$$\frac{29.29 \text{ Ci/year}}{4.46 \text{ Ci/gram}} \times \frac{1}{290 \text{ days}} \times \frac{1}{1000 \text{ g per kg}} =$$

$$2.26 \times 10^{-5} \text{ kg } ^{14}\text{C per operating day}$$

$$\frac{2.26 \times 10^{-5} \text{ kg } ^{14}\text{C per operating day}}{102 \text{ kg U per operating day}} = 2.22 \times 10^{-7} \text{ kg product per kg U input}$$

Table 2-3, page 2-18 of the Bray-Miller-Rieke "Assessment of ^{14}C " document provides releases of gaseous Carbon 14 which we have revised as footnoted:

<u>Pathway</u>	<u>Annual ^{14}C Release Ci/year</u>	<u>Footnote</u>
Gaseous radwaste treatment system	7.0	(1)
Condenser steam-jet air ejector offgas vent	0.11	(2)
Steam generator blowdown tank vent	4.5×10^{-4}	(2)
Turbine gland seal condenser exhaust	9.2×10^{-7}	(2)
Fuel handling building ventilation	0.69	(3)
Containment building purge exhaust	1.0	(1)
Auxiliary building ventilation	8.0×10^{-4}	(2)
Turbine building ventilation	1.8×10^{-3}	(2)
Total annual ^{14}C release	8.81	

- (1) See last paragraph page 2-47 and top of page 2-48, NUREG-0017. (27)
- (2) No reason found for changing this.
- (3) This comes from "leakers" among the irradiated fuel elements and is not derived from irradiation of the coolant.

$$\frac{8.81 \text{ Ci/year}}{4.46 \text{ Ci/gram}} \times \frac{1}{290 \text{ days}} \times \frac{1}{1000 \text{ g per kg}} = \frac{6.81 \times 10^{-6} \text{ kg}}{^{14}\text{C per day released}}$$

$$\frac{6.81 \times 10^{-6} \text{ kg } ^{14}\text{C per day}}{102 \text{ kg U per operating day}} = 6.67 \times 10^{-8} \text{ kg } ^{14}\text{C released per kg U input}$$

$$\begin{aligned} \text{Release factor} &= \frac{6.67 \times 10^{-8} \text{ kg } ^{14}\text{C released per kg U input}}{2.22 \times 10^{-7} \text{ kg } ^{14}\text{C produced per kg U input}} \\ &= 0.30 \end{aligned}$$

TABLE B-8. Boiling Water Reactor

Released Material	Chemical Release Factors, kg/kg U (input)					
	Airborne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Sulfur Oxides	0.3	2	8.2.11			
Nitrogen Oxides	0.2	2	8.2.12			
Hydrocarbons	8×10^{-3}	2	8.2.13			
Particulates	7×10^{-3}	2	8.2.14			
Chlorine	6×10^{-2}	1	8.2.15			
Calcium	2	2	8.2.1			
Magnesium	4×10^{-1}	2	8.2.2			
Sodium	2×10^{-1}	2	8.2.3			
Bicarbonate	2	2	8.2.4			
Chloride	9×10^{-2}	2	8.2.5			
Sulfate	4	2	8.2.6			
Nitrate	2×10^{-2}	2	8.2.7			
Phosphate	1×10^{-3}	2	8.2.8			
Silica	5×10^{-1}	2	8.2.9			

Radionuclide Release Factor, kg Released/kg Radionuclide (input)			
Carbon-14	0.3	2	8.3

B.8 BOILING WATER REACTOR

B.8.1 ASSUMPTIONS

The following values were extracted from Calculation 9-1 in Reference 1:

- 84 kg U (input)/day
- 292 operating days/yr.

From the above data, the annual uranium input is 24,528 kg.

A recirculating cooling tower system with mechanical draft wet cooling towers will dissipate excess heat to the atmosphere. A small quantity of water entrained in the air passing through the cooling tower is lost from the system as "drift." Drift eliminators are used in Hanford No. 2's cooling tower to minimize drift to approximately 285 gpm or 1.55×10^6 L/day (Reference 25, p. 3.3-1). This drift is of the same composition as the circulating water and is assumed an airborne release (see Calculations 8.2.1 to 8.2.9).

