VIRGINIA ELECTRIC AND POWER COMPANY

SURRY POWER STATION

OFFSITE DOSE CALCULATION MANUAL

UNITS 1 AND 2

Recommend Approval:

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REFERENCES:

1. Surry Power Station Technical Specifications.

2. Regulatory Guide 1.109, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I," Rev. 1, U.S. Nuclear Regulatory Commission, October 1977.

3. Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light - Water - Cooled Reactors," Rev. 1, U.S. Nuclear Regulatory Commission, July 1977.

4. U.S. Nuclear Regulatory Commission, "Preparation of Radiological Effluent Technical Specifications for Nuclear Power Plants," NUREG-0133, October 1978.

5. U.S. Nuclear Regulatory Commission, "XOQDOQ, Program for the Meteorological Evaluation of Routine Effluent Releases at Nuclear Power Stations," NUREG-0324, September 1977.

6. U.S. Nuclear Regulatory Commission, "User's Guide to GASPAR Code," NUREG-0597, June 1980.

7. Surry Power Station Radioactive Release Reports for 1976, 1977, 1978, 1979, 1980, and 1981.

8. Virginia Electric and Power Company, Surry Power Station, Units 1 and 2, Updated Final Safety Analysis Report.

IMPLEMENTATION:

The provisions in the Surry Offsite Dose Calculation Manual will be implemented upon approval of the Surry Power Station Radiological Effluent Technical Specifications by the NRC.

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OFFSITE DOSE CALCULATION MANUAL

SECTION 1

Introduction

1. PURPOSE

The Offsite Dose Calculation Manual (ODCM) provides the methodology and parameters to be used in the calculation of offsite doses due to radioactive liquid and gaseous effluents to assure compliance with the dose limitations of the Radiological Effluent Technical Specifications. These dose limitations assure that:

1) the concentration of radioactive liquid effluents to the unrestricted area will be limited to the concentration levels of 10CFR20, Appendix B, Table II;

2) the exposure to the maximum exposed member of the public in the unrestricted area from radioactive liquid effluents will not result in doses greater than the liquid dose limits of 10CFR50, Appendix I;

3) the dose rate at and beyond the site boundary from radioactive gaseous effluents will be limited to the annual dose limits of 10CFR20;

4) the exposure to the maximum exposed member of the public in the unrestricted area from radioactive gaseous effluents will not result in doses greater than the gaseous dose limits of 10CFR50, Appendix I; and

5) the exposure to the maximum exposed member of the public will not exceed 40CFR190 dose limits.

The Manual provides the methodology and parameters to be used in the assessment of the radiation doses due to the radioactive liquid and gaseous effluents released from the station. Examples are provided to demonstrate methodology, and do not necessarily reflect procedure calculations.

The Manual provides the methodology and parameters to be used in the calculation of radioactive liquid and gaseous effluent monitoring instrumentation alarm/trip setpoints to ensure compliance with the concentration and dose rate limitations of the Radiological Effluent Technical Specifications. The Manual provides simplified drawings of the radioactive liquid and gaseous effluent waste streams.

The Manual gives the specific locations for collecting radiological environmental monitoring samples.

2. SCOPE

The methodology used to assure compliance with the dose, dose rate, and concentration limitations described above shall be used to prepare the radioactive liquid and gaseous effluent procedures and reports required by the Technical Specifications. This manual does not include the procedures and forms required to document compliance with the surveillance requirements in the Technical Specifications.

Changes to this manual shall be reviewed and approved by the Station Nuclear Safety and Operating Committee prior to implementation. Changes to this manual shall be submitted to the Nuclear Regulatory Commission by inclusion in the Semi-Annual Radioactive Release Report for the period during which the change was made effective.

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SECTION 2

Liquid Effluent Radiation Monitor Setpoints

1. TECHNICAL SPECIFICATION REQUIREMENT

Technical Specification 3.7.E requires that: "The radioactive liquid and gaseous effluent monitoring instrumentation channels shown in Table 3.7-5(a) and Table 3.7-5(b) shall be operable with their alarm/trip setpoints set to ensure that the limits of Specifications 3.11.A.1 and 3.11.B.1 are not exceeded. The alarm/trip setpoints of these channels shall be determined and adjusted in accordance with the Offsite Dose Calculation Manual".

2. APPLICABLE MONITORS

Radioactive liquid effluent monitors for which alarm/trip setpoints are determined in accordance with this Manual are:

Release Point	Radiation Monitor Plant Instrument Number
Liquid Radwaste Effluent Line	LW-108
Component Cooling Service Water System Effluent Line	SW-107
Circulating Water Discharge Line	SW-120, SW-220

Monitor locations on the liquid effluent waste stream are shown in Figure 2.0.

3. SETPOINT CALCULATION

3.1 Maximum setpoint values shall be calculated using the following equation:

$$c = \frac{CF}{f}$$

where:

c = the setpoint, in uCi/ml, of the radioactivity monitor measuring the radioactivity concentration in the effluent line prior to dilution;

C = the effluent concentration limit for this monitor used in implementing 10CFR20 for the site, in uCi/ml;

f = the flow setpoint as measured at the radiation monitor location, GPM;

F = the dilution water flow calculated as:

F = f + (200,000 GPM x No. of Circ. Pumps in Service).

3.2 Each of the condenser circulating water channels (SW-120, SW-220) monitors the effluent (service water including component cooling service water, circulating water, and liquid radwaste) in the circulating water discharge tunnel beyond the last point of possible radioactive material addition. No dilution is assumed for this pathway. Therefore, the equation in 3.1 above becomes:

$$c = C$$

The setpoint becomes the effluent concentration limit for these monitors used in implementing 10CFR20 for the site.

3.3 In addition, for added conservatism, setpoints are calculated for the liquid radwaste effluent line (LW-108) and the component cooling service water system effluent line (SW-107).

For the liquid radwaste effluent line (LW-108), the equation in 3.1 becomes:

$$c = \frac{CFK_{LW}}{f}$$

where;

K_{LW} = The fraction of the effluent concentration limit used in implementing 10CFR20 for the site attributable to liquid radwaste effluent line pathway.

For the component cooling service water system effluent line (SW-107), the equation in 3.1 becomes:

$$c = \frac{CFK_{cc}}{f}$$

where;

K_{cc} = The fraction of the effluent concentration limit used in implementing 10CFR20 for the site attributable to the component cooling service water effluent line pathway.

The sum $K_{LW} + K_{cc} \leq 1.0$.

4. EXAMPLE

4.1 The following information is obtained from an isotopic analysis of the effluent from the liquid radwaste effluent:

Radionuclide Released	Average Undiluted Concentration Released (uCi/ml)
Co-60	3.09E-06
Cs-137	4.08E-06
Cs-134	2.65E-06
Co-58	3.19E-06
Fe-59	1.78E-06

4.2 The following information is obtained from an isotopic analysis of the effluent from the component cooling service water system:

Radionuclide Released	Average Undiluted Concentration Released (uCi/ml)
Co-60	5.67E-08
Cs-137	6.73E-08
Co-58	5.30E-08

4.3 Calculate, K_{LW} and K_{cc}, the fraction of the effluent limit for the liquid radwaste and component cooling service water pathways.

Liquid Waste:

Radionuclide Released	MPC	$\frac{uCi/ml_i}{MPC_i}$
Co-60	3E-05	1.03E-01
Cs-137	2E-05	2.04E-01
Cs-134	9E-06	2.94E-01
Co-58	9E-05	3.54E-02
Fe-59	5E-05	3.56E-02

$$\sum_i \frac{uCi/ml_i}{MPC_i} = 6.72E-01$$

Component Cooling Service Water:

Radionuclide Released	MPC	$\frac{uCi/ml_i}{MPC_i}$
Co-60	3E-05	1.89E-03
Cs-137	2E-05	3.37E-03
Co-58	9E-05	5.89E-04

$$\sum_i \frac{uCi/ml_i}{MPC_i} = 5.85E-03$$

Calculate the fraction of maximum allowable concentration (FMAC) using the following equation:

$$FMAC = \frac{f}{F} \times \sum_i \frac{uCi/ml_i}{MPC_i}.$$

The flow rate for the liquid radwaste pathway is 50 GPM and 18,000 GPM for the component cooling service water pathway. Three circulating water pumps are available.

FMAC for liquid waste:

$$FMAC = \frac{50}{[\ 50 + (200{,}000 \times 3)\ ]} \times 6.72E-01$$

$$FMAC = 5.60E-05$$

FMAC for component cooling service water:

$$\text{FMAC} = \frac{18{,}000}{[\ 18{,}000 + (200{,}000 \times 3)\ ]} \times 5.85\text{E-}03$$

$$\text{FMAC} = 1.7\text{E-}04$$

$$K_{LW} = \frac{5.6\text{E-}05}{5.6\text{E-}05 + 1.7\text{E-}04} = 0.25$$

$$K_{cc} = 0.75$$

4.4 The liquid radwaste monitor (LW-108) is calibrated for Cs-137, therefore:

$$C\ (\text{uCi/ml}) = \sum_i \frac{\text{uCi/ml}_i}{\text{MPC}_i} \times \text{MPC}_{\text{Cs-137}}$$

$$C = 6.72\text{E-}01 \times 2\text{E-}05$$

$$C = 1.34\text{E-}05$$

4.5 The liquid radwaste monitor (LW-108) setpoint would be calculated as:

$$c = \frac{1.34\text{E-}05 \times [\ 50 + (200{,}000 \times 3)\ ]}{50} \times 0.25$$

$$c = 4.02\text{E-}02\ \text{uCi/ml}$$

4.6 The component cooling service water monitor (SW-107) is calibrated for Cs-137, therefore:

$$C\ (\text{uCi/ml}) = \sum_i \frac{\text{uCi/ml}_i}{\text{MPC}_i} \times \text{MPC}_{\text{Cs-137}}$$

$$C = 5.85\text{E-}03 \times 2\text{E-}05 = 1.17\text{E-}07$$

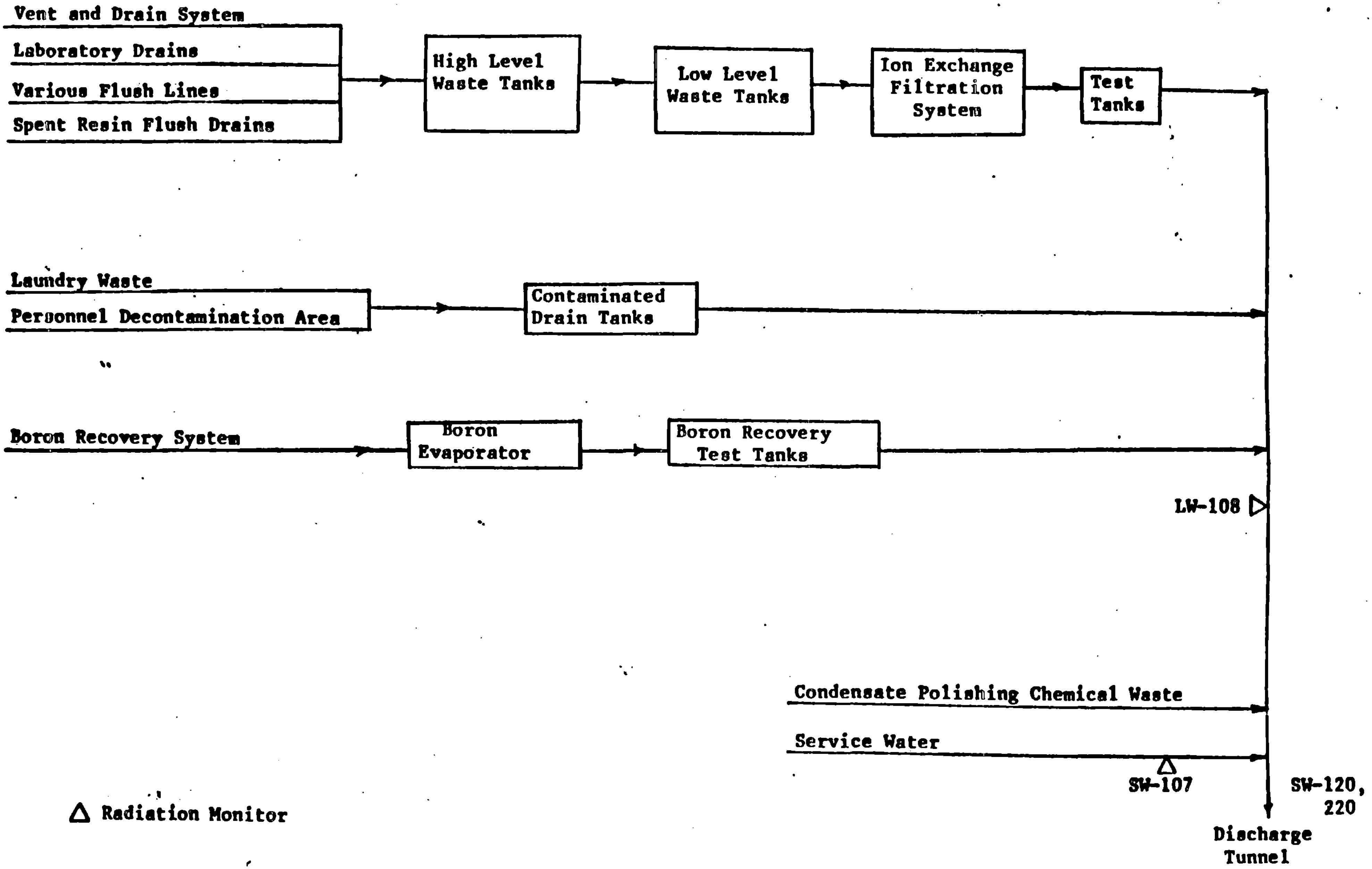
4.7 The component cooling service water monitor (SW-107) setpoint would be calculated as:

$$c = \frac{1.17\text{E-}07 \times [\ 18{,}000 + (200{,}000 \times 3)\ ]}{18{,}000} \times 0.75$$

$$c = 3.01\text{E-}06\ \text{uCi/ml}$$

4.8 The setpoints may be multiplied by the appropriate monitor conversion factor to determine the setpoints in CPM (counts per minute).

Figure 2.0



SURRY LIQUID

EFFLUENT SYSTEM

SURRY POWER STATION

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SECTION 3

Liquid Effluent Concentration Limit

1. TECHNICAL SPECIFICATION REQUIREMENT

Technical Specification 3.11.A.1.a. requires that: "The concentration of radioactive materials released in liquid waste effluents to unrestricted areas (see Figure 5.1-1) shall be limited to the concentrations specified in 10CFR20, Appendix B, Table II, Column 2, for radionuclides other than dissolved or entrained noble gases. For dissolved or entrained noble gases, the concentration shall be limited to 2 x 10^{-4} microcuries/ml".

2. CALCULATION

2.1 The daily concentrations of radioactive materials in liquid waste to unrestricted areas must meet the following:

$$\frac{\text{Volume of Waste Discharged + Volume of Dilution Water}}{\text{Volume of Waste Discharged x } \sum_i \frac{\text{uCi/ml}_i}{\text{MPC}_i}} \geq 1$$

where:

uCi/ml_i = the concentration of nuclide i in the liquid effluent discharge;

MPC_i = the maximum permissible concentration in unrestricted areas of nuclide, i, expressed as uCi/ml from 10CFR Part 20, Appendix B, Table II, for radionuclides other than noble gases and 2E-04 uCi/ml for dissolved or entrained noble gases.

3. EXAMPLE

3.1 Compilation of data from liquid effluent release records for a day indicated the following radionuclides and concentrations were released from the liquid radwaste effluent line.

Radionuclide	Concentration (uCi/ml)	MPC	uCi/ml/MPC
Co-60	4.00E-06	3E-05	1.33E-01
Cs-137	3.00E-06	2E-05	1.50E-01
Cs-134	1.00E-06	9E-06	1.11E-01
Co-58	4.50E-06	9E-05	5.00E-02
I-131	5.00E-08	3E-07	1.67E-01

$$\sum_i \frac{\text{uCi/ml}_i}{\text{MPC}_i} = 6.11\text{E-01}$$

Volume of Dilution Water for day = 1.71E+07 gal.

Volume of Waste Discharged for day = 2.88E+05 gal.

3.2 The daily concentration must meet the following:

$$\frac{\text{Volume of Waste Discharged} + \text{Volume of Dilution Water}}{\text{Volume of Waste Discharged} \times \sum_i \frac{\text{uCi/ml}_i}{\text{MPC}_i}} \geq 1$$

$$\frac{2.88\text{E}+05 + 1.71\text{E}+07}{2.88\text{E}+05 \times 6.11\text{E}-01} \geq 1$$

$$98.8 \geq 1$$

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SECTION 4

Liquid Effluent Dose Limit

1. TECHNICAL SPECIFICATION REQUIREMENT

Technical Specification 3.11.A.2.a requires that: "The dose or dose commitment to the maximum exposed member of the public from radioactive materials in liquid effluents released, from each reactor unit, to unrestricted areas shall be limited:

(i) During any calendar quarter to less than or equal to 1.5 mrems to the total body and to less than or equal to 5 mrems to critical organ, and,

(ii) During any calendar year to less than or equal to 3 mrems to the total body and to less than or equal to 10 mrems to critical organ.

2. CALCULATIONS

2.1 Dose contribution shall be calculated for all radionuclides identified in liquid effluents released to unrestricted areas based on the following expressions:

$$D = t\ F\ M \sum_{i} C_i\ A_i$$

where:

D = the cumulative dose commitment to the total body or critical organ, from the liquid effluents for the time period t, in mrem;

t = the length of the time period over which C_i and F are averaged for all liquid releases, hours;

M = the mixing ratio (reciprocal of the dilution factor) at the point of exposure, dimensionless, 0.2 from Appendix 11A, Surry UFSAR;

F = the near field average dilution factor for C_i during any liquid effluent release. Defined as the ratio of the average undiluted liquid waste flow during release to the average flow from the site discharge structure to unrestricted areas;

C_i = the average concentration of radionuclide, i, in undiluted liquid effluent during time period, t, from any liquid releases, in uCi/ml;

A_i = the site related ingestion dose commitment factor to the total body or critical organ of an adult for each identified principal gamma and beta emmitter listed in Table 4.0, in mrem-ml per hr-uCi;

$$A_i = 1.14E{+}05\ (21BF_i + 5BI_i)\ DF_i$$

where:

1.14E+05 = 1E+06 pCi/uCi x 1E+03 ml/kg ÷ 8760 hr/yr, units conversion factor;

21 = adult fish consumption, Kg/yr, from NUREG-0133;

5 = adult invertebrate consumption, Kg/yr, from NUREG-0133;

BI_i = the bioaccumulation factor for nuclide, i, in invertebrates, pCi/kg per pCi/l, from Table A-1 of Regulatory Guide 1.109, Rev. 1;

BF_i = the bioaccumulation factor for nuclide, i, in fish, pCi/kg per pCi/l, from Table A-1 of Regulatory Guide 1.109, Rev. 1.

DF_i = the critical organ dose conversion factor for nuclide, i, for adults, in mrem/pCi, from Table E-11 of Regulatory Guide 1.109, Rev. 1.

Thyroid and GI-LLI organ doses must be calculated to determine which is the critical organ for the period being considered. The pathway analysis used to determine the critical organ is presented in HP-ODCM-A2.

3. EXAMPLE

3.1 Compilation of data from release records for a 31 day period provides the following information:

Total Volume of Undiluted Liquid Effluent Released = 4.86E+10 ml

Total Volume of Dilution Water Used During Period = 2.26E+14 ml

Average Concentration of Radionuclides in Undiluted Liquid Effluent

Cs-134 - 5.64E-06 uCi/ml
Cs-137 - 8.35E-06 uCi/ml
I-131 - 5.66E-06 uCi/ml
Co-58 - 2.22E-06 uCi/ml
Co-60 - 1.65E-06 uCi/ml
H-3 - 8.07E-04 uCi/ml

3.2 31 Day Total Body Calculation:

$$D = t\ F\ M \sum_i C_i\ A_i$$

Obtain total body A_i values from Table 4.0
t = 744 hours.

Nuclide	C_i (uCi/ml)	x	$A_i\left(\frac{\text{mrem-ml}}{\text{uCi-hr}}\right)$	=	$\left(\frac{\text{mrem}}{\text{hr}}\right)$
Cs-134	5.46E-06	x	1.33E+04	=	7.26E-02
Cs-137	8.35E-06	x	7.85E+03	=	6.55E-02
I-131	5.66E-06	x	1.79E+02	=	1.01E-03
Co-58	2.22E-06	x	1.35E+03	=	3.00E-03
Co-60	1.65E-06	x	3.82E+03	=	6.30E-03
H-3	8.07E-04	x	2.82E-01	=	2.28E-04

$$\sum_i C_i\ A_i = 1.49E-01$$

$$F = \frac{4.86E{+}10\ (ml)}{2.26E{+}14\ (ml)}$$

Therefore, $$D = 744(hr) \times \frac{4.86E{+}10\ (ml)}{2.26E{+}14\ (ml)} \times 0.2 \times 1.49E{-}01\ \left(\frac{mrem}{hr}\right)$$

D = 4.77E-03 mrem to Total Body.

3.3 31 Day Thyroid Calculation:

$$D = t\ F\ M \sum_i C_i\ A_i$$

Obtain Thyroid A_i values from Table 4.0.

t = 744 hours.

Nuclide	C_i (uCi/ml)	x	$A_i\left(\frac{mrem\text{-}ml}{uCi\text{-}hr}\right)$	=	$\left(\frac{mrem}{hr}\right)$
Cs-134	5.46E-06	x	0	=	0
Cs-137	8.35E-06	x	0	=	0
I-131	5.66E-06	x	1.02E+05	=	5.77E-01
Co-58	2.22E-06	x	0	=	0
Co-60	1.65E-06	x	0	=	0
H-3	8.07E-04	x	2.82E-01	=	2.28E-04
			$\sum_i C_i\ A_i$	=	5.77E-01

$$F = \frac{4.86E{+}10\ (ml)}{2.26E{+}14\ (ml)}$$

Therefore, $$D = 744(hr) \times \frac{4.86E{+}10\ (ml)}{2.26E{+}14\ (ml)} \times 0.2 \times 5.77E{-}01\ \left(\frac{mrem}{hr}\right)$$

D = 1.85E-02 mrem to thyroid.

3.4 31 Day GI-LLI Calculation:

$$D = t\ F\ M \sum_i C_i\ A_i$$

Obtain GI-LLI A_i values from Table 4.0.

t = 744 hours.

Nuclide	C_i (uCi/ml)	x	$A_i (\frac{mrem-ml}{uCi-hr})$	=	$(\frac{mrem}{hr})$
Cs-134	5.46E-06	x	2.85E+02	=	1.56E-03
Cs-137	8.35E-06	x	2.32E+02	=	1.93E-03
I-131	5.66E-06	x	8.23E+01	=	4.66E-04
Co-58	2.22E-06	x	1.22E+04	=	2.71E-02
Co-60	1.65E-06	x	3.25E+04	=	5.36E-02
H-3	8.07E-04	x	2.82E-01	=	2.28E-04

$$\sum_i C_i A_i = 8.49E-02$$

$$F = \frac{4.86E+10 \text{ (ml)}}{2.26E+14 \text{ (ml)}}$$

Therefore,

$$D = 744\text{(hr)} \times \frac{4.86E+10 \text{ (ml)}}{2.26E+14 \text{ (ml)}} \times 0.2 \times 8.49E-02 \ (\frac{mrem}{hr})$$

$$D = 2.72E-03 \text{ mrem to GI-LLI.}$$

3.5 For this case, the critical organ would be the thyroid.

4. QUARTERLY COMPOSITE ANALYSES

For radionuclides not determined in each batch or weekly composite, the dose contribution to the current monthly or calendar quarter cumulative summation may be approximated by assuming an average monthly concentration based on the previous monthly or quarterly composite analyses. However, for reporting purposes, the calculated dose contribution shall be based on the actual composite analyses.

TABLE 4.0

LIQUID INGESTION PATHWAY DOSE FACTOR FOR SURRY POWER STATION

UNIT NOS. 1 AND 2

Radionuclide	Total Body A_i $\frac{\text{mrem/hr}}{\text{uCi/ml}}$	Thyroid A_i $\frac{\text{mrem/hr}}{\text{uCi/ml}}$	GI-LLI A_i $\frac{\text{mrem/hr}}{\text{uCi/ml}}$
H-3	2.82E-01	2.82E-01	2.82E-01
Na-24	4.57E-01	4.57E-01	4.57E-01
Cr-51	5.58E+00	3.34E-01	1.40E+03
Mn-54	1.35E+03	-	2.16E+04
Fe-55	8.23E+03	-	2.03E+04
Fe-59	7.27E+04	-	6.32E+05
Co-58	1.35E+03	-	1.22E+04
Co-60	3.82E+03	-	3.25E+04
Zn-65	2.32E+05	-	3.23E+05
Rb-86	2.91E+02	-	1.23E+02
Sr-87	1.43E+02	-	8.00E+02
Sr-90	3.01E+04	-	3.55E+03
Y-91	2.37E+00	-	4.89E+04
Zr-95	3.46E+00	-	1.62E+04
Zr-97	8.13E-02	-	5.51E+04
Nb-95	1.34E+02	-	1.51E+06
Mo-99	2.43E+01	-	2.96E+02
Ru-103	4.60E+01	-	1.25E+04
Ru-106	2.01E+02	-	1.03E+05
Ag-110m	8.60E+02	-	5.97E+05
Sb-124	1.09E+02	6.70E-01	7.84E+03
Sb-125	4.20E+01	1.79E-01	1.94E+03
Te-125m	2.91E+01	6.52E+01	8.66E+02
Te-127m	6.68E+01	1.40E+02	1.84E+03
Te-129m	1.47E+02	3.20E+02	4.69E+03
Te-131m	5.71E+01	1.08E+02	6.80E+03
Te-132	1.24E+02	1.46E+02	6.24E+03
I-131	1.79E+02	1.02E+05	8.23E+01
I-132	9.96E+00	9.96E+02	5.35E+00
I-133	3.95E+01	1.90E+04	1.16E+02
I-134	5.40E+00	2.62E+02	1.32E-02
I-135	2.24E+01	4.01E+03	6.87E+01
Cs-134	1.33E+04	-	2.85E+02
Cs-136	2.04E+03	-	3.21E+02
Cs-137	7.85E+03	-	2.32E+02
Cs-138	5.94E+00	-	5.12E-05
Ba-140	1.08E+02	-	3.38E+03
La-140	2.10E-01	-	5.83E+04
Ce-141	2.63E-01	-	8.86E+03
Ce-143	4.94E-02	-	1.67E+04
Ce-144	9.59E+00	-	6.04E+04
Np-239	1.91E-03	-	7.11E+02

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SECTION 5

Liquid Effluent Dose Projections

1. TECHNICAL SPECIFICATION REQUIREMENT

Technical Specification 3.11.A.3.a requires that: "The Liquid Radwaste Treatment System shall be used to reduce the radioactive materials in liquid wastes prior to their discharge when the projected doses due to liquid effluent releases to unrestricted areas (see Figure 5.1-1) when averaged over 31 days would exceed 0.06 mrem to the total body or 0.2 mrem to the critical organ."

2. PROJECTED TOTAL BODY DOSE

2.1 Determine D_{TB} = total body dose from liquid effluents in the previous 31 day period, calculated according to H.P.-ODCM-4.

2.2 Estimate R_1 = ratio of the estimated volume of liquid effluent releases in the present 31 day period to the volume released in the previous 31 day period.

2.3 Estimate F_1 = ratio of the estimated liquid effluent radioactivity in the present 31 day period to the liquid effluent activity in the previous 31 day period.

2.4 Determine PD_{TB} = projected total body dose in a 31 day period.

$$PD_{TB} = D_{TB}\ (R_1F_1)$$

3. PROJECTED CRITICAL ORGAN DOSE

3.1 Determine D_o = critical organ dose from liquid effluents in the previous 31 day period, calculated according to H.P.-ODCM-4.

3.2 Estimate R_1 as in Step 2.2.

3.3 Estimate F_1 as in Step 2.3.

3.4 Determine PD_o = projected critical organ dose in a 31 day period.

$$PD_o = D_o\ (R_1F_1)$$

Historical data pertaining to the volumes and radioactivity of liquid effluents released in connection to specific station functions, as maintenance or refueling outages, shall be used in the above projections as appropriate.

4. EXAMPLE

4.1 A critical organ dose in a 31 day period due to liquid effluent releases was calculated in H.P.-ODCM-4.3.3 using the data in H.P.-ODCM-4.3.1. Therefore, D = 1.85E-02 mrem to the thyroid.

4.2 According to H.P.-ODCM-4.3.1, the total volume of undiluted liquid effluent released was 4.86E+10 ml. It is estimated that the liquid effluent release may double to 9.72E+10 ml in the present 31 day period. Therefore, $R_1 = \frac{9.72E+10}{4.86E+10} = 2.0$.

4.3 From H.P.-ODCM-4.3.1, the total concentration of radionuclides in undiluted liquid effluents is 8.33E-04 uCi/ml. The total concentration of radionuclides in undiluted liquid effluents in the present 31 day period is estimated to be 1.00E-03 uCi/ml. Therefore, $F_1 = \frac{1.00E-03}{8.33E-04} = 1.2$.

4.4 The projected total body dose in a 31 day period is:

$$PD_{TB} = D_{TB} (R_1 F_1)$$

$$PD_{TB} = 1.85E-02 \text{ (mrem)} \times 2.0 \times 1.2$$

$$PD_{TB} = 4.44E-02 \text{ mrem.}$$

4.5 The projected critical organ dose, PD_o, in a 31 day period would be similarly obtained.

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SECTION 6

Gaseous Effluent Radiation Monitor Setpoints

1. TECHNICAL SPECIFICATION REQUIREMENT

Technical Specification 3.7.E requires that: "The radioactive liquid and gaseous effluent monitoring instrumentation channels shown in Table 3.7-5(a) and Table 3.7-5(b) shall be operable with their alarm/trip setpoints set to ensure that the limits of Specifications 3.11.A.1 and 3.11.B.1 are not exceeded. The alarm/trip setpoints of these channels shall be determined and adjusted in accordance with the Offsite Dose Calculation Manual (ODCM)".

2. APPLICABLE MONITORS

Radioactive gaseous effluent monitors for which alarm/trip setpoints are determined in accordance with this Manual are:

Release Point	Radiation Monitor Plant Instrument Number
Process Vent	GW-102
Condenser Air Ejector	SV-111, 211
Ventilation Vent	VG-110

Monitor locations on the gaseous effluent waste streams are shown in Figure 6.0.

3. SETPOINT CALCULATIONS

3.1 The setpoint calculations for each monitor listed above shall be determined such that the following relationship is maintained:

$$D_{pv} + D_{cae1} + D_{cae2} + D_{vv} \leq D$$

where:

D = The Technical Specification 3.11.B.1 dose limits implementing 10CFR20 for the site, mrem/yr;

D_{pv} = The noble gas site boundary dose rate from process vent gaseous effluent releases, mrem/yr;

D_{cae1} = The noble gas site boundary dose rate from Unit 1 condenser air ejector gaseous effluent releases, mrem/yr;

D_{cae2} = The noble gas site boundary dose rate from Unit 2 condenser air ejector gaseous effluent releases, mrem/yr;

D_{vv} = The noble gas site boundary dose rate from ventilation vent gaseous effluent releases, mrem/yr.

3.2 Setpoint values shall be determined using the following equation:

$$C_m = \frac{(R_m)\ 2.12E\text{-}03}{F_m}$$

where:

m = The release pathway, process vent (pv), Unit 1 condenser air ejector (cae1), Unit 2 condenser air ejector (cae2), or ventilation vent (vv);

C_m = The effluent concentration limit implementing Technical Specification 3.11.B.1 for the site, uCi/ml;

R_m = The release rate limit for pathway m determined from the methodology in HP-ODCM-7, using Xe-133 as the nuclide to be released, uCi/sec;

2.12E-03 = CFM per ml/sec; and

F_m = The maximum flow rate for pathway m, CFM.

3.3 According to NUREG-0133, the radioactive effluent radiation monitor alarm/trip setpoints should be based on the radioactive noble gases. It is not considered to be practicable to apply instantaneous alarm/trip setpoints to integrating monitors sensitive to radioiodines, radioactive materials in particulate form, and radionuclides other than noble gases.

4. EXAMPLE

4.1 Assume Unit 1 is operating and Unit 2 is shut down. To calculate the limiting release rate, the following information is obtained from process vent release records:

Radionuclide	Release Rate (Curies/sec)
Xe-133	4.43E-06
Xe-135	3.04E-07
Kr-88	2.84E-10
Xe-131m	1.38E-07

and ventilation vent release records:

Radionuclide	Release Rate (Curies/sec)
Xe-133	1.77E-05
Xe-135	1.21E-06
Kr-88	1.14E-09
Xe-131m	5.52E-07

and Unit 1 condenser air ejector release records:

Radionuclide	Release Rate (Curies/sec)
Xe-133	2.11E-08
Xe-135	1.22E-09

4.2 Determine the fraction of the total noble gas total body dose that is attributable to each pathway using the methodology and Tables 7.0 and 7.1 in HP-ODCM-7.

Process Vent:

Radionuclide	K_{ipv}	x	$\dot{Q}_{ipv}$	=	
Xe-133	2.94E+02	x	4.43E-06	=	1.30E-03
Xe-135	1.81E+03	x	3.04E-07	=	5.50E-04
Kr-88	1.47E+04	x	2.84E-10	=	4.17E-06
Xe-131m	9.15E+01	x	1.38E-07	=	1.26E-05
			$\sum_i K_{ipv} \times \dot{Q}_{ipv}$	=	1.87E-03

Ventilation Vent:

Radionuclide	K_{ivv}	x	$\dot{Q}_{ivv}$	=	
Xe-133	1.76E+04	x	1.77E-05	=	3.12E-01
Xe-135	1.09E+05	x	1.21E-06	=	1.32E-01
Kr-88	8.82E+05	x	1.14E-09	=	1.01E-03
Xe-131m	5.49E+03	x	5.52E-07	=	3.03E-03
			$\sum_i K_{ivv} \times \dot{Q}_{ivv}$	=	4.48E-01

Unit 1 Condenser Air Ejector:

Radionuclide	K_{ivv}	x	$\dot{Q}_{icael}$	=	
Xe-133	1.76E+04	x	2.11E-08	=	3.71E-04
Xe-135	1.09E+05	x	1.22E-09	=	1.33E-04
			$\sum_i K_{ivv} \times \dot{Q}_{icael}$	=	5.04E-04

The total body noble gas dose for process vent, ventilation vent, and Unit 1 condenser air ejector, mrem/yr. = 1.87E-03 + 4.48E-01 + 5.04E-04

The total body noble gas dose for process vent, ventilation vent, and Unit 1 condenser air ejector, mrem/yr. = 4.50E-01

Process vent fractional dose $= \frac{1.87E-03}{4.50E-01} = 4.16E-03$

Ventilation vent fractional dose $= \frac{4.48E-01}{4.50E-01} = 9.96E-01$

Unit 1 condenser air ejector fractional dose $= \dfrac{5.04E-04}{4.50E-01} = 1.12E-03$

4.3 Determine the fraction of the total noble gas skin dose that is attributable to each pathway using the methodology and Tables 7.0 and 7.1 in HP-ODCM-7.

Process Vent:

Radio-nuclide	$(L_{ipv}$	+	1.1	x	$M_{ipv})$	x	$\dot{Q}_{ipv}$	=	
Xe-133	(3.06E+02	+	1.1	x	3.53E+02)	x	4.43E-06	=	3.08E-03
Xe-135	(1.86E+03	+	1.1	x	1.92E+03)	x	3.04E-07	=	1.21E-03
Kr-88	(2.37E+03	+	1.1	x	1.52E+04)	x	2.84E-10	=	5.42E-06
Xe-131m	(4.76E+02	+	1.1	x	1.56E+02)	x	1.38E-07	=	8.94E-05

$$\sum_i (L_{ipv} + 1.1\ M_{ipv})\ \dot{Q}_{ipv} = 4.38E-03$$

Ventilation Vent:

Radio-nuclide	$(L_{ivv}$	+	1.1	x	$M_{ivv})$	x	$\dot{Q}_{ivv}$	=	
Xe-133	(1.84E+04	+	1.1	x	2.12E+04)	x	1.77E-05	=	7.38E-01
Xe-135	(1.12E+05	+	1.1	x	1.15E+05)	x	1.21E-06	=	2.89E-01
Kr-88	(1.42E+05	+	1.1	x	9.12E+05)	x	1.14E-09	=	1.31E-03
Xe-131m	(2.86E+04	+	1.1	x	9.36E+03)	x	5.52E-07	=	2.14E-02

$$\sum_i (L_{ivv} + 1.1\ M_{ivv})\ \dot{Q}_{ivv} = 1.05E+00$$

Unit 1 Condenser Air Ejector:

Radio-nuclide	$(L_{ivv}$	+	1.1	x	$M_{ivv})$	x	$\dot{Q}_{icael}$	=	
Xe-133	(1.84E+04	+	1.1	x	2.12E+04)	x	2.11E-08	=	8.80E-04
Xe-135	(1.12E+05	+	1.1	x	1.15E+05)	x	1.22E-09	=	2.91E-04

$$\sum_i (L_{ivv} + 1.1\ M_{ivv})\ \dot{Q}_{icael} = 1.17E-03$$

The skin noble gas dose for process vent, ventilation vent, and Unit 1 condenser air ejector, mrem/yr. = 4.38E-03 + 1.05E+00 + 1.17E-03

The skin noble gas dose for process vent, ventilation vent, and Unit 1 condenser air ejector, mrem/yr. = 1.06E+00

Process vent fractional dose $= \dfrac{4.38E-03}{1.06E+00} = 4.13E-03$

Ventilation vent fractional dose $= \dfrac{1.05E+00}{1.06E+00} = 9.91E-01$

Unit 1 condenser air ejector $= \dfrac{1.17E-03}{1.06E+00} = 1.10E-03$

4.4 Determine the release rate limit for total body dose, R_{pv}, from the methodology in HP-ODCM-7, using Xe-133 as the nuclide to be released.

The part of Technical Specification 3.11.B.1.a(i) total body dose limit that is attributable to the process vent = 500 mrem/yr x 4.16E-03 = 2.08 mrem/yr.

From the methodology in HP-ODCM-7.2.1,

$$K_{ipv}\ \dot{Q}_{ipv} \leq 2.08 \text{ mrem/yr.}$$

Calculating $\dot{Q}_{ipv}$ for Xe-133,

$$\dot{Q}_{Xe-133} = \frac{2.08 \text{ mrem/yr}}{K_{Xe-133}}$$

$$\dot{Q}_{Xe-133} = \frac{2.08 \text{ mrem/yr}}{2.94E+02 \ \dfrac{\text{mrem/yr}}{\text{Curie/sec.}}}$$

$$\dot{Q}_{Xe-133} = 7.07E-03 \text{ Curie/sec.} = 7.07E+03 \text{ uCi/sec.}$$

4.5 Determine the release rate limit for total body dose, R_{vv}, from the methodology in HP-ODCM-7, using Xe-133 as the nuclide to be released.

The part of Technical Specification 3.11.B.1.a(i) total body dose limit that is attributable to the ventilation vent = 500 mrem/yr x 9.96E-01 = 498 mrem/yr.

From the methodology in HP-ODCM-7.2.1,

$$K_{ivv}\ \dot{Q}_{ivv} \leq 2.08 \text{ mrem/yr.}$$

Calculating $\dot{Q}_{ivv}$ for Xe-133,

$$\dot{Q}_{Xe-133} = \frac{498 \text{ mrem/yr}}{K_{Xe-133}}$$

$$\dot{Q}_{Xe-133} = \frac{498 \text{ mrem/yr}}{1.76E+04 \ \dfrac{\text{mrem/yr}}{\text{Curie/sec.}}}$$

$$\dot{Q}_{Xe-133} = 2.83E-02 \text{ Curie/sec.} = 2.83E+04 \text{ uCi/sec.}$$

4.6 Determine the release rate limit for total body dose, R_{cael}, from the methodology in HP-ODCM-7, using Xe-133 as the nuclide to be released.

The part of Technical Specification 3.11.B.1.a(i) total body dose limit that is attributable to the Unit 1 condenser air ejector = $500 \frac{\text{mrem}}{\text{yr}} \times 1.12E-03 = 0.56 \frac{\text{mrem}}{\text{yr}}$.

From the methodology in HP-ODCM-7.2.1,

$$K_{ivv} \dot{Q}_{icael} \leq 0.56 \text{ mrem/yr.}$$

Calculating $\dot{Q}_{icael}$ for Xe-133,

$$\dot{Q}_{Xe-133} = \frac{0.56 \text{ mrem/yr}}{K_{Xe-133}}$$

$$\dot{Q}_{Xe-133} = \frac{0.56 \text{ mrem/yr}}{1.76E+04 \ \frac{\text{mrem/yr}}{\text{Curie/sec.}}}$$

$$\dot{Q}_{Xe-133} = 3.18E-05 \text{ Curie/sec.} = 3.18E+01 \text{ uCi/sec.}$$

4.7 Determine the release rate limit for skin dose, R_{pv}, from the methodology in HP-ODCM-7, using Xe-133 as the nuclide to be released.

The part of Technical Specification 3.11.B.1.a(i) skin dose limit that is attributable to the process vent = 3000 mrem/yr x 4.13E-03 = 1.24E+01 mrem/yr.

From the methodology in HP-ODCM-7.2.1,

$$(L_{ipv} + 1.1\ M_{ipv})\ \dot{Q}_{ipv} \leq 1.24E+01 \text{ mrem/yr.}$$

$$\dot{Q}_{Xe-133} = \frac{1.24E+01 \text{ mrem/yr}}{(L_{Xe-133} + 1.1\ M_{Xe-133})\ \frac{\text{mrem/yr}}{\text{Curie/sec.}}}$$

$$\dot{Q}_{Xe-133} = \frac{1.24E+01 \text{ mrem/yr}}{(3.06E+02 + 1.1 \times 3.53E+02)\ \frac{\text{mrem/yr}}{\text{Curie/sec.}}}$$

$$\dot{Q}_{Xe-133} = 1.79E-02 \text{ Curie/sec.} = 1.79E+04 \text{ uCi/sec.}$$

4.8 Determine the release rate limit for skin dose, R_{vv}, from the methodology in HP-ODCM-7, using Xe-133 as the nuclide to be released.

The part of Technical Specification 3.11.B.1.a(i) skin dose limit that is attributable to the ventilation vent = 3000 mrem/yr x 9.91E-01 = 2.973E+03 mrem/yr.

From the methodology in HP-ODCM-7.2.1,

$$(L_{ivv} + 1.1\ M_{ivv})\ \dot{Q}_{ivv} \leq 2.973\text{E+03 mrem/yr.}$$

$$\dot{Q}_{Xe\text{-}133} = \frac{2.973\text{E+03 mrem/yr}}{(L_{Xe\text{-}133} + 1.1\ M_{Xe\text{-}133})\ \frac{\text{mrem/yr}}{\text{Curie/sec.}}}$$

$$\dot{Q}_{Xe\text{-}133} = \frac{2.973\text{E+03 mrem/yr}}{(1.84\text{E+04} + 1.1 \times 2.12\text{E+04})\ \frac{\text{mrem/yr}}{\text{Curie/sec.}}}$$

$$\dot{Q}_{Xe\text{-}133} = 7.13\text{E-02 Curie/sec.} = 7.13\text{E+04 uCi/sec.}$$

4.9 Determine the release rate limit for skin dose, R_{cael}, from the methodology in HP-ODCM-7, using Xe-133 as the nuclide to be released.

The part of Technical Specification 3.11.B.1.a(i) skin dose limit that is attributable to the Unit 1 condenser air ejector = 3000 mrem/yr x 1.10E-03 = 3.303E+00 mrem/yr.

From the methodology in HP-ODCM-7.2.1,

$$(L_{icael} + 1.1\ M_{icael})\ \dot{Q}_{icael} \leq 3.30\text{E+00 mrem/yr.}$$

$$\dot{Q}_{Xe\text{-}133} = \frac{3.30\text{E+00 mrem/yr}}{(L_{Xe\text{-}133} + 1.1\ M_{Xe\text{-}133})\ \frac{\text{mrem/yr}}{\text{Curie/sec.}}}$$

$$\dot{Q}_{Xe\text{-}133} = \frac{3.30\text{E+00 mrem/yr}}{(1.84\text{E+04} + 1.1 \times 2.12\text{E+04})\ \frac{\text{mrem/yr}}{\text{Curie/sec.}}}$$

$$\dot{Q}_{Xe\text{-}133} = 7.91\text{E-05 Curie/sec.} = 7.91\text{E+01 uCi/sec.}$$

4.10 The calculations indicate that the total body dose limits result in the most restrictive release rate limits. Therefore,

$$C_{pv} = \frac{(R_{pv})\ 2.12\text{E-03}}{F_{pv}}$$

$$C_{pv} = \frac{(7.07E+03) \times 2.12E-03}{300}$$

$$C_{pv} = 5.0E-02 \text{ uCi/ml}$$

and

$$C_{vv} = \frac{(R_{vv})\ 2.12E-03}{F_{vv}}$$

$$C_{vv} = \frac{(2.83E+04) \times 2.12E-03}{172{,}000}$$

$$C_{vv} = 3.49E-04 \text{ uCi/ml}$$

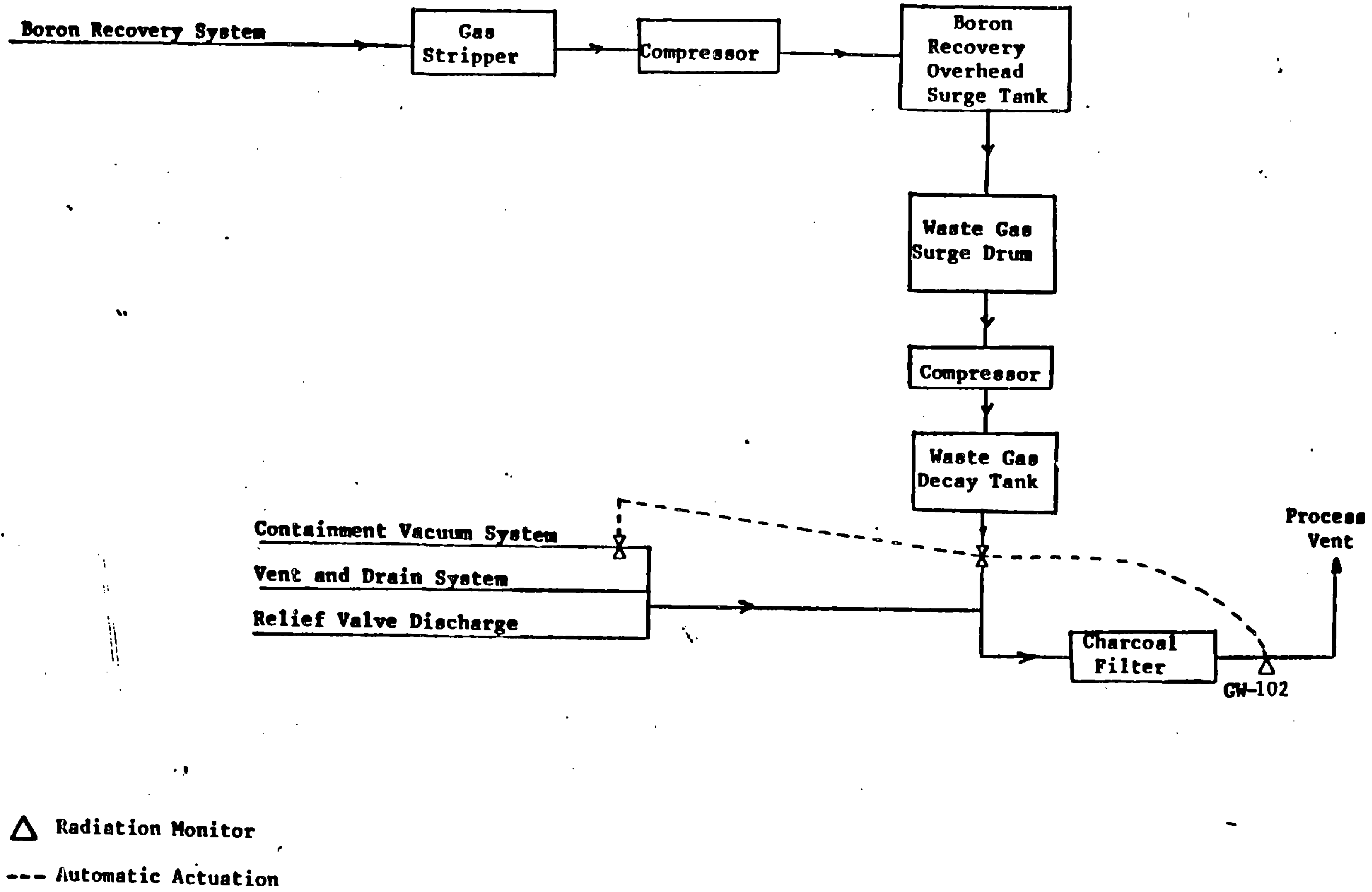
and

$$C_{cael} = \frac{(R_{cael})\ 2.12E-03}{F_{cael}}$$

$$C_{cael} = \frac{(3.18E+01)\ 2.12E-03}{5}$$

$$C_{cael} = 1.35E-02 \text{ uCi/ml}$$

4.11 Setpoints in CPM (counts per minute) can be determined by multiplying the above effluent concentration limits by the appropriate monitor conversion factors.



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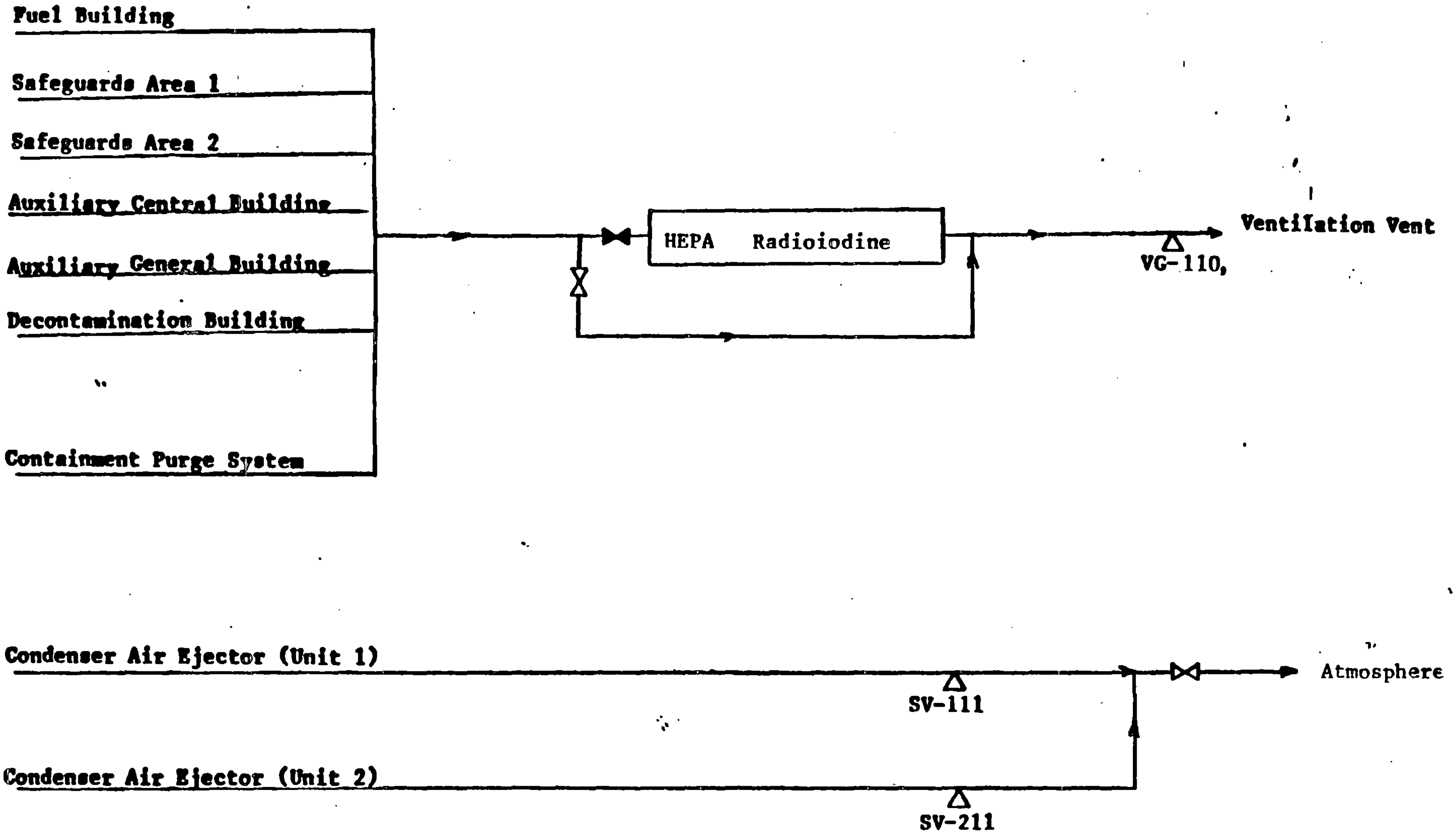

SURRY GASEOUS
EFFLUENT SYSTEM

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SECTION 7

Gaseous Effluent Release Rate

1. TECHNICAL SPECIFICATION REQUIREMENT

Technical Specification 3.11.B.1.a requires that: "The dose rate due to radioactive materials released in gaseous effluents from the site to areas at and beyond the site boundary (see Figure 5.1-1) shall be limited to the following:

(i) for noble gases: Less than or equal to 500 mrem/yr to the total body and less than or equal to 3000 mrem/yr to the skin, and

(ii) for iodine - 131, for tritium, and for all radionuclides in particulate form with half-lives greater than 8 days: Less than or equal to 1500 mrem/yr to the critical organ".

2. CALCULATION

1. The dose rate limit for noble gases shall be determined to be within the Technical Specification limit by limiting the release rate to the lessor of:

$$\sum_i [K_{ivv} \dot{Q}_{ivv} + K_{ipv} \dot{Q}_{ipv}] \leq 500 \text{ mrem/yr to total body,}$$

or

$$\sum_i [(L_{ivv} + 1.1M_{ivv}) \dot{Q}_{ivv} + (L_{ipv} + 1.1M_{ipv}) \dot{Q}_{ipv}] \leq 3000 \text{ mrem/yr}$$

to the skin

where:

Subscripts =	vv, refers to vent releases from the building ventilation vent; pv, refers to the vent releases from the process vent; i, refers to individual radionuclide;
K_{ivv}, K_{ipv} =	The total body dose factor for ventilation vent or process vent release due to gamma emissions for each identified noble gas radionuclide, i, in mrem/yr per Curie/sec. Factors are listed in Table 7.0 and Table 7.1;
L_{ivv}, L_{ipv} =	The skin dose factor for ventilation vent or process vent release due to beta emissions for each identified noble gas radionuclide i, in mrem/yr per Curie/sec. Factors are listed in Table 7.0 and Table 7.1;

M_{ivv}, M_{ipv} = The air dose factor for ventilation vent or process vent release due to gamma emissions for each identified noble gas radionuclide, i, in mrad/yr per Curie/sec. Factors are listed in Table 7.0 and Table 7.1;

$\dot{Q}_{ivv}, \dot{Q}_{ipv}$ = The release rate for ventilation vent or process vent of noble gas radionuclide, i, in gaseous effluents in Curie/sec (per site);

1.1 = The unit conversion factor that converts air dose to skin dose, in mrem/mrad.

2. The dose rate limit for iodine - 131, for tritium, and for all radionuclides in particulate form with half-live greater than 8 days shall be determined to be within the Technical Specification limit by limiting the release rate to:

$$\sum_i [P_{ivv} \dot{Q}_{ivv} + P_{ipv} \dot{Q}_{ipv}] \leq 1500 \text{ mrem/yr to critical organ}$$

where:

P_{ivv}, P_{ipv} = The critical organ dose factor for ventilation vent or process vent for I-131, H-3, and all radionuclides in particulate form with half-lives greater than 8 days for the inhalation pathway, in mrem/yr per Curie/sec. Factors are listed in Table 7.2;

$\dot{Q}_{ivv}, \dot{Q}_{ipv}$ = The release rate for ventilation vent or process vent of I-131, H-3, and all radionuclides, i, in particulate form with half-lives greater than 8 days in gaseous effluents in Curie/sec (per site).

3. All gaseous releases, not through the process vent, are considered ground level and shall be included in the determination of Q_{ivv}.

3. EXAMPLE

3.1 For demonstration of methodology, see HP-ODCM-6.4.

TABLE 7.0

GAMMA AND BETA DOSE FACTORS FOR SURRY POWER STATION

UNIT NOS. 1 AND 2

X/Q = 6.0E-05 sec/m^3 at 499 meters N Direction

Dose Factors for Ventilation Vent

Noble Gas Radionuclide	K_{ivv} Total Body $\frac{\text{mrem/yr}}{\text{Curie/Sec}}$	L_{ivv} Skin $\frac{\text{mrem/yr}}{\text{Curie/Sec}}$	M_{ivv} Gamma Air $\frac{\text{mrad/yr}}{\text{Curie/sec}}$	N_{ivv} Beta Air $\frac{\text{mrad/yr}}{\text{Curie/sec}}$
Kr-83m	4.54E+00	-	1.16E+03	1.73E+04
Kr-85m	7.02E+04	8.76E+04	7.38E+04	1.18E+05
Kr-85	9.66E+02	8.04E+04	1.03E+03	1.17E+05
Kr-87	3.55E+05	5.84E+05	3.70E+05	6.18E+05
Kr-88	8.82E+05	1.42E+05	9.12E+05	1.76E+05
Kr-89	9.96E+05	6.06E+05	1.04E+06	6.36E+05
Kr-90	9.36E+05	4.37E+05	9.78E+05	4.70E+05
Xe-131m	5.49E+03	2.86E+04	9.36E+03	6.66E+04
Xe-133m	1.51E+04	5.96E+04	1.96E+04	8.88E+04
Xe-133	1.76E+04	1.84E+04	2.12E+04	6.30E+04
Xe-135m	1.87E+05	4.27E+04	2.02E+05	4.43E+04
Xe-135	1.09E+05	1.12E+05	1.15E+05	1.48E+05
Xe-137	8.52E+04	7.32E+05	9.06E+04	7.62E+05
Xe-138	5.30E+05	2.48E+05	5.53E+05	2.85E+05
Ar-41	5.30E+05	1.61E+05	5.58E+05	1.97E+05

TABLE 7.1

GAMMA AND BETA DOSE FACTORS FOR SURRY POWER STATION

UNIT NOS. 1 AND 2

$X/Q = 1.0E-06\ sec/m^3$ at 644 meters S Direction

Dose Factors for Process Vent

Noble Gas Radionuclide	K_{ipv} Total Body mrem/yr / Curie/Sec	L_{ipv} Skin mrem/yr / Curie/Sec	M_{ipv} Gamma Air mrad/yr / Curie/sec	N_{ipv} Beta Air mrad/yr / Curie/sec
Kr-83m	7.56E-02	-	1.93E+01	2.88E+02
Kr-85m	1.17E+03	1.46E+03	1.23E+03	1.97E+03
Kr-85	1.61E+01	1.34E+03	1.72E+01	1.95E+03
Kr-87	5.92E+03	9.73E+03	6.17E+03	1.03E+02
Kr-88	1.47E+04	2.37E+03	1.52E+04	2.93E+03
Kr-89	1.66E+04	1.01E+04	1.73E+04	1.06E+04
Kr-90	1.56E+04	7.29E+03	1.63E+04	7.83E+03
Xe-131m	9.15E+01	4.76E+02	1.56E+02	1.11E+03
Xe-133m	2.51E+02	9.94E+02	3.27E+02	1.48E+03
Xe-133	2.94E+02	3.06E+02	3.53E+02	1.05E+03
Xe-135m	3.12E+03	7.11E+02	3.36E+03	7.39E+02
Xe-135	1.81E+03	1.86E+03	1.92E+03	2.46E+03
Xe-137	1.42E+03	1.22E+04	1.51E+03	1.27E+04
Xe-138	8.83E+03	4.13E+03	9.21E+03	4.75E+03
Ar-41	8.84E+03	2.69E+03	9.30E+03	3.28E+03

TABLE 7.2

INHALATION PATHWAY DOSE FACTORS FOR SURRY POWER STATION

UNIT NOS. 1 AND 2

Ventilation Vent X/Q = 6.0E-05 sec/m^3 at 499 Meters N Direction
Process Vent X/Q = 1.0E-06 sec/m^3 at 644 Meters S Direction

Radionuclide	P_{ivy} $\frac{\text{mrem/yr}}{\text{Curie/sec}}$	P_{ipy} $\frac{\text{mrem/yr}}{\text{Curie/sec}}$
H-3	6.75E+04	1.12E+03
Cr-51	5.13E+03	8.55E+01
Mn-54	ND	ND
Fe-59	ND	ND
Co-58	ND	ND
Co-60	ND	ND
Zn-65	ND	ND
Rb-86	ND	ND
Sr-89	ND	ND
Sr-90	ND	ND
Y-91	ND	ND
Zr-95	ND	ND
Nb-95	ND	ND
Ru-103	ND	ND
Ru-106	ND	ND
Ag-110m	ND	ND
Te-127m	3.64E+05	6.07E+03
Te-129m	3.80E+05	6.33E+03
Cs-134	ND	ND
Cs-136	ND	ND
Cs-137	ND	ND
Ba-140	ND	ND
Ce-141	ND	ND
Ce-144	ND	ND
I-131	9.75E+08	1.62E+07

ND - No data for dose factor according to R.G. 1.109, Rev. 1.

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SECTION 8

Noble Gas Effluent Air Dose Limits

1. TECHNICAL SPECIFICATION REQUIREMENT

Technical Specification 3.11.B.2.a requires that: "The air dose due to noble gases released in gaseous effluents, from each reactor unit, from the site to areas at and beyond site boundary (see Figure 5.1-1) shall be limited to the following:

(i) During any calendar quarter: Less than or equal to 5 mrads for gamma radiation and less than or equal to 10 mrads for beta radiation and,

(ii) During any calendar year: Less than or equal to 10 mrads for gamma radiation and less than or equal to 20 mrads for beta radiation.

2. CALCULATIONS

2.1 The air dose to areas at or beyond the site boundary due to noble gases shall be determined by the following:

For gamma radiation:

$$Dg = 3.17E-08 \sum_{i} [M_{ivv} \overline{Q}_{ivv} + M_{ipv} \overline{Q}_{ipv}]$$

For beta radiation:

$$Db = 3.17E-08 \sum_{i} [N_{ivv} \overline{Q}_{ivv} + N_{ipv} \overline{Q}_{ipv}]$$

where:

Subscripts = vv, refers to vent releases from the building ventilation vent;

pv, refers to the vent releases from the process vent;

i, refers to individual radionuclide;

Dg = the air dose for gamma radiation, in mrad;

Db = the air dose for beta radiation, in mrad;

M_{ivv}, M_{ipv} = the air dose factors for ventilation vent or process vent release due to gamma emissions for each identified noble gas radionuclide, i, in mrad/yr per Curie/sec. Factors are listed in Tables 7.0 and 7.1;

N_{ivv}, N_{ipv} = the air dose factor for ventilation vent or process vent release due to beta emissions for each identified noble gas radionuclide, i, in mrad/yr per Curie/sec. Factors are listed in Tables 7.0 and 7.1;

$\overline{Q}_{ivv}$, $\overline{Q}_{ipv}$ = the release for ventilation vent or process vent of noble gas radionuclide, i, in gaseous effluents for 31 days, quarter, or year as appropriate in Curies (per site);

3.17E-08 = the inverse of the number of seconds in a year.

2.2 All gaseous releases, not through the process vent, are considered ground level and shall be included in the determination of $\overline{Q}_{ivv}$.

3. EXAMPLE

3.1 Compilation of data from release records for the process vent for a quarter provides the following information:

Noble Gas Radionuclide	Activity Released (Curies)
Xe-133	6.25E+01
Xe-135	2.24E-01
Xe-131m	6.71E-02
Xe-133m	3.81E-02

3.2 Compilation of data from release records for the ventilation vents for a quarter provides the following information:

Noble Gas Radionuclide	Activity Released (Curies)
Xe-133	5.62E+02
Xe-135	2.02E+00
Xe-131m	6.04E-01
Xe-133m	3.43E-01

3.3 The air dose for gamma radiation is calculated from:

$$Dg = 3.17E\text{-}08 \; \Sigma \; [M_{ivv} \; \overline{Q}_{ivv} + M_{ipv} \; \overline{Q}_{ipv}]$$

The appropriate values of M_{ivv} and M_{ipv} shall be obtained from Tables 7.0 and 7.1.

Noble Gas Radionuclide	M_{ivv} (mrad/yr per Curie/sec)	x	$\overline{Q}_{ivv}$ (Curie)	=	$\frac{\text{(mrad-sec)}}{\text{yr}}$
Xe-133	2.12E+04	x	5.62E+02	=	1.19E+07
Xe-135	1.15E+05	x	2.02E+00	=	2.32E+05
Xe-131m	9.36E+03	x	6.04E-01	=	5.65E+03
Xe-133m	1.96E+04	x	3.43E-01	=	6.72E+03
			$\Sigma_i M_{ivv} \overline{Q}_{ivv}$	=	1.21E+07

Noble Gas Radionuclide	M_{ipv} (mrad/yr per Curie/sec)	x	$\bar{Q}_{ipv}$ (Curie)	=	$\frac{\text{(mrad-sec)}}{\text{yr}}$
Xe-133	3.53E+02	x	6.25E+01	=	2.21E+04
Xe-135	1.92E+03	x	2.24E-01	=	4.30E+02
Xe-131m	1.56E+02	x	6.71E-02	=	1.05E+01
Xe-133m	3.27E+02	x	3.81E-02	=	1.25E+01

$$\sum_i M_{ipv} \bar{Q}_{ipv} = 2.26\text{E+04}$$

$$Dg = 3.17\text{E-08} \left(\frac{\text{yr}}{\text{sec}}\right) \left[1.21\text{E+07} \left(\frac{\text{mrad-sec}}{\text{yr}}\right) + 2.26\text{E+04} \left(\frac{\text{mrad-sec}}{\text{yr}}\right) \right]$$

$$Dg = 3.84\text{E-01 mrad}$$

3.4 A similar approach could be taken to calculate Db.

SURRY POWER STATION

OFFSITE DOSE CALCULATION MANUAL

SECTION 9

Iodine - 131, Tritium, and Radionuclides in Particulate Form Gaseous Effluent Dose Limits

1. TECHNICAL SPECIFICATION REQUIREMENT

Technical Specification 3.11.B.3.a requires that: "The dose to the maximum exposed member of the public from all I-131, from tritium, and from all radionuclides in particulate form with half-lives greater than 8 days in gaseous effluents released, from each reactor unit, from the site to areas at and beyond the site boundary (see Figure 5.1-1) shall be limited to the following:

(i) During any calendar quarter: Less than or equal to 7.5 mrems to the critical organ, and

(ii) During any calendar year: Less than or equal to 15 mrems to the critical organ".

2. CALCULATION

2.1 The dose to the maximum exposed member of the public from iodine-131, from tritium, and from all radionuclides in particulate form with half-lives greater than 8 days in gaseous effluents from the site to areas at and beyond the site boundary shall be determined as follows:

$$Dr = 3.17E\text{-}08 \sum_i [(RM_{ivv} \tilde{Q}_{ivv} + RM_{ipv} \tilde{Q}_{ipv}) + (RI_{ivv} \tilde{Q}_{ivv} + RI_{ipv} \tilde{Q}_{ipv})]$$

where:

Subscripts = vv, refers to vent releases from the building ventilation vent;

pv, refers to the vent releases from the process vent;

Dr = the dose to the critical organ of the maximum exposed member of the public in mrem;

RM_{ivv}, RM_{ipv} = the milk pathway dose factor for ventilation vent or process vent release due to iodine-131, tritium, and from all radionuclides in particulate form with half-lives greater than 8 days, in mrem/yr per Curie/sec. Factors are listed in Table 9.0;

RI_{ivv}, RI_{ipv} = the inhalation pathway dose factor for ventilation vent or process vent release due to iodine-131, tritium, and from all radionuclides in particulate form with half-lives greater than 8 days, in mrem/yr per Curie/sec. Factors are listed in Table 9.1;

$\tilde{Q}_{ivv}$, $\tilde{Q}_{ipv}$ = the release for ventilation vent or process vent of iodine-131, tritium, and from all radionuclides in particulate form with half-lives greater than 8 days in Curies (per site);

3.17E-08 = the inverse of the number of seconds in a year.

2.2 All gaseous releases, not through process vent, are considered ground level and shall be included in the determination of $\tilde{Q}_{ivv}$.

3. EXAMPLE

3.1 Compilation of data from release records for the process vent for a quarter provides the following information:

Radionuclide	Activity Released (Curies)
I-131	7.20E-04
H-3	2.45E-01
Co-58	1.10E-06

3.2 Compilation of data from release records for the ventilation vent for a quarter provides the following information:

Radionuclide	Activity Released (Curies)
I-131	6.48E-03
H-3	2.21E+00
Co-58	9.90E-05

3.3 The dose to the critical organ of the maximum exposed member of the public is calculated from:

$$Dr = 3.17E\text{-}08 \sum_{i} [(RM_{ivv}\ \tilde{Q}_{ivv} + RM_{ipv}\ \tilde{Q}_{ipv}) + (RI_{ivv}\ \tilde{Q}_{ivv} + RI_{ipv}\ \tilde{Q}_{ipv})]$$

The appropriate values of RM_{ivv}, RM_{ipv}, RI_{ivv} and RI_{ipv} shall be obtained from Tables 9.0 and 9.1.

Radionuclide	RM_{ivv} (mrem/yr per Curie/sec)	x	$\tilde{Q}_{ivv}$ (Curies)	=	$\frac{\text{(mrem-sec)}}{\text{yr}}$
I-131	6.21E+08	x	6.48E-03	=	4.02E+06
H-3	7.20E+02	x	2.21E+00	=	1.59E+03
Co-58	-	x	9.90E-05	=	-
			$\sum_i RM_{ivv}\ \tilde{Q}_{ivv}$	=	4.02E+06

Due to lack of information, according to Regulatory Guide 1.109, Rev. 1, Co-58 is not included in these calculations.

Radionuclide	RM_{ipv} (mrem/yr per Curie/sec)	x	$\tilde{Q}_{ipv}$ (Curies)	=	$\frac{\text{(mrem-sec)}}{\text{yr}}$
I-131	2.97E+08	x	7.20E-04	=	2.14E+05
H-3	3.12E+02	x	2.45E-01	=	7.64E+01
Co-58	-	x	1.10E-06	=	-
			$\sum_i RM_{ipv}\ \tilde{Q}_{ipv}$	=	2.14E+05

Radionuclide	RI_{ivv} (mrem/yr per Curie/sec)	x	$\tilde{Q}_{ivv}$ (Curies)	=	$\frac{\text{(mrem-sec)}}{\text{yr}}$
I-131	4.45E+06	x	6.48E-03	=	2.88E+04
H-3	1.94E+02	x	2.21E+00	=	4.29E+02
Co-58	-	x	9.90E-05	=	-
			$\sum_{i} RI_{ivv} \tilde{Q}_{ivv}$	=	2.92E+04

Due to lack of information, according to Regulatory Guide 1.109, Rev. 1, Co-58 is not included in these calculations.

Radionuclide	RI_{ipv} (mrem/yr per Curie/sec)	x	$\tilde{Q}_{ipv}$ (Curies)	=	$\frac{\text{(mrem-sec)}}{\text{yr}}$
I-131	1.93E+06	x	7.20E-04	=	1.39E+03
H-3	8.41E+01	x	2.45E-01	=	2.06E+01
Co-58	-	x	1.10E-06	=	-
			$\sum_{i} RI_{ipv} \tilde{Q}_{ipv}$	=	1.41E+03

$$Dr = 3.17E{-}08\ [(4.02E{+}06 + 2.14E{+}05) + (2.92E{+}04 + 1.41E{+}03)]$$

$$Dr = 1.35E{-}01\ \text{(mrem)}$$

TABLE 9.0

CRITICAL PATHWAY DOSE FACTORS FOR SURRY POWER STATION

UNIT NOS. 1 AND 2

Ventilation Vent D/Q = 9.0E-10 m^{-2} at 5150 Meters S Direction

Process Vent D/Q = 4.3E-10 m^{-2} at 5150 Meters S Direction

Radionuclide	RM_{ivv} $\frac{mrem/yr}{Curie/sec}$	RM_{ipv} $\frac{mrem/yr}{Curie/sec}$
H-3	7.20E+02	3.12E+02
Mn-54	ND	ND
Fe-59	ND	ND
Co-58	ND	ND
Co-60	ND	ND
Zn-65	ND	ND
Rb-86	ND	ND
Sr-89	ND	ND
Sr-90	ND	ND
Y-91	ND	ND
Zr-95	ND	ND
Nb-95	ND	ND
Ru-103	ND	ND
Ru-106	ND	ND
Ag-110m	ND	ND
Te-127m	8.06E+04	3.85E+04
Te-129m	1.25E+05	5.98E+04
I-131	6.21E+08	2.97E+08
Cs-134	ND	ND
Cs-136	ND	ND
Cs-137	ND	ND
Ba-140	ND	ND
Ce-141	ND	ND
Ce-144	ND	ND

ND - No data for dose factor according to R.G. 1.109, Rev. 1.