B.8.2 AIRBORNE RELEASES

B.8.2.1 Calcium

(25, Table 3.6-1)

$$116 \text{ mg/L} \times 1.55 \times 10^6 \text{ L/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 179.8 \text{ kg Ca/day}$$

$$\therefore \frac{179.8 \text{ kg Ca/day}}{84 \text{ kg U/day}} = 2.14 \frac{\text{kg Ca}}{\text{kg U}}$$

B.8.2.2 Magnesium

(25, Table 3.6-1)

$$21 \text{ mg/L} \times 1.55 \times 10^6 \text{ L/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 32.55 \text{ kg Mg/day}$$

$$\therefore \frac{32.55 \text{ kg Mg/day}}{84 \text{ kg U/day}} = .3875 \frac{\text{kg Mg}}{\text{kg U}}$$

B.8.2.3 Sodium

(25, Table 3.6-1)

$$12 \text{ mg/L} \times 1.55 \times 10^6 \text{ L/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 18.6 \text{ kg Na/day}$$

$$\therefore \frac{18.5 \text{ kg Na/day}}{84 \text{ kg U/day}} = .22 \frac{\text{kg Na}}{\text{kg U}}$$

B.8.2.4 Bicarbonate

(25, Table 3.6-1)

$$92 \text{ mg/l} \times 1.55 \times 10^6 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 142.6 \text{ kg HCO}_3^-/\text{day}$$

$$\therefore \frac{142.6 \text{ kg HCO}_3^-/\text{day}}{84 \text{ kg U/day}} = 1.7 \frac{\text{kg HCO}_3^-}{\text{kg U}}$$

B.8.2.5 Chloride

(25, Table 3.6-1)

$$5 \text{ mg/l} \times 1.55 \times 10^6 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 7.75 \text{ kg Chloride/day}$$

$$\therefore \frac{7.75 \text{ kg Chloride/day}}{84 \text{ kg U/day}} = .093 \frac{\text{kg Chloride}}{\text{kg U}}$$

B.8.2.6 Sulfate

(25, Table 3.6-1)

$$236 \text{ mg/l} \times 1.55 \times 10^6 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 365.8 \text{ kg SO}_4/\text{day}$$

$$\therefore \frac{365.8 \text{ kg SO}_4/\text{day}}{84 \text{ kg U/day}} = 4.35 \frac{\text{kg SO}_4}{\text{kg U}}$$

B.8.2.7 Nitrate

(25, Table 3.6-1)

$$1.24 \text{ mg/l} \times 1.55 \times 10^6 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 1.922 \text{ kg NO}_3/\text{day}$$

$$\therefore \frac{1.922 \text{ kg NO}_3/\text{day}}{84 \text{ kg U/day}} = .023 \frac{\text{kg NO}_3}{\text{kg U}}$$

B.8.2.8 Phosphate

(25, Table 3.6-1)

$$.06 \text{ mg/l} \times 1.55 \times 10^6 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = .093 \text{ kg PO}_4/\text{day}$$

$$\therefore \frac{.093 \text{ kg PO}_4/\text{day}}{84 \text{ kg U/day}} = 1.1 \times 10^{-3} \frac{\text{kg PO}_4}{\text{kg U}}$$

3.3.2.9 Silica

25, Table 3.6-1

$$30 \text{ mg/l} \times 1.55 \times 10^6 \text{ l/day} \times \frac{\text{kg}}{10^6 \text{ mg}} = 46.5 \text{ kg Silica/day}$$

$$\therefore \frac{46.5 \text{ kg Silica/day}}{84 \text{ kg U/day}} = .55 \frac{\text{kg Silica}}{\text{kg U}}$$

B.8.2.10 Combustion Products

Three standby diesel engines will be test run for about 2 hr/mo. Two will consume 340 gph of fuel each. The third will use 170 gph^(25, p. 3.7-1). The engines burn No. 2 fuel oil^(26, p. 2.3.4.3) and will exhaust annually the following effluents^(25, p. 3.7-1):

SO ₂	1,400 lb
NO _x	980 lb
	34 lb particulates
Hydrocarbons	412 lb

The heating boiler also consumes No. 2 fuel oil containing 0.4% sulfur at a rate of 432 gph and will produce annually:⁽²⁵⁾