TABLE 9.1

INHALATION PATHWAY DOSE FACTORS FOR SURRY POWER STATION

UNIT NOS. 1 AND 2

Ventilation Vent X/Q = 3.0E-07 sec/m^3 at 5150 Meters S Direction

Process Vent X/Q = 1.3E-07 sec/m^3 at 5150 Meters S Direction

Radionuclide	RI_{ivv} $\frac{mrem/yr}{Curie/sec}$	RI_{ipv} $\frac{mrem/yr}{Curie/sec}$
H-3	1.94E+02	8.41E+01
Cr-51	1.73E+01	7.48E+00
Mn-54	ND	ND
Fe-59	ND	ND
Co-58	ND	ND
Co-60	ND	ND
Zn-65	ND	ND
Rb-86	ND	ND
Sr-89	ND	ND
Sr-90	ND	ND
Y-91	ND	ND
Zr-95	ND	ND
Nb-95	ND	ND
Ru-103	ND	ND
Ru-106	ND	ND
Ag-110m	ND	ND
Te-127m	1.46E+03	6.33E+02
Te-129m	1.64E+03	7.12E+02
I-131	4.45E+06	1.93E+06
Cs-134	ND	ND
Cs-136	ND	ND
Cs-137	ND	ND
Ba-140	ND	ND
Ce-141	ND	ND
Ce-144	ND	ND

ND - No data for dose factor according to R.G. 1.109, Rev. 1.

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SECTION 10

Gaseous Effluent Dose Projections

1. TECHNICAL SPECIFICATION REQUIREMENT

Technical Specification 3.11.B.4.a requires that: "The Gaseous Radwaste Treatment System, and the Ventilation Exhaust Treatment System shall be used to reduce radioactive materials in gaseous waste prior to their discharge when the projected gaseous effluent air doses due to gaseous effluent releases, from each reactor unit, from the site to areas at or beyond the site boundary (see Figure 5.1-1) would exceed 0.2 mrad for gamma radiation and 0.4 mrad for beta radiation over 31 days. The Ventilation Exhaust Treatment System shall be used to reduce radioactive materials in gaseous waste prior to their discharge when the projected doses due to gaseous effluent releases, from each reactor unit, from the site to areas at and beyond the site boundary (see Figure 5.1-1) would exceed 0.3 mrem to the critical organ over 31 days".

2. PROJECTED GAMMA DOSE

2.1 Determine Dg = the 31 day gamma air dose in the previous 31 day period calculated according to H.P.-ODCM-8.

2.2 Estimate Rg = ratio of the volume of gaseous effluent in the present 31 day period to the volume released during the previous 31 day period.

2.3 Estimate Fg = ratio of the estimated noble gas effluent activity in the present 31 day period to the noble gas effluent activity during the previous 31 day period.

2.4 Determine PD_g = projected 31 day gamma air dose

$$PD_g = D_g \; (R_g \; F_g)$$

3. PROJECTED BETA DOSE

3.1 Determine D_b = the 31 day beta air dose in the previous 31 day period, calculated according to H.P.-ODCM-8.

3.2 Estimate R_g and F_g as in Steps 2.2 and 2.3 above.

3.3 Determine PD_b = projected 31 day period beta air dose

$$PD_b = D_b \; (R_g \; F_g)$$

4. PROJECTED MAXIMUM EXPOSED MEMBER OF THE PUBLIC DOSE

4.1 Determine D_{max} = the 31 day maximum exposed member of the public dose in the previous 31 day period, calculated according to H.P.-ODCM-9.

4.2 Estimate F_i = ratio of the estimated activity from I-131, radioactive materials in particulate form with half-lives greater than 8 days, and tritium in the present 31 day period to the activity of I-131, radioactive materials in particulate form with half-lives greater than 8 days, and tritium in the previous 31 day period.

4.3 Determine PD_{max} = projected 31 day maximum exposed member of the public dose.

$$PD_{max} = D_{max} (R_g F_i)$$

Historical data pertaining to the volumes and radioactive concentrations of gaseous effluents released in connection to specific station functions, such as containment purges, shall be used in the above estimates as appropriate.

5. EXAMPLE

5.1 Compilation of data from release records for the process vent in a 31 day period provides the following information:

Noble Gas Radionuclide	Activity Released (Curie)
Xe-133	2.08E+01
Xe-135	7.47E-02
Xe-131m	2.24E-02
Xe-133m	1.27E-02

5.2 Compilation of data from release records for the ventilation vents in a 31 day period provides the following information:

Noble Gas Radionuclide	Activity Released (Curie)
Xe-133	1.87E+02
Xe-135	6.73E-01
Xe-131m	2.01E-01
Xe-133m	1.14E-01

5.3 The air dose for gamma radiation is calculated according to H.P.-ODCM-8 from:

$$D_g = 3.17E\text{-}08 \sum_i [M_{ivv} \overline{Q}_{ivv} + M_{ipv} \overline{Q}_{ipv}]$$

The appropriate values of M_{ivv} and M_{ipv} are obtained from Tables 7.0 and 7.1.

Noble Gas Radionuclide	M_{ivv} (mrad/yr per Curie/sec)	x	$\overline{Q}_{ivv}$ (Curie)	=	$\frac{\text{(mrad-sec)}}{\text{yr}}$
Xe-133	2.12E+04	x	1.87E+02	=	3.96E+06
Xe-135	1.15E+05	x	6.73E-01	=	7.74E+04
Xe-131m	9.36E+03	x	2.01E-01	=	1.88E+03
Xe-133m	1.96E+04	x	1.14E-01	=	2.23E+03
			$\sum_i M_{ivv} \overline{Q}_{ivv}$	=	4.04E+06

Noble Gas Radionuclide	M_{ipv} (mrad/yr per Curie/sec)	x	$\overline{Q}_{ipv}$ (Curie)	=	$\frac{\text{(mrad-sec)}}{\text{yr}}$
Xe-133	3.53E+02	x	2.08E+01	=	7.34E+03
Xe-135	1.92E+03	x	7.47E-02	=	1.43E+02
Xe-131m	1.56E+02	x	2.24E-02	=	3.49E+00
Xe-133m	3.27E+02	x	1.27E-02	=	4.15E+00
			$\sum_i M_{ipv}\,\overline{Q}_{ipv}$	=	7.49E+03

$$Dg = 3.17\text{E-}08 \left(\frac{\text{yr}}{\text{sec}}\right) \left[\, 4.04\text{E+}06 \left(\frac{\text{mrad-sec}}{\text{yr}}\right) + 7.49\text{E+}03 \left(\frac{\text{mrad-sec}}{\text{yr}}\right) \right]$$

Dg = 1.28E-01 mrad

5.4 Total volume of gaseous effluent released in 31 day period is:

$$\left[\begin{array}{c}\text{31 day average flow}\\ \text{rate (CFM) for}\\ \text{process vent}\end{array} + \begin{array}{c}\text{31 day average flow rate}\\ \text{(CFM) for ventilation}\\ \text{vent}\end{array}\right] \times 4.46\text{E+}04\ \frac{\text{min}}{\text{31 day}}$$

Total Volume (ft^3) = (295 CFM + 120,000 CFM) x 4.46E+04

Total Volume (ft^3) = 5.37E+09

Estimated total volume in 31 day period = 4.46E+09 (ft^3)

$$\text{Therefore, } Rg = \frac{4.46\text{E+}09}{5.37\text{E+}09} = 0.83$$

5.5 The total activity released in 31 day period is:

31 day process vent total activity (Curies) + 31 day ventilation vent A + B total activity (Curies)

Total activity released = (2.09E+01 Curies + 1.88E+02 Curies)

Total activity released = 2.09E+02 Curies

Estimated total activity released = 2.50E+02 Curies

$$\text{Therefore, } Fg = \frac{2.50\text{E+}02}{2.09\text{E+}02} = 1.20$$

5.6 The projected 31 day gamma air dose is:

$$PD_g' = D_g\ (Rg\ Fg)$$

PD_g = 1.28E-01 mrad x 0.83 x 1.20

PD_g = 1.27E-01 mrad

SURRY POWER STATION

OFFSITE DOSE CALCULATION MANUAL

SECTION 11

Total Dose

1. TECHNICAL SPECIFICATION REQUIREMENT

Technical Specification 3.11.C.1 requires that: "The annual (calendar year) dose or dose commitment to the maximum exposed member of the public, due to releases of radioactivity and radiation, from uranium fuel cycle sources shall be limited to less than or equal to 25 mrems to the total body or critical organ (except the thyroid, which shall be limited to less than or equal to 75 mrems)".

2. CALCULATION

Cumulative dose contributions from liquid and gaseous effluents shall be determined in accordance with the methodology presented in H.P.-ODCM Sections 4, 8, 9, or Regulatory Guide 1.109, Rev. 1 (see Appendix B).

If the dose to the maximum exposed member of the public exceeds twice the limits of Specifications 3.11.A.2, 3.11.B.2, or 3.11.B.3, the dose commitment shall include the contribution from direct radiation. Direct radiation shall be determined from an evaluation of environmental TLD's or calculated using the simple methodology presented in Lamarsh, Introduction to Nuclear Engineering, June 1977, or point kernal computer codes such as QAD.

SURRY POWER STATION

OFFSITE DOSE CALCULATION MANUAL

SECTION 12

Semiannual Radioactive Effluent Release Report Dose Assessment

1. TECHNICAL SPECIFICATION REQUIREMENT

Technical Specification 6.9.1.12 requires that the Semiannual Radioactive Release Report submitted within 60 days after January 1 of each year include, in part, an assessment of the radiation doses to individuals due to the radioactive liquid and gaseous effluents from the station during the previous calendar year, and an assessment of the radiation doses to the maximum exposed member of the public from reactor releases and radiation.

2. DOSE ASSESSMENT

1. The radiation doses to individuals due to the radioactive liquid and gaseous effluents from the station during the previous calendar year shall be calculated using the methodology presented in this Manual or in Regulatory Guide 1.109 (Revision 1), October 1977, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10CFR Part 50, Appendix I" (see Appendix B). Population doses are not to be included in the dose assessment.

2. The dose to the maximum exposed member of the public due to the radioactive liquid and gaseous effluents from the station shall be incorporated with the dose assessment performed above. If the dose to the maximum exposed member of the public exceeds twice the limits of Specifications 3.11.A.2, 3.11.B.2 or 3.11.B.3, the dose assessment shall include the contribution from direct radiation. U.S. Nuclear Regulatory Commission NUREG-0543, February 1980, "Methods for Demonstrating LWR Compliance With the EPA Uranium Fuel Cycle Standard (40CFR Part 190)", states "There is reasonable assurance that sites with up to four operating reactors that have releases within Appendix I design objective values are also in conformance with the EPA Uranium Fuel Cycle Standard, 40CFR Part 190".

3. The meteorological conditions during the previous calendar year or historical annual average atmospheric dispersion conditions shall be used for determining the gaseous pathway doses.

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OFFSITE DOSE CALCULATION MANUAL

SECTION 13

Radiological Environmental Monitoring Locations

1.0 LAND BASED SAMPLES

Particulate and Charcoal Air Samples

Hog Island Reserve (HIR) -	Route 650 to Hog Island Reserve, end of dirt road of reserve. On Vepco pole on right side of road.
Bacon's Castle (BC) -	50 yards back on Rt. 617 from intersection of Rt. 617 and Rt. 10 on Vepco pole near Addison's Grocery #2.
Alliance (ALL) -	Route 10 to Route 634 north; 1.4 miles on Vepco pole on right side of road.
Colonial Parkway (CP) -	Take Route 31 from James River Ferry, Jamestown, to Route 359. Take Colonial Parkway for approx. 2.9 miles; sampler on right side of road on Vepco pole.
Dow Chemical -	Route 60 east to Dow Chemical Road at Badische Corp. sign. Follow road parallel to railroad tracks. At first curve in road, turn left at substation. Air sampler inside substation.
Fort Eustis (FE) -	Route 60 east to Fort Eustis entrance road. Straight to circle, first right out of circle onto Lee Blvd. Left on Harrison Road to stop sign; continue on Harrison Road to small railroad house on left. Vepco pole by this house on left.
Newport News (N.N.) -	Route 60 east (Warwick Blvd.) to 34th Street. Left on 34th Street, one block to Jefferson Avenue, left on Jefferson Avenue. Sampler inside Vepco substation.
Surry Station (SS) -	On roof inside station gate on top of storeroom area Unit #1 side.

Environmental TLD's

Control - (00)	Control TLD located in shield in count room.
Surry Station - (01)	See air sample location - Surry Power Station
West North West - (02)	Located on the center, rear fence of the sewage treatment plant.
Station Discharge - (03)	End of discharge structure.

Environmental TLD's (cont'd)

North North West - (04)	Take dirt road on left, on the north side of discharge canal. At the end of the road, walk through the gate and TLD will be located on a pine tree.
North - (05)	Prior to entrance to Hog Island Game Reserve, located on Vepco property sign, on left side of Route 650.
North North East - (06)	Take the second dirt road to the construction site, prior to the intersection of the other construction site roadway, TLD is located on a tree.
North East - (07)	Located on the northern property line, approx. 1250 feet from Route 650. TLD is attached to a Vepco property sign.
East North East - (08)	Located on the northern property line, approx. 2500 feet from Route 650. TLD is located on Vepco property sign.
East (exclusion) - (09)	Located on a telephone pole on the back corner of the Vepco construction project parking lot.
West - (10)	Located on Vepco property sign approx. 1600 feet from Route 650.
West South West - (11)	Located on telephone pole approx. 800 feet from Route 650.
South West - (12)	Located on a telephone pole, on Route 650, at the curve in road.
South South West - (13)	Located on a telephone pole on Route 650.
South - (14)	Take road to warehouse off of Route 650. TLD located on first telephone pole on the right.
South South East - (15)	Drive to the primary meteorological tower. Walk toward Vepco property line and turn right. TLD is located on a telephone pole, approx. 600 feet.
South East - (16)	Drive to the primary meteorological tower. Walk toward Vepco property line and turn left. TLD located on telephone pole, approx. 1000 feet.
East - (17)	TLD located behind the low level radwaste storage facility. Contact the environmentalists to obtain sample.

Environmental TLD's (cont'd)

Station Intake - (18)	Located at loading pier. TLD on loading dock boom.
Hog Island Reserve - (19)	See Air Sampler Location (HIR).
Bacon's Castle - (20)	See Air Sampler Location (BC).
Route 633 - (21)	Route 10 west to Route 633 north, approx. 2.0 miles on Vepco pole on right side of road.
Alliance - (22)	See Air Sampler Location (ALL).
Surry - (23)	On Route 10 west one block prior to reaching caution light at intersection of Route 10 and Route 31 in town of Surry. On Vepco pole on left side of road.
Route 636 & 637 - (24)	Route 10 to Route 634 north, approx. 1.5 miles take left on Route 636, approx. 2 miles to Route 637. On Vepco pole on left side of road approx. 50 yards past Cobham Wharf Road (Rt. 636) and Route 637 junction.
Scotland Wharf - (25)	Route 10 to Route 31 north toward toll ferry. On Vepco pole on left side of road, left of the ferry toll collection booth.
Jamestown - (26)	Take ferry from Scotland Wharf to Jamestown. On Vepco pole on left side of road, left of the toll collection booth.
Colonial Parkway - (27)	See Air Sampler Location (CP).
Route 617 & 618 - (28)	Route 31 from ferry on Jamestown side to Route 359 to Colonial Parkway. Parkway toward Williamsburg approx. 3.0 miles turn left into Smith dairy, turn left past house. Take road between out-buildings, (dirt road) to hard surface road. Take right on hard surface road, approx. 1.3 miles to intersection of Routes 617 and 618. On Vepco pole on right side of road, at intersection.
Kingsmill - (29)	Route 31 from ferry on Jamestown side to Route 359 to Colonial Parkway. Approx. 0.40 miles on Colonial Parkway after crossing College Creek Bridge and before crossing Halfway Creek Bridge. On large pine tree on right side of road.

Environmental TLD's (cont'd)

Williamsburg - (30)	On Colonial Parkway follow signs to Williamsburg information center. Turn into entrance road to information center. Approx. 30 yards from entrance on Vepco pole on right side of road.
Kingsmill North - (31)	Route 199 to Mounts Bay Road (entrance to Kingsmill on the James), past guard house on Southall Road to first left on Peyton Road, take left again on Peyton Road to house #109. In backyard on pine tree.
Budweiser - (32)	Route 199 to Route 60 east to stoplight at Busch Brewery. Take left at light into plant. TLD on tree directly in front of the plant.
Water Plant - (33)	Route 60 east past Busch Gardens to Ron Springs Drive take right on Ron Springs Drive to gate of water treatment plant. On Vepco pole on right side of road at gate of water treatment plant.
DOW - (34)	See Air Sampler Location (DOW).
Lee Hall - (35)	Route 60 east to Lee Hall Village. On Vepco pole on right side of road across from Lee Hall train station.
Goose Island - (36)	Route 60 east to Fort Eustis entrance road. Right into Fort Eustis then straight past guard building to circle. First right out of circle on Lee Blvd. until dead end in a parking lot at harbor. On Vepco pole on right side of parking lot.
Fort Eustis - (37)	See Air Sampler Location (FE).
Newport News - (38)	See Air Sampler Location (NN).
Control, James River Bridge - (39)	Route 17 across bridge to Isle of Wight side. Turn right behind state building after exiting bridge. On Vepco pole behind state building.
Control, Benn's Church - (40)	At Benn's Church on Vepco pole toward rear of church on exit road near Route 258.
Smithfield - (41)	Route 10 and Route 258 intersection on west side of town. A stoplight near Little's Supermarket. On Vepco pole at intersection.

Environmental TLD's (cont'd)

Rushmere - (42)	Route 676 to Route 686 (bear right). First road to left into Rushmere Shores, take left on dirt road prior to reaching waterfront homes. Go to first intersection, on Vepco pole at corner of intersection on dirt road.
Route 628 - (43)	Route 10 to Route 676 to left on Route 628. On Vepco pole under first power line crossing on right side of road.

Milk Samples

Judkins Dairy -	Approx. 2.0 miles from intersection of Route 10 and Route 617. First dairy on left side of road.
Colonial Parkway (Smith) Dairy -	Route 31 from James River Ferry, Jamestown, to Route 359 to Colonial Parkway. Approx. 3.0 miles on Colonial Parkway first dairy on left side of road.
William's Dairy -	Eleven miles from light at Benn's Church take right on Route 634 (Kings Fork Road), approx. 2.0 miles to Route 460, across Route 460, approx. 1.5 miles on right side of road.
Epps Dairy - State Split - State Collects -	Route 617 to Route 10, left on Route 10 approx. 400 yards on left side of road.
Lee Hall (Ross) Dairy - State Split - State Collects -	Route 60 east to Lee Hall Village. On left side of road prior to reaching Lee Hall train station.

Well Water WW

Hog Island Reserve -	See air sampler location (HIR). Sample from faucet at nearest out-building by air sampler.
Bacon's Castle -	See air sampler location (BC). Sample from faucet at Addison's Grocery #2 at intersection of Route 10 and Route 617.
Jamestown -	See Jamestown TLD location. Sample from pump in picnic area.

Well Water (cont'd)

Surry Station - Surry Power Station on Route 650. Sample from faucet in Environmental Science Building behind south annex.

Surface Water SW

Chippokes Creek - Route 10 to Route 633 to Route 634 left to first bridge. Take sample at bridge.

Williamsburg, Waller Mill Reservoir - Colonial Parkway past visitors information center. Follow signs to I-64 (Route 132 to Route 143 north). On Route 143 north turn left under sign that reads "Richmond". Follow road that runs parallel to I-64 past school exit road, past school entrance road, left at next road, past Waller Mill Park entrance to reservoir on right next to road. Sample from reservoir.

Newport News Reservoir - Route 60 to Fort Eustis Blvd. (exit road from Fort Eustis). Past Fort Eustis approx. 0.5 mile to bridge crossing reservoir. Sample from reservoir.

Smithfield Reservoir - Route 10 to Route 258 west, right on Route 709 approx. 2.0 miles to reservoir on left side of road. Take sample from reservoir.

Crop Samples

In Bacon's Castle area, usually from Slade's farm on Route 650 approx. 2.0 miles from intersection of Route 650 and Route 617 toward Surry Power Station and/or from Brock's farm near intersection for Route 650 and Route 617.

2.0 RIVER BASED SAMPLES

River Water Samples W

Chicahominy River - obain sample from the mouth of Chicahominy River.

Surry Station Discharge

Hog Island Point

Surry Station Intake

Newport News - sample obtained downstream of the mouth of Warwick River.

Silt Samples D

Chicahominy River - mouth of the Chicahominy River.

Surry Station Discharge

Hog Island Point

Point of Shoals

Newport News

Clam C

Chicahominy River

Jamestown

Surry Station Discharge

Hog Island Point

Lawnes Creek

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SECTION 14

Interlaboratory Comparison Program

1. TECHNICAL SPECIFICATION REQUIREMENT

Technical Specification 3.11.D.3.a requires that: "Analyses shall be performed on radioactive materials (which contain nuclides produced at nuclear power stations) supplied as part of an Interlaboratory Comparison Program that has been approved by the Commission. The Interlaboratory Comparison Program is described in the ODCM".

2. PROGRAM

In order to comply with the above Technical Specification, analyses are performed as part of the EPA's Environmental Radioactivity Laboratory Intercomparison Studies (Cross-Check) Program.

Participation includes the following analyses:

Program	Cross-Check Of:
Milk	I-131, Cs-137, Ba-140, K, Sr-89, -90
Water	Gross Beta Gamma: Co-60, Ru-106, Cs-134, I-131, Cs-137, Cr-51, Zn-65 I-131 H-3 (Tritium) Sr-89, 90 Blind - any combination of above radionuclides.
Air Filter	Gross Beta Cs-137, Sr-90

3. RESULTS

Results will be reported in the Radiological Environmental Monitoring Report.

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Appendix A

	Section	Date
A1.	Meteorological Analysis	
A2.	Liquid Pathway Analysis	
A3.	Gaseous Pathway Analysis	

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OFFSITE DOSE CALCULATION MANUAL

Section A1 Meteorological Analysis

1. PURPOSE

The purpose of the meteorological analysis was to determine the annual average X/Q and D/Q values at critical locations around the station for ventilation vent (ground level) and process vent (mixed mode) releases. The annual average X/Q and D/Q values were used in performing a dose pathway analysis to determine both the maximum exposed individual at site boundary and member of the public. The X/Q and D/Q values resulting in the maximum exposures were incorporated into the dose factors in Tables 7.0, 7.1, 7.2, and 9.0.

2. METEOROLOGICAL DATA, PARAMETERS, AND METHODOLOGY

Onsite meteorological data for the period January 1, 1979, through December 31, 1981, was used in calculations. This data included windspeed, wind direction, and differential temperature for the purpose of determining joint frequency distributions for those releases characterized as ground level (i.e. ventilation vent), and those characterized as mixed mode (i.e. process vent). The portions of release characterized as ground level were based on $\Delta T_{158.9ft-28.2ft}$ and 28.2 foot wind data, and the portions characterized as mixed mode were based on $\Delta T_{158.9ft-28.2ft}$ and 158.9ft wind data.

X/Q's and D/Q's were calculated using the NRC computer code "XOQDOQ - Program for the Meteorological Evaluation of Routine Effluent Releases at Nuclear Power Stations", September, 1977. The code is based upon a straight line airflow model implementing the assumptions outlined in Section C (excluding C1a and C1b) of Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light - Water - Cooled Reactors".

The open terrain adjustment factors were applied to the X/Q values as recommended in Regulatory Guide 1.111. The site region is characterized flat terrain such that open terrain correction factors are considered appropriate. The ground level ventilation vent release calculations included a building wake correction based on a 1516m^2 containment minimum cross-sectional area. The effective release height used in mixed mode release calculations was based on a process vent release height of 131 ft, and plume rise due to momentum for a vent diameter of 3 in. with plume exit velocity of 100 ft/sec. Ventilation vent, and vent releases other than from the process vent, are considered ground level as specified in Regulatory Guide 1.111 for release points less than the height of adjacent solid structures. Terrain elevations were obtained from Surry Power Station Units 1 and 2 Virginia Electric and Power Company Updated Final Safety Analysis Report Table 11A-11.

X/Q and D/Q values were calculated for the nearest site boundary, resident, milk cow, and vegetable garden by sector for process vent and ventilation vent releases at distances specified from North Anna Power Station Annual Environmental Survey Data for 1981. X/Q values were also calculated for the nearest discharge canal bank for process and ventilation vent releases.

According to the definition for short term in NUREG-0133, "Preparation of Radiological Effluent Technical Specifications for Nuclear Power Stations", October, 1978, some gaseous releases may fit this category, primarily waste gas decay tank releases and containment purges. However, these releases are considered long term for dose calculations as past releases were both random in time of day and duration as evidenced by reviewing past release reports. Therefore, the use of annual average concentrations is appropriate according to NUREG-0133.

The X/Q and D/Q values calculated from 1979, 1980, 1981 meteorological data are comparable to the values presented in the North Anna Power Station UFSAR.

3. RESULTS

The X/Q value that resulted in the maximum total body, skin, and inhalation exposure for ventilation vent releases was 6.0E-05 sec/m^3 at a site boundary location 499 meters N sector. For process vent releases, the site boundary X/Q value was 1.0E-06 sec/m^3 at a location 644 meters S sector. The discharge canal bank X/Q value that resulted in the maximum inhalation exposure for ventilation vent releases was 7.8E-05 sec/m^3 at a location 290 meters NW sector. The discharge canal bank X/Q value for process vent was 1.6E-06 sec/m^3 at a location 290 meters NW sector.

Pathway analysis indicated that the maximum exposure from iodine-131, and from all radionuclides in particulate form with half-lives greater than 8 days was through the grass-cow-milk pathway. The D/Q value from ventilation vent releases resulting in the maximum exposure was 9.0E-10 per m^2 at a location 5150 meters S sector. For process vent releases, the D/Q value was 4.3E-10 per m^2 at a location 5150 meters S sector. For tritium, the X/Q value from ventilation vent releases resulting in the maximum exposure for the milk pathway was 3.0E-07 sec/m^3, and 1.3E-07 sec/m^3 for process vent releases at a location 5150 meters S sector. The inhalation pathway is the only other pathway existing at this location. Therefore, the X/Q values given for tritium also apply for the inhalation pathway.

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SECTION A2 Liquid Pathway Analysis

1. PURPOSE

The purpose of the liquid pathway analysis was to determine the maximum exposed member of the public in unrestricted areas as a result of radioactive liquid effluent releases. The analysis includes a determination of the most restrictive liquid pathway, most restrictive age group, and the critical organ. This analysis is required for Technical Specification 3.11.A.

2. DATA, PARAMETERS, AND METHODOLOGY

Radioactive liquid effluent release data for the years 1976, 1977, 1978, 1979, 1980, and 1981 was compiled from the Surry Power Station effluent release reports. The data for each year, along with appropriate site specific parameters and default selected parameters, was entered into the NRC computer code LADTAP as described in NUREG-0133, "Preparation of Radiological Effluent Technical Specifications for Nuclear Power Plants", October 1978.

Liquid radioactive effluents from both units are released to the James River via the discharge canal. Possible pathways of exposure for release from the station include ingestion of fish and invertebrates and shoreline activities. The irragated food pathway and potable water pathway do not exist at this location. Access to the discharge canal by the general public is gained two ways: access for bank fishing is controlled by the station and is limited to Vepco employees or guests of Vepco employees, and boating access is open to the public as far upstream as the inshore end of the discharge canal groin. It has been estimated that boat sport fishing would be performed a maximum of 800 hours per year, and that bank fishing would be performed a maximum of 160 hours per year.

For an individual fishing in the discharge canal, no river dilution was assumed for the fish pathway. For an individual located beyond the discharge canal groins, a river dilution factor of 5 was assumed as appropriate according to Regulatory Guide 1.109, Rev. 1, and the fish, invertebrate, and shoreline pathways were considered to exist. Dose factors, bioaccumulation factors, and shorewidth factors given in Regulatory Guide 1.109, Rev. 1, and in LADTAP were used, as were usage terms for shoreline activities and ingestion of fish and invertebrates. The dose to an individual fishing on the discharge bank was determined by multiplying the annual dose calculated with GASPAR by the fractional year the individual spent fishing in the canal.

3. RESULTS

For the years 1976, 1977, 1979, 1980, and 1981, the invertebrate pathway resulted in the largest dose. In 1978 the fish pathway resulted in the largest dose. The maximum exposed member of the public was determined to utilize the James River. The critical age group was the adult and the critical organ was either the thyroid or GI-LLI. The ingestion dose factor, A_i, in HP-ODCM-4 includes the fish and invertebrate pathways. A_i dose factors were calculated for the total body, thyroid, and GI-LLI organs.

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Section A3 Gaseous Pathway Analysis

1. PURPOSE

A gaseous effluent pathway analysis was performed to determine the location that would result in the maximum doses due to noble gases for use in demonstrating compliance with Technical Specifications 3.11.B.1.a and 3.11.B.2.a. The analysis also included a determination of the location, pathway, and critical organ, of the maximum exposed member of the public, as a result of the release of iodine-131, tritium, and for all radionuclides in particulate form with half-lives greater than 8 days for use in demonstrating compliance with Technical Specifications 3.11.B.3.a. In addition, the analysis includes the determination of the critical organ, maximum age group, and sector location of an exposed individual through the inhalation pathway from iodine-131, tritium, and particulates for use in demonstrating compliance with Technical Specification 3.11.B.1.a.

2. DATA, PARAMETERS, AND METHODOLOGY

Annual average X/Q values were calculated, as described in ODCM-A1, for the nearest site boundary in each directional sector and at other critical locations accessible to the public inside site boundary. The largest X/Q value was determined to be 6.0E-05 sec/m^3 at site boundary for ventilation vent releases at a location 499 meters N direction, and 1.0E-06 sec/m^3 at site boundary for process vent releases at a location 644 meters S direction. The maximum doses to total body and skin, and air doses for gamma and beta radiation due to noble gases would be at these site boundary locations. The doses from both release points are summed in ODCM calculations to calculate total maximum dose.

Technical Specification 3.11.B.1.a(ii) dose limits apply specifically to the inhalation pathway. Therefore, the locations and X/Q values determined for maximum noble gas doses can be used to determine the maximum dose from iodine-131, tritium, and for all radionuclides in particulate form with half-lives greater than 8 days for the inhalation pathway.

The NRC computer code GASPAR, "Evaluation of Atmospheric Releases", Revised 8/19/77, was run using 1976, 1977, 1978, 1979, 1980, and 1981 Surry Power Station gaseous effluent release report data. Doses from iodine-131, tritium, and particulates for the inhalation pathway were calculated using the 6.0E-05 sec/m^3 site boundary X/Q. Except for the source term data and the X/Q value, computer code default parameters were used. The results for each year indicated that the critical age group was the child and the critical organ was the thyroid for the inhalation pathway. In 1979, the teen was the critical age group. However, the dose calculated for the teen was only slightly greater than for the child and the doses could be considered equivalent.

The gamma and beta dose factors K_{ivv}, L_{ivv}, M_{ivv}, and N_{ivv} in HP-ODCM-Table 7.0 were obtained by performing a units conversion of the appropriate dose factors from Table B-1, Regulatory Guide 1.109, Rev. 1, to mrem/yr per Ci/m^3 or mrad/yr per Ci/m^3, and multiplying by the ventilation vent site boundary X/Q value of 6.0E-05 sec/m^3. The same approach was used in calculating the gamma and beta dose factors K_{ipv}, L_{ipv}, M_{ipv}, and N_{ipv} in HP-ODCM-Table 7.1 using the process vent site boundary X/Q value of 1.0E-06 sec/m^3.

The inhalation pathway dose factors P_{ivv} and P_{ipv} in HP-ODCM-Table 7.2 were calculated using the following equation:

$$P_i = K' \text{ (BR) } DFA_i \text{ (X/Q) (mrem/yr per Curie/sec)}$$

where,

K' = a constant of unit conversion, 1E+12 pCi/Ci;

BR = the breathing rate of the child age group, 3700 m^3/yr, from Table E-5, Regulatory Guide 1.109, Rev. 1;

DFA_i = the thyroid organ inhalation dose factor for child age group for the ith radionuclide, in mrem/pCi, from Table E-9, Regulatory Guide 1.109, Rev. 1;

X/Q = the ventilation vent site boundary X/Q, 6.0E-05 sec/m^3, or the process vent site boundary X/Q, 1.0E-06 sec/m^3 as appropriate.

Technical Specification 3.11.B.3.a requires that the dose to the maximum exposed member of the public from iodine-131, tritium, and from all radionuclides in particulate form with half-lives greater 8 days be less than or equal to the specified limits. Dose calculations were performed for an exposed member of the public within site boundary unrestricted areas, discharge canal bank, and to an exposed member of the public beyond site boundary at real residences with the largest X/Q values using the NRC computer code GASPAR. Doses to members of the public were also calculated for the vegetable garden, meat animal, and milk-cow pathways with the largest D/Q values using the NRC computer code GASPAR.

It was determined that the member of the public within site boundary would be using the discharge canal bank for fishing a maximum of 160 hours per year. The maximum annual X/Q at this location was determined to be 7.8E-05 sec/m^3 at 290 meters NW direction. After applying a correction for the fractional part of year an individual would be fishing at this location, the dose was calculated to be less than an individual would receive at site boundary.

The member of the public receiving the largest dose beyond site boundary was determined to be located 5150 meters S sector. The critical pathway was the grass-cow-milk, the maximum age group was the infant, and the critical organ the thyroid. For each year 1976, 1977, 1978, 1979, 1980 and 1981 the dose to the infant from the grass-cow-milk pathway was greater than the dose to the member of the public within site boundary, nearest residence, vegetable or meat pathways. Therefore, the maximum exposed member of the public was determined to be the infant, exposed through the grass-cow-milk pathway, critical organ thyroid, at a location 5150 meters S sector. The only other pathway existing at this location for the infant is the inhalation.

The RM_{ivv} and RM_{ipv} dose factors, except for tritium, in HP-ODCM-Table 9.0 were calculated by multiplying the appropriate D/Q value with the following equation:

$$RM_i' = K' \frac{Q_F \, (U_{ap})}{\lambda_i + \lambda_w} \; F_m \, (r) \, (DFL_i) \left[\frac{fpfs}{Y_p} + \frac{(1-fpfs)e^{-\lambda_i t_h}}{Y_s} \right] e^{-\lambda_i t_f}$$

where,

K' = a constant of unit conversion, 1E+12 pCi/Ci;

Q_F = the cow's consumption rate, 50, in Kg/day (wet weight);

U_{ap} = the infant milk consumption rate, 330, liters/yr;

Y_p = the agricultural productivity by unit area of pasture feed grass, 0.7, Kg/m^2;

Y_s = the agricultural productivity by unit area of stored feed, 2.0, in Kg/m^2;

F_m = the stable element transfer coefficients, from Table E-1, Regulatory Guide 1.109, Rev. 1;

r = fraction of deposited activity retained on cow's feed grass, 1.0 for radioiodine, and 0.2 for particulates;

DFL_i = the thyroid ingestion dose factor for the ith radionuclide for the infant, in mrem/pCi, from Table E-14, Regulatory Guide 1.109, Rev. 1;

λ_i = the decay constant for the ith radionuclide, in sec^{-1};

λ_w = the decay constant for removal of activity on leaf and plant surfaces by weathering, 5.73E-07 sec^{-1} (corresponding to a 14 day half-life);

t_f = the transport time from pasture to cow, to milk, to receptor, 1.73E+05, in sec;

t_h = the transport time from pasture, to harvest, to cow, to milk, to receptor, 7.78E+06, in sec;

f_p = fraction of the year that the cow is on pasture, 0.67 (dimensionless), 8 months per year from NUREG-0597;

f_s = fraction of the cow feed that is pasture grass while the cow is on pasture, 1.0 (dimensionless).

Parameters used in the above equation were obtained from NUREG-0133 and Regulatory Guide 1.109, Rev. 1.

Since the concentration of tritium in milk is based on the airborne concentration rather than the deposition, the following equation is used:

$$R_{H-3} = K' \, K''' \, F_m \, Q_F \, U_{ap} \, (DFL_{H-3}) \, [0.75(0.5/H)] \times \bar{X}/Q$$

where,

K''' = a constant of unit conversion, 1E+03 gm/kg;

H = absolute humidity of the atmosphere, 8.0, gm/m^3;

0.75 = the fraction of total feed that is water;

0.5 = the ratio of the specific activity of the feed grass to the atmospheric water;

X/Q = the annual average concentration at a location 5150 meters S sector, 3.0E-07 sec/m^3 for ventilation vent releases, and 1.3E-07 sec/m^3 for the process vent releases.