SO ₂	13,650 lb
NO _x	9,800 lb
Particulates	340 lb

B.8.2.11 Sulfur Oxides

$$(1,400 \text{ lb} + 13,650 \text{ lb})/\text{yr} \times 1 \text{ kg}/2.205 \text{ lb} = 6,825.4 \text{ kg SO}_2/\text{yr}$$

$$\therefore \frac{6,825 \text{ kg SO}_2/\text{yr}}{24,528 \text{ kg U/yr}} = 0.278 \frac{\text{kg SO}_2}{\text{kg U}}$$

B.8.2.12 Nitrogen Oxides

$$(980 \text{ lb} + 9,800 \text{ lb})/\text{yr} \times \text{kg}/2.205 \text{ lb} = 4,889 \text{ kg NO}_x/\text{yr}$$

$$\therefore \frac{4,889 \text{ kg NO}_x/\text{yr}}{24,528 \text{ kg U/yr}} = 0.199 \frac{\text{kg NO}_x}{\text{kg U}}$$

B.8.2.13 Hydrocarbons

$$412 \text{ lb } H_xC_x/\text{yr} \times 1 \text{ kg}/2.205 \text{ lb} = 187 \text{ kg } H_xC_x/\text{yr}$$

$$\therefore \frac{187 \text{ kg } H_xC_x/\text{yr}}{24,528 \text{ kg U/yr}} = 7.6 \times 10^{-3} \frac{\text{kg } H_xC_x}{\text{kg U}}$$

B.8.2.14 Particulates

$$34 + 340 \text{ lb/yr} \times \text{kg}/2.205 \text{ lb} = 170 \text{ kg Particulates/yr}$$

$$\therefore \frac{170 \text{ kg/yr}}{24,528 \text{ kg U/yr}} = 6.9 \times 10^{-3} \frac{\text{kg Particulates}}{\text{kg U}}$$

B.8.2.15 Chlorine

Approximately 240 lb/day of chlorine is added to the circulating water line upstream of the main condenser. A small portion of this will be dispersed to the atmosphere and the remainder consumed^(25, p. 3.6-2). In absence of other data, a loss of 5% shall be assumed:

$$240 \text{ lb/day} \times .05 \text{ loss} \times \text{kg}/2.205 \text{ lb} = 5.44 \text{ kg Cl/day}$$

$$\therefore \frac{5.44 \text{ kg Cl/day}}{84 \text{ kg U/day}} = .065 \frac{\text{kg Cl}}{\text{kg U}}$$

B.8.3 CARBON-14

A release factor of 0.294 was derived as follows: Calculation 9-1 of Appendix A provided the daily throughput,

$$139,344 \text{ kg } UO_2 \times \frac{238 \text{ U}}{270 \text{ } UO_2} \times \frac{1}{5} \times \frac{1}{292 \text{ days}} = 84 \text{ kg U per day}$$

The activity value is obtained from Reference 18, p. 2-9:

BWR Fuel ^{17}O (n, α) ^{14}C	4.1
BWR Fuel ^{14}N (n,p) ^{14}C	17.3
BWR Coolant ^{17}O (n, α) ^{14}C	9.2
BWR Coolant ^{14}N (n,p) ^{14}C	<u>0.26</u>
Total Annual Production ^{14}C in Ci/GW-year	30.86

A 1250 MWe reactor at 80% capacity factor produces 1000 MWe-year/year or one GWe-year. Therefore, Ci/GW-year is the same as Ci per operating year for a 1250 MWe at 80%. Then, utilizing the specific activity of ^{14}C of 4.46 Ci/gram:

$$\frac{30.86 \text{ Ci/year}}{4.46 \text{ Ci/gram}} \times \frac{1}{292 \text{ days}} \times \frac{1}{1000 \text{ g per kg}}$$

$$= 2.37 \times 10^{-5} \text{ kg } ^{14}\text{C per operating day}$$

$$\frac{2.37 \times 10^{-5} \text{ kg } ^{14}\text{C per operating day}}{84 \text{ kg U per operating day}} = 2.82 \times 10^{-7} \text{ kg } ^{14}\text{C per kg U input}$$

Table 2-2, Page 2-12 of Reference 18 provides BWR releases of gaseous Carbon-14:

Pathway	Annual ^{14}C Release Ci/year
Condenser steam-jet air ejector off-gas	9.0
Turbine gland seal condenser exhaust	0.015
Reactor building purge exhaust	0.011
Turbine building ventilation	0.038
Radwaste building ventilation	6.04×10^{-6}
Total annual release of ^{14}C in Ci/year	9.064

$$\frac{9.064 \text{ Ci/year}}{4.46 \text{ Ci/gram}} \times \frac{1}{292 \text{ days}} \times \frac{1}{1000 \text{ g per kg}} = 6.96 \times 10^{-6} \text{ kg } ^{14}\text{C per day}$$

$$\frac{6.96 \times 10^{-6} \text{ kg } ^{14}\text{C per day releases}}{84 \text{ kg U per day}} = 8.28 \times 10^{-8} \text{ kg } ^{14}\text{C released per kg U input}$$

$$\begin{aligned} \text{Release factor} &= \frac{8.28 \times 10^{-8} \text{ kg } ^{14}\text{C released per kg U input}}{2.82 \times 10^{-7} \text{ kg } ^{14}\text{C produced per kg U input}} \\ &= 0.294 \end{aligned}$$

Also, the 9.064 Ci/yr is in good agreement with measurements at Nine Mile Point 1 reported by C. O. Kunz, W. E. Mahoney, and T. W. Miller of the Radiation Survey Laboratories, N. Y. State Department of Health in their paper "Carbon-14 Gaseous Effluents from Boiling Water Reactors." We therefore feel that our factor of 0.294 for BWR can be considered of Level 2 reliability.

TABLE B-9. Fuel Reprocessing

Material Released	Chemical Release Factors, kg/kg U (input)					
	Airborne			Liquid		
	Factor	Reliability	Ref. Calc.	Factor	Reliability	Ref. Calc.
Fluorine	1×10^{-4}	1	9.2.1			
Sodium				1×10^{-1}	1	9.3.1
Chloride				7×10^{-3}	1	9.3.2
Radionuclide Release Factor, kg released/kg radionuclide (input)						
Carbon 14	1.0	2	9.4			

B.9 FUEL REPROCESSING

B.9.1 ASSUMPTIONS

The following effluents were listed in Reference 4 for the WASH-1248 model fuel reprocessing plant. The effluent data below was normalized to the 900 MTU/yr capacity of the WASH 1248 model plant. Release factors shall be calculated directly from this data.

B.9.2 AIRBORNE RELEASE

B.9.2.1 Fluorine

(4, p. F-21)

$$\frac{.1 \text{ MT F/yr}}{900 \text{ MTU/yr}} = 1.1 \times 10^{-4} \frac{\text{MT F}}{\text{MTU}} = 1.1 \times 10^{-4} \frac{\text{kg F}}{\text{kg U}}$$

B.9.3 LIQUID RELEASES

B.9.3.1 Sodium (water)

(4, p. F-22)

$$\frac{137 \text{ MT Na/yr}}{900 \text{ MTU/yr}} = 1.5 \times 10^{-1} \frac{\text{MT Na}}{\text{MTU}} = 1.5 \times 10^{-1} \frac{\text{kg Na}}{\text{kg U}}$$

B.9.3.2 Chloride (water)

(4, p. F-22)

$$\frac{6.3 \text{ MT Chloride/yr}}{900 \text{ MTU/yr}} = 7 \times 10^{-3} \frac{\text{MT Chloride}}{\text{MTU}} = 7 \times 10^{-3} \frac{\text{kg Chloride}}{\text{kg U}}$$

B.9.4 CARBON 14

This is a mixture of liquid and airborne release but eventually becomes entirely airborne. A release factor of 1.0 (unity) for the ¹⁴C released from the reference fuel reprocessing facility was derived as follows:

Assumptions

1. The reference reprocessing facility will serve a mix of one-third BWRs and two-thirds PWRs (measured in gross MWe plant capacity).
2. The irradiated fuel will remain an average of six months in the irradiated fuel storage basins at the reactors (^{14}C from leaking fuel pins was already accounted for in our Calculations 7.4 and 8.3).
3. The time from reactor discharge to reprocessing dissolver will average 1-1/2 years.
4. The fuel casks are always sealed in transit. All ^{14}C evolved from leaking fuel pins in transit is therefore part of reprocessing plant accountability. The casks are solidly connected to the low-level gas system before they are vented and flushed through the radwaste system and eventually vented through the 100 meter stack at the reprocessing plant.
5. No equipment will have been installed as yet for the capture of ^{14}C when the reprocessing plant is initially operated, which is the situation we are appraising.