Other parameters have been previously defined.

The inhalation pathway dose factors RI_{ivv} and RI_{ipv} in HP-ODCM-Table 9.1 were calculated using the following equation:

$$RI_i = K' (BR) DFA_i (X/Q) \text{ (mrem/yr per Curie/sec)}$$

where,

K' = a constant of unit conversion, 1E+12 pCi/Ci;

BR = the breathing rate of the infant age group, 1400 m^3/yr, from Table E-5, Regulatory Guide 1.109, Rev. 1;

DFA_i = the thyroid organ inhalation dose factor for infant age group for the ith radionuclide, in mrem/pCi, from Table E-10, Regulatory Guide 1.109, Rev. 1;

X/Q = the ventilation vent X/Q, 3.0E-07 sec/m^3, or the process vent site boundary X/Q, 1.3E-07 sec/m^3, at a location 5150 meters S sector.

The GASPAR computer runs using 1976, 1977, 1978, 1979, 1980 and 1981 Surry effluent release data were reviewed to determine the percent of total dose from the cow milk and inhalation pathways for I-133. I-133 contributed less than 1% of the total dose to an infant's thyroid except for the year 1977 when the percent I-133 was 1.77. The calculations indicate that I-133 is a negligible dose contributer and it's inclusion in a sampling and analysis program, and dose calculations is unnecessary.

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APPENDIX B

Revision 1*
October 1977

U.S. NUCLEAR REGULATORY COMMISSION
REGULATORY GUIDE
OFFICE OF STANDARDS DEVELOPMENT

REGULATORY GUIDE 1.109

CALCULATION OF ANNUAL DOSES TO MAN FROM ROUTINE RELEASES OF REACTOR EFFLUENTS FOR THE PURPOSE OF EVALUATING COMPLIANCE WITH 10 CFR PART 50, APPENDIX I

USNRC REGULATORY GUIDES

Regulatory Guides are issued to describe and make available to the public methods acceptable to the NRC staff of implementing specific parts of the Commission's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide guidance to applicants. Regulatory Guides are not substitutes for regulations, and compliance with them is not required. Methods and solutions different from those set out in the guides will be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the Commission.

Comments and suggestions for improvements in these guides are encouraged at all times, and guides will be revised, as appropriate, to accommodate comments and to reflect new information or experience. This guide was revised as a result of substantive comments received from the public and additional staff review.

Comments should be sent to the Secretary of the Commission, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, Attention: Docketing and Service Branch.

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*The substantial number of changes in this revision has made it impractical to indicate the changes with lines in the margin.

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A. INTRODUCTION

Appendix I, "Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion 'As Low As Is Reasonably Achievable' for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents," to 10 CFR Part 50 provides numerical guidance for radioactive effluent design objectives and technical specification requirements for limiting conditions of operation for light-water-cooled nuclear power plants.

To implement Appendix I, the NRC staff has developed a series of guides that provide methods acceptable to the staff for the calculation of preoperational estimates of effluent releases, dispersion of the effluent in the atmosphere and different water bodies, and estimation of the associated radiation doses* to man. This guide describes basic features of these calculational models and suggests parameters for the estimation of radiation doses to man from effluent releases. The methods used herein are general approaches that the NRC staff has developed for application in lieu of specific parameters for individual sites. The use of site-specific values by the applicant is encouraged. However, the assumptions and methods used to obtain these parameters should be fully described and documented.

Portions of this guide supersede Regulatory Guide 1.42, Revision 1, "Interim Licensing Policy on as Low as Practicable for Gaseous Radioiodine Releases from Light-Water-Cooled Nuclear Power Reactors," which has been withdrawn.

B. DISCUSSION

Appendix I to 10 CFR Part 50 provides guidance on the doses to members of the general public resulting from effluent releases that may be considered to be as low as is reasonably achievable. This guide describes basic features of the calculational models and assumptions in use by the NRC staff for the estimation of doses.

Appendix A of this guide describes suggested models and assumptions for calculating the estimated doses to man from discharges to the hydrosphere. Appendix B of this guide describes suggested models and assumptions for calculating doses from noble gases discharged to the atmosphere, and Appendix C gives models and assumptions for estimating doses from radioiodines and other radionuclides released to the atmosphere. Appendix D describes the models and assumptions for calculating population doses (man-rem and man-thyroid-rem) from radionuclide releases to the atmosphere and hydrosphere. Appendix E presents tabular data pertaining to two or more of the other appendices. Appendix F provides a discussion of, and derivation for, the I function used in computing gamma doses from elevated noble gas releases.

In providing guidance for implementing Section II of Appendix I, the NRC staff has made use of the maximum exposed individual approach. In this approach the numerical design objectives of Section II are compared to the calculated radiation exposures to maximum individuals in each of four age groups.

The population is considered to be made up of infants (0 to 1 year), children (1 to 11 years), teenagers (11 to 17 years), and adults (17 years and older). For the purpose of evaluating dose commitment, the maximum infant is assumed to be newborn, the maximum child is taken to be 4 years old, the maximum teenager is taken to be 14 years old, and the maximum adult is taken to be 17 years old.

Maximum individuals are characterized as "maximum" with regard to food consumption, occupancy, and other usage of the region in the vicinity of the plant site and as such represent individuals with habits representing reasonable deviations from the average for the population in general. In all physiological and metabolic respects the maximum exposed individuals are assumed to have those characteristics that represent the averages for their corresponding age group in the general

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*In this guide, the term "dose," when applied to individuals, is used instead of the more precise term "dose equivalent," as defined by the International Commission on Radiological Units and Measurements (ICRU). When applied to the evaluation of internal deposition of radioactivity, the term "dose," as used here, includes the prospective dose component arising from retention in the body beyond the period of environmental exposure, *i.e.*, the dose commitment. The dose commitment is evaluated over a period of 50 years.

population. Although specific individuals will almost certainly display dietary, recreational, and other living habits considerably different from those suggested here, and actual physiological and metabolic parameters may vary considerably, the NRC staff considers the maximum exposed individual to be a well-defined reference for implementation of Section II of Appendix I. The characterization of maximum exposed individuals is subject to continuing review by the NRC staff, and the applicant is encouraged to use information and data applicable to a specific region or site when possible. Where site-specific information and data is used, its justification should be documented for the NRC staff's review.

Since the radiation dose commitment per unit intake of a given radionuclide usually varies as a function of age, four sets of internal dose conversion factors have been calculated. These dose factors are appropriate for the four different age groups defined above. Specifically, these dose factors are based on continuous intake over a one-year environmental exposure period and an associated dose commitment extending over a 50-year period from initiation of intake.

The models and assumptions described in Appendices A, B, C, and D of this guide are acceptable to the NRC staff for calculating doses to individuals and populations. If other models are selected, they should include the same exposure pathways considered in the models described in this guide. The assumptions and methods used should be fully described and documented.

As discussed in Section III.A.2 of Appendix I to 10 CFR Part 50, the applicant may take into account any real phenomena or actual exposure conditions. Such conditions could include actual values for agricultural productivity, dietary habits, residence times, dose attenuation by structures, measured environmental transport factors (such as bioaccumulation factors), or similar values actually determined for a specific site. The applicant should provide enough information on the measurements or other methods used to derive these substitute values to enable the NRC staff to evaluate their validity.

C. REGULATORY POSITION

Equations are provided below by which the NRC staff will estimate radiation exposure for maximum individuals and the population within 50 miles. These equations are appropriate for the exposure pathways that the staff routinely considers in its evaluations. In addition, other exposure pathways that may arise due to unique conditions at a specific site should be considered if they are likely to provide a significant contribution to the total dose. A pathway is considered significant if a conservative evaluation yields an additional dose increment equal to or more than 10 percent of the total from all pathways considered in this guide.

1. Doses from Liquid Effluent Pathways

The NRC staff will calculate radiation doses from potable water, aquatic food, shoreline deposits, and irrigated food pathways by using the following equations, which are described in detail in Appendix A of this guide.

a. Potable Water

$$R_{apj} = 1100 \frac{U_{ap}M_p}{F} \sum_i Q_i D_{aipj} \exp(-\lambda_i t_p) \tag{1}$$

b. Aquatic Foods

$$R_{apj} = 1100 \frac{U_{ap}M_p}{F} \sum_i Q_i B_{ip} D_{aipj} \exp(-\lambda_i t_p) \tag{2}$$

c. Shoreline Deposits

$$R_{apj} = 110{,}000 \frac{U_{ap}M_p W}{F} \sum_i Q_i T_i D_{aipj} [\exp(-\lambda_i t_p)][1 - \exp(-\lambda_i t_b)] \tag{3}$$

d. **Irrigated Foods**

For all radionuclides except tritium:

$$R_{apj} = U_{ap}^{veg} \sum_i d_i \exp(-\lambda_i t_h) D_{aipj} \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{f_I B_{iv} [1 - \exp(-\lambda_i t_b)]}{P \lambda_i} \right]$$

$$+ U_{ap}^{animal} \sum_i F_{iA} D_{aipj} \left\{ Q_F d_i \exp(-\lambda_i t_h) \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} \right.\right.$$

$$\left.\left. + \frac{f_I B_{iv} [1 - \exp(-\lambda_i t_b)]}{P \lambda_I} \right] + C_{iAw} Q_{Aw} \right\} \qquad (4)$$

For tritium:

$$R_{apj} = U_{ap}^{veg} C_v D_{apj} + U_{ap}^{animal} D_{apj} F_A (C_v Q_F + C_{Aw} Q_{Aw}) \qquad (5)$$

where

B_{ip}	is the equilibrium bioaccumulation factor for nuclide i in pathway p, expressed as the ratio of the concentration in biota (in pCi/kg) to the radionuclide concentration in water (in pCi/liter), in liters/kg;
B_{iv}	is the concentration factor for uptake of radionuclide i from soil by edible parts of crops, in pCi/kg (wet weight) per pCi/kg dry soil;
C_{iAw}	is the concentration of radionuclide i in water consumed by animals, in pCi/liter;
C_{iv}	is the concentration of radionuclide i in vegetation, in pCi/kg;
D_{aipj}	is the dose factor, specific to a given age group a, radionuclide i, pathway p, and organ j, which can be used to calculate the radiation dose from an intake of a radionuclide, in mrem/pCi, or from exposure to a given concentration of a radionuclide in sediment, expressed as a ratio of the dose rate (in mrem/hr) and the areal radionuclide concentration (in pCi/m^2);
d_i	is the deposition rate of nuclide i, in pCi/m^2 per hr;
F	is the flow rate of the liquid effluent, in ft^3/sec;
f_I	is the fraction of the year crops are irrigated, dimensionless;
F_{iA}	is the stable element transfer coefficient that relates the daily intake rate by an animal to the concentration in an edible portion of animal product, in pCi/liter (milk) per pCi/day or pCi/kg (animal product) per pCi/day;
M_p	is the mixing ratio (reciprocal of the dilution factor) at the point of exposure (or the point of withdrawal of drinking water or point of harvest of aquatic food), dimensionless;
P	is the effective "surface density" for soil, in kg(dry soil)/m^2;
Q_{Aw}	is the consumption rate of contaminated water by an animal, in liters/day;
Q_F	is the consumption rate of contaminated feed or forage by an animal, in kg/day (wet weight);
Q_i	is the release rate of nuclide i, in Ci/yr;
r	is the fraction of deposited activity retained on crops, dimensionless;
R_{apj}	is the total annual dose to organ j of individuals of age group a from all of the nuclides i in pathway p, in mrem/yr;

t_b	is the period of time for which sediment or soil is exposed to the contaminated water, in hours;
t_e	is the time period that crops are exposed to contamination during the growing season, in hours;
t_h	is a holdup time that represents the time interval between harvest and consumption of the food, in hours;
T_i	is the radioactive half life of nuclide i, in days;
t_p	is the average transit time required for nuclides to reach the point of exposure. For internal dose, t_p is the total time elapsed between release of the nuclides and ingestion of food or water, in hours;
U_{ap}	is a usage factor that specifies the exposure time or intake rate for an individual of age group a associated with pathway p, in hr/yr, ℓ/yr, or kg/yr;
W	is the shoreline width factor, dimensionless;
Y_v	is the agricultural productivity (yield), in kg(wet weight)/m^2;
λ_{Ei}	is the effective removal rate constant for radionuclide i from crops, in hr^{-1}, where $\lambda_{Ei} = \lambda_i + \lambda_w$, λ_i is the radioactive decay constant, and λ_w is the removal rate constant for physical loss by weathering (see Appendix E, Table E-15);
λ_i	is the radioactive decay constant of nuclide i, in hr^{-1};
1100	is the factor to convert from (Ci/yr)/(ft^3/sec) to pCi/liter; and
110,000	is the factor to convert from (Ci/yr)/(ft^3/sec) to pCi/liter and to account for the proportionality constant used in the sediment radioactivity model.

These equations yield the dose rates to various organs of individuals from the exposure pathways mentioned above. Appendix I of 10 CFR Part 50 requires that the annual doses or dose commitments to the total body or any organ of any individual from the sum of the exposure pathways from liquid effluents associated with each reactor should not exceed 3 mrem and 10 mrem, respectively.

2. Gamma and Beta Doses from Noble Gases Discharged to the Atmosphere

The NRC staff will calculate radiation doses from noble gases using the following equations from Appendix B of this guide. Atmospheric dispersion models are found in Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion for Gaseous Effluents on Routine Releases from Light-Water-Cooled Reactors."

a. Annual Gamma Air Dose from Noble Gas Releases from Free-Standing Stacks More Than 80 Meters High

$$D^{\gamma}(r,\theta) = \frac{260}{r(\Delta\theta)} \sum_n \frac{1}{u_n} \sum_s f_{ns} \sum_k \mu_a(E_k)\, E_k I(H,u,s,\sigma_z,E_k) \sum_i Q_{ni}^{D} A_{ki} \qquad (6)$$

where

A_{ki}	is the photon yield for gamma-ray photons in energy group k from the decay of radionuclide i, in photons/disintegration;
$D^{\gamma}(r,\theta)$	is the annual gamma air dose at a distance r (meters) in the sector at angle θ, in mrad/yr;
E_k	is the energy of the kth photon energy group, in MeV/photon;

f_{ns}	is the joint frequency of occurrence of stability class s and wind speed class n for sector θ, dimensionless;
$I(H,u,s,\sigma_z,E_k)$	is the dimensionless numerical integration constant accounting for the distribution of radioactivity according to meteorological conditions of wind speed (u) and atmospheric stability (s) which in part determine the effective stack height (H) and the vertical plume standard deviation (σ_z). In addition, I is a function of the photon energy E_k and is $I = I_1 + kI_2$ as formulated in Slade (Appendix B, Reference 1);
Q_{ni}^D	is the release rate of radionuclide i, corrected for decay during transit to the distance r under wind speed u_n, in Ci/yr;
u_n	is the mean wind speed of wind speed class n, in m/sec;
$\Delta\theta$	is the sector width over which atmospheric conditions are averaged, in radians;
$\mu_a(E_k)$	is the air energy absorption coefficient for the kth photon energy group, in m^{-1}; and
260	is the conversion factor to obtain $D^\gamma(r,\theta)$, in mrad/yr, and has the units of mrad-radians-m^3-disintegration/sec-MeV-Ci.

b. Annual Gamma Air Dose from All Other Noble Gas Releases; Annual Beta Air Dose from All Noble Gas Releases

$$D^\gamma(r,\theta) \text{ or } D^\beta(r,\theta) = 3.17 \times 10^4 \sum_i Q_i[\chi/Q]^D(r,\theta)(DF_i^\gamma \text{ or } DF_i^\beta) \qquad (7)$$

where

DF_i^γ, DF_i^β	are the gamma and beta air dose factors for a uniform semi-infinite cloud of radionuclide i, in mrad-m^3/pCi-yr;
$D^\gamma(r,\theta)$ or $D^\beta(r,\theta)$	are the annual gamma and beta air doses at the distance r in the sector at angle θ from the discharge point, in mrad/yr;
Q_i	is the release rate of the radionuclide i, in Ci/yr;
$[\chi/Q]^D(r,\theta)$	is the annual average gaseous dispersion factor (corrected for radioactive decay) at the distance r in sector θ in sec/m^3 (see Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors," for methods to estimate χ/Q); and
3.17×10^4	is the number of pCi per Ci divided by the number of seconds per year.

c. Annual Total Body Dose from Noble Gas Releases from Free-Standing Stacks More Than 80 Meters High

$$D^T(r,\theta) = 1.11\, S_F \sum_k D_k^\gamma(r,\theta)\exp[-\mu_a^T(E_k)t_d] \qquad (8)$$

where

$D^T(r,\theta)$	is the annual total body dose at the distance r in sector θ, in mrem/yr;
$D_k^\gamma(r,\theta)$	is the annual gamma air dose associated with the kth photon energy group at the distance r in sector θ, in mrad/yr;

S_F is the attenuation factor that accounts for the dose reduction due to shielding provided by residential structures, dimensionless;

t_d is the product of tissue density and depth used to determine a total body dose, in g/cm^2;

$\mu_a^T(E_k)$ is the tissue energy absorption coefficient, in cm^2/g; and

1.11 is the average ratio of tissue to air energy absorption coefficients.

d. Annual Skin Dose from Noble Gas Releases from Free-Standing Stacks More Than 80 Meters High

$$D^S(r,\theta) = 1.11 S_F D^\gamma(r,\theta) + 3.17 \times 10^4 \sum_i Q_i[\chi/Q]^D(r,\theta)DFS_i \qquad (9)$$

where

DFS_i is the beta skin dose factor for a semi-infinite cloud of radionuclide i, which includes the attenuation by the outer "dead" layer of the skin, in mrem-m^3/pCi-yr; and

$D^S(r,\theta)$ is the annual skin dose at the distance r in sector θ, in mrem/yr.

All other parameters are as defined in preceding paragraphs.

e. Annual Total Body Dose from All Other Noble Gas Releases

$$D_\infty^T(r,\theta) = S_F \sum_i \chi_i(r,\theta)DFB_i \qquad (10)$$

where

DFB_i is the total body dose factor for a semi-infinite cloud of the radionuclide i, which includes the attenuation of 5 g/cm^2 of tissue, in mrem-m^3/pCi-yr;

$D_\infty^T(r,\theta)$ is the annual total body dose due to immersion in a semi-infinite cloud at the distance r in sector θ, in mrem/yr; and

$\chi_i(r,\theta)$ is the annual average ground-level concentration of radionuclide i at the distance r in sector θ, in pCi/m^3.

All other parameters are as defined above.

f. Annual Skin Dose from All Other Noble Gas Releases

$$D_\infty^S(r,\theta) = 1.11\, S_F \sum_i \chi_i(r,\theta)DF_i^\gamma + \sum_i \chi_i(r,\theta)DFS_i \qquad (11)$$

where

$D_\infty^S(r,\theta)$ is the annual skin dose due to immersion in a semi-infinite cloud at the distance r in sector θ, in mrem/yr.

All other parameters are as defined above.

3. Doses from Radioiodines and Other Radionuclides* Released to the Atmosphere

The NRC staff will calculate radiation doses from radioiodines and other radionuclides released to the atmosphere using the following equations from Appendix C of this guide.

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*Not including noble gases.

a. Annual Organ Dose from External Irradiation from Radionuclides Deposited onto the Ground Surface

$$D_j^G(r,\theta) = 8760\, S_F \sum_i C_i^G(r,\theta) DFG_{ij} \qquad (12)$$

where

$C_i^G(r,\theta)$	is the ground plane concentration of radionuclide i at distance r in sector θ, in pCi/m^2;
DFG_{ij}	is the open field ground plane dose conversion factor for organ j from radionuclide i, in $mrem\text{-}m^2/pCi\text{-}hr$;
$D_j^G(r,\theta)$	is the annual dose to the organ j at location (r,θ), in mrem/yr;
S_F	is a shielding factor that accounts for the dose reduction due to shielding provided by residential structures during occupancy, dimensionless; and
8760	is the number of hours in a year.

b. Annual Organ Dose from Inhalation of Radionuclides in Air

$$D_{ja}^A(r,\theta) = R_a \sum_i \chi_i(r,\theta) DFA_{ija} \qquad (13)$$

where

$D_{ja}^A(r,\theta)$	is the annual dose to organ j of an individual in the age group a at location (r,θ) due to inhalation, in mrem/yr;
DFA_{ija}	is the inhalation dose factor for radionuclide i, organ j, and age group a, in mrem/pCi;
R_a	is the annual air intake for individuals in the age group a, in m^3/yr; and
$\chi_i(r,\theta)$	is the annual average concentration of radionuclide i in air at location (r,θ), in pCi/m^3.

c. Annual Organ Dose from Ingestion of Atmospherically Released Radionuclides in Food

$$D_{ja}^D(r,\theta) = \sum_i DFI_{ija}\left[U_a^v f_g C_i^v(r,\theta) + U_a^m C_i^m(r,\theta) + U_a^F C_i^F(r,\theta) + U_a^L f_\ell C_i^L(r,\theta)\right] \qquad (14)$$

where

$C_i^v(r,\theta)$, $C_i^m(r,\theta)$, $C_i^L(r,\theta)$, $C_i^F(r,\theta)$	are the concentrations of radionuclide i in produce (non-leafy-vegetables, fruits, and grains), milk, leafy vegetables, and meat, respectively, at location (r, θ), in pCi/kg or pCi/ℓ;
$D_{ja}^D(r,\theta)$	is the annual dose to the organ j of an individual in age group a from ingestion of produce, milk, leafy vegetables, and meat at location (r,θ), in mrem/yr;
DFI_{ija}	is the ingestion dose factor for radionuclide i, organ j, and age group a, in mrem/pCi;
f_g, f_ℓ	are the respective fractions of the ingestion rates of produce and leafy vegetables that are produced in the garden of interest; and
U_a^v, U_a^m, U_a^F, U_a^L	are the annual intake (usage) of produce, milk, meat, and leafy vegetables, respectively, for individuals in the age group a, in kg/yr or ℓ/yr (equivalent to U_{ap}).

4. Integrated Doses to the Population

The NRC staff will calculate integrated doses to the local population from all pathways discussed in Sections C.1, 2, and 3. Because of the various conditions under which the equations in Appendix D are used, they are not presented in this section. It is recommended that Appendix D be read for a detailed discussion of the staff's models.

5. Summary of Staff Position

A brief summary of the staff position on methods of evaluating compliance with the numerical guides for design objectives of Appendix I is presented in Table 1. Methods of evaluating compliance with the cost-benefit provisions of Appendix I are addressed in Regulatory Guide 1.110, "Cost-Benefit Analysis for Radwaste Systems for Light-Water-Cooled Nuclear Power Reactors."

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for utilizing this regulatory guide.

This guide reflects current Nuclear Regulatory Commission practice. Therefore, except in those cases in which the license applicant or licensee proposes an acceptable alternative method, the method described herein for complying with specified portions of the Commission's regulations is being and will continue to be used in the evaluation of submittals for operating license or construction permit applications until the guide is revised as a result of suggestions from the public or additional staff review.

TABLE 1

SUMMARY OF STAFF POSITION - METHODS OF EVALUATING COMPLIANCE WITH APPENDIX I

TYPE OF DOSE	APPENDIX I* DESIGN OBJECTIVES	RM-50-2 DESIGN OBJECTIVES*	POINT OF DOSE EVALUATION	EQUATIONS TO BE USED
Liquid Effluents				
Dose to total body from all pathways	3 mrem/yr per unit	5 mrem/yr per site	Location of the highest dose offsite.**	1, 2, 3, 4, & 5.
Dose to any organ from all pathways	10 mrem/yr per unit	5 mrem/yr per site	Same as above.	1, 2, 3, 4, & 5
Non-tritium releases	- - - -	5 Ci/yr per unit	- - - -	- - - -
Gaseous Effluents* **				
Gamma dose in air	10 mrad/yr per unit	10 mrad/yr per site	Location of the highest dose offsite.+	6 or 7, as appropriate
Beta dose in air	20 mrad/yr per unit	20 mrad/yr per site	Same as above.	7
Dose to total body of an individual	5 mrem/yr per unit	5 mrem/yr per site	Location of the highest dose offsite.**	8 or 10, as appropriate
Dose to skin of an individual	15 mrem/yr per unit	15 mrem/yr per site	Same as above.	9 or 11, as appropriate

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See footnotes at end of table, on following page.

TABLE 1 (Continued)

SUMMARY OF STAFF POSITION -
METHODS OF EVALUATING COMPLIANCE WITH APPENDIX I

TYPE OF DOSE	APPENDIX I* DESIGN OBJECTIVES	RM-50-2 DESIGN OBJECTIVES*	POINT OF DOSE EVALUATION	EQUATIONS TO BE USED
Radioiodines and Particulates†† Released to the Atmosphere				
Dose to any organ from all pathways	15 mrem/yr per unit	15 mrem/yr per site	Location of the highest dose offsite.†††	12, 13, & 14
I-131 releases	- - - -	1 Ci/yr per unit	- - - -	- - - -

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*Evaluated for a maximum individual, as described in Section B of this guide.

**Evaluated at a location that is anticipated to be occupied during plant lifetime or evaluated with respect to such potential land and water usage and food pathways as could actually exist during the term of plant operation.

***Calculated only for noble gases.

†Evaluated at a location that could be occupied during the term of plant operation.

††Doses due to carbon-14 and tritium intake from terrestrial food chains are included in this category.

†††Evaluated at a location where an exposure pathway and dose receptor actually exist at the time of licensing. However, if the applicant determines design objectives with respect to radioactive iodine on the basis of existing conditions and if potential changes in land and water usage and food pathways could result in exposures in excess of the guideline values given above, the applicant should provide reasonable assurance that a monitoring and surveillance program will be performed to determine: (1) the quantities of radioactive iodine actually released to the atmosphere and deposited relative to those estimated in the determination of design objectives; (2) whether changes in land and water usage and food pathways which would result in individual exposures greater than originally estimated have occurred; and (3) the content of radioactive iodine in foods involved in the changes, if and when they occur.

APPENDIX A

METHODS FOR CALCULATING DOSES TO MAN FROM LIQUID EFFLUENT PATHWAYS

The equations for estimating radiation exposure to man from four principal exposure pathways in the aquatic environment (potable water, aquatic foods, shoreline deposits, and irrigated foods) are listed in Section C, "Regulatory Position," of this guide.

1. Generalized Equation for Calculating Radiation Dose via Liquid Pathways

Equation (A-1) is the generalized equation for calculating the radiation dose to man via liquid effluent pathways.

$$R_{aipj} = C_{ip} U_{ap} D_{aipj} \tag{A-1}$$

where

C_{ip} is the concentration of nuclide i in the media of pathway p, in pCi/ℓ, pCi/kg, or pCi/m^2;

D_{aipj} is the dose factor, specific to age group a, radionuclide i, pathway p, and organ j. It represents the dose due to the intake of a radionuclide, in mrem/pCi, or from exposure to a given concentration of a radionuclide in sediment, in mrem per hr/pCi per m^2;

R_{aipj} is the annual dose to organ j of an individual of age group a from nuclide i via pathway p, in mrem/yr; and

U_{ap} is the exposure time or intake rate (usage) associated with pathway p for age group a, in hr/yr, ℓ/yr or kg/yr (as appropriate).

The three factors making up Equation (A-1) are discussed in the following sections, most of which were taken directly from the WASH-1258 report (Ref. 1). (An updated version of the portion of the WASH-1258 report describing models and computer programs is contained in the BNWL-1754 report (Ref. 2).)

a. Radionuclide Concentration in Environmental Media (C_{ip})

The concentrations in environmental media of interest can be estimated from the mixing ratio M_p, the discharge flow F, the radionuclide release rate Q_i, and other terms presented in the pathway equations that appear later in this discussion.

b. Usage (U_{ap})

The second term of Equation (A-1) is the usage term U_{ap}. Usage is expressed as a consumption rate in kg/yr or liters/yr or as an exposure time in hr/yr, as appropriate for the pathway and age group under consideration.

The NRC staff encourages the use of site-specific data, whenever possible. Such data should be documented. In the absence of site-specific data, however, the usage values (consumption rates and exposure times) presented in Appendix E, Table E-5, are recommended.

c. Dose Factor (D_{aipj})

Dose factors for internal exposure via ingestion are provided in Appendix E, Tables E-11, 12, 13, and 14. Appendix E also provides further discussion of the data, models, and assumptions used.

Material deposited from sedimentation in an aquatic system represents a fairly large, nearly uniform thin sheet of contamination. The factors for converting surface contamination given in pCi/m^2 to the dose rate at one meter above a uniformly contaminated plane have been described by Soldat and others (Refs. 3 and 4). Dose factors for exposure to soil sediment have units of mrem/hr per pCi/m^2 and are presented in Appendix E, Table E-6.

2. Equations for Liquid Pathways

This section develops the equations required for the liquid pathway models. The principal difference between pathways is the manner in which the radionuclide concentrations are calculated. The doses from the four pathways should be added to determine the total dose.

a. Potable Water

The annual dose from ingestion of water is calculated from Equation (A-2) below:

$$R_{apj} = 1100 \frac{M_p U_{ap}}{F} \sum_i Q_i D_{aipj} \exp(-\lambda_i t_p) \qquad \text{(A-2)}$$

Symbols for this equation were defined earlier, in Section C.1 of this guide.

The summation process adds the dose contribution from each nuclide to yield the total dose for the pathway-organ combination selected. The expression $(1100\ Q_i M_p/F)\exp(-\lambda_i t_p)$ yields the concentration of nuclide i at the time the water is consumed, in pCi/ℓ. This concentration is the term C_{ip} in Equation (A-1). As a minimum, the transit time t_p may be set equal to 12 hours to allow for radionuclide transport through the water purification plant and the water distribution system (Ref. 5). The transit time should be increased as appropriate to allow for travel from the point of effluent release to the water purification plant intake. Credit may be taken for radionuclide removal by water purification processes using techniques such as those outlined in Reference 3.

It should be noted that, depending on the hydrological dispersion model employed, the mixing ratio, M_p, or dilution factor may not be explicitly defined. In those instances (e.g., buildup of activity in a cooling pond), the relative concentration in the mixed stream (compared to the effluent concentration) may be supplied as a function of the radiological decay constant, with any potential effluent recycling taken into account. Suggested hydrological dispersion models are presented in Regulatory Guide 1.113, "Estimating Aquatic Dispersion of Effluents from Accidental and Routine Reactor Releases for the Purpose of Implementing Appendix I."

b. Aquatic Foods

The concentrations of radionuclides in aquatic foods are assumed to be directly related to the concentrations of the nuclides in water. Equilibrium ratios between the two concentrations, called bioaccumulation factors in this guide, can be found in the literature (Ref. 6). The inclusion of the bioaccumulation factor B_{ip} in Equation (A-2) yields Equation (A-3), which is suitable for calculating the internal dose from consumption of aquatic foods.

$$R_{apj} = 1100 \frac{U_{ap} M_p}{F} \sum_i Q_i B_{ip} D_{aipj} \exp(-\lambda_i t_p) \qquad \text{(A-3)}$$

Values of B_{ip} are given in Table A-1; the other parameters have been previously defined. The methodology presented in Reference 7 for the development of site-specific freshwater bioaccumulation factors is considered to be acceptable by the NRC staff.

The transit time t_p may be set equal to 24 hours* to allow for radionuclide decay during transit through the food chain, as well as during food preparation.

c. Dose from Shoreline Deposits

The calculation of individual dose from shoreline deposits is complex since it involves estimation of sediment load, transport, and concentrations of radionuclides associated with

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*Here, and in a number of other instances, the NRC staff has found it necessary to set forth guidance as to a parameter value in the absence of empirical data. In such instances judgments have been made after considering values assumed by others and model sensitivity to the parameter value in question. In this particular instance, the total body dose from fish ingestion, for a typical situation, was found to vary by less than a factor of two for a range of environmental transit times of from one to seven days.

TABLE A-1

BIOACCUMULATION FACTORS TO BE USED IN THE ABSENCE OF SITE-SPECIFIC DATA

(pCi/kg per pCi/liter)*

	FRESHWATER		SALTWATER	
ELEMENT	FISH	INVERTEBRATE	FISH	INVERTEBRATE
H	9.0E-01	9.0E-01	9.0E-01	9.3E-01
C	4.6E 03	9.1E 03	1.8E 03	1.4E 03
NA	1.0E 02	2.0E 02	6.7E-02	1.9E-01
P	1.0E 05	2.0E 04	2.9E 04	3.0E 04
CR	2.0E 02	2.0E 03	4.0E 02	2.0E 03
MN	4.0E 02	9.0E 04	5.5E 02	4.0E 02
FE	1.0E 02	3.2E 03	3.0E 03	2.0E 04
CO	5.0E 01	2.0E 02	1.0E 02	1.0E 03
NI	1.0E 02	1.0E 02	1.0E 02	2.5E 02
CU	5.0E 01	4.0E 02	6.7E 02	1.7E 03
ZN	2.0E 03	1.0E 04	2.0E 03	5.0E 04
BR	4.2E 02	3.3E 02	1.5E-02	3.1E 00
RB	2.0E 03	1.0E 03	8.3E 00	1.7E 01
SR	3.0E 01	1.0E 02	2.0E 00	2.0E 01
Y	2.5E 01	1.0E 03	2.5E 01	1.0E 03
ZR	3.3E 00	6.7E 00	2.0E 02	8.0E 01
NB	3.0E 04	1.0E 02	3.0E 04	1.0E 02
MO	1.0E 01	1.0E 01	1.0E 01	1.0E 01
TC	1.5E 01	5.0E 00	1.0E 01	5.0E 01
RU	1.0E 01	3.0E 02	3.0E 00	1.0E 03
RH	1.0E 01	3.0E 02	1.0E 01	2.0E 03
TE**	4.0E 02	6.1E 03	1.0E 01	1.0E 02
I	1.5E 01	5.0E 00	1.0E 01	5.0E 01
CS	2.0E 03	1.0E 03***	4.0E 01	2.5E 01
BA	4.0E 00	2.0E 02	1.0E 01	1.0E 02
LA	2.5E 01	1.0E 03	2.5E 01	1.0E 03
CE	1.0E 00	1.0E 03	1.0E 01	6.0E 02
PR	2.5E 01	1.0E 03	2.5E 01	1.0E 03
ND	2.5E 01	1.0E 03	2.5E 01	1.0E 03
W	1.2E 03	1.0E 01	3.0E 01	3.0E 01
NP	1.0E 01	4.0E 02	1.0E 01	1.0E 01

---

*Values in Table A-1 are taken from Reference 6 unless otherwise indicated.

**Data taken from Reference 8.

***Data taken from Reference 7.

suspended and deposited materials. One method of approaching this problem was presented in the Year 2000 Study (Ref. 3). Based on this model, an estimate of the radionuclide concentration in shoreline sediments can be obtained from the following expression:

$$C_{is} = K_c \frac{C_{iw}[1 - \exp(-\lambda_i t_b)]}{\lambda_i} \qquad \text{(A-4)}$$

where

C_{is} is the concentration of nuclide i in sediment, in pCi/kg;

C_{iw} is the concentration of nuclide i in water adjacent to the sediment, in pCi/liter;

K_c is an assumed transfer constant from water to sediment, in liters/kg per hr;

t_b is the length of time the sediment is exposed to the contaminated water, nominally 15 years (approximate midpoint of facility operating life), in hours; and

λ_i is the decay constant* of nuclide i, in hours^{-1}. In the original evaluation of the equation, λ_i was chosen to be the radiological decay constant. The true value should include an as yet unknown "environmental" removal constant.

The value of K_c was derived for several radionuclides by using data from water and sediment samples collected over a period of several years in the Columbia River between Richland, Washington, and the river mouth and in Tillamook Bay, Oregon, 75 km south of the river mouth (Refs. 9 and 10). Since the primary use of the equation is to facilitate estimates of the exposure rate from gamma emitters one meter above the sediment, an effective surface contamination was estimated. This surface contamination was assumed to be contained within the top 2.5 cm (1 in.) of sediment (with a mass of 40 kg/m^2 of surface). The dose contribution from the radionuclides at depths below 2.5 cm was ignored. The resulting equation is

$$S_i = 100 T_i C_{iw} W[1 - \exp(-\lambda_i t_b)] \qquad \text{(A-5)}$$

where

S_i is the "effective" surface contamination, in pCi/m^2, that is used in subsequent calculations;

T_i is the radiological half-life of nuclide i, in days;

W is a shore-width factor that describes the geometry of the exposure; and

100 is equal to $[K_c(\ell/\text{kg-hr})*40(\text{kg/m}^2)*24(\text{hr/day})/0.693]$, in ℓ/m^2-day.

Shore-width factors were derived from experimental data (Ref. 11) and are summarized in Table A-2. They represent the fraction of the dose from an infinite plane source that is estimated for these shoreline situations.

The combination of Equations (A-4) and (A-5) into the general Equation (A-1) leads to Equation (A-6) below for calculation of radiation dose from exposure to shoreline sediments.

$$R_{apj} = U_{ap} \sum_i S_i D_{aipj} = 100\, U_{ap} W \sum_i C_{iw} T_i D_{aipj} [1 - \exp(-\lambda_i t_b)] \qquad \text{(A-6)}$$

As in the development of Equation (A-2), the expression $(1100\, Q_i\, M_p/F)\exp(-\lambda_i t_p)$ may be substituted for C_{iw}. This results in the following relationship:

$$R_{apj} = 110{,}000 \frac{U_{ap} M_p W}{F} \sum_i Q_i T_i D_{aipj} [\exp(-\lambda_i t_p)][1 - \exp(-\lambda_i t_b)] \qquad \text{(A-7)}$$

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*If the presence of a radionuclide in water and sediment is controlled primarily by radioactive equilibrium with its parent nuclide, the water concentration and decay constant of the parent should be used in Equations (A-4) and (A-5).

TABLE A-2

SHORE-WIDTH FACTORS FOR USE IN EQUATIONS (A-5), (A-6), AND (A-7)

EXPOSURE SITUATION	SHORE-WIDTH FACTOR, W
Discharge canal bank	0.1
River shoreline	0.2
Lake shore	0.3
Nominal ocean site	0.5
Tidal basin	1.0

d. Dose from Foods Grown on Land with Contaminated Water

The equations in the following paragraphs can be used to calculate doses from radionuclides released in liquid effluents but appearing in crops or animal products. Separate expressions are presented for tritium because of its unique environmental behavior.

(1) Vegetation

The concentration of radioactive material in vegetation results from deposition onto the plant foliage and from uptake from the soil of activity deposited on the ground. The model used for estimating the transfer of radionuclides from irrigation water to crops through water deposited on leaves and uptake from soil was derived for a study of the potential doses to people from a nuclear power complex in the year 2000 (Ref. 3).

The equation for the model (for radionuclides except tritium) is presented below in slightly modified form. The first term in brackets relates to the concentration derived from direct foliar deposition during the growing season. The second term relates to uptake from soil and reflects the long-term deposition during operation of the nuclear facility. Thus, for a uniform release rate, the concentration C_{iv} of radionuclide i in the edible portion of crop species v, in units of pCi/kg, is given by:

$$C_{iv} = d_i \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{f_I B_{iv}[1 - \exp(-\lambda_i t_b)]}{P \lambda_i} \right] \exp(-\lambda_i t_h) \qquad \text{(A-8)}$$

where the terms are defined in Section C, "Regulatory Position." Appendix E, Table E-15, presents suggested values for the parameters r, Y_v, t_e, P, and t_h. Values for B_{iv} are in Table E-1.

The deposition rate, d_i, from irrigated water is defined by the relation

$$d_i = C_{iw} I \text{ (water deposition)} \qquad \text{(A-9)}$$

where

C_{iw} is the concentration of radionuclide i in water used for irrigation, in pCi/liter, and

I is the average irrigation rate, in liters/m^2/hr, during the growing season.

For a cow grazing on fresh forage, t_e in Equation (A-8) is set equal to 720 hours (30 days), the typical time for a cow to return to a particular portion of the grazing site (Refs. 3 and 12).

For tritium, the equation for estimating C_{iv} is (see Ref. 13):

$$C_v = C_w \qquad \text{(A-10)}$$

(2) Animal Products

The radionuclide concentration in an animal product such as meat or milk is dependent on the amount of contaminated feed or forage eaten by the animal and its intake of contaminated water. The radionuclide concentration in animal products C_{iA} in terms of pCi/liter or pCi/kg is proportional to the animal's intake of the radionuclide in feed or forage (subscript F) and in water (subscript w):

$$C_{iA} = F_{iA}[C_{iF}Q_F + C_{iAw}Q_{Aw}] \tag{A-11}$$

The second set of terms in the brackets in Equation (A-11) can be omitted if the animal does not drink contaminated water. Values for Q_F and Q_{Aw} are presented in Appendix E, Table E-3. Values for B_{iv} and F_{iA} are given in Appendix E, Table E-1.*

(3) Total Dose from Food Grown on Land

The total dose R_{apj} from irrigated foods and animal products (excluding tritium) is given by:

$$R_{apj} = U_{ap}^{veg} \sum_i C_{iv}D_{aipj} + U_{ap}^{animal} \sum_i C_{iA}D_{aipj} \tag{A-12}$$

If values for C_{iv} from Equation (A-8) and C_{iA} from Equation (A-11) are substituted in Equation (A-12):

$$\begin{aligned} R_{apj} = {} & U_{ap}^{veg} \sum_i d_i \exp(-\lambda_i t_h) D_{aipj} \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{f_I B_{iv}[1 - \exp(-\lambda_i t_b)]}{P\lambda_i} \right] \\ & + U_{ap}^{animal} \sum_i F_{iA} D_{aipj} \left\{ Q_F d_i \exp(-\lambda_i t_h) \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} \right.\right. \\ & \left.\left. + \frac{f_I B_{iv}[1 - \exp(-\lambda_i t_b)]}{P\lambda_i} \right] + C_{iAw} Q_{Aw} \right\} \end{aligned} \tag{A-13}$$

where the terms are defined in Section C, "Regulatory Position."

It should be noted that the two components of Equation (A-12) imply that contributions from the individual vegetable and animal products have already been summed. In actual use, it will be necessary to compute separately the milk and meat portions of the dose due to animal products (also applicable to Equation (A-16)).

For tritium, the concentration in animal products (milk or meat) is given by the following equation:

$$C_A = F_a(C_v Q_F + C_{Aw} Q_{Aw}) \tag{A-14}$$

where the terms are defined in Section C, "Regulatory Position."

Since by Equation (A-10) $C_v = C_w$, and since for all practical purposes $C_{Aw} = C_w$, Equation (A-14) can be restated as follows:

$$C_A = F_A C_w (Q_F + Q_{Aw}) \tag{A-15}$$

---

*Values for F_{iA} appear as F_m and F_f in Table E-1.

Similarly, the above equations for tritium concentration can be combined with the general Equation (A-1):

$$R_{apj} = U_{ap}^{veg} C_v D_{apj} + U_{ap}^{animal} C_A D_{apj} \qquad \text{(A-16)}$$

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APPENDIX B

MODELS FOR CALCULATING DOSES FROM NOBLE GASES DISCHARGED TO THE ATMOSPHERE

The following analytical models are used for calculating doses from exposure to noble gases discharged to the atmosphere. Separate models are given for air and tissue doses due to gamma and beta rays. Except for the case of noble gas doses resulting from elevated releases, all models assume immersion in a semi-infinite cloud.

1. Annual Gamma Air Dose* from Noble Gas Releases from Free-Standing Stacks More Than 80 Meters High

Slade (Ref. 1) describes a derivation of equations for estimating annual air doses from photon emitters dispersed in the atmosphere. The following expression can be used for calculating annual doses:

$$D^{\gamma}(r,\theta) = \frac{260}{r(\Delta\theta)} \sum_{n} \frac{1}{u_n} \sum_{s} f_{ns} \sum_{k} \mu_a(E_k) E_k I(H,u,s,\sigma_z,E_k) \sum_{i} Q^{D}_{ni} A_{ki} \qquad \text{(B-1)}$$

Symbols for this equation were defined earlier, in Regulatory Position C.2.a of this guide. A discussion of, and derivation for, the I function are presented in Appendix F of this guide.

The photons are combined into energy groups, and each photon intensity within a group is weighted by its energy and energy absorption coefficient. Thus, the effective fraction of disintegrations of the nuclide i yielding photons corresponding to the photon energy group k, A_{ki}, is determined to be

$$A_{ki} = \sum_{m} [A_m E_m \mu_a(E_m)]/[E_k \mu_a(E_k)] \qquad \text{(B-2)}$$

where

A_m	is the fraction of the disintegrations of nuclide i yielding photons of energy E_m;
E_m	is the energy of the mth photon within the kth energy group, in MeV; and
$\mu_a(E_m)$	is the energy absorption coefficient in air associated with the photon energy E_m, in m^{-1}.

All other parameters are as previously defined. The summation is carried out over all photons within energy group k. Data for the photon energies and abundances for most of the noble gas nuclides were taken from Reference 2. For radionuclides not contained in Reference 2, data were obtained from Reference 3.

Decay during travel from the point of release to the receptor is

$$Q^{D}_{ni} = Q_i \exp(-\lambda_i r/u_n) \qquad \text{(B-3)}$$

---

*The term "gamma air dose" refers to the components of the air dose associated with photons emitted during nuclear and atomic transformations, i.e., gamma and x-rays. Annihilation and bremsstrahlung photon radiations are possible contributors to this component of the air dose.

where

Q_i is the initial release rate of nuclide i, in Ci/yr;

r is the distance from the source to the receptor, in m; and

λ_i is the decay constant of nuclide i, in sec^{-1}.

All other parameters are as previously defined.

2. Annual Gamma Air Dose from All Other Noble Gas Releases and Annual Beta Air Dose* from All Noble Gas Releases

Plumes of gaseous effluents are considered semi-infinite in the case of ground-level noble gas releases. The annual average ground-level concentration of radionuclide i at location (r,θ) is determined from

$$\chi_i(r,\theta) = 3.17 \times 10^4 Q_i[\chi/Q]^D(r,\theta) \qquad \text{(B-4)}$$

where

$\chi_i(r,\theta)$ is the annual average ground-level concentration of nuclide i at the distance r in the sector at angle θ from the release point, in pCi/m^3, and

$[\chi/Q]^D(r,\theta)$ is the annual average gaseous dispersion factor (corrected for radioactive decay) in the sector at angle θ at the distance r from the release point, in sec/m^3. (See Regulatory Guide 1.111 for atmospheric dispersion models.)

All other parameters are as previously defined.

The associated annual gamma or beta air dose is then

$$D^\gamma(r,\theta) \text{ or } D^\beta(r,\theta) = \sum_i \chi_i(r,\theta)(DF_i^\gamma \text{ or } DF_i^\beta) \qquad \text{(B-5)}$$

where the terms are as defined in Regulatory Position C.2.b.

Table B-1 presents a tabulation of the dose factors for the noble gases of interest.

3. Annual Total Body and Skin Doses from Noble Gas Effluents

It is also necessary to determine annual doses to real individuals in unrestricted areas. The staff computes the total body dose from external radiation at a depth of 5 cm into the body and the skin dose at a depth of 7 mg/cm^2 of tissue (Ref. 4).**

a. Releases from Free-Standing Stacks More Than 80 Meters High

The annual total body dose is computed as follows:

$$D^T(r,\theta) = 1.11 \times S_F \sum_k D_k^\gamma(r,\theta)\exp[-\mu_a^T(E_k)t_d] \qquad \text{(B-6)}$$

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*The term "beta air dose" refers to the component of the air dose associated with particle emissions during nuclear and atomic transformations, i.e., $\beta+$, $\beta-$, and conversion electrons.

**See discussion in Appendix E, Section 3.

TABLE B-1

DOSE FACTORS FOR EXPOSURE TO A SEMI-INFINITE CLOUD OF NOBLE GASES

Nuclide	β-air* (DF_i^β)	β-Skin** (DFS_i)	γ-Air* (DF_i^γ)	γ-Body** (DFB_i)
Kr-83m	2.88E-04***	---	1.93E-05	7.56E-08
Kr-85m	1.97E-03	1.46E-03	1.23E-03	1.17E-03
Kr-85	1.95E-03	1.34E-03	1.72E-05	1.61E-05
Kr-87	1.03E-02	9.73E-03	6.17E-03	5.92E-03
Kr-88	2.93E-03	2.37E-03	1.52E-02	1.47E-02
Kr-89	1.06E-02	1.01E-02	1.73E-02	1.66E-02
Kr-90	7.83E-03	7.29E-03	1.63E-02	1.56E-02
Xe-131m	1.11E-03	4.76E-04	1.56E-04	9.15E-05
Xe-133m	1.48E-03	9.94E-04	3.27E-04	2.51E-04
Xe-133	1.05E-03	3.06E-04	3.53E-04	2.94E-04
Xe-135m	7.39E-04	7.11E-04	3.36E-03	3.12E-03
Xe-135	2.46E-03	1.86E-03	1.92E-03	1.81E-03
Xe-137	1.27E-02	1.22E-02	1.51E-03	1.42E-03
Xe-138	4.75E-03	4.13E-03	9.21E-03	8.83E-03
Ar-41	3.28E-03	2.69E-03	9.30E-03	8.84E-03

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* $\frac{\text{mrad-m}^3}{\text{pCi-yr}}$

** $\frac{\text{mrem-m}^3}{\text{pCi-yr}}$

***2.88E-04 = 2.88×10^{-4}

Symbols for this equation are defined in Regulatory Position C.2.c of this guide. The factor S_F accounts for the dose reduction provided by the shielding effect of typical residential structures (see Appendix E, Section 4 and Table E-15).

The skin dose has two components, the gamma and beta contributions. The skin dose rate is computed by

$$D^S(r,\theta) = 1.11 \times S_F D^\gamma(r,\theta) + 3.17 \times 10^4 \sum_i Q_i [\chi/Q]^D(r,\theta) DFS_i \qquad \text{(B-7)}$$

Symbols for this equation are defined in Regulatory Position C.2.d of this guide.

The skin beta dose factors DFS were determined using the decay scheme source documents cited above and the methods used in References 5, 6, and 7. They are presented in Table B-1.

b. All Other Releases

The annual total body dose is computed as follows:

$$D_\infty^T(r,\theta) = S_F \sum_i \chi_i(r,\theta) DFB_i \qquad \text{(B-8)}$$

Symbols for this equation are defined in Regulatory Position C.2.e of this guide.

The annual skin dose is computed as follows:

$$D_\infty^S(r,\theta) = 1.11 \times S_F \sum_i \chi_i(r,\theta) DF_i^\gamma + \sum_i \chi_i(r,\theta) DFS_i \qquad \text{(B-9)}$$

Symbols for this equation are defined in Regulatory Position C.2.f of this guide.

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APPENDIX C

MODELS FOR CALCULATING DOSES VIA ADDITIONAL PATHWAYS FROM RADIOIODINES AND OTHER RADIONUCLIDES* DISCHARGED TO THE ATMOSPHERE

1. Annual External Dose from Direct Exposure to Activity Deposited on the Ground Plane

The ground plane concentration of radionuclide i at the location (r,θ) with respect to the release point may be determined by

$$C_i^G(r,\theta) = \frac{[1.0 \times 10^{12}]\ [\delta_i(r,\theta)\ Q_i]}{\lambda_i}[1 - \exp(-\lambda_i t_b)] \qquad \text{(C-1)}$$

where

$C_i^G(r,\theta)$	is the ground plane concentration of the radionuclide i in the sector at angle θ at the distance r from the release point, in pCi/m^2;
Q_i	is the annual release rate of nuclide i to the atmosphere, in Ci/yr;
t_b	is the time period over which the accumulation is evaluated, which is 15 years (mid-point of plant operating life). This is a simplified method of approximating the average deposition over the operating lifetime of the facility;
$\delta_i(r,\theta)$	is the annual average relative deposition of effluent species i at location (r,θ), considering depletion of the plume during transport, in m^{-2};
λ_i	is the radiological decay constant for nuclide i, in yr^{-1}; and
1.0×10^{12}	is the number of pCi per Ci.

The annual dose resulting from direct exposure to the contaminated ground plane, from all radionuclides, is then

$$D_j^G(r,\theta) = 8760\ S_F \sum_i C_i^G(r,\theta) DFG_{ij} \qquad \text{(C-2)}$$

where the terms are defined in Regulatory Position C.3.a of this guide.

Values for the open field ground plane dose conversion factors for the skin and total body are given in Appendix E, Table E-6. The annual dose to all other organs is taken to be equivalent to the total body dose. The factor S_F is assumed to have a value of 0.7, dimensionless.

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*Does not include noble gases.

2. Annual Dose from Inhalation of Radionuclides in Air

The annual average airborne concentration of radionuclide i at the location (r,θ) with respect to the release point may be determined as

$$\chi_i(r,\theta) = 3.17 \times 10^4 Q_i [\chi/Q]^D(r,\theta) \qquad \text{(C-3)}$$

where

Q_i	is the release rate of nuclide i to the atmosphere, in Ci/yr;
$\chi_i(r,\theta)$	is the annual average ground-level concentration of nuclide i in air in sector θ at distance r, in pCi/m^3;
$[\chi/Q]^D(r,\theta)$	is the annual average atmosphere dispersion factor, in sec/m^3 (see Regulatory Guide 1.111). This includes depletion (for radioiodines and particulates) and radioactive decay of the plume; and
3.17×10^4	is the number of pCi/Ci divided by the number of sec/yr.

The annual dose associated with inhalation of all radionuclides, to organ j of an individual in age group a, is then

$$D_{ja}^A(r,\theta) = R_a \sum_i \chi_i(r,\theta) DFA_{ija} \qquad \text{(C-4)}$$

Values for DFA_{ija} are given in Appendix E, Tables E-7 through E-10; values for R_a are given in Appendix E, Table E-5. All other symbols are as defined earlier in Regulatory Position C.3.b.

3. Concentrations of Airborne Radionuclides in Foods

The concentration of radioactive material in vegetation results from deposition onto the plant foliage and from uptake of activity initially deposited on the ground. The model used for estimating the transfer of radionuclides from the atmosphere to food products is similar to the model developed for estimating the transfer of radionuclides from irrigation water given in Appendix A of this guide.

a. Parameters for Calculating Nuclide Concentrations in Forage, Produce, and Leafy Vegetables

For all radioiodines and particulate radionuclides, except tritium and carbon-14, the concentration of nuclide i in and on vegetation at the location (r,θ) is estimated using

$$C_i^v(r,\theta) = d_i(r,\theta) \left\{ \frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{B_{iv}[1 - \exp(-\lambda_i t_b)]}{P \lambda_i} \right\} \exp(-\lambda_i t_h) \qquad \text{(C-5)}$$

See Regulatory Position C.1 of this guide for definitions of terms. Values for the parameters r, t_e, Y_v, P, and t_h are provided in Appendix E, Table E-15. For the parameters t_e, Y_v, and t_h, different values are given (in Appendix E) to allow the use of Equation (C-5) for different purposes: estimating concentrations in produce consumed by man; in leafy vegetables consumed by man; in forage consumed directly as pasture grass by dairy cows, beef cattle, or goats; and in forage consumed as stored feed by dairy cows, beef cattle, or goats.

The deposition rate from the plume is defined by

$$d_i(r,\theta) = 1.1 \times 10^8 \delta_i(r,\theta) Q_i \qquad \text{(C-6)}$$

where

$d_i(r,\theta)$ is the deposition rate of radionuclide i onto ground at location (r,θ), in pCi/m^2-hr;

$\delta_i(r,\theta)$ is the relative deposition of radionuclide i, considering depletion and decay in transit to location (r,θ), in m^{-2} (see Regulatory Guide 1.111); and

1.1×10^8 is the number of pCi per Ci (10^{12}) divided by the number of hours per year (8760).

For radioiodines, the model considers only the elemental fraction of the effluent. The deposition should be computed only for that fraction of the effluent that is estimated to be elemental iodine. Measurements at operating facilities indicate that about half the radioiodine emissions may be considered nonelemental (Ref. 1). With this consideration included, Equation (C-6) for radioiodine becomes

$$d_i(r,\theta) = 5.5 \times 10^7 \delta_i(r,\theta) Q_i \qquad \text{(C-7)}$$

where Q_i is the total (elemental and nonelemental) radioiodine emission rate. The retention factor r for elemental radioiodine on vegetation should be taken as unity, since the experimental measurements (Refs. 1, 2, and 3) used to evaluate this transfer mechanism consisted of direct comparison of the gross radioiodine concentration on vegetation and the concentration in air (Refs. 4 and 5).

For radioiodines, the deposition model is based only on the dry deposition process. Wet deposition, including "washout" of the organic and non-organic iodine fractions, should be considered at some sites depending on the meteorological conditions (see Regulatory Guide 1.111).

For particulates, the deposition model considers both wet and dry deposition. There is also a retention factor (r of Equation (C-5)) that accounts for the interception and capture of the deposited activity by the vegetative cover. A value of 0.2 is taken for this factor (Refs. 6 and 7). All nuclides except noble gases, tritium, carbon-14, and the iodines are treated as particulates.

Carbon-14 is assumed to be released in oxide form (CO or CO_2). The concentration of carbon-14 in vegetation is calculated by assuming that its ratio to the natural carbon in vegetation is the same as the ratio of carbon-14 to natural carbon in the atmosphere surrounding the vegetation (see Refs. 8 and 9). Also, in the case of intermittent releases, such as from gaseous waste decay tanks, the parameter p is employed to account for the fractional equilibrium ratio achieved. The parameter p is defined as the ratio of the total annual release time (for C-14 atmospheric releases) to the total annual time during which photosynthesis occurs (taken to be 4400 hrs), under the condition that the value of p should never exceed unity. For continuous C-14 releases, p is taken to be unity. These considerations yield the following relationship:

$$\begin{aligned} C^v_{14}(r,\theta) &= 3.17 \times 10^7 pQ_{14}[\chi/Q](r,\theta)\ 0.11/0.16 \\ &= 2.2 \times 10^7 pQ_{14}[\chi/Q](r,\theta) \qquad \text{(C-8)} \end{aligned}$$

where

$C^v_{14}(r,\theta)$ is the concentration of carbon-14 in vegetation grown at location (r,θ), in pCi/kg;

Q_{14} is the annual release rate of carbon-14, in Ci/yr;

p is the fractional equilibrium ratio, dimensionless;

0.11 is the fraction of total plant mass that is natural carbon, dimensionless;

0.16 is equal to the concentration of natural carbon in the atmosphere, in g/m^3; and

3.17×10^7 is equal to $(1.0 \times 10^{12}\,pCi/Ci)(1.0 \times 10^3\,g/kg)/(3.15 \times 10^7\,sec/yr)$.

The concentration of tritium in vegetation is calculated from its concentration in the air surrounding the vegetation. Using the method described in Reference 10, the NRC staff derived the following equation:

$$\begin{aligned} C_T^v(r,\theta) &= 3.17 \times 10^7 Q_T[\chi/Q](r,\theta)(0.75)(0.5/H) \\ &= 1.2 \times 10^7 Q_T[\chi/Q](r,\theta)/H \qquad \text{(C-9)} \end{aligned}$$

where

$C_T^v(r,\theta)$ is the concentration of tritium in vegetation grown at location (r,θ), in pCi/kg;

H is the absolute humidity of the atmosphere at location (r,θ), in g/m^3;

Q_T is the annual release rate of tritium, in Ci/yr;

0.5 is the ratio of tritium concentration in plant water to tritium concentration in atmospheric water, dimensionless; and

0.75 is the fraction of total plant mass that is water, dimensionless.

b. Parameters for Calculating Nuclide Concentrations in Milk

The radionuclide concentration in milk is dependent on the amount and contamination level of the feed consumed by the animal. The radionuclide concentration in milk is estimated as

$$C_i^m(r,\theta) = F_m C_i^v(r,\theta) Q_F \exp(-\lambda_i t_f) \qquad \text{(C-10)}$$

where

$C_i^m(r,\theta)$ is the concentration in milk of nuclide i, in pCi/liter;

$C_i^v(r,\theta)$ is the concentration of radionuclide i in the animal's feed, in pCi/kg;

F_m is the average fraction of the animal's daily intake of radionuclide i which appears in each liter of milk, in days/liter (see Appendix E, Tables E-1 and E-2 for cow and goat data, respectively; for nuclides not listed in Table E-2, use the values in Table E-1);

Q_F is the amount of feed consumed by the animal per day, in kg/day;

t_f is the average transport time of the activity from the feed into the milk and to the receptor (a value of 2 days is assumed); and

λ_i is the radiological decay constant of nuclide i, in $days^{-1}$.

The concentration of radionuclide i in the animal's feed is estimated as

$$C_i^v(r,\theta) = f_p f_s C_i^p(r,\theta) + (1 - f_p)C_i^s(r,\theta) + f_p(1 - f_s)C_i^s(r,\theta) \qquad \text{(C-11)}$$

where

$C_i^p(r,\theta)$ is the concentration of radionuclide i on pasture grass (calculated using Equation (C-5) with t_h=0), in pCi/kg;

$C_i^s(r,\theta)$ is the concentration of radionuclide i in stored feeds (calculated using Equation (C-5) with t_h=90 days), in pCi/kg;

f_p is the fraction of the year that animals graze on pasture; and

f_s is the fraction of daily feed that is pasture grass when the animal grazes on pasture.

The values of the parameters t_h, t_e, Y_v, and t_f that will be employed in evaluating the milk pathway, unless site-specific data is supplied, are provided in Appendix E, Table E-15.

c. Parameters for Calculating Nuclide Concentration in Meat

As in the milk pathway, the radionuclide concentration in meat is dependent on the amount and contamination level of the feed consumed by the animal. The radionuclide concentration in meat is estimated as

$$C_i^F(r,\theta) = F_f C_i^V(r,\theta) Q_F \exp(-\lambda_i t_s) \tag{C-12}$$

where

$C_i^F(r,\theta)$ is the concentration of nuclide i in animal flesh, in pCi/kg;

F_f is the fraction of the animal's daily intake of nuclide i which appears in each kilogram of flesh, in days/kg (see Appendix E, Table E-1 for values); and

t_s is the average time from slaughter to consumption (see Appendix E, Table E-15).

All the other symbols are as previously defined.

Beef cattle will be assumed to be on open pasture for the grazing periods outlined for milk cattle.

4. Annual Dose from Atmospherically Released Radionuclides in Foods

The annual dose to organ j of an individual in age group a resulting from ingestion of all radionuclides in produce, milk, meat, and leafy vegetables is given by

$$D_{ja}^D(r,\theta) = \sum_i DFI_{ija} \left[U_a^V f_g C_i^V(r,\theta) + U_a^m C_i^m(r,\theta) + U_a^F C_i^F(r,\theta) + U_a^L f_\ell C_i^L(r,\theta)\right] \tag{C-13}$$

where

$D_{ja}^D(r,\theta)$ is the annual dose to organ j of an individual in age group a from dietary intake of atmospherically released radionuclides, in mrem/yr;

DFI_{ija} is the dose conversion factor for the ingestion of nuclide i, organ j, and age group a, in mrem/pCi (from Tables E-11 through E-14 of Appendix E of this guide); and

U_a^V, U_a^m, U_a^F, U_a^L are the ingestion rates of produce (non-leafy vegetables, fruit, and grains), milk, meat, and leafy vegetables, respectively, for individuals in age group a (from Table E-5 of Appendix E of this guide).

All the other symbols are as previously defined. Values of f_g and f_ℓ to be assumed in the absence of site-specific information are given in Table E-15 of Appendix E as 0.76 and 1.0, respectively.

REFERENCES FOR APPENDIX C

1. B. H. Weiss et al., "Detailed Measurement of I-131 in Air, Vegetation and Milk Around Three Operating Reactor Sites," NUREG-75/021, U.S. Nuclear Regulatory Commission, Washington, D.C., March 1975.

2. D. F. Bunch (ed.), "Controlled Environmental Radioiodine Test, Progress Report Number Two," USAEC Report IDO-12063, January 1968.

3. J. D. Zimbrick and P. G. Voilleque, "Controlled Environmental Radioiodine Tests at the National Reactor Testing Station, Progress Report Number Four," USAEC Report IDO-12065, December 1968.

4. F. O. Hoffman, "Environmental Variables Involved with the Estimation of the Amount of ^{131}I in Milk and the Subsequent Dose to the Thyroid," Institute für Reaktorsicherheit, Cologne, West Germany, IRS-W-6, June 1973.

5. F. O. Hoffman, "A Reassessment of the Parameters Used To Predict the Environmental Transport of ^{131}I from Air to Milk," Institute für Reaktorsicherheit, IRS-W-13, April 1975.

6. C. A. Pelletier and P. G. Voilleque, "The Behavior of ^{137}Cs and Other Fallout Radionuclides on a Michigan Dairy Farm," Health Phys., Vol. 21, p. 777, 1971.

7. P. G. Voilleque and C. A. Pelletier, "Comparison of External Irradiation and Consumption of Cow's Milk as Critical Pathways for ^{137}Cs, ^{54}Mn and ^{144}Ce-^{144}Pr Released to the Atmosphere," Health Phys., Vol. 27, p. 189, 1974.

8. Y. C. Ng et al., "Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices, IV Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere," USAEC Report UCRL-50163, Part IV, 1968.

9. R. C. Weast (ed.), "Handbook of Chemistry and Physics," CRC Press, Cleveland, Ohio, 1970.

10. L. R. Anspaugh et al., "The Dose to Man via the Food-Chain Transfer Resulting from Exposure to Tritiated Water Vapor," USAEC Report UCRL-73195, Rev. 1, 1972.

APPENDIX D

MODELS FOR CALCULATING POPULATION DOSES FROM NUCLEAR POWER PLANT EFFLUENTS

Calculation of the annual population-integrated total body and thyroid doses* should be performed for the three effluent types identified in this guide. These doses should be evaluated for the population within a 50-mile radius of the site, as specified in paragraph D, Section II of Appendix I to 10 CFR Part 50.

For the purpose of calculating the annual population-integrated dose, the 50-mile region should be divided into a number of subregions consistent with the nature of the region. These subregions may represent, for example, the reaches of a river or land areas over which the appropriate dispersion factor is averaged. Dispersion factors, population data, and other information describing existing or planned uses of the subregions should be developed.

1. General Expressions for Population Dose

For pathways in which the permanent and transient population of the subregion can be considered to be exposed to the average radionuclide concentrations estimated for the subregion, the annual population-integrated dose is calculated as follows:

$$D_j^P = 0.001 \sum_d P_d \sum_a D_{jda} f_{da} \qquad \text{(D-1)}$$

where

D_{jda} is the annual dose to organ j (total body or thyroid) of an average individual of age group a in subregion d, in mrem/yr;

D_j^P is the annual population-integrated dose to organ j (total body or thyroid), in man-rems or thyroid man-rems;

f_{da} is the fraction of the population in subregion d that is in age group a;

P_d is the population associated with subregion d; and

0.001 is the conversion factor from mrem to rem.

The annual dose to the total body or thyroid of an average individual should be evaluated with the usage factors of Table E-4 of Appendix E. Models and equations for the detailed dose calculations are presented in Appendices A, B, and C of this guide. The annual population-integrated doses from ingestion of potable water, inhalation of airborne effluents, and external exposure to airborne or deposited radionuclides should be evaluated. In addition to the pathways for which equations are presented in Appendices A, B, and C, other exposure pathways should be evaluated if conditions at a specific site indicate that they might provide a significant contribution to the total population dose from all pathways. In this context, a significant contribution is defined as 10 percent or more.

For pathways that involve food products produced in the subregion, the food products may be distributed to other areas for consumption. For all the food that is produced within the 50-mile radius, the radioactivity concentrations are averaged over the entire area by weighting the concentrations in each subregion by the amount produced in each subregion. This average concentration is used in calculating the population doses. The 50-mile average concentration of nuclide i in food p is computed as

$$\bar{C}_{ip} = (1/V_p) \exp(-\lambda_i t_p) \sum_d C_{dip} v_{dp} \qquad \text{(D-2)}$$

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*The population-integrated dose is the summation of the dose received by all individuals and has units of man-rem when applied to the total body dose and units of man-thyroid-rem when applied to the summation of thyroid dose.

where

C_{dip} is the average concentration over subregion d of the nuclide i in pathway p, in pCi/kg or pCi/liter (see Appendices A and C of this guide for models and equations for calculation of pathway concentrations);

$\bar{C}_{ip}$ is the 50-mile average concentration of nuclide i in pathway p, in pCi/kg or pCi/liter;

t_p is the transport time of the food medium p through the distribution system, in days (Table D-1 presents estimates of the transport times that may be used in lieu of site-specific data);

v_{dp} is the annual mass or volume of food medium p produced in subregion d, in kg or liters;

V_p is the mass or volume of the food medium p produced annually with the 50-mile radius about the site, in kg or liters; and

λ_i is the radiological decay constant for nuclide i, in days^{-1}

The population served by all the food produced within 50 miles of the site is estimated as

$$P_p^* = V_p / \sum_a U_{ap} f_a \qquad \text{(D-3)}$$

where

f_a is the fraction of the population within the age group a;

P_p^* is the estimated population that can be served by the quantity of food p likely to be produced within 50 miles of the site;

U_{ap} is the use or consumption factor of food medium p for the average individual in age group a, in kg/yr or liters/yr (taken from Table E-4); and

V_p is the annual mass or volume of food medium p likely to be produced within a 50-mile radius about the site, in kg or liters.

The annual population-integrated dose is then calculated as

$$D_j^P = 0.001 \sum_p P_p \sum_i \sum_a f_a \bar{C}_{ip} U_{ap} DF_{ai} \qquad \text{(D-4)}$$

where

$$P_p = \begin{cases} P_p^* & \text{if } P_p^* < P_{50} \\ P_{50} & \text{if } P_p^* \geq P_{50} \end{cases}$$

and

DF_{ai} is the ingestion dose factor for age group a and nuclide i, in mrem/pCi (taken from Appendix E, Tables E-11 to E-14);

TABLE D-1

RECOMMENDED VALUES FOR THE TRANSPORT TIMES IN THE FOOD DISTRIBUTION SYSTEM*

FOOD MEDIUM	DISTRIBUTION TRANSPORT TIME (in days)
Fruits, grains, and vegetables	14
Milk	4
Meat and poultry	20
Sport fish	7
Commercial fish	10
Drinking water	1

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*To be used in lieu of site-specific data on food distribution.

D_j^p is the annual population-integrated dose to organ j (total body or thyroid), in man-rem/yr or thyroid man-rem/yr;

P_p is the population consuming food medium p; and

P_{50} is the total population within 50 miles.

All other factors are as defined above.

Note that the above formulation limits the evaluation of the exposed population evaluation to the population residing within 50 miles as specified in paragraph D, Section II of Appendix I to 10 CFR Part 50. In calculating the annual population-integrated total body and thyroid doses, the age distribution of the population within 50 miles may be assumed to be the same as the age distribution of the U.S. population (Ref. 1). Reference 1 indicates the fractional breakdown to be as follows: children, 0.18; teenagers, 0.11; and adults, 0.71. Infants (0-1 year in age) are not projected to exceed 2% of the population (Ref. 1), and their population fraction has been included in that given above for children.

2. Use of the Models

a. Population-Integrated Doses from Liquid Effluents

The annual total body and thyroid population-integrated doses due to exposure to liquid effluents should be evaluated for the following principal pathways: potable water, aquatic food products, external irradiation from shoreline deposits, and terrestrial food products irrigated with water that has received the liquid effluent.

(1) Doses from Potable Water

The annual population-integrated total body and thyroid doses from water consumption are evaluated for all subregions that have water intakes existing or designated at the time of the license application. The products of the individual doses and the population exposed in each such subregion within 50 miles from the site are summed to obtain the total dose. The formulation expressed in Equation (D-1) may be used.

The total body and thyroid dose of the individuals should be evaluated using Equation (A-2) in Appendix A of this guide, together with the age-dependent usage factors U_{ap} obtained from Table D-1. The dilution from the discharge point to the usage point should be evaluated using appropriate hydrological models for the various subregions.

If the population served by a particular water supply system is not known, it can be estimated by the following:

$$P_w = v/c \qquad \text{(D-5)}$$

where

c is the average daily usage of individuals on the system, in gal/day per person;

P_w is the estimated population served by the water system; and

v is the average daily intake of the water supply system, in gal/day.

If the industrial usage from the water supply system is known, it can be subtracted from the average daily intake of the system before this value is entered into Equation (D-5).

The population served by a water supply system whose intake is within the 50-mile radius may include individuals who reside outside the circle. This population may be pro-rated to include only the population within the 50-mile radius. Conversely, a water supply system with an intake beyond the 50-mile radius may serve the population within the 50-mile radius, whose exposure via drinking water should be included in the 50-mile population dose evaluation.

(2) Doses from Aquatic Food Products

The annual population-integrated total body and thyroid doses from consumption of aquatic food products are evaluated using the production of sport and commercial harvests in the various subregions. The mixing ratio (or dilution) should be evaluated for each subregion using an appropriate hydrological model. For sport harvests, the entire edible harvest is assumed to be ingested by the population within 50 miles. The formulation expressed by Equation (D-4) should be used with the population P_p given by the results of Equation (D-3). The age-specific ingestion rates of Table E-4 may be used in lieu of site-specific data.

For commercial harvests, the production within 50 miles from the site is considered as part of the total U.S. harvest. Equation (D-2) should be used to compute the average concentration, with V_p as the total estimated U.S. commercial harvest of the aquatic food medium p. The annual population-integrated dose is then computed using Equation (D-4) with $P_p = P_{50}$. The age-specific factors of Table E-4 may be used in lieu of site-specific data.