Calculations

The annual contribution of ^{14}C received in the irradiated fuel shipped from a 1250 MWe PWR is computed as follows (see Calculation 7.4):

$$\begin{array}{l} 22.2 \times 10^{-8} \text{ kg } ^{14}\text{C} \text{ produced per kg U Input} \\ \underline{6.67 \times 10^{-8} \text{ kg } ^{14}\text{C released per kg U Input}} \\ 15.53 \times 10^{-8} \text{ kg } ^{14}\text{C retained and shipped in the fuel} \\ \text{per kg U input} \end{array}$$

From Appendix A, reference Calculation 8-1 and Section 11A Pressurized Water Reactor, page 11-2, we assume 1/3 of fuel is changed out each year:

$$\begin{array}{l} 101,033 \text{ kg UO}_2 \times \frac{238}{270} \times \frac{1}{3} = 29,686 \text{ kg/year discharged} \\ 15.53 \times 10^{-8} \text{ kg } ^{14}\text{C per year kg U input} \times 29,686 \text{ kg/year discharged} \\ = 4.61 \times 10^{-3} \text{ kg } ^{14}\text{C per year shipped with the irradiated PWR fuel.} \end{array}$$

The annual contribution of ^{14}C received in the irradiated fuel shipped from a 1250 MWe BWR is computed as follows (see Reference Calculation 8.3):

$$\begin{array}{r} 28.2 \times 10^{-8} \text{ kg } ^{14}\text{C} \text{ produced per kg U input} \\ \underline{8.28 \times 10^{-8} \text{ kg } ^{14}\text{C} \text{ released per kg U input}} \\ 19.92 \times 10^{-8} \text{ kg } ^{14}\text{C} \text{ retained in fuel} \end{array}$$

From Appendix A, Reference Calculation 9.1, and Section 11B, page 11-45, we assume 1/5 of the fuel is changed out each year:

$$\begin{aligned} 139,344 \text{ kg UO}_2 \times \frac{238}{270} \times \frac{1}{5} &= 24,565.83 \text{ kg/year U discharged} \\ 19.92 \times 10^{-8} \text{ kg } ^{14}\text{C} \text{ per kg U fuel discharged} \times 24,565.83 \text{ kg/year} \\ \text{U discharged} &= 4.89 \times 10^{-3} \text{ kg } ^{14}\text{C/year shipped with the irradiated BWR} \\ &\text{fuel} \end{aligned}$$

In accordance with our assumption of a mix of two 1250 MWe PWR reactors for each BWR reactor:

$$\begin{array}{r} 29.686 \text{ MT/year U from 1250 MWe PWR and } 4.61 \times 10^{-3} \text{ kg } ^{14}\text{C in fuel} \\ 29.686 \text{ MT/year U from 1250 MWe PWR and } 4.61 \times 10^{-3} \text{ kg } ^{14}\text{C in fuel} \\ \underline{24.566 \text{ MT/year U from 1250 MWe BWR and } 4.89 \times 10^{-3} \text{ kg } ^{14}\text{C in fuel}} \\ 83.938 \text{ MT/year U total mix of} \quad 14.11 \times 10^{-3} \text{ kg } ^{14}\text{C arriving} \\ \text{three reactors} \quad \text{in fuel} \end{array}$$

$$27.98 \text{ MT/year U average per 1250 MWe reactor} \quad 4.70 \times 10^{-3} \text{ kg } ^{14}\text{C} \\ \text{arriving in fuel}$$

From Section 12, page 12-1, the reference LWR fuel reprocessing facility has an annual capacity of 1500 MTU/year (as charged into a reactor);

$$\frac{1500 \text{ MT/year U}}{27.98 \text{ MT/year U}} \times 4.70 \times 10^{-3} \text{ kg } ^{14}\text{C} = 0.252 \text{ kg } ^{14}\text{C} = 0.252 \text{ kg } ^{14}\text{C} \\ \text{processed in fuel per year (and} \\ \text{released). This is equivalent to} \\ 1,124 \text{ Ci/year.}$$

Section 12 provided a separate, independent calculation of ^{14}C released based on ORNL/NUREG/TM-12 "Carbon-14 Production in Nuclear Reactors," February 1977. This was listed as $8\text{E-}4$ kg/day in Table 12-6 on page 12-50 of Section 12:

$$8 \times 10^{-4} \text{ kg/day} \times 300 \text{ production days} = 0.240 \text{ kg } ^{14}\text{C} \text{ released per year}$$

This is a reasonably close check to our $0.252 \text{ kg } ^{14}\text{C}$ which we derived in this Appendix B.