(3) Doses from Shoreline Deposits

The annual population-integrated total body and thyroid doses from recreational activities on the shoreline of the receiving water body are evaluated by summing the product of the individual doses in each subregion and the population exposed therein. All subregions within the 50-mile radius should be considered where existing or designated recreational facilities exist. If available, actual recreational usage in the vicinity of each facility should be used. The formulation of Equation (D-1) is appropriate.

(4) Doses from Consumption of Terrestrial Food Products Irrigated by Waters Receiving the Liquid Effluent

The annual population-integrated total body and thyroid doses from consumption of food irrigated with water from the body receiving the liquid effluent are evaluated following the procedures outlined in the development of Equation (D-4). Note that the term V_p of Equations (D-2) and (D-3) denotes the total production of food medium p within 50 miles, not just the total production of irrigated food medium p. The consumption rate data of Table D-1 may be used in lieu of site-specific data in the evaluation of Equation (D-4).

b. Population-Integrated Doses from Airborne Effluents

The annual total body and thyroid population-integrated doses should be evaluated for the following principal exposure pathways: noble gas submersion, inhalation of airborne effluents, ingestion of contaminated terrestrial foods (milk, meat, and produce), and external irradiation from activity deposited on the ground. Available state or county agricultural production data may be used for estimating the population-integrated doses from food consumption.

For the evaluation of exposures from atmospheric releases, the 50-mile region should be divided into 160 subregions formed by sectors centered on the 16 compass points (N, NNE, NE, etc.) and annuli at distances of 1, 2, 3, 4, 5, 10, 20, 30, 40, and 50 miles from the center of the facility. The atmospheric dispersion factors (χ/Q) or similar factors should be evaluated at the radial midpoint for each of the subregions using appropriate atmospheric dispersion models such as those described in Regulatory Guide 1.111.

(1) Doses due to Exposure to Noble Gases

The annual population-integrated total body dose due to noble gas effluents should be evaluated by summing the products of the individual doses in each subregion and the population in each subregion. Equation (D-1) may be used. For external exposure, the model does not differentiate between age groups. A structural shielding factor of 0.5 should be applied in conjunction with the dose factor data of Table B-1.

(2) Doses due to Inhalation of Radioiodines and Particulates

The annual population-integrated total body and thyroid doses from inhalation of airborne effluents should be evaluated by summing the products of the individual doses received in each subregion and the population in each subregion. Equation (D-1) may be used. The age-specific inhalation rates of Table E-4 may be used with the data of Tables E-7 to E-10.

(3) Doses due to Ingestion of Terrestrial Food Products

The annual population-integrated total body and thyroid doses from ingestion of terrestrial food products should be evaluated using the production data for each subregion. For milk, meat, and commercial vegetables, the formulation of Equation (D-2) should be used to calculate the average concentrations in the foods. These concentrations are then used in Equation (D-4), along with the data of Tables D-1, E-4, and E-11 to E-14, to calculate population doses.

(4) Doses due to External Irradiation from Activity Deposited on the Ground

The annual population-integrated total body and thyroid doses from external exposure to surface deposition of the effluent should be evaluated using Equation (D-1). A household shielding and occupancy factor of 0.5 should be applied in conjunction with the dose factors of Table E-6.

REFERENCE FOR APPENDIX D

1. "Current Population Reports," Bureau of the Census, Series P-25, No. 541, U.S. Dept. of Commerce, 1975.

APPENDIX E

NUMERICAL DATA FOR THE CALCULATION OF ANNUAL DOSES TO MAN FROM ROUTINE RELEASES OF REACTOR EFFLUENTS

This appendix contains data for use in the equations presented in the Regulatory Position and in Appendices A, B, C, and D of this guide. The numerical values presented in this appendix are those routinely used by the NRC staff. In instances where more appropriate information of a site-specific nature has been developed and documented, that information should be used.

In a number of instances the staff has found it necessary to provide guidance as to the value of a particular parameter in the absence of substantial empirical data. In such instances the staff has exercised judgment and has considered values used by others and the sensitivity of the results to the value assumed.

Information is provided below under four broad categories: environmental data, human data, dose factors, and other parameters.

1. Environmental Data

Table E-1 provides values for the following stable element transfer coefficients:

a. B_{iv} for the estimation of produce, leafy vegetable, or pasture grass radioactivity from that in soil (pCi/kg in vegetation per pCi/kg in soil);

b. F_m for the estimation of cow milk activity from that in feed (pCi/ℓ in milk per pCi/day ingested by the animal); and

c. F_f for the estimation of meat activity from that in feed (pCi/kg in meat per pCi/day ingested by the animal).

The data are largely derived from Reference 1. The value of the cow milk transfer coefficient for radioiodine is based on the staff's review of the literature (Refs. 2-9).

Values of transfer coefficients for goat milk are presented in Table E-2 for a limited number of nuclides. For nuclides not listed in Table E-2, the milk transfer coefficient from Table E-1 should be used.

Various animal parameter values are presented in Table E-3 for use in estimating animal product activity levels as functions of the corresponding levels in feed and water supplies.

2. Human Data

Tables E-4 and E-5 present usage rates of various environmental media by average individuals and maximum individuals, respectively, according to age group. "Seafood" is used to indicate intake of aquatic invertebrates such as lobster, crab, clams, and oysters. Ingestion of aquatic plant material is not normally assumed.

3. Dose Factors

Dose factors for external irradiation from a uniformly contaminated ground plane are presented in Table E-6 (Refs. 10 and 11), in units of mrem/hr per pCi/m^2. These factors are applicable for surface contamination via deposition of liquid effluents on shoreline sediments or airborne effluents on ground surfaces. Dose factors are provided for the total body and skin only. Doses to other organs are assumed equal to the total body dose.

Dose factors provided in Table E-6 are derived from a consideration of the dose rate to air 1 meter above the ground plane and the penetration of the radiation into the body. The total body dose is computed at a penetration depth of 5 cm; the skin dose is computed at a depth of 7 mg/cm^2. These tissue depths are indicated by Reference 12, where it is suggested that, for

TABLE E-1

STABLE ELEMENT TRANSFER DATA*

Element	B_{iv} Veg/Soil	F_m(Cow) Milk (d/ℓ)	F_f Meat (d/kg)
H**	4.8E 00	1.0E-02	1.2E-02
C**	5.5E 00	1.2E-02	3.1E-02
Na	5.2E-02	4.0E-02***	3.0E-02
P	1.1E 00	2.5E-02	4.6E-02
Cr	2.5E-04	2.2E-03	2.4E-03
Mn	2.9E-02	2.5E-04	8.0E-04
Fe	6.6E-04	1.2E-03	4.0E-02
Co	9.4E-03	1.0E-03	1.3E-02
Ni	1.9E-02	6.7E-03	5.3E-02
Cu	1.2E-01	1.4E-02	8.0E-03
Zn	4.0E-01	3.9E-02	3.0E-02
Rb	1.3E-01	3.0E-02	3.1E-02
Sr	1.7E-02	8.0E-04***	6.0E-04
Y	2.6E-03	1.0E-05	4.6E-03
Zr	1.7E-04	5.0E-06	3.4E-02
Nb	9.4E-03	2.5E-03	2.8E-01
Mo	1.2E-01	7.5E-03	8.0E-03
Tc	2.5E-01	2.5E-02	4.0E-01
Ru	5.0E-02	1.0E-06	4.0E-01
Rh	1.3E 01	1.0E-02	1.5E-03
Ag	1.5E-01	5.0E-02	1.7E-02
Te	1.3E 00	1.0E-03	7.7E-02
I	2.0E-02	6.0E-03†	2.9E-03
Cs	1.0E-02	1.2E-02***	4.0E-03
Ba	5.0E-03	4.0E-04***	3.2E-03
La	2.5E-03	5.0E-06	2.0E-04
Ce	2.5E-03	1.0E-04***	1.2E-03
Pr	2.5E-03	5.0E-06	4.7E-03
Nd	2.4E-03	5.0E-06	3.3E-03
W	1.8E-02	5.0E-04	1.3E-03
Np	2.5E-03	5.0E-06	2.0E-04††

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[*] Data presented in this table is from Reference 1 unless otherwise indicated.

[**] Meat and milk coefficients are based on specific activity considerations.

[***] From Reference 15.

[†] See text.

[††] From Reference 13.

TABLE E-2

NUCLIDE TRANSFER PARAMETERS FOR GOAT'S MILK*

Element	F_m (days/liter)
H	0.17
C	0.10
P	0.25
Fe	1.3E-04
Cu	0.013
Sr	0.014**
I	0.06**
Cs	0.30**

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*Values in this table are from References 1 and 14 unless otherwise indicated.

**From Reference 15.

TABLE E-3

ANIMAL CONSUMPTION RATES

Animal	Q_F Feed or Forage (kg/day [wet weight])	Q_{Aw} Water (ℓ/day)
Milk cow	50 (Ref. 10)	60 (Ref. 16)
Beef cattle	50 (Ref. 10)	50 (Ref. 16)
Goats	6 (Ref. 17)	8 (Ref. 18)

TABLE E-4

RECOMMENDED VALUES FOR U_{ap} TO BE USED FOR THE AVERAGE INDIVIDUAL IN LIEU OF SITE-SPECIFIC DATA

Pathway	Child	Teen	Adult
Fruits, vegetables, & grain (kg/yr)*	200	240	190
Milk (ℓ/yr)*	170	200	110
Meat & poultry (kg/yr)*	37	59	95
Fish (kg/yr)*	2.2	5.2	6.9
Seafood (kg/yr)*	0.33	0.75	1.0
Drinking water (ℓ/yr)**	260	260	370
Shoreline recreation (hr/yr)**	9.5	47	8.3
Inhalation (m^3/yr)	3700***	8000***	8000†

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*Consumption rate obtained from Reference 19 and age-prorated using techniques in Reference 10.

**Data obtained directly from Reference 10.

***Inhalation rate derived from data provided in Reference 20.

†Data obtained directly from Reference 20.

TABLE E-5

RECOMMENDED VALUES FOR U_{ap} TO BE USED FOR THE MAXIMUM EXPOSED INDIVIDUAL IN LIEU OF SITE-SPECIFIC DATA

Pathway	Infant	Child	Teen	Adult
Fruits, vegetables & grain (kg/yr)[*,**]	-	520	630	520
Leafy vegetables (kg/yr)[*]	-	26	42	64
Milk (ℓ/yr)[*]	330	330	400	310
Meat & poultry (kg/yr)[*]	-	41	65	110
Fish (fresh or salt) (kg/yr)[***]	-	6.9	16	21
Other seafood (kg/yr)[*]	-	1.7	3.8	5
Drinking water (ℓ/yr)[†]	330	510	510	730
Shoreline recreation (hr/yr)[†]	-	14	67	12
Inhalation (m^3/yr)	1400[††]	3700[†††]	8000[†††]	8000[††]

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[*] Consumption rate obtained from Reference 19 for average individual and age-prorated and maximized using techniques contained in Reference 10.

[**] Consists of the following (on a mass basis): 22% fruit, 54% vegetables (including leafy vegetables), and 24% grain.

[***] Consumption rate for adult obtained by averaging data from References 10 and 21-24 and age-prorated using techniques contained in Reference 10.

[†] Data obtained directly from Reference 10.

[††] Data obtained directly from Reference 20.

[†††] Inhalation rate derived from data provided in Reference 20.

TABLE E-6

EXTERNAL DOSE FACTORS FOR STANDING ON CONTAMINATED GROUND

(mrem/hr per pCi/m^2)

Element	Total Body	Skin
H-3	0.0	0.0
C-14	0.0	0.0
NA-24	2.50E-08	2.90E-08
P-32	0.0	0.0
Cr-51	2.20E-10	2.60E-10
Mn-54	5.80E-09	6.80E-09
Mn-56	1.10E-08	1.30E-08
Fe-55	0.0	0.0
Fe-59	8.00E-09	9.40E-09
Co-58	7.00E-09	8.20E-09
Co-60	1.70E-08	2.00E-08
Ni-63	0.0	0.0
Nr-65	3.70E-09	4.30E-09
Cu-64	1.50E-09	1.70E-09
Zn-65	4.00E-09	4.60E-09
Zn-69	0.0	0.0
Br-83	6.40E-11	9.30E-11
Br-84	1.20E-08	1.40E-08
Br-85	0.0	0.0
Rb-86	6.30E-10	7.20E-10
Rb-88	3.50E-09	4.00E-09
Rb-89	1.50E-08	1.80E-08
Sr-89	5.60E-13	6.50E-13
Sr-91	7.10E-09	8.30E-09
Sr-92	9.00E-09	1.00E-08
Y-90	2.20E-12	2.60E-12
Y-91M	3.80E-09	4.40E-09
Y-91	2.40E-11	2.70E-11
Y-92	1.60E-09	1.90E-09
Y-93	5.70E-10	7.80E-10
Zr-95	5.00E-09	5.80E-09
Zr-97	5.50E-09	6.40E-09
Nb-95	5.10E-09	6.00E-09
Mo-99	1.90E-09	2.20E-09
Tc-99M	9.60E-10	1.10E-09
Tc-101	2.70E-09	3.00E-09
Ru-103	3.60E-09	4.20E-09
Ru-105	4.50E-09	5.10E-09
Ru-106	1.50E-09	1.80E-09
Ag-110M	1.80E-08	2.10E-08
Te-125M	3.50E-11	4.80E-11
Te-127M	1.10E-12	1.30E-12
Te-127	1.00E-11	1.10E-11
Te-129M	7.70E-10	9.00E-10
Te-129	7.10E-10	8.40E-10
Te-131M	8.40E-09	9.90E-09
Te-131	2.20E-09	2.60E-06
Te-132	1.70E-09	2.00E-09
I-130	1.40E-08	1.70E-08
I-131	2.80E-09	3.40E-09
I-132	1.70E-08	2.00E-08
I-133	3.70E-09	4.50E-09
I-134	1.60E-08	1.90E-08
I-135	1.20E-08	1.40E-08

TABLE E-6 (Continued)

Element	Total Body	Skin
Cs-134	1.20E-08	1.40E-08
Cs-136	1.50E-08	1.70E-08
Cs-137	4.20E-09	4.90E-09
Cs-138	2.10E-08	2.40E-08
Ba-139	2.40E-09	2.70E-09
Ba-140	2.10E-09	2.40E-09
Ba-141	4.30E-09	4.90E-09
Ba-142	7.90E-09	9.00E-09
La-140	1.50E-08	1.70E-08
La-142	1.50E-08	1.80E-08
Ce-141	5.50E-10	6.20E-10
Ce-143	2.20E-09	2.50E-09
Ce-144	3.20E-10	3.70E-10
Pr-143	0.0	0.0
Pr-144	2.00E-10	2.30E-10
Nd-147	1.00E-09	1.20E-09
W-187	3.10E-09	3.60E-09
Np-239	9.50E-10	1.10E-09

calculational purposes, the average depth of the blood-forming organs may be assumed to be 5 cm. Reference 12 also identifies the cells of the basal layer of epidermis as the tissue of interest in the computation of skin dose and states an average depth for these cells of 7 mg/cm^2. This guidance is reflected in the dose factors presented in Table E-6 and also in those presented in Appendix B, Table B-1, for use in calculating external doses from noble gases.

Dose factors for internal exposure are provided in Tables E-7 through E-14, in units of mrem per pCi intake (Ref. 25). Tables E-7 through E-10 are for inhalation (one table for each of the four age groups), while Tables E-11 through E-14 are for ingestion. Dose factors provided for the inhalation of H-3 include an increase of 50 percent to account for the additional amount of this isotope absorbed through the skin (Ref. 25).

As discussed in Section B, "Discussion," these dose factors are appropriate for continuous intake over a one-year period and include the dose commitment over a 50-year period. The calculational scheme by which these dose factors are derived includes elementary consideration of changing physical and metabolic characteristics during the period over which the dose commitment is evaluated. For example, environmental exposure of an infant over a one-year period is treated as follows: dose during the first year is computed based on infant physiological and metabolic characteristics considering both the buildup and decay of the appropriate organ burden; dose during years 1-10 is computed based on child physiological and metabolic data considering decay of the organ burden from its peak value at age 1; dose during years 11-16 is treated in a similar fashion using teenager characteristics; and dose during adulthood is computed based on the physiological and metabolic characteristics of an adult. Age-dependent parameters are changed in steps at the breaks between age groups.

4. Other Parameters

Table E-15 has been provided as a central location for the recommended values of many of the miscellaneous parameters appearing in equations in this guide. In some instances, a parameter's value or units is a function of the equation it is used in. Additionally, for some parameters used in calculating activities in vegetation, the value is also a function of the exposure pathway. Table E-15 has been organized to note these complications.

Values of the parameter S_F, a structural shielding and occupancy factor, are given in Table E-15 as 0.7 (for maximum individuals) and 0.5 (for the general population). Using the general approach given in Reference 26, the staff estimates an average structural shielding factor of 0.5 for typical reactor effluents. Assuming the maximum individual spends about 50 percent of the time indoors, the overall shielding and occupancy factor is then approximately 0.7. The factor of 0.5 is used directly for population dose calculations. These factors are applicable for external gamma exposure from noble gases and for external exposure from contaminated ground surfaces.

TABLE E-7

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INHALATION DOSE FACTORS FOR ADULTS
(MREM PER PCI INHALED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
H 3	NO DATA	1.58E-07	1.58E-07	1.58E-07	1.58E-07	1.58E-07	1.58E-07
C 14	2.27E-06	4.26E-07	4.26E-07	4.26E-07	4.26E-07	4.26E-07	4.26E-07
NA 24	1.28E-06	1.28E-06	1.28E-06	1.28E-06	1.28E-06	1.28E-06	1.28E-06
P 32	1.65E-04	9.64E-06	6.26E-06	NO DATA	NO DATA	NO DATA	1.08E-05
CR 51	NO DATA	NO DATA	1.25E-08	7.44E-09	2.85E-09	1.80E-06	4.15E-07
MN 54	NO DATA	4.95E-06	7.87E-07	NO DATA	1.23E-06	1.75E-04	9.67E-06
MN 56	NO DATA	1.55E-10	2.29E-11	NO DATA	1.63E-10	1.18E-06	2.53E-06
FE 55	3.07E-06	2.12E-06	4.93E-07	NO DATA	NO DATA	9.01E-06	7.54E-07
FE 59	1.47E-06	3.47E-06	1.32E-06	NO DATA	NO DATA	1.27E-04	2.35E-05
CO 58	NO DATA	1.98E-07	2.59E-07	NO DATA	NO DATA	1.16E-04	1.33E-05
CO 60	NO DATA	1.44E-06	1.85E-06	NO DATA	NO DATA	7.46E-04	3.56E-05
NI 63	5.40E-05	3.93E-06	1.81E-06	NO DATA	NO DATA	2.23E-05	1.67E-06
NI 65	1.92E-10	2.62E-11	1.14E-11	NO DATA	NO DATA	7.00E-07	1.54E-06
CU 64	NO DATA	1.83E-10	7.69E-11	NO DATA	5.78E-10	8.48E-07	6.12E-06
ZN 65	4.05E-06	1.29E-05	5.82E-06	NO DATA	8.62E-06	1.08E-04	6.68E-06
ZN 69	4.23E-12	8.14E-12	5.65E-13	NO DATA	5.27E-12	1.15E-07	2.04E-09
BR 83	NO DATA	NO DATA	3.01E-08	NO DATA	NO DATA	NO DATA	2.90E-08
BR 84	NO DATA	NO DATA	3.91E-08	NO DATA	NO DATA	NO DATA	2.05E-13
BR 85	NO DATA	NO DATA	1.60E-09	NO DATA	NO DATA	NO DATA	LT E-24
RB 86	NO DATA	1.69E-05	7.37E-06	NO DATA	NO DATA	NO DATA	2.08E-06
RB 88	NO DATA	4.84E-08	2.41E-08	NO DATA	NO DATA	NO DATA	4.18E-19
RB 89	NO DATA	3.20E-08	2.12E-08	NO DATA	NO DATA	NO DATA	1.16E-21
SR 89	3.80E-05	NO DATA	1.09E-06	NO DATA	NO DATA	1.75E-04	4.37E-05
SR 90	1.24E-02	NO DATA	7.62E-04	NO DATA	NO DATA	1.20E-03	9.02E-05
SR 91	7.74E-09	NO DATA	3.13E-10	NO DATA	NO DATA	4.56E-06	2.39E-05
SR 92	8.43E-10	NO DATA	3.64E-11	NO DATA	NO DATA	2.06E-06	5.38E-06
Y 90	2.61E-07	NO DATA	7.01E-09	NO DATA	NO DATA	2.12E-05	6.32E-05
Y 91M	3.26E-11	NO DATA	1.27E-12	NO DATA	NO DATA	2.40E-07	1.66E-10
Y 91	5.78E-05	NO DATA	1.55E-06	NO DATA	NO DATA	2.13E-04	4.81E-05
Y 92	1.29E-09	NO DATA	3.77E-11	NO DATA	NO DATA	1.96E-06	9.19E-06

TABLE E-7, CONT'D

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INHALATION DOSE FACTORS FOR ADULTS
(MREM PER PCI INHALED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
Y 93	1.18E-08	NO DATA	3.26E-10	NO DATA	NO DATA	6.06E-06	5.27E-05
ZR 95	1.34E-05	4.30E-06	2.91E-06	NO DATA	6.77E-06	2.21E-04	1.88E-05
ZR 97	1.21E-08	2.45E-09	1.13E-09	NO DATA	3.71E-09	9.84E-06	6.54E-05
NB 95	1.76E-06	9.77E-07	5.26E-07	NO DATA	9.67E-07	6.31E-05	1.30E-05
MO 99	NO DATA	1.51E-08	2.87E-09	NO DATA	3.64E-08	1.14E-05	3.10E-05
TC 99M	1.29E-13	3.64E-13	4.63E-12	NO DATA	5.52E-12	9.55E-08	5.20E-07
TC101	5.22E-15	7.52E-15	7.38E-14	NO DATA	1.35E-13	4.99E-08	1.36E-21
RU103	1.91E-07	NO DATA	8.23E-08	NO DATA	7.29E-07	6.31E-05	1.38E-0[illegible]
RU105	9.88E-11	NO DATA	3.89E-11	NO DATA	1.27E-10	1.37E-06	6.02E-06
RU106	8.64E-06	NO DATA	1.09E-06	NO DATA	1.67E-05	1.17E-03	1.14E-04
AG110M	1.35E-06	1.25E-06	7.43E-07	NO DATA	2.46E-06	5.79E-04	3.78E-05
TE125M	4.27E-07	1.98E-07	5.84E-08	1.31E-07	1.55E-06	3.92E-05	8.83E-06
TE127M	1.58E-06	7.21E-07	1.96E-07	4.11E-07	5.72E-06	1.20E-04	1.87E-05
TE127	1.75E-10	8.03E-11	3.87E-11	1.32E-10	6.37E-10	8.14E-07	7.17E-06
TE129M	1.22E-06	5.84E-07	1.98E-07	4.30E-07	4.57E-06	1.45E-04	4.79E-05
TE129	6.22E-12	2.99E-12	1.55E-12	4.87E-12	2.34E-11	2.42E-07	1.96E-08
TE131M	8.74E-09	5.45E-09	3.63E-09	6.88E-09	3.86E-08	1.82E-05	6.95E-05
TE131	1.39E-12	7.44E-13	4.49E-13	1.17E-12	5.46E-12	1.74E-07	2.30E-09
TE132	3.25E-08	2.69E-08	2.02E-08	2.37E-08	1.82E-07	3.60E-05	6.37E-05
I 130	5.72E-07	1.68E-06	6.60E-07	1.42E-04	2.61E-06	NO DATA	9.61E-07
I 131	3.15E-06	4.47E-06	2.56E-06	1.49E-03	7.66E-06	NO DATA	7.85E-07
I 132	1.45E-07	4.07E-07	1.45E-07	1.43E-05	6.48E-07	NO DATA	5.08E-08
I 133	1.08E-06	1.85E-06	5.65E-07	2.69E-04	3.23E-06	NO DATA	1.11E-06
I 134	8.05E-08	2.16E-07	7.69E-08	3.73E-06	3.44E-07	NO DATA	1.26E-10
I 135	3.35E-07	8.73E-07	3.21E-07	5.60E-05	1.39E-06	NO DATA	6.56E-07
CS134	4.66E-05	1.06E-04	9.10E-05	NO DATA	3.59E-05	1.22E-05	1.30E-06
CS136	4.88E-06	1.83E-05	1.38E-05	NO DATA	1.07E-05	1.50E-06	1.46E-06
CS137	5.98E-05	7.76E-05	5.35E-05	NO DATA	2.78E-05	9.40E-06	1.05E-06
CS138	4.14E-08	7.76E-08	4.05E-08	NO DATA	6.00E-08	6.07E-09	2.33E-13
BA139	1.17E-10	8.32E-14	3.42E-12	NO DATA	7.78E-14	4.70E-07	1.12E-07

TABLE E-7, CONT'D

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INHALATION DOSE FACTORS FOR ADULTS
(MREM PER PCI INHALED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
BA140	4.88E-06	6.13E-09	3.21E-07	NO DATA	2.09E-09	1.59E-04	2.73E-05
BA141	1.25E-11	9.41E-15	4.20E-13	NO DATA	8.75E-15	2.42E-07	1.45E-17
BA142	3.29E-12	3.38E-15	2.07E-13	NO DATA	2.86E-15	1.49E-07	1.96E-26
LA140	4.30E-08	2.17E-08	5.73E-09	NO DATA	NO DATA	1.70E-05	5.73E-05
LA142	8.54E-11	3.88E-11	9.65E-12	NO DATA	NO DATA	7.91E-07	2.64E-07
CE141	2.49E-06	1.69E-06	1.91E-07	NO DATA	7.83E-07	4.52E-05	1.50E-05
CE143	2.33E-08	1.72E-08	1.91E-09	NO DATA	7.60E-09	9.97E-06	2.83E-05
CE144	4.29E-04	1.79E-04	2.30E-05	NO DATA	1.06E-04	9.72E-04	1.02E-04
PR143	1.17E-06	4.69E-07	5.80E-08	NO DATA	2.70E-07	3.51E-05	2.50E-05
PR144	3.76E-12	1.56E-12	1.91E-13	NO DATA	8.81E-13	1.27E-07	2.69E-18
ND147	6.59E-07	7.62E-07	4.56E-08	NO DATA	4.45E-07	2.76E-05	2.16E-05
W 187	1.06E-09	8.85E-10	3.10E-10	NO DATA	NO DATA	3.63E-06	1.94E-05
NP239	2.87E-08	2.82E-09	1.55E-09	NO DATA	8.75E-09	4.70E-06	1.49E-05

TABLE E-8

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INHALATION DOSE FACTORS FOR TEENAGER (MREM PER PCI INHALED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
H 3	NO DATA	1.59E-07	1.59E-07	1.59E-07	1.59E-07	1.59E-07	1.59E-07
C 14	3.25E-06	6.09E-07	6.09E-07	6.09E-07	6.09E-07	6.09E-07	6.09E-07
NA 24	1.72E-06	1.72E-06	1.72E-06	1.72E-06	1.72E-06	1.72E-06	1.72E-06
P 32	2.36E-04	1.37E-05	8.95E-06	NO DATA	NO DATA	NO DATA	1.16E-05
CR 51	NO DATA	NO DATA	1.69E-08	9.37E-09	3.84E-09	2.62E-06	3.75E-07
MN 54	NO DATA	6.39E-06	1.05E-06	NO DATA	1.59E-06	2.48E-04	8.35E-06
MN 56	NO DATA	2.12E-10	3.15E-11	NO DATA	2.24E-10	1.90E-06	7.18E-06
FE 55	4.18E-06	2.98E-06	6.93E-07	NO DATA	NO DATA	1.55E-05	7.99E-07
FE 59	1.99E-06	4.62E-06	1.79E-06	NO DATA	NO DATA	1.91E-04	2.23E-05
CO 58	NO DATA	2.59E-07	3.47E-07	NO DATA	NO DATA	1.68E-04	1.19E-05
CO 60	NO DATA	1.89E-06	2.48E-06	NO DATA	NO DATA	1.09E-03	3.24E-05
NI 63	7.25E-05	5.43E-06	2.47E-06	NO DATA	NO DATA	3.84E-05	1.77E-06
NI 65	2.73E-10	3.66E-11	1.59E-11	NO DATA	NO DATA	1.17E-06	4.59E-06
CU 64	NO DATA	2.54E-10	1.06E-10	NO DATA	8.01E-10	1.39E-06	7.68E-06
ZN 65	4.82E-06	1.67E-05	7.80E-06	NO DATA	1.08E-05	1.55E-04	5.83E-06
ZN 69	6.04E-12	1.15E-11	8.07E-13	NO DATA	7.53E-12	1.98E-07	3.56E-08
BR 83	NO DATA	NO DATA	4.30E-08	NO DATA	NO DATA	NO DATA	LT E-24
BR 84	NO DATA	NO DATA	5.41E-08	NO DATA	NO DATA	NO DATA	LT E-24
BR 85	NO DATA	NO DATA	2.29E-09	NO DATA	NO DATA	NO DATA	LT E-24
RB 86	NO DATA	2.38E-05	1.05E-05	NO DATA	NO DATA	NO DATA	2.21E-06
RB 88	NO DATA	6.82E-08	3.40E-08	NO DATA	NO DATA	NO DATA	3.65E-15
RB 89	NO DATA	4.40E-08	2.91E-08	NO DATA	NO DATA	NO DATA	4.22E-17
SR 89	5.43E-05	NO DATA	1.56E-06	NO DATA	NO DATA	3.02E-04	4.64E-05
SR 90	1.35E-02	NO DATA	8.35E-04	NO DATA	NO DATA	2.06E-03	9.56E-05
SR 91	1.10E-08	NO DATA	4.39E-10	NO DATA	NO DATA	7.59E-06	3.24E-05
SR 92	1.19E-09	NO DATA	5.08E-11	NO DATA	NO DATA	3.43E-06	1.49E-05
Y 90	3.73E-07	NO DATA	1.00E-08	NO DATA	NO DATA	3.66E-05	6.99E-05
Y 91M	4.63E-11	NO DATA	1.77E-12	NO DATA	NO DATA	4.00E-07	3.77E-09
Y 91	8.26E-05	NO DATA	2.21E-06	NO DATA	NO DATA	3.67E-04	5.11E-05
Y 92	1.84E-09	NO DATA	5.36E-11	NO DATA	NO DATA	3.35E-06	2.06E-05

TABLE E-8, CONT'D

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INHALATION DOSE FACTORS FOR TEFNAGER
(MREM PER PCI INHALED)

NUCLIDE	BONE	LIVFR	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
Y 93	1.69E-08	NO DATA	4.65E-10	NO DATA	NO DATA	1.04E-05	7.24E-05
ZR 95	1.82E-05	5.73E-06	3.94E-06	NO DATA	8.42E-06	3.36E-04	1.86E-05
ZR 97	1.72E-08	3.40E-09	1.57E-09	NO DATA	5.15E-09	1.62E-05	7.88E-05
NB 95	2.32E-06	1.29E-06	7.08E-07	NO DATA	1.25E-06	9.39E-05	1.21E-05
MO 99	NO DATA	2.11E-08	4.03E-09	NO DATA	5.14E-08	1.92E-05	3.36E-05
TC 99M	1.73E-13	4.83E-13	6.24E-12	NO DATA	7.20E-12	1.44E-07	7.66E-07
TC101	7.40E-15	1.05E-14	1.03E-13	NO DATA	1.90E-13	8.34E-08	1.09E-16
RU103	2.63E-07	NO DATA	1.12E-07	NO DATA	9.29E-07	9.79E-05	1.36E-05
RU105	1.40E-10	NO DATA	5.42E-11	NO DATA	1.76E-10	2.27E-06	1.13E-05
RU106	1.23E-05	NO DATA	1.55E-06	NO DATA	2.38E-05	2.01E-03	1.20E-04
AG110M	1.73E-06	1.64E-06	9.99E-07	NO DATA	3.13E-06	8.44E-04	3.41E-05
TE125M	6.10E-07	2.80E-07	8.34E-08	1.75E-07	NO DATA	6.70E-05	9.38E-06
TE127M	2.25E-06	1.02E-06	2.73E-07	5.48E-07	8.17E-06	2.07E-04	1.99E-05
TE127	2.51E-10	1.14F-10	5.52E-11	1.77E-10	9.10E-10	1.40E-06	1.01E-05
TE129M	1.74E-06	8.23E-07	2.81E-07	5.72E-07	6.49E-06	2.47E-04	5.06E-05
TE129	8.87E-12	4.22E-12	2.20E-12	6.48E-12	3.32E-11	4.12E-07	2.02E-07
TE131M	1.23E-08	7.51E-09	5.03E-09	9.06E-09	5.49E-08	2.97E-05	7.76E-05
TE131	1.97E-12	1.04E-12	6.30E-13	1.55E-12	7.72E-12	2.92E-07	1.89E-09
TE132	4.50E-08	3.63E-08	2.74E-08	3.07E-08	2.44E-07	5.61E-05	5.79E-05
I 130	7.80E-07	2.24E-06	8.96E-07	1.86E-04	3.44E-06	NO DATA	1.14E-06
I 131	4.43E-06	6.14E-06	3.30E-06	1.83E-03	1.05E-05	NO DATA	8.11F-07
I 132	1.99E-07	5.47E-07	1.97E-07	1.89E-05	8.65E-07	NO DATA	1.59E-07
I 133	1.52E-06	2.56E-06	7.78E-07	3.65E-04	4.49E-06	NO DATA	1.29E-06
I 134	1.11E-07	2.90E-07	1.05E-07	4.94E-06	4.58E-07	NO DATA	2.55E-09
I 135	4.62E-07	1.18E-06	4.36E-07	7.76E-05	1.86E-06	NO DATA	8.69E-07
CS134	6.28E-05	1.41E-04	6.86E-05	NO DATA	4.69E-05	1.83E-05	1.22E-06
CS136	6.44E-06	2.42E-05	1.71E-05	NO DATA	1.38E-05	2.22E-06	1.36E-06
CS137	8.38E-05	1.06E-04	3.89E-05	NO DATA	3.80E-05	1.51E-05	1.06E-06
CS138	5.82E-08	1.07E-07	5.58E-08	NO DATA	8.28E-08	9.84E-09	3.38E-11
BA139	1.67E-10	1.18E-13	4.87E-12	NO DATA	1.11E-13	8.08E-07	8.06E-07

TABLE E-8, CONT'D

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INHALATION DOSE FACTORS FOR TEENAGER
(MREM PER PCI INHALED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
BA140	6.84E-06	8.38E-09	4.40E-07	NO DATA	2.85E-09	2.54E-04	2.86E-05
BA141	1.78E-11	1.32E-14	5.93E-13	NO DATA	1.23E-14	4.11E-07	9.33E-14
BA142	4.62E-12	4.63E-15	2.84E-13	NO DATA	3.92E-15	2.39E-07	5.99E-20
LA140	5.99E-08	2.95E-08	7.82E-09	NO DATA	NO DATA	2.68E-05	6.09E-05
LA142	1.20E-10	5.31E-11	1.32E-11	NO DATA	NO DATA	1.27E-06	1.50E-06
CE141	3.55E-06	2.37E-06	2.71E-07	NO DATA	1.11E-06	7.67E-05	1.58E-05
CE143	3.32E-08	2.42E-08	2.70E-09	NO DATA	1.08E-08	1.63E-05	3.19E-05
CE144	6.11E-04	2.53E-04	3.28E-05	NO DATA	1.51E-04	1.67E-03	1.08E-04
PR143	1.67E-06	6.64E-07	8.28E-08	NO DATA	3.86E-07	6.04E-05	2.67E-05
PR144	5.37E-12	2.20E-12	2.72E-13	NO DATA	1.26E-12	2.19E-07	2.94E-14
ND147	9.83E-07	1.07E-06	6.41E-08	NO DATA	6.28E-07	4.65E-05	2.28E-05
W 187	1.50E-09	1.22E-09	4.29E-10	NO DATA	NO DATA	5.92E-06	2.21E-05
NP239	4.23E-08	3.99E-09	2.21E-09	NO DATA	1.25E-08	8.11E-06	1.65E-05

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PAGE 1 OF 3

INHALATION DOSE FACTORS FOR CHILD
(MREM PER PCI INHALED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
H 3	NO DATA	3.04E-07	3.04E-07	3.04E-07	3.04E-07	3.04E-07	3.04E-07
C 14	9.70E-06	1.82E-06	1.82E-06	1.82E-06	1.82E-06	1.82E-06	1.82E-06
NA 24	4.35E-06	4.35E-06	4.35E-06	4.35E-06	4.35E-06	4.35E-06	4.35E-06
P 32	7.04E-04	3.09E-05	2.67E-05	NO DATA	NO DATA	NO DATA	1.14E-05
CR 51	NO DATA	NO DATA	4.17E-08	2.31E-08	6.57E-09	4.59E-06	2.93E-07
MN 54	NO DATA	1.16E-05	2.57E-06	NO DATA	2.71E-06	4.26E-04	6.19E-06
MN 56	NO DATA	4.48E-10	8.43E-11	NO DATA	4.52E-10	3.55E-06	3.33E-05
FE 55	1.28E-05	6.80E-06	2.10E-06	NO DATA	NO DATA	3.00E-05	7.75E-07
FE 59	5.59E-06	9.04E-06	4.51E-06	NO DATA	NO DATA	3.43E-04	1.91E-05
CO 58	NO DATA	4.79E-07	8.55E-07	NO DATA	NO DATA	2.99E-04	9.29E-06
CO 60	NO DATA	3.55E-06	6.12E-06	NO DATA	NO DATA	1.91E-03	2.60E-05
NI 63	2.22E-04	1.25E-05	7.56E-06	NO DATA	NO DATA	7.43E-05	1.71E-06
NI 65	8.08E-10	7.99E-11	4.44E-11	NO DATA	NO DATA	2.21E-06	2.27E-05
CU 64	NO DATA	5.39E-10	2.90E-10	NO DATA	1.63E-09	2.59E-06	9.92E-06
ZN 65	1.15E-05	3.06E-05	1.90E-05	NO DATA	1.93E-05	2.69E-04	4.41E-06
ZN 69	1.81E-11	2.61E-11	2.41E-12	NO DATA	1.58E-11	3.84E-07	2.75E-06
BR 83	NO DATA	NO DATA	1.28E-07	NO DATA	NO DATA	NO DATA	LT E-24
BR 84	NO DATA	NO DATA	1.48E-07	NO DATA	NO DATA	NO DATA	LT E-24
BR 85	NO DATA	NO DATA	6.84E-09	NO DATA	NO DATA	NO DATA	LT E-24
RB 86	NO DATA	5.36E-05	3.09E-05	NO DATA	NO DATA	NO DATA	2.16E-06
RB 88	NO DATA	1.52E-07	9.90E-08	NO DATA	NO DATA	NO DATA	4.66E-09
RB 89	NO DATA	9.33E-08	7.85E-08	NO DATA	NO DATA	NO DATA	5.11E-10
SR 89	1.62E-04	NO DATA	4.66E-06	NO DATA	NO DATA	5.83E-04	4.52E-05
SR 90	2.73E-02	NO DATA	1.74E-03	NO DATA	NO DATA	3.99E-03	9.28E-05
SR 91	3.28E-08	NO DATA	1.24E-09	NO DATA	NO DATA	1.44E-05	4.70E-05
SR 92	3.54E-09	NO DATA	1.42E-10	NO DATA	NO DATA	6.49E-06	6.55E-05
Y 90	1.11E-06	NO DATA	2.99E-08	NO DATA	NO DATA	7.07E-05	7.24E-05
Y 91M	1.37E-10	NO DATA	4.98E-12	NO DATA	NO DATA	7.60E-07	4.64E-07
Y 91	2.47E-04	NO DATA	6.59E-06	NO DATA	NO DATA	7.10E-04	4.97E-05
Y 92	5.50E-09	NO DATA	1.57E-10	NO DATA	NO DATA	6.46E-06	6.46E-05

TABLE E-9, CONT'D

PAGE 2 OF 3

INHALATION DOSE FACTORS FOR CHILD
(MREM PER PCI INHALED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
Y 93	5.04E-08	NO DATA	1.38E-09	NO DATA	NO DATA	2.01E-05	1.05E-04
ZR 95	5.13E-05	1.13E-05	1.00E-05	NO DATA	1.61E-05	6.03E-04	1.65E-05
ZR 97	5.07E-08	7.54E-09	4.32E-09	NO DATA	1.05E-08	3.06E-05	9.49E-05
NB 95	6.35E-06	2.48E-06	1.77E-06	NO DATA	2.33E-06	1.66E-04	1.00E-05
MO 99	NO DATA	4.66E-08	1.15E-08	NO DATA	1.06E-07	3.66E-05	3.42E-05
TC 99M	4.81E-13	9.41E-13	1.56E-11	NO DATA	1.37E-11	2.57E-07	1.30E-06
TC101	2.19E-14	2.30E-14	2.91E-13	NO DATA	3.92E-13	1.58E-07	4.41E-09
RU103	7.55E-07	NO DATA	2.90E-07	NO DATA	1.90E-06	1.79E-04	1.21E-05
RU105	4.13E-10	NO DATA	1.50E-10	NO DATA	3.63E-10	4.30E-06	2.67E-05
RU106	3.68E-05	NO DATA	4.57E-06	NO DATA	4.97E-05	3.87E-03	1.16E-04
AG110M	4.56E-06	3.08E-06	2.47E-06	NO DATA	5.74E-06	1.48E-03	2.71E-05
TE125M	1.82E-06	6.29E-07	2.47E-07	5.20E-07	NO DATA	1.29E-04	9.13E-06
TE127M	6.72E-06	2.31E-06	8.16E-07	1.64E-06	1.72E-05	4.00E-04	1.93E-05
TE127	7.49E-10	2.57E-10	1.65E-10	5.30E-10	1.91E-09	2.71E-06	1.52E-05
TE129M	5.19E-06	1.85E-06	8.22E-07	1.71E-06	1.36E-05	4.76E-04	4.91E-05
TE129	2.64E-11	9.45E-12	6.44E-12	1.93E-11	6.94E-11	7.93E-07	6.89E-06
TE131M	3.63E-08	1.60E-08	1.37E-08	2.64E-08	1.08E-07	5.56E-05	8.32E-05
TE131	5.87E-12	2.28E-12	1.78E-12	4.59E-12	1.59E-11	5.55E-07	3.60E-07
TE132	1.30E-07	7.36E-08	7.12E-08	8.58E-08	4.79E-07	1.02E-04	3.72E-05
I 130	2.21E-06	4.43E-06	2.28E-06	4.99E-04	6.61E-06	NO DATA	1.38E-06
I 131	1.30E-05	1.30E-05	7.37E-06	4.39E-03	2.13E-05	NO DATA	7.68E-07
I 132	5.72E-07	1.10E-06	5.07E-07	5.23E-05	1.69E-06	NO DATA	8.65E-07
I 133	4.48E-06	5.49E-06	2.08E-06	1.04E-03	9.13E-06	NO DATA	1.48E-06
I 134	3.17E-07	5.84E-07	2.69E-07	1.37E-05	8.92E-07	NO DATA	2.58E-07
I 135	1.33E-06	2.36E-06	1.12E-06	2.14E-04	3.62E-06	NO DATA	1.20E-06
CS134	1.76E-04	2.74E-04	6.07E-05	NO DATA	8.93E-05	3.27E-05	1.04E-06
CS136	1.76E-05	4.62E-05	3.14E-05	NO DATA	2.58E-05	3.93E-06	1.13E-06
CS137	2.45E-04	2.23E-04	3.47E-05	NO DATA	7.63E-05	2.81E-05	9.78E-07
CS138	1.71E-07	2.27E-07	1.50E-07	NO DATA	1.68E-07	1.84E-08	7.29E-08
BA139	4.98E-10	2.66E-13	1.45E-11	NO DATA	2.33E-13	1.56E-06	1.56E-05

TABLE E-9, CONT'D

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INHALATION DOSE FACTORS FOR CHILD
(MREM PER PCI INHALED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
BA140	2.00E-05	1.75E-08	1.17E-06	NO DATA	5.71E-09	4.71E-04	2.75E-05
BA141	5.29E-11	2.95E-14	1.72E-12	NO DATA	2.56E-14	7.89E-07	7.44E-08
BA142	1.35E-11	9.73E-15	7.54E-13	NO DATA	7.87E-15	4.44E-07	7.41E-10
LA140	1.74E-07	6.08E-08	2.04E-08	NO DATA	NO DATA	4.94E-05	6.10E-05
LA142	3.50E-10	1.11E-10	3.49E-11	NO DATA	NO DATA	2.35E-06	2.05E-05
CE141	1.06E-05	5.28E-06	7.83E-07	NO DATA	2.31E-06	1.47E-04	1.53E-05
CE143	9.89E-08	5.37E-08	7.77E-09	NO DATA	2.26E-08	3.12E-05	3.44E-05
CE144	1.83E-03	5.72E-04	9.77E-05	NO DATA	3.17E-04	3.23E-03	1.05E-04
PR143	4.99E-06	1.50E-06	2.47E-07	NO DATA	8.11E-07	1.17E-04	2.63E-05
PR144	1.61E-11	4.99E-12	8.10E-13	NO DATA	2.64E-12	4.23E-07	5.32E-08
ND147	2.92E-06	2.36E-06	1.84E-07	NO DATA	1.30E-06	8.87E-05	2.22E-05
W 187	4.41E-09	2.61E-09	1.17E-09	NO DATA	NO DATA	1.11E-05	2.46E-05
NP239	1.26E-07	9.04E-09	6.35E-09	NO DATA	2.63E-08	1.57E-05	1.73E-05

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INHALATION DOSE FACTORS FOR INFANT
(MREM PER PCI INHALED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
H 3	NO DATA	4.62E-07	4.62E-07	4.62E-07	4.62E-07	4.62E-07	4.62E-07
C 14	1.89E-05	3.79E-06	3.79E-06	3.79E-06	3.79E-06	3.79E-06	3.79E-06
NA 24	7.54E-06	7.54E-06	7.54E-06	7.54E-06	7.54E-06	7.54E-06	7.54E-06
P 32	1.45E-03	8.03E-05	5.53E-05	NO DATA	NO DATA	NO DATA	1.15E-05
CR 51	NO DATA	NO DATA	6.39E-08	4.11E-08	9.45E-09	9.17E-06	2.55E-07
MN 54	NO DATA	1.81E-05	3.56E-06	NO DATA	3.56E-06	7.14E-04	5.04E-06
MN 56	NO DATA	1.10E-09	1.58E-10	NO DATA	7.86E-10	8.95E-06	5.12E-05
FE 55	1.41E-05	8.39E-06	2.38E-06	NO DATA	NO DATA	6.21E-05	7.82E-07
FE 59	9.69E-06	1.68E-05	6.77E-06	NO DATA	NO DATA	7.25E-04	1.77E-05
CO 58	NO DATA	8.71E-07	1.30E-06	NO DATA	NO DATA	5.55E-04	7.95E-06
CO 60	NO DATA	5.73E-06	8.41E-06	NO DATA	NO DATA	3.22E-03	2.28E-05
NI 63	2.42E-04	1.46E-05	8.29E-06	NO DATA	NO DATA	1.49E-04	1.73E-06
NI 65	1.71E-09	2.03E-10	8.79E-11	NO DATA	NO DATA	5.80E-06	3.58E-05
CU 64	NO DATA	1.34E-09	5.53E-10	NO DATA	2.84E-09	6.64E-06	1.07E-05
ZN 65	1.38E-05	4.47E-05	2.22E-05	NO DATA	2.32E-05	4.62E-04	3.67E-05
ZN 69	3.85E-11	6.91E-11	5.13E-12	NO DATA	2.87E-11	1.05E-06	9.44E-06
BR 83	NO DATA	NO DATA	2.72E-07	NO DATA	NO DATA	NO DATA	LT E-24
BR 84	NO DATA	NO DATA	2.86E-07	NO DATA	NO DATA	NO DATA	LT E-24
BR 85	NO DATA	NO DATA	1.46E-08	NO DATA	NO DATA	NO DATA	LT E-24
RB 86	NO DATA	1.36E-04	6.30E-05	NO DATA	NO DATA	NO DATA	2.17E-06
RB 88	NO DATA	3.98E-07	2.05E-07	NO DATA	NO DATA	NO DATA	2.42E-07
RB 89	NO DATA	2.29E-07	1.47E-07	NO DATA	NO DATA	NO DATA	4.87E-08
SR 89	2.84E-04	NO DATA	8.15E-06	NO DATA	NO DATA	1.45E-03	4.57E-05
SR 90	2.92E-02	NO DATA	1.85E-03	NO DATA	NO DATA	8.03E-03	9.36E-05
SR 91	6.83E-08	NO DATA	2.47E-09	NO DATA	NO DATA	3.76E-05	5.24E-05
SR 92	7.50E-09	NO DATA	2.79E-10	NO DATA	NO DATA	1.70E-05	1.00E-04
Y 90	2.35E-06	NO DATA	6.30E-08	NO DATA	NO DATA	1.92E-04	7.43E-05
Y 91M	2.91E-10	NO DATA	9.90E-12	NO DATA	NO DATA	1.99E-06	1.68E-06
Y 91	4.20E-04	NO DATA	1.12E-05	NO DATA	NO DATA	1.75E-03	5.02E-05
Y 92	1.17E-08	NO DATA	3.29E-10	NO DATA	NO DATA	1.75E-05	9.04E-05

TABLE E-10, CONT'D

PAGE 2 OF 3

INHALATION DOSE FACTORS FOR INFANT
(MREM PER PCI INHALED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
Y 93	1.07E-07	NO DATA	2.91E-09	NO DATA	NO DATA	5.46E-05	1.19E-04
ZR 95	8.24E-05	1.99E-05	1.45E-05	NO DATA	2.22E-05	1.25E-03	1.55E-05
ZR 97	1.07E-07	1.83E-08	8.36E-09	NO DATA	1.85E-08	7.88E-05	1.00E-04
NB 95	1.12E-05	4.59E-06	2.70E-06	NO DATA	3.37E-06	3.42E-04	9.05E-06
MO 99	NO DATA	1.18E-07	2.31E-08	NO DATA	1.89E-07	9.63E-05	3.48E-05
TC 99M	9.98E-13	2.06E-12	2.66E-11	NO DATA	2.22E-11	5.79E-07	1.45E-06
TC101	4.65E-14	5.98E-14	5.80E-13	NO DATA	6.99E-13	4.17E-07	6.03E-07
RU103	1.44E-06	NO DATA	4.85E-07	NO DATA	3.03E-06	3.94E-04	1.15E-05
RU105	8.74E-10	NO DATA	2.93E-10	NO DATA	6.42E-10	1.12E-05	3.46E-05
RU106	6.20E-05	NO DATA	7.77E-06	NO DATA	7.61E-05	8.26E-03	1.17E-04
AG110M	7,13E-06	5.16E-06	3.57E-06	NO DATA	7.80E-06	2.62E-03	2.36E-05
TE125M	3.40E-06	1.42E-06	4.70E-07	1.16E-06	NO DATA	3.19E-04	9.22E-06
TE127M	1.19E-05	4.93E-06	1.48E-06	3.48E-06	2.68E-05	9.37E-04	1.95E-05
TE127	1.59E-09	6.81E-10	3.49E-10	1.32E-09	3.47E-09	7.39E-06	1.74E-05
TE129M	1.01E-05	4.35E-06	1.59E-06	3.91E-06	2.27E-05	1.20E-03	4.93E-05
TE129	5.63E-11	2.48E-11	1.34E-11	4.82E-11	1.25E-10	2.14E-06	1.88E-05
TE131M	7.62E-08	3.93E-08	2.59E-08	6.38E-08	1.89E-07	1.42E-04	8.51E-05
TE131	1.24E-11	5.87E-12	3.57E-12	1.13E-11	2.85E-11	1.47E-06	5.87E-06
TE132	2.66E-07	1.69E-07	1.26E-07	1.99E-07	7.39E-07	2.43E-04	3.15E-05
I 130	4.54E-06	9.91E-06	3.98E-06	1.14E-03	1.09E-05	NO DATA	1.42E-06
I 131	2.71E-05	3.17E-05	1.40E-05	1.06E-02	3.70E-05	NO DATA	7.56E-07
I 132	1.21E-06	2.53E-06	8.99E-07	1.21E-04	2.82E-06	NO DATA	1.36E-06
I 133	9.46E-06	1.37E-05	4.00E-06	2.54E-03	1.60E-05	NO DATA	1.54E-06
I 134	6.58E-07	1.34E-06	4.75E-07	3.18E-05	1.49E-06	NO DATA	9.21E-07
I 135	2.76E-06	5.43E-06	1.98E-06	4.97E-04	6.05E-06	NO DATA	1.31E-06
CS134	2.83E-04	5.02E-04	5.32E-05	NO DATA	1.36E-04	5.69E-05	9.53E-07
CS136	3.45E-05	9.61E-05	3.78E-05	NO DATA	4.03E-05	8.40E-06	1.02E-06
CS137	3.92E-04	4.37E-04	3.25E-05	NO DATA	1.23E-04	5.09E-05	9.53E-07
CS138	3.61E-07	5.58E-07	2.84E-07	NO DATA	2.93E-07	4.67E-08	6.26E-07
BA139	1.06E-09	7.03E-13	3.07E-11	NO DATA	4.73E-13	4.25E-06	3.64E-05

TABLE E-10, CONT'D

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INHALATION DOSE FACTORS FOR INFANT
(MREM PER PCI INHALED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
BA140	4.00E-05	4.00E-08	2.07E-06	NO DATA	9.59E-09	1.14E-03	2.74E-05
BA141	1.12E-10	7.70E-14	3.55E-12	NO DATA	4.64E-14	2.12E-06	3.39E-06
BA142	2.84E-11	2.36E-14	1.40E-12	NO DATA	1.36E-14	1.11E-06	4.95E-07
LA140	3.61E-07	1.43E-07	3.68E-08	NO DATA	NO DATA	1.20E-04	6.06E-05
LA142	7.36E-10	2.69E-10	6.46E-11	NO DATA	NO DATA	5.87E-06	4.25E-05
CE141	1.98E-05	1.19E-05	1.42E-06	NO DATA	3.75E-06	3.69E-04	1.54E-05
CE143	2.09E-07	1.98E-07	1.59E-08	NO DATA	4.03E-08	8.30E-05	3.55E-05
CE144	2.28E-03	8.65E-04	1.26E-04	NO DATA	3.84E-04	7.03E-03	1.06E-04
PR143	1.00E-05	3.74E-06	4.99E-07	NO DATA	1.41E-06	3.09E-04	2.66E-05
PR144	3.42E-11	1.32E-11	1.72E-12	NO DATA	4.80E-12	1.15E-06	3.06E-06
ND147	5.67E-06	5.81E-06	3.57E-07	NO DATA	2.25E-06	2.30E-04	2.23E-05
W 187	9.26E-09	6.44E-09	2.23E-09	NO DATA	NO DATA	2.83E-05	2.54E-05
NP239	2.65E-07	2.37E-08	1.34E-08	NO DATA	4.73E-08	4.25E-05	1.78E-05

TABLE E-11

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INGESTION DOSE FACTORS FOR ADULTS
(MREM PER PCI INGESTED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
H 3	NO DATA	1.05E-07	1.05E-07	1.05E-07	1.05E-07	1.05E-07	1.05E-07
C 14	2.84E-06	5.68E-07	5.68E-07	5.68E-07	5.68E-07	5.68E-07	5.68E-07
NA 24	1.70E-06	1.70E-06	1.70E-06	1.70E-06	1.70E-06	1.70E-06	1.70E-06
P 32	1.93E-04	1.20E-05	7.46E-06	NO DATA	NO DATA	NO DATA	2.17E-05
CR 51	NO DATA	NO DATA	2.66E-09	1.59E-09	5.86E-10	3.53E-09	6.69E-07
MN 54	NO DATA	4.57E-06	8.72E-07	NO DATA	1.36E-06	NO DATA	1.40E-05
MN 56	NO DATA	1.15E-07	2.04E-08	NO DATA	1.46E-07	NO DATA	3.67E-06
FE 55	2.75E-06	1.90E-06	4.43E-07	NO DATA	NO DATA	1.06E-06	1.09E-06
FE 59	4.34E-06	1.02E-05	3.91E-06	NO DATA	NO DATA	2.85E-06	3.40E-05
CO 58	NO DATA	7.45E-07	1.67E-06	NO DATA	NO DATA	NO DATA	1.51E-05
CO 60	NO DATA	2.14E-06	4.72E-06	NO DATA	NO DATA	NO DATA	4.02E-05
NI 63	1.30E-04	9.01E-06	4.36E-06	NO DATA	NO DATA	NO DATA	1.88E-06
NI 65	5.28E-07	6.86E-08	3.13E-08	NO DATA	NO DATA	NO DATA	1.74E-06
CU 64	NO DATA	8.33E-08	3.91E-08	NO DATA	2.10E-07	NO DATA	7.10E-06
ZN 65	4.84E-06	1.54E-05	6.96E-06	NO DATA	1.03E-05	NO DATA	9.70E-06
ZN 69	1.03E-08	1.97E-08	1.37E-09	NO DATA	1.28E-08	NO DATA	2.96E-09
BR 83	NO DATA	NO DATA	4.02E-08	NO DATA	NO DATA	NO DATA	5.79E-08
BR 84	NO DATA	NO DATA	5.21E-08	NO DATA	NO DATA	NO DATA	4.09E-13
BR 85	NO DATA	NO DATA	2.14E-09	NO DATA	NO DATA	NO DATA	LT E-24
RB 86	NO DATA	2.11E-05	9.83E-06	NO DATA	NO DATA	NO DATA	4.16E-06
RB 88	NO DATA	6.05E-08	3.21E-08	NO DATA	NO DATA	NO DATA	8.36E-19
RB 89	NO DATA	4.01E-08	2.82E-08	NO DATA	NO DATA	NO DATA	2.33E-21
SR 89	3.08E-04	NO DATA	8.84E-06	NO DATA	NO DATA	NO DATA	4.94E-05
SR 90	7.58E-03	NO DATA	1.86E-03	NO DATA	NO DATA	NO DATA	2.19E-04
SR 91	5.67E-06	NO DATA	2.29E-07	NO DATA	NO DATA	NO DATA	2.70E-05
SR 92	2.15E-06	NO DATA	9.30E-08	NO DATA	NO DATA	NO DATA	4.26E-05
Y 90	9.62E-09	NO DATA	2.58E-10	NO DATA	NO DATA	NO DATA	1.02E-04
Y 91M	9.09E-11	NO DATA	3.52E-12	NO DATA	NO DATA	NO DATA	2.67E-10
Y 91	1.41E-07	NO DATA	3.77E-09	NO DATA	NO DATA	NO DATA	7.76E-05
Y 92	8.45E-10	NO DATA	2.47E-11	NO DATA	NO DATA	NO DATA	1.48E-05

TABLE E-11, CONT'D

PAGE 2 OF 3

INGESTION DOSE FACTORS FOR ADULTS
(MREM PER PCI INGESTED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
Y 93	2.68E-09	NO DATA	7.40E-11	NO DATA	NO DATA	NO DATA	8.50E-05
ZR 95	3.04E-08	9.75E-09	6.60E-09	NO DATA	1.53E-08	NO DATA	3.09E-05
ZR 97	1.68E-09	3.39E-10	1.55E-10	NO DATA	5.12E-10	NO DATA	1.05E-04
NB 95	6.22E-09	3.46E-09	1.86E-09	NO DATA	3.42E-09	NO DATA	2.10E-05
MO 99	NO DATA	4.31E-06	8.20E-07	NO DATA	9.76E-06	NO DATA	9.99E-06
TC 99M	2.47E-10	6.98E-10	8.89E-09	NO DATA	1.06E-08	3.42E-10	4.13E-07
TC101	2.54E-10	3.66E-10	3.59E-09	NO DATA	6.59E-09	1.87E-10	1.10E-21
RU103	1.85E-07	NO DATA	7.97E-08	NO DATA	7.06E-07	NO DATA	2.16E-05
RU105	1.54E-08	NO DATA	6.08E-09	NO DATA	1.99E-07	NO DATA	9.42E-06
RU106	2.75E-06	NO DATA	3.48E-07	NO DATA	5.31E-06	NO DATA	1.78E-04
AG110M	1.60E-07	1.48E-07	8.79E-08	NO DATA	2.91E-07	NO DATA	6.04E-05
TE125M	2.68E-06	9.71E-07	3.59E-07	8.06E-07	1.09E-05	NO DATA	1.07E-05
TE127M	6.77E-06	2.42E-06	8.25E-07	1.73E-06	2.75E-05	NO DATA	2.27E-05
TE127	1.10E-07	3.95E-08	2.38E-08	8.15E-08	4.48E-07	NO DATA	8.68E-06
TE129M	1.15E-05	4.29E-06	1.82E-06	3.95E-06	4.80E-05	NO DATA	5.79E-05
TE129	3.14E-08	1.18E-08	7.65E-09	2.41E-08	1.32E-07	NO DATA	2.37E-08
TE131M	1.73E-06	8.46E-07	7.05E-07	1.34E-06	8.57E-06	NO DATA	8.40E-05
TE131	1.97E-08	8.23E-09	6.22E-09	1.62E-08	8.63E-08	NO DATA	2.79E-09
TE132	2.52E-06	1.63E-06	1.53E-06	1.80E-06	1.57E-05	NO DATA	7.71E-05
I 130	7.56E-07	2.23E-06	8.80E-07	1.89E-04	3.48E-06	NO DATA	1.92E-06
I 131	4.16E-06	5.95E-06	3.41E-06	1.95E-03	1.02E-05	NO DATA	1.57E-06
I 132	2.03E-07	5.43E-07	1.90E-07	1.90E-05	8.65E-07	NO DATA	1.02E-07
I 133	1.42E-06	2.47E-06	7.53E-07	3.63E-04	4.31E-06	NO DATA	2.22E-06
I 134	1.06E-07	2.88E-07	1.03E-07	4.99E-06	4.58E-07	NO DATA	2.51E-10
I 135	4.43E-07	1.16E-06	4.28E-07	7.65E-05	1.86E-06	NO DATA	1.31E-06
CS134	6.22E-05	1.48E-04	1.21E-04	NO DATA	4.79E-05	1.59E-05	2.59E-06
CS136	6.51E-06	2.57E-05	1.85E-05	NO DATA	1.43E-05	1.96E-06	2.92E-06
CS137	7.97E-05	1.09E-04	7.14E-05	NO DATA	3.70E-05	1.23E-05	2.11E-06
CS138	5.52E-08	1.09E-07	5.40E-08	NO DATA	8.01E-08	7.91E-09	4.65E-13
BA139	9.70E-08	6.91E-11	2.84E-09	NO DATA	6.46E-11	3.92E-11	1.72E-07

TABLE E-11, CONT'D

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INGESTION DOSE FACTORS FOR ADULTS
(MREM PER PCI INGESTED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
BA140	2.03E-05	2.55E-08	1.33E-06	NO DATA	8.67E-09	1.46E-08	4.18E-05
BA141	4.71E-08	3.56E-11	1.59E-09	NO DATA	3.31E-11	2.02E-11	2.22E-17
BA142	2.13E-08	2.19E-11	1.34E-09	NO DATA	1.85E-11	1.24E-11	3.00E-26
LA140	2.50E-09	1.26E-09	3.33E-10	NO DATA	NO DATA	NO DATA	9.25E-05
LA142	1.28E-10	5.82E-11	1.45E-11	NO DATA	NO DATA	NO DATA	4.25E-07
CE141	9.36E-09	6.33E-09	7.18E-10	NO DATA	2.94E-09	NO DATA	2.42E-05
CE143	1.65E-09	1.22E-06	1.35E-10	NO DATA	5.37E-10	NO DATA	4.56E-05
CE144	4.88E-07	2.04E-07	2.62E-08	NO DATA	1.21E-07	NO DATA	1.65E-04
PR143	9.20E-09	3.69E-09	4.56E-10	NO DATA	2.13E-09	NO DATA	4.03E-05
PR144	3.01E-11	1.25E-11	1.53E-12	NO DATA	7.05E-12	NO DATA	4.33E-18
ND147	6.29E-09	7.27E-09	4.35E-10	NO DATA	4.25E-09	NO DATA	3.49E-05
W 197	1.03E-07	8.61E-08	3.01E-08	NO DATA	NO DATA	NO DATA	2.82E-05
NP239	1.19E-09	1.17E-10	6.45E-11	NO DATA	3.65E-10	NO DATA	2.40E-05

TABLE E-12

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INGESTION DOSE FACTORS FOR TEENAGER
(MREM PER PCI INGESTED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
H 3	NO DATA	1.06E-07	1.06E-07	1.06E-07	1.06E-07	1.06E-07	1.06E-07
C 14	4.06E-06	8.12E-07	8.12E-07	8.12E-07	8.12E-07	8.12E-07	8.12E-07
NA 24	2.30E-06	2.30E-06	2.30E-06	2.30E-06	2.30E-06	2.30E-06	2.30E-06
P 32	2.76E-04	1.71E-05	1.07E-05	NO DATA	NO DATA	NO DATA	2.32E-05
CR 51	NO DATA	NO DATA	3.60E-09	2.00E-09	7.89E-10	5.14E-09	6.05E-07
MN 54	NO DATA	5.90E-06	1.17E-06	NO DATA	1.76E-06	NO DATA	1.21E-05
MN 56	NO DATA	1.58E-07	2.81E-08	NO DATA	2.00E-07	NO DATA	1.04E-05
FE 55	3.78E-06	2.68E-06	6.25E-07	NO DATA	NO DATA	1.70E-06	1.16E-06
FE 59	5.87E-06	1.37E-05	5.29E-06	NO DATA	NO DATA	4.32E-06	3.24E-05
CO 58	NO DATA	9.72E-07	2.24E-06	NO DATA	NO DATA	NO DATA	1.34E-05
CO 60	NO DATA	2.81E-06	6.33E-06	NO DATA	NO DATA	NO DATA	3.66E-05
NI 63	1.77E-04	1.25E-05	6.00E-06	NO DATA	NO DATA	NO DATA	1.99E-06
NI 65	7.49E-07	9.57E-08	4.36E-08	NO DATA	NO DATA	NO DATA	5.19E-06
CU 64	NO DATA	1.15E-07	5.41E-08	NO DATA	2.91E-07	NO DATA	8.92E-06
ZN 65	5.76E-06	2.00E-05	9.33E-06	NO DATA	1.28E-05	NO DATA	8.47E-06
ZN 69	1.47E-08	2.60E-08	1.96E-09	NO DATA	1.83E-08	NO DATA	5.16E-08
BR 83	NO DATA	NO DATA	5.74E-08	NO DATA	NO DATA	NO DATA	LT E-24
BR 84	NO DATA	NO DATA	7.22E-08	NO DATA	NO DATA	NO DATA	LT E-24
BR 85	NO DATA	NO DATA	3.05E-09	NO DATA	NO DATA	NO DATA	LT E-24
RB 86	NO DATA	2.98E-05	1.40E-05	NO DATA	NO DATA	NO DATA	4.41E-06
RB 88	NO DATA	8.52E-08	4.54E-08	NO DATA	NO DATA	NO DATA	7.30E-15
RB 89	NO DATA	5.50E-08	3.89E-08	NO DATA	NO DATA	NO DATA	8.43E-17
SR 89	4.40E-04	NO DATA	1.26E-05	NO DATA	NO DATA	NO DATA	5.24E-05
SR 90	8.30E-03	NO DATA	2.05E-03	NO DATA	NO DATA	NO DATA	2.33E-04
SR 91	8.07E-06	NO DATA	3.21E-07	NO DATA	NO DATA	NO DATA	3.66E-05
SR 92	3.05E-06	NO DATA	1.30E-07	NO DATA	NO DATA	NO DATA	7.77E-05
Y 90	1.37E-08	NO DATA	3.69E-10	NO DATA	NO DATA	NO DATA	1.13E-04
Y 91M	1.29E-10	NO DATA	4.93E-12	NO DATA	NO DATA	NO DATA	6.09E-09
Y 91	2.01E-07	NO DATA	5.39E-09	NO DATA	NO DATA	NO DATA	8.24E-05
Y 92	1.21E-09	NO DATA	3.50E-11	NO DATA	NO DATA	NO DATA	3.32E-05

TABLE E-12, CONT'D

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INGESTION DOSE FACTORS FOR TEENAGER
(MREM PER PCI INGESTED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
Y 93	3.83E-09	NO DATA	1.05E-10	NO DATA	NO DATA	NO DATA	1.17E-04
ZR 95	4.12E-08	1.30E-08	8.94E-09	NO DATA	1.91E-08	NO DATA	3.00E-05
ZR 97	2.37E-09	4.69E-10	2.16E-10	NO DATA	7.11E-10	NO DATA	1.27E-04
NB 95	8.22E-09	4.56E-09	2.51E-09	NO DATA	4.42E-09	NO DATA	1.95E-05
MO 99	NO DATA	6.03E-06	1.15E-06	NO DATA	1.38E-05	NO DATA	1.08E-05
TC 99M	3.32E-10	9.26E-10	1.20E-08	NO DATA	1.38E-08	5.14E-10	6.08E-07
TC101	3.60E-10	5.12E-10	5.03E-09	NO DATA	9.26E-09	3.12E-10	8.75E-17
RU103	2.55E-07	NO DATA	1.09E-07	NO DATA	8.99E-07	NO DATA	2.13E-05
RU105	2.18E-08	NO DATA	8.46E-09	NO DATA	2.75E-07	NO DATA	1.76E-05
RU106	3.92E-06	NO DATA	4.94E-07	NO DATA	7.56E-06	NO DATA	1.88E-04
AG110M	2.05E-07	1.94E-07	1.18E-07	NO DATA	3.70E-07	NO DATA	5.45E-05
TE125M	3.83E-06	1.38E-06	5.12E-07	1.07E-06	NO DATA	NO DATA	1.13E-05
TE127M	9.67E-06	3.43E-06	1.15E-06	2.30E-06	3.92E-05	NO DATA	2.41E-05
TE127	1.58E-07	5.60E-08	3.40E-08	1.09E-07	6.40E-07	NO DATA	1.22E-05
TE129M	1.63E-05	6.05E-06	2.58E-06	5.26E-06	6.82E-05	NO DATA	6.12E-05
TE129	4.48E-08	1.67E-08	1.09E-08	3.20E-08	1.88E-07	NO DATA	2.45E-07
TE131M	2.44E-06	1.17E-06	9.76E-07	1.76E-06	1.22E-05	NO DATA	9.39E-05
TE131	2.79E-08	1.15E-08	8.72E-09	2.15E-08	1.22E-07	NO DATA	2.29E-09
TE132	3.49E-06	2.21E-06	2.08E-06	2.33E-06	2.12E-05	NO DATA	7.00E-05
I 130	1.03E-06	2.98E-06	1.19E-06	2.43E-04	4.59E-06	NO DATA	2.29E-06
I 131	5.85E-06	8.19E-06	4.40E-06	2.39E-03	1.41E-05	NO DATA	1.62E-06
I 132	2.79E-07	7.30E-07	2.62E-07	2.46E-05	1.15E-06	NO DATA	3.18E-07
I 133	2.01E-06	3.41E-06	1.04E-06	4.76E-04	5.98E-06	NO DATA	2.58E-06
I 134	1.46E-07	3.87E-07	1.39E-07	6.45E-06	6.10E-07	NO DATA	5.10E-09
I 135	6.10E-07	1.57E-06	5.82E-07	1.01E-04	2.48E-06	NO DATA	1.74E-06
CS134	8.37E-05	1.97E-04	9.14E-05	NO DATA	6.26E-05	2.39E-05	2.45E-06
CS136	8.59E-06	3.38E-05	2.27E-05	NO DATA	1.84E-05	2.90E-06	2.72E-06
CS137	1.12E-04	1.49E-04	5.19E-05	NO DATA	5.07E-05	1.97E-05	2.12E-06
CS138	7.76E-08	1.49E-07	7.45E-08	NO DATA	1.10E-07	1.28E-08	6.76E-11
BA139	1.39E-07	9.78E-11	4.05E-09	NO DATA	9.22E-11	6.74E-11	1.24E-06

TABLE E-12, CONT'D

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INGESTION DOSE FACTORS FOR TEENAGER
(MREM PER PCI INGESTED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
BA140	2.84E-05	3.48E-08	1.83E-06	NO DATA	1.18E-08	2.34E-08	4.38E-05
BA141	6.71E-08	5.01E-11	2.24E-09	NO DATA	4.65E-11	3.43E-11	1.43E-13
BA142	2.99E-08	2.99E-11	1.84E-09	NO DATA	2.53E-11	1.99E-11	9.18E-20
LA140	3.48E-09	1.71E-09	4.55E-10	NO DATA	NO DATA	NO DATA	9.82E-05
LA142	1.79E-10	7.95E-11	1.98E-11	NO DATA	NO DATA	NO DATA	2.42E-05
CE141	1.33E-08	8.88E-09	1.02E-09	NO DATA	4.18E-09	NO DATA	2.54E-05
CE143	2.35E-09	1.71E-06	1.91E-10	NO DATA	7.67E-10	NO DATA	5.14E-05
CE144	6.96E-07	2.88E-07	3.74E-08	NO DATA	1.72E-07	NO DATA	1.75E-04
PR143	1.31E-08	5.23E-09	6.52E-10	NO DATA	3.04E-09	NO DATA	4.31E-05
PR144	4.30E-11	1.76E-11	2.18E-12	NO DATA	1.01E-11	NO DATA	4.74E-14
ND147	9.38E-09	1.02E-08	6.11E-10	NO DATA	5.99E-09	NO DATA	3.68E-05
W 187	1.46E-07	1.19E-07	4.17E-08	NO DATA	NO DATA	NO DATA	3.22E-05
NP239	1.76E-09	1.66E-10	9.22E-11	NO DATA	5.21E-10	NO DATA	2.67E-05