The following table of pathways for releases is little more than a guess, since, without an operating reprocessing plant, it has not been possible to actually measure ^{14}C effluents:

<u>Pathway</u>	<u>% of Release</u>
Fuel receiving and storage	1
Shearing of fuel assemblies	25
Dissolution of fuel	49
Solvent extraction, partitioning and stripping	<u>25</u>
	100

In accordance with our Assumption 5, gaseous effluent from each of these pathways would be collected and would eventually be exhausted from the 100 meter stack as part of the 3115 cubic meters per minute flow (110,000 cfm).

All of the knowledgeable people we have consulted are of the opinion that all of the ^{14}C is released in gaseous forms as CO , CO_2 , CH_4 , C_2H_6 , and a minor amount in other gases, all of which would be released through the 100 meter stack. Willis Davis, Jr., in ORNL/NUREG/TM-12, "Carbon 14 Production in Nuclear Reactors" on "Abstract" page, says ". . . However, some small fraction may remain in aqueous raffinate and will not be released until these are converted to solids . . ." We agree this is possibly true. However, the waste solidification process is now a required part of a reprocessing plant. This small fraction, if it exists, is merely a delayed release in the same plant. ORNL/NUREG/TM-12 also points out: "Cladding metal and other core hardware

will contain significant quantities of ^{14}C . Very little of this will be released from BWR, PWR, and LMFBR hardware at fuel reprocessing plants; instead, the contained ^{14}C , 30 to 60 Ci/GW(e)-year for LWRS . . . , will remain within the metal, which will be retained onsite or in a federal repository." Our figures have not dealt with this 30 to 60 Ci/year, since it is not available as either a gas or a liquid effluent at either the reactors or the fuel reprocessing plant. We therefore can conclude that the ^{14}C release factor for the LWR Reprocessing Plant is unity:

$$\text{Release factor} = \frac{0.252 \text{ kg } ^{14}\text{C} \text{ released to environment/year}}{0.252 \text{ kg } ^{14}\text{C} \text{ received in fuel/year}} = 1$$

NOTE: If the 30 to 60 Ci/GWe-year ^{14}C contained in the cladding metals and other core hardware could have, somehow, been entirely released in the reprocessing plant:

$$60 \text{ Ci/year} \times \frac{1500 \text{ MT/year U reprocessing plant capacity}}{27.98 \text{ MT/year U per reactor}} = 3216 \text{ Ci/year}$$

$$\frac{3216 \text{ Ci of } ^{14}\text{C}}{4.46 \text{ Ci/gram } ^{14}\text{C}} = 721.2 \text{ gram} = 0.721 \text{ kg } ^{14}\text{C}$$

$$30 \text{ Ci/year} \times \frac{1500 \text{ MT/year U}}{27.98 \text{ MT/year U/reactor}} \times \frac{1}{4.46 \text{ Ci/year}} = 0.360 \text{ kg } ^{14}\text{C}$$

Any such amounts, or any portion thereof, if released would almost certainly form a gaseous compound, be released, so that the release factor would still be 1 (unity).

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RELEASE
RATES FOR
FUEL FABRICATION

APPENDIX C

RELEASE RATES FOR A UO₂ FUEL FABRICATION FACILITY

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The following tables give the chemical release rates from the Wilmington General Electric UO₂ fuel fabrication facility (NEDO-20197). Some of these release rates are used in release factor calculations in Appendix B.

TABLE C-1. Airborne-Chemical: General Electric

Effluent	Emission Point	Source	Particulate?	Soluble?	Chemical Form	Release Rate ^(a) (kg/MTU)	Dil. Index (m ³ /MTU)	Toxicity MPC ₃ (ng/m ³)	Basis	Ref.
Nitrogen oxides	Stack	Chemical conversion, calciner burners, metal cleaning and plating, vorcinerator (R)	No	Yes	NO _x (mostly NO ₂)	54.1	6.01 E8	.09	A-7	I
Hydrocarbons	"	Calcinator burners, boilers	No	No	H _x C _y	.06				
Carbon (black)	"	Calcinator burners, boilers	No	No	CO ₂	.85	2.43 E7	.035	A	I
F	"	Chemical conversion	No	Yes (both)	F, F ₂	.0031	1.55 E5	.02	A	I
1, 1, 1 (vapor degreaser)	"	Vapor degreaser	No			5.48				
Zr ₂ O ₂	"	Incinerator	No	No	Zr, O ₂	5.43	1.09 E8	.05	A	I
Ethyl acetate	"	Lab hoods	No	Slight		.548	3.91 E4	.14	A	I
Nitric acid	"	Lab hoods	No	Yes	HNO ₃	5.48	1.10 E7	.05	A	I
Ammonia	"	Waste treatment	No	Yes	NH ₃	822	4.56 E9	.18	A	I
Boron Carbide	"	Absorber rods	No	No	B ₄ C	.164	1.64 E7	.10	A-13	I
Xylo1	"	Paint booth	No			3.83	8.80 E5	4.35	A	I
Bu1anol	Stack	Paint booth	No	Yes	CH ₃ CH ₂ CH ₂ CH ₂ OH	4.38	2.92 E6	1.5	A	I
Methyl butyl	"	Paint booth	No	Slight		2.74	6.68 E5	4.1	A	I
Glycol ethyl ether	"	Paint booth	No	Very slight		2.19	5.92 E5	3.7	A	I
Isopropyl alcohol	"	Paint booth	No	Yes		13.7	1.40 E6	9.8	A	I
Sawdust	"	Woodworking	Yes							
CrO ₃	"	Chrome plating	No	No, but yes if in Na ₂ CR ₂ O ₇ form	CrO ₃	.0228	2.28 E7	.001	A	I
Sulfur dioxide				Yes	SO ₂			.13	A	I

(a) Based on release numbers from Reference 1, Appendix C (NEEO-20197, Environmental Report, General Electric Nuclear Facility, Wilmington, NC, General Electric Co., January 1974), Table 4-3 and a plant capacity of 725.4 MTU/year deduced from Ref. 1, App. C, note at the bottom of Table 1-1. For fluoride calculation ventilation flow value came from Ref. 1, App. C, Table 3-1 (Conversion Exhaust-35750 SCFM).

TABLE C-2. Liquid-Chemical: General Electric

Effluent	Emission Point	Source	Particulate?	Soluble?	Chemical Form	Release Rate (kg/MTU)	Toxicity			
							Dil. Index (L/MTU)	MPC (mg/L)	Basis	Ref.
F	Holding lagoon overflow	Process waste	No	Yes	F ⁻	2.9	2.90 E6	1	E,F	II
Ammonia	"	"	No	Yes	NH ₃ ⁻ , NH ₄ ⁺	4.8	4.80 E8	0.01	E,F	II
NO ₃	"	"	No	Yes	NO ₃ ⁻	32.9	3.29 E7	10	F	III
Nickel	"	"	No	Yes	Ni ⁺⁺	.009	1.80 E5	0.05	E,F	II
Chromium	"	"	No	Yes	Cr ⁺⁺ (Cr ₂ O ₇)	.009	4.50 E5	0.02	E,F	II
Copper	"	"	No	Yes	Cu ⁺⁺	.011	1.10 E5	.1	F	III
Phosphorus	"	"	No	Yes	PO ₄ ⁻⁻⁻	.091	9.10 E6	.1	C	II
Chlorine	"	"	No	Yes	Cl ⁻	1.30	4.33 E10	.15	J	II
SO ₄	"	"	No	Yes	SO ₄	9.58	9.16 E4	50	E,F	II
BOD		Treated sanitary wastes	No	Yes		2.28				
CaO			No		CaO	negligible		30	E,F	II
CaF ₂			No		CaF ₂	negligible			E,F	II

(a) Based on release numbers from Reference 1, Appendix C (NEDO-20197, Environmental Report, General Electric Nuclear Facility, Wilmington, N.C., General Electric Co., January 1974), Table 4-3 and a plant capacity of 725.4 MTU/year deduced from Reference 1, Appendix C, note at the bottom of Table 1-1.

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