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INGESTION DOSE FACTORS FOR CHILD
(MREM PER PCI INGESTED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
H 3	NO DATA	2.03E-07	2.03E-07	2.03E-07	2.03E-07	2.03E-07	2.03E-07
C 14	1.21E-05	2.42E-06	2.42E-06	2.42E-06	2.42E-06	2.42E-06	2.42E-06
NA 24	5.80E-06	5.80E-06	5.80E-06	5.80E-06	5.80E-06	5.80E-06	5.80E-06
P 32	8.25E-04	3.86E-05	3.18E-05	NO DATA	NO DATA	NO DATA	2.28E-05
CR 51	NO DATA	NO DATA	8.90E-09	4.94E-09	1.35E-09	9.02E-09	4.72E-07
MN 54	NO DATA	1.07E-05	2.85E-06	NO DATA	3.00E-06	NO DATA	8.98E-06
MN 56	NO DATA	3.34E-07	7.54E-08	NO DATA	4.04E-07	NO DATA	4.84E-05
FE 55	1.15E-05	6.10E-06	1.89E-06	NO DATA	NO DATA	3.45E-06	1.13E-06
FE 59	1.65E-05	2.67E-05	1.33E-05	NO DATA	NO DATA	7.74E-06	2.78E-05
CO 58	NO DATA	1.80E-06	5.51E-06	NO DATA	NO DATA	NO DATA	1.05E-05
CO 60	NO DATA	5.29E-06	1.56E-05	NO DATA	NO DATA	NO DATA	2.93E-05
NI 63	5.38E-04	2.88E-05	1.83E-05	NO DATA	NO DATA	NO DATA	1.94E-06
NI 65	2.22E-06	2.09E-07	1.22E-07	NO DATA	NO DATA	NO DATA	2.56E-05
CU 64	NO DATA	2.45E-07	1.48E-07	NO DATA	5.92E-07	NO DATA	1.15E-05
ZN 65	1.37E-05	3.65E-05	2.27E-05	NO DATA	2.30E-05	NO DATA	6.41E-06
ZN 69	4.38E-08	6.33E-08	5.85E-09	NO DATA	3.84E-08	NO DATA	3.99E-06
BR 83	NO DATA	NO DATA	1.71E-07	NO DATA	NO DATA	NO DATA	LT E-24
BR 84	NO DATA	NO DATA	1.98E-07	NO DATA	NO DATA	NO DATA	LT E-24
BR 85	NO DATA	NO DATA	9.12E-09	NO DATA	NO DATA	NO DATA	LT E-24
RB 86	NO DATA	6.70E-05	4.12E-05	NO DATA	NO DATA	NO DATA	4.31E-06
RB 88	NO DATA	1.90E-07	1.32E-07	NO DATA	NO DATA	NO DATA	9.32E-09
RB 89	NO DATA	1.17E-07	1.04E-07	NO DATA	NO DATA	NO DATA	1.02E-09
SR 89	1.32E-03	NO DATA	3.77E-05	NO DATA	NO DATA	NO DATA	5.11E-05
SR 90	1.70E-02	NO DATA	4.31E-03	NO DATA	NO DATA	NO DATA	2.29E-04
SR 91	2.40E-05	NO DATA	9.06E-07	NO DATA	NO DATA	NO DATA	5.30E-05
SR 92	9.03E-06	NO DATA	3.62E-07	NO DATA	NO DATA	NO DATA	1.71E-04
Y 90	4.11E-08	NO DATA	1.10E-09	NO DATA	NO DATA	NO DATA	1.17E-04
Y 91M	3.82E-10	NO DATA	1.37E-11	NO DATA	NO DATA	NO DATA	7.48E-07
Y 91	6.02E-07	NO DATA	1.61E-08	NO DATA	NO DATA	NO DATA	8.02E-05
Y 92	3.60E-09	NO DATA	1.03E-10	NO DATA	NO DATA	NO DATA	1.04E-04

TABLE E-13, CONT'D

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INGESTION DOSE FACTORS FOR CHILD
(MREM PER PCI INGESTED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
Y 93	1.14E-08	NO DATA	3.13E-10	NO DATA	NO DATA	NO DATA	1.70E-04
ZR 95	1.16E-07	2.55E-08	2.27E-08	NO DATA	3.65E-08	NO DATA	2.66E-05
ZR 97	6.99E-09	1.01E-09	5.96E-10	NO DATA	1.45E-09	NO DATA	1.53E-04
NB 95	2.25E-08	8.76E-09	6.26E-09	NO DATA	8.23E-09	NO DATA	1.62E-05
MO 99	NO DATA	1.33E-05	3.29E-06	NO DATA	2.84E-05	NO DATA	1.10E-05
TC 99M	9.23E-10	1.81E-09	3.00E-08	NO DATA	2.63E-08	9.19E-10	1.03E-06
TC101	1.07E-09	1.12E-09	1.42E-08	NO DATA	1.91E-08	5.92E-10	3.56E-09
RU103	7.31E-07	NO DATA	2.81E-07	NO DATA	1.84E-06	NO DATA	1.89E-05
RU105	6.45E-08	NO DATA	2.34E-08	NO DATA	5.67E-07	NO DATA	4.21E-05
RU106	1.17E-05	NO DATA	1.46E-06	NO DATA	1.58E-05	NO DATA	1.82E-04
AG110M	5.39E-07	3.64E-07	2.91E-07	NO DATA	6.78E-07	NO DATA	4.33E-05
TE125M	1.14E-05	3.09E-06	1.52E-06	3.20E-06	NO DATA	NO DATA	1.10E-05
TE127M	2.89E-05	7.78E-06	3.43E-06	6.91E-06	8.24E-05	NO DATA	2.34E-05
TE127	4.71E-07	1.27E-07	1.01E-07	3.26E-07	1.34E-06	NO DATA	1.84E-05
TE129M	4.87E-05	1.36E-05	7.56E-06	1.57E-05	1.43E-04	NO DATA	5.94E-05
TE129	1.34E-07	3.74E-08	3.18E-08	9.56E-08	3.92E-07	NO DATA	8.34E-06
TE131M	7.20E-06	2.49E-06	2.65E-06	5.12E-06	2.41E-05	NO DATA	1.01E-04
TE131	8.30E-08	2.53E-08	2.47E-08	6.35E-08	2.51E-07	NO DATA	4.36E-07
TE132	1.01E-05	4.47E-06	5.40E-06	6.51E-06	4.15E-05	NO DATA	4.50E-05
I 130	2.92E-06	5.90E-06	3.04E-06	6.50E-04	8.82E-06	NO DATA	2.76E-06
I 131	1.72E-05	1.73E-05	9.83E-06	5.72E-03	2.84E-05	NO DATA	1.54E-06
I 132	8.00E-07	1.47E-06	6.76E-07	6.82E-05	2.25E-06	NO DATA	1.73E-06
I 133	5.92E-06	7.32E-06	2.77E-06	1.36E-03	1.22E-05	NO DATA	2.95E-06
I 134	4.19E-07	7.78E-07	3.58E-07	1.79E-05	1.19E-06	NO DATA	5.16E-07
I 135	1.75E-06	3.15E-06	1.49E-06	2.79E-04	4.83E-06	NO DATA	2.40E-06
CS134	2.34E-04	3.84E-04	8.10E-05	NO DATA	1.19E-04	4.27E-05	2.07E-06
CS136	2.35E-05	6.46E-05	4.18E-05	NO DATA	3.44E-05	5.13E-06	2.27E-06
CS137	3.27E-04	3.13E-04	4.62E-05	NO DATA	1.02E-04	3.67E-05	1.96E-06
CS138	2.28E-07	3.17E-07	2.01E-07	NO DATA	2.23E-07	2.40E-08	1.46E-07
BA139	4.14E-07	2.21E-10	1.20E-08	NO DATA	1.93E-10	1.30E-10	2.39E-05

TABLE E-13, CONT'D

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INGESTION DOSE FACTORS FOR CHILD
(MREM PER PCI INGESTED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
BA140	8.31E-05	7.28E-08	4.85E-06	NO DATA	2.37E-08	4.34E-08	4.21E-05
BA141	2.00E-07	1.12E-10	6.51E-09	NO DATA	9.69E-11	6.58E-10	1.14E-07
BA142	8.74E-08	6.29E-11	4.88E-09	NO DATA	5.09E-11	3.70E-11	1.14E-09
LA140	1.01E-08	3.53E-09	1.17E-09	NO DATA	NO DATA	NO DATA	9.84E-05
LA142	5.24E-10	1.67E-10	5.23E-11	NO DATA	NO DATA	NO DATA	3.31E-05
CE141	3.97E-08	1.98E-08	2.94E-09	NO DATA	8.68E-09	NO DATA	2.47E-05
CE143	6.99E-09	3.79E-06	5.49E-10	NO DATA	1.59E-09	NO DATA	5.55E-05
CE144	2.08E-06	6.52E-07	1.11E-07	NO DATA	3.61E-07	NO DATA	1.70E-04
PR143	3.93E-08	1.18E-08	1.95E-09	NO DATA	6.39E-09	NO DATA	4.24E-05
PR144	1.29E-10	3.99E-11	6.49E-12	NO DATA	2.11E-11	NO DATA	8.59E-08
ND147	2.79E-08	2.26E-08	1.75E-09	NO DATA	1.24E-08	NO DATA	3.58E-05
W 187	4.29E-07	2.54E-07	1.14E-07	NO DATA	NO DATA	NO DATA	3.57E-05
NP239	5.25E-09	3.77E-10	2.65E-10	NO DATA	1.09E-09	NO DATA	2.79E-05

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INGESTION DOSE FACTORS FOR INFANT
(MREM PER PCI INGESTED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
H 3	NO DATA	3.08E-07	3.08E-07	3.08E-07	3.08E-07	3.08E-07	3.08E-07
C 14	2.37E-05	5.06E-06	5.06E-06	5.06E-06	5.06E-06	5.06E-06	5.06E-06
NA 24	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05
P 32	1.70E-03	1.00E-04	6.59E-05	NO DATA	NO DATA	NO DATA	2.30E-05
CR 51	NO DATA	NO DATA	1.41E-08	9.20E-09	2.01E-09	1.79E-08	4.11E-07
MN 54	NO DATA	1.99E-05	4.51E-06	NO DATA	4.41E-06	NO DATA	7.31E-06
MN 56	NO DATA	8.18E-07	1.41E-07	NO DATA	7.03E-07	NO DATA	7.43E-05
FE 55	1.39E-05	8.98E-06	2.40E-06	NO DATA	NO DATA	4.39E-06	1.14E-06
FE 59	3.08E-05	5.38E-05	2.12E-05	NO DATA	NO DATA	1.59E-05	2.57E-05
CO 58	NO DATA	3.60E-06	8.98E-06	NO DATA	NO DATA	NO DATA	8.97E-06
CO 60	NO DATA	1.08E-05	2.55E-05	NO DATA	NO DATA	NO DATA	2.57E-05
NI 63	6.34E-04	3.92E-05	2.20E-05	NO DATA	NO DATA	NO DATA	1.95E-06
NI 65	4.70E-06	5.32E-07	2.42E-07	NO DATA	NO DATA	NO DATA	4.05E-05
CU 64	NO DATA	6.09E-07	2.82E-07	NO DATA	1.03E-06	NO DATA	1.25E-05
ZN 65	1.94E-05	6.31E-05	2.91E-05	NO DATA	3.06E-05	NO DATA	5.33E-05
ZN 69	9.33E-08	1.68E-07	1.25E-08	NO DATA	6.98E-08	NO DATA	1.37E-05
BR 83	NO DATA	NO DATA	3.63E-07	NO DATA	NO DATA	NO DATA	LT E-24
BR 84	NO DATA	NO DATA	3.82E-07	NO DATA	NO DATA	NO DATA	LT E-24
BR 85	NO DATA	NO DATA	1.94E-08	NO DATA	NO DATA	NO DATA	LT E-24
RB 86	NO DATA	1.70E-04	8.40E-05	NO DATA	NO DATA	NO DATA	4.35E-06
RB 88	NO DATA	4.98E-07	2.73E-07	NO DATA	NO DATA	NO DATA	4.85E-07
RB 89	NO DATA	2.86E-07	1.97E-07	NO DATA	NO DATA	NO DATA	9.74E-08
SR 89	2.51E-03	NO DATA	7.20E-05	NO DATA	NO DATA	NO DATA	5.16E-05
SR 90	1.85E-02	NO DATA	4.71E-03	NO DATA	NO DATA	NO DATA	2.31E-04
SR 91	5.00E-05	NO DATA	1.81E-06	NO DATA	NO DATA	NO DATA	5.92E-05
SR 92	1.92E-05	NO DATA	7.13E-07	NO DATA	NO DATA	NO DATA	2.07E-04
Y 90	8.69E-08	NO DATA	2.35E-09	NO DATA	NO DATA	NO DATA	1.20E-04
Y 91M	8.10E-10	NO DATA	2.76E-11	NO DATA	NO DATA	NO DATA	2.70E-06
Y 91	1.13E-06	NO DATA	3.01E-08	NO DATA	NO DATA	NO DATA	8.10E-05
Y 92	7.65E-09	NO DATA	2.15E-10	NO DATA	NO DATA	NO DATA	1.46E-04

TABLE E-14, CONT'D

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INGESTION DOSE FACTORS FOR INFANT
(MREM PER PCI INGESTED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
Y 93	2.43E-08	NO DATA	6.62E-10	NO DATA	NO DATA	NO DATA	1.92E-04
ZR 95	2.06E-07	5.02E-08	3.56E-08	NO DATA	5.41E-08	NO DATA	2.50E-05
ZR 97	1.48E-08	2.54E-09	1.16E-09	NO DATA	2.56E-09	NO DATA	1.62E-04
NB 95	4.20E-08	1.73E-08	1.00E-08	NO DATA	1.74E-08	NO DATA	1.46E-05
MO 99	NO DATA	3.40E-05	6.63E-06	NO DATA	5.08E-05	NO DATA	1.12E-05
TC 99M	1.92E-09	3.96E-09	5.10E-08	NO DATA	4.26E-08	2.07E-09	1.15E-06
TC101	2.27E-09	2.86E-09	2.83E-08	NO DATA	3.40E-08	1.56E-09	4.86E-07
RU103	1.48E-06	NO DATA	4.95E-07	NO DATA	3.08E-06	NO DATA	1.80E-05
RU105	1.36E-07	NO DATA	4.58E-08	NO DATA	1.00E-06	NO DATA	5.41E-05
RU106	2.41E-05	NO DATA	3.01E-06	NO DATA	2.85E-05	NO DATA	1.83E-04
AG110M	9.96E-07	7.27E-07	4.81E-07	NO DATA	1.04E-06	NO DATA	3.77E-05
TE125M	2.33E-05	7.79E-06	3.15E-06	7.84E-06	NO DATA	NO DATA	1.11E-05
TE127M	5.85E-05	1.94E-05	7.08E-06	1.69E-05	1.44E-04	NO DATA	2.36E-05
TE127	1.00E-06	3.35E-07	2.15E-07	8.14E-07	2.44E-06	NO DATA	2.10E-05
TE129M	1.00E-04	3.43E-05	1.54E-05	3.84E-05	2.50E-04	NO DATA	5.97E-05
TE129	2.84E-07	9.79E-08	6.63E-08	2.38E-07	7.07E-07	NO DATA	2.27E-05
TE131M	1.52E-05	6.12E-06	5.05E-06	1.24E-05	4.21E-05	NO DATA	1.03E-04
TE131	1.76E-07	6.50E-08	4.94E-08	1.57E-07	4.50E-07	NO DATA	7.11E-06
TE132	2.08E-05	1.03E-05	9.61E-06	1.52E-05	6.44E-05	NO DATA	3.81E-05
I 130	6.00E-06	1.32E-05	5.30E-06	1.48E-03	1.45E-05	NO DATA	2.83E-06
I 131	3.59E-05	4.23E-05	1.86E-05	1.39E-02	4.94E-05	NO DATA	1.51E-06
I 132	1.66E-06	3.37E-06	1.20E-06	1.58E-04	3.76E-06	NO DATA	2.73E-06
I 133	1.25E-05	1.82E-05	5.33E-06	3.31E-03	2.14E-05	NO DATA	3.08E-06
I 134	8.69E-07	1.78E-06	6.33E-07	4.15E-05	1.99E-06	NO DATA	1.84E-06
I 135	3.64E-06	7.24E-06	2.64E-06	6.49E-04	8.07E-06	NO DATA	2.62E-06
CS134	3.77E-04	7.03E-04	7.10E-05	NO DATA	1.81E-04	7.42E-05	1.91E-06
CS136	4.59E-05	1.35E-04	5.04E-05	NO DATA	5.38E-05	1.10E-05	2.05E-06
CS137	5.22E-04	6.11E-04	4.33E-05	NO DATA	1.64E-04	6.64E-05	1.91E-06
CS138	4.81E-07	7.82E-07	3.79E-07	NO DATA	3.90E-07	6.09E-08	1.25E-06
BA139	8.81E-07	5.84E-10	2.55E-08	NO DATA	3.51E-10	3.54E-10	5.58E-05

TABLE E-14, CONT'D

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INGESTION DOSE FACTORS FOR INFANT
(MREM PER PCI INGESTED)

NUCLIDE	BONE	LIVER	T.BODY	THYROID	KIDNEY	LUNG	GI-LLI
BA140	1.71E-04	1.71E-07	8.81E-06	NO DATA	4.06E-08	1.05E-07	4.20E-05
BA141	4.25E-07	2.91E-10	1.34E-08	NO DATA	1.75E-10	1.77E-10	5.19E-06
BA142	1.84E-07	1.53E-10	9.06E-09	NO DATA	8.81E-11	9.26E-11	7.59E-07
LA140	2.11E-08	8.32E-09	2.14E-09	NO DATA	NO DATA	NO DATA	9.77E-05
LA142	1.10E-09	4.04E-10	9.67E-11	NO DATA	NO DATA	NO DATA	6.86E-05
CE141	7.87E-08	4.80E-08	5.65E-09	NO DATA	1.48E-08	NO DATA	2.48E-05
CE143	1.48E-08	9.82E-06	1.12E-09	NO DATA	2.86E-09	NO DATA	5.73E-05
CE144	2.98E-06	1.22E-06	1.67E-07	NO DATA	4.93E-07	NO DATA	1.71E-04
PR143	8.13E-08	3.04E-08	4.03E-09	NO DATA	1.13E-08	NO DATA	4.29E-05
PR144	2.74E-10	1.06E-10	1.38E-11	NO DATA	3.84E-11	NO DATA	4.93E-06
ND147	5.53E-08	5.68E-08	3.48E-09	NO DATA	2.19E-08	NO DATA	3.60E-05
W 187	9.03E-07	6.28E-07	2.17E-07	NO DATA	NO DATA	NO DATA	3.69E-05
NP239	1.11E-08	9.93E-10	5.61E-10	NO DATA	1.98E-09	NO DATA	2.87E-05

TABLE E-15

RECOMMENDED VALUES FOR OTHER PARAMETERS

Parameter Symbol	Definition	Equation(s) Where Used	Values	Reference(s)*
f_g	Fraction of produce ingested grown in garden of interest	14 & C-13	0.76	--
f_ℓ	Fraction of leafy vegetables grown in garden of interest	14 & C-13	1.0	--
P	Effective surface density of soil (assumes a 15 cm plow layer, expressed in dry weight)	4, A-8, A-13, & C-5	240 kg/m^2	10
r	Fraction of deposited activity retained on crops, leafy vegetables, or pasture grass	4, A-8, & A-13 C-5	0.25 1.0 (for iodines) 0.2 (for other particulates)	27 2, 4, 13, 28-31
S_F	Attenuation factor accounting for shielding provided by residential structures	8, 9, 10, 11, 12, B-6, B-7, B-8, B-9, & C-2	0.7 (for maximum individual) 0.5 (for general population)	26 26
t_b	Period of long-term buildup for activity in sediment or soil (nominally 15 yr)	3, 4, A-4, A-5, A-6, A-7, A-8, A-13, & C-5	1.31×10^5 hr	--
t_e	Period of crop, leafy vegetable, or pasture grass exposure during growing season	4, A-8, A-13, & C-5	720 hrs (30 days, for grass-cow-milk-man pathway) 1440 hrs (60 days, for crop/vegetation-man pathway)	10 & 32
t_f	Transport time from animal feed-milk-man	C-10	2 days (for maximum individual) 4 days (for general population)	-- --

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*Parameter values given without references are based on staff judgments.

TABLE E-15 (Continued)

Parameter Symbol	Definition	Equation(s) Where Used	Values	Reference(s)*
t_h	Time delay between harvest of vegetation or crops and ingestion			
	i) For ingestion of forage by animals	4, A-8, A-13, & C-5	Zero (for pasture grass) 2160 hr (90 days for stored feed)	--
	ii) For ingestion of crops by man	4, A-8, A-13, & C-5	24 hr (1 day, for leafy vegetables & maximum individual) 1440 hr (60 days, for produce & maximum individual) 336 hr (14 days, for general population)	--
t_p	Environmental transit time, release to receptor (add time from release to exposure point to minimums shown for distribution)	1 & A-2	12 hr (for maximum individual) 24 hr (for general population)	--
		2 & A-3	24 hr (for maximum individual) 168 hr (7 days for population sport fish doses) 240 hr (10 days for population commercial fish doses	--
		3 & A-7	Zero	
t_s	Average time from slaughter of meat animal to consumption	C-12	20 days	--
Y_v	Agricultural productivity by unit area (measured in wet weight)	4, A-8, A-13, & C-5	0.7 kg/m^2 (for grass-cow-milk-man pathway)	33
			2.0 kg/m^2 (for produce or leafy vegetables ingested by man)	34
λ_w	Rate constant for removal of activity on plant or leaf surfaces by weathering (corresponds to a 14-day half-life)	----	0.0021 hr^{-1}	--

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*Parameter values given without references are based on staff judgments.

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APPENDIX F

METHODS FOR EVALUATING THE I FUNCTION

The NRC staff calculates ground-level gamma radiation doses from elevated noble gas releases using Equation (6) in Regulatory Position C.2.a of this guide. Equation (6) is based on the model presented in Slade (Ref. 1), which can be characterized as a vertically finite sector-averaged Gaussian plume model. Use of the model involves volume integration over a distributed source, resulting in certain integrals that define the I function, denoted by $\bar{I}_T$ in Reference 1.

1. Derivation of the I Function

The derivation of the I function presented below is taken directly from Reference 1, which should be consulted for further details.

The sector-average airborne radionuclide concentration resulting from a continuous release is given by the Gaussian plume model as (see Equation 7.60 of Ref. 1):

$$\bar{\chi}(R,z) = \frac{Q^D}{\sqrt{2\pi}\,\sigma_z \bar{u} R\theta}\left\{\exp\left[-\frac{(z-h)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+h)^2}{2\sigma_z^2}\right]\right\} \qquad \text{(F-1)}$$

where

h	is the effective release height, in meters;
Q^D	is the effective release rate, considering decay in transit, in Ci/sec;
R	is the downwind distance, in meters;
$\bar{u}$	is the average wind speed, in m/sec;
$\bar{\chi}(R,z)$	is the sector-average concentration at location (R,z), in Ci/m^3;
z	is the vertical distance above the ground plane, in meters;
θ	is the sector width, in radians; and
σ_z	is the vertical plume spread, in meters.

Equation (F-1) may be restated, for simplicity, as:

$$\bar{\chi}(R,z) = \frac{Q^D G(z)}{\sqrt{2\pi}\,\sigma_z \bar{u} R\theta} \qquad \text{(F-2)}$$

where

$$G(z) = \exp\left[-\frac{(z-h)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+h)^2}{2\sigma_z^2}\right] \qquad \text{(F-3)}$$

where the terms are as defined above.

The gamma dose rate to air at a distance of r meters from a point source of q curies is expressed by (see Equation 7.33 of Ref. 1):

$$D' = \frac{\mu_a q(3.7\times10^{10})E(1.6\times10^{-6})B(\mu,\mu_a,r)\exp(-\mu r)}{4\pi r^2(1293)(100)} \qquad \text{(F-4)}$$

where

$B(\mu,\mu_a,r)$	is the buildup factor, dimensionless;
D'	is the dose rate to air, in rad/sec;
E	is the gamma ray energy per disintegration, in MeV;
q	is the point source strength, in curies;
r	is the distance, in meters;
μ	is the attenuation coefficient for air, in m^{-1};
μ_a	is the energy absorption coefficient for air, in m^{-1};
100	is the number of ergs per gram-rad;
1293	is the density of air at standard temperature and pressure, in g/m^3;
1.6×10^{-6}	is the number of ergs per MeV; and
3.7×10^{10}	is the number of disintegrations, per Ci-sec.

Equation (F-4) may be simplified as follows:

$$D' = \frac{K\mu_a qEB(\mu,\mu_a,r)\exp(-\mu r)}{4\pi r^2} \qquad \text{(F-5)}$$

where

$$K = \frac{(3.7 \times 10^{10})(1.6 \times 10^{-6})}{(1293)(100)} = 0.46 \qquad \text{(F-6)}$$

The next step is to incorporate Equation (F-2) into Equation (F-5) to arrive at an expression for the differential dose rate dD' from the differential volume dV containing the radionuclide concentration $\bar{\chi}(R,z)$. Consider a volume element of the plume located z meters above the ground and at a horizontal distance L meters from receptor location (R, 0) (see Figure 7.20 of Ref. 1). All such volume elements located at the horizontal distance L are included in the ring-shaped differential volume $2\pi L dL dz$. If R is sufficiently large that the concentration averaged over all such volume elements can be approximated by $\bar{\chi}(R,z)$, the contribution of the ring-shaped differential volume dV to the air dose rate at location (R,0) is given as

$$dD' = \frac{K\mu_a EB(\mu,\mu_a,r)\exp(-\mu r)}{4\pi r^2}\,\bar{\chi}(R,z)\,dV \qquad \text{(F-7)}$$

where q has been replaced by $\overline{\chi}(R,z)dV$. Substituting $(L^2 + z^2)^{1/2}$ for r and $2\pi LdLdz$ for dV in Equation (F-7), and integrating, the following expression is obtained:

$$D' = \frac{K\mu_a EQ^D}{2\sqrt{2\pi}\,\bar{u}R\sigma_z\theta} \int_0^\infty\!\!\int_0^\infty \frac{B\left[\mu,\mu_a,(L^2 + z^2)^{1/2}\right] G(z)\exp\left[-\mu(L^2 + z^2)^{1/2}\right]}{L^2 + z^2}\, LdLdz \tag{F-8}$$

The I function, denoted by I_T in Reference 1, is defined as

$$I = \frac{1}{2^{3/2}\sigma_z} \int_0^\infty\!\!\int_0^\infty \frac{B\left[\mu,\mu_a,(L^2 + z^2)^{1/2}\right] G(z)\exp\left[-\mu(L^2 + z^2)^{1/2}\right]}{L^2 + z^2}\, LdLdz \tag{F-9}$$

which, when substituted into Equation (F-8), yields

$$D' = \frac{K\mu_a EQ^D}{\sqrt{\pi}\,\bar{u}R\theta}\, I \tag{F-10}$$

The constant K, equal to 0.46, when divided by $\sqrt{\pi}$ yields the factor 0.260, which is the same as the factor of 260 in Equation (6) of Regulatory Position C.2.a, after multiplying by the number of mrad per rad.

The buildup factor given in Reference 1 is of the form

$$B(\mu,\mu_a,r) = 1 + k\mu r \tag{F-11}$$

where

$$k = \frac{\mu - \mu_a}{\mu_a} \tag{F-12}$$

Substituting the above expression for the buildup factor into Equation (F-9), the I function is then given as

$$I = I_1 + kI_2 \tag{F-13}$$

where the I_1 and I_2 integrals can be written for this form of the buildup factor as

$$I_1 = \frac{1}{2^{3/2}\sigma_z} \int_0^\infty G(z)E_1(\mu z)dz \tag{F-14}$$

and

$$I_2 = \frac{1}{2^{3/2}\sigma_z} \int_0^\infty G(z)\exp(-\mu z)dz \tag{F-15}$$

where $E_1(\mu z)$ is the exponential integral defined by

$$E_1(\mu z) = \int_{\mu z}^\infty \frac{\exp(-\mu r)}{\mu r}\, d(\mu r) \tag{F-16}$$

2. Evaluation of the I Function

In Reference 1 the I_1 and I_2 integrals have been evaluated and the results presented graphically. Extraction of the data from these six-cycle log-log multicurve plots is a formidable task. A more satisfactory approach is to prepare a tabulation of the integrals as evaluated using numerical methods. These data can then be interpolated in implementing Equation (6) of Regulatory Position C.2.a.

The NRC staff has developed a computer routine that evaluates the I function as formulated in Equation (F-9). The I function as expressed in Equation (F-9) is independent of the buildup factor form. A listing of this routine is provided in Figure F-1. Communication with the routine is through the COMMON statement, which also communicates with the function subprogram BULDUP, which defines the dose buildup factor $B(\mu,\mu_a,r)$ desired by the user.

Also, Yankee Atomic Electric Company has supplied a routine written by Dr. John N. Hamawi of that company (Ref. 2). This routine evaluates the I_1 and I_2 integrals as formulated in Equations (F-14) and (F-15), respectively. A listing of the routine is provided in Figure F-2 (reproduced with the permission of Yankee Atomic Electric Company). With the exceptions of changes in the title, the addition of the COMMON statement, the computing of I from I_1 and I_2, and comment cards as to its authorship, the routine is reproduced as written by Dr. Hamawi. The staff has compared the two routines and found their results to be in excellent agreement. The routine supplied by the Yankee Atomic Electric Company was found to be considerably faster than the staff's routine.

```
      SUBROUTINE DINT
      COMMON/DATAIT/GMU,ZK,HS,SIGMZ,EBAR,DI,M
C**
C    DOSE INTEGRAL SUBROUTINE -K.F. ECKERMAN 11-24-74
C    SUBROUTINE EVALUATES THE DOSE INTEGRAL 'IT' AS DEFINED BY EQN 7.61
C    IN MET & AE-1968.  THE TWO DIMENSIONAL INTEGRATION IS EVALUATED
C    USING GAUSSIAN-LEGENDRE QUADRATURE OF ORDER 48.
C
C     COMMON INFO
C         GMU-MASS ATTENUATION COEFFICIENT (1/METERS)
C         ZK-BUILDUP FACTOR (MU-MUA)/MUA IF USED
C         HS-RELEASE PUINT HEITH
C         RELEASE POINT HEIGHT (METERS)
C         SIGMZ-STANDARD DEVIATION OF PLUME (METERS)
C         EBAR-GAMMA RAY ENERGY (MEV)
C         DI-DOSE INTEGRAL
C         M-ENERGY GROUP INDEX IF NEEDED
C     NOTE-ZK,EBAR,& M ARE USED BY BULDUP
C**
      DIMENSION X(24),W(24)
      DATA NN/48/,A/2.828427125/
      DATA X/
     10.0323801709, 0.0970046992, 0.1612223560, 0.2247637903,
     20.2873624873, 0.3487558862, 0.4086864819, 0.4669029047,
     30.5231609747, 0.5772247260, 0.6288673967, 0.6778723796,
     40.7240341309, 0.7671590325, 0.8070662040, 0.8435882616,
     50.8765720202, 0.9058791367, 0.9313866907, 0.9529877031,
     60.9705915925, 0.9841245837, 0.9935301722, 0.9987710072/
      DATA W/
     10.0647376968, 0.0644661644, 0.0639242385, 0.0631141922,
     20.0620394231, 0.0607044391, 0.0591148396, 0.0572772921,
     30.0551995036, 0.0528901894, 0.0503590355, 0.0476166584,
     40.0446705608, 0.0415450829, 0.0382413510, 0.0347772225,
     50.0311672278, 0.0274265097, 0.0235707608, 0.0196161604,
     60.0155793157, 0.0114772345, 0.0073275539, 0.0031533460/
      SUM=0.
      B=0.5/(SIGMZ*SIGMZ)
      ZLB=HS-4.*SIGMZ
      ZUB=HS+4.*SIGMZ
      IF(ZLB.LT.0.)ZLB=0.
      YUB=15./GMU
      C=0.5*(ZUB-ZLB)
      G=0.5*(ZUB+ZLB)
      E=0.5*YUB
      DO 70 II=1,NN
      I=II-II/2
      F=1.
      EX=0.
      IF(MOD(II,2).EQ.0)F=-1.
      ZZ=F*X(I)*C+G
      ARGU=B*(ZZ-HS)*(ZZ-HS)
      IF(ARGU.GT.20.)GO TO 55
      EX=EXP(-ARGU)
   55 ARGU=B*(ZZ+HS)*(ZZ+HS)
      IF(ARGU.GT.20.)GO TO 58
      EX=EX+EXP(-ARGU)
   58 IF(EX.EQ.0.)GO TO 70
      DO 60 KK=1,NN
      K=KK-KK/2
      F=1.
      IF(MOD(KK,2).EQ.0)F=-1.
```

Figure P-1. Staff-Written Computer Listing

```
      YY=F*X(K)*E+E
      D1=YY*YY+ZZ*ZZ
      ARGU=GMU*SQRT(D1)
      IF(ARGU.GT.20.)GO TO 60
      EX1=EX*EXP(-ARGU)*BULDUP(ARGU)*YY/D1
      SUM=SUM+W(I)*W(K)*EX1
   60 CONTINUE
   70 CONTINUE
      DI=SUM*C*E/(A*SIGMZ)
      RETURN
      END
```

Figure F-1 (continued)

```
      SUBROUTINE DINT
      REAL MU
      COMMON/DATAIT/MU,ZK,M,SIGZ,DI,L
C**
C   DOSE INTEGRAL ROUTINE WRITTEN BY
C                DR. JOHN N. HAMAWI
C         YANKEE ATOMIC ELECTRIC COMPANY
C            NUCLEAR SERVICES DIVISION
C                20 TURNPIKE ROAD
C       WESTBOROUGH, MASSACHUSETTS 01581
C   YAEC REPORT NO. 1105
C
C   COMMON INFO
C      MU-MASS ATTENUATION COEFFICIENT (1/METERS)
C      ZK-BUILDUP FACTOR (MU-MUA)/MUA
C      SIGZ-STANDARD DEVIATION OF PLUME (METERS)
C      DI-DOSE INTEGRAL -I TOTAL
C      L- DETERMINES NUMBER OF INTERVALS USED IN INTEGRATION
C**
      DIMENSION CDATA(5),E(49),B(49),P(49)
      DATA M/9/,CDATA/5.0D+3,1.0D+4,2.0D+4,5.0D+4,1.0D+5/
      DATA A0,A1,A2,A3,A4,A5/ -0.57721566, 0.99999193, - 0.24991055,
     C  0.05519968,-0.00976004, 0.00107857/
      DATA B0,B1,B2,B3/ 0.2677737343, 8.6347608925, 18.0590169730,
     C  8.5733287401/
      DATA C0,C1,C2,C3/ 3.9584969228, 21.0996530827, 25.6329561486,
     C  9.5733223454/
      DATA D,D1,D2,D3,D4,D5,D6,D7,D8,D9/
     C  3543.75,989.,5888.,-928.,10496.,-4540.,10496.,-928.,5888.,989./
C**** COMPUTE LIMITS OF INTEGRATION ZMIN AND ZMAX, AND INTERVAL WIDTH
      IF(L.LT.2.OR.L.GT.6) L = 6
      C = CDATA(L-1)
      N = L*(M-1) + 1
      SIGZ2 = SIGZ*SIGZ
      ALFA = M - MU*SIGZ2
      BETA = SIGZ* SQRT(2.0*ALOG(C))
      IF(ALFA.GT.0.0) GO TO 150
      ZMIN = 0.0
      ZMAX = ALFA +  SQRT(ALFA*ALFA + BETA*BETA)
      GO TO 200
  150 ZMIN = ALFA - BETA
      IF(ZMIN.LT.0.0) ZMIN = 0.0
      ZMAX = ALFA + BETA
  200 DZ = (ZMAX-ZMIN)/(N-1)
C**** COMPUTE EXPONENTIAL INTEGRAL TERMS E(I) (SPECIAL PROCED. FOR E(1))
      E(1) = 2.18907-ALOG(MU*DZ)
      DO 250 I = 1, N
      Z = ZMIN + (I-1)*DZ
      X = MU*Z
      IF(X.LE.0.0) GO TO 250
      X2 = X*X
      X3 = X*X2
      X4 = X*X3
      X5 = X*X4
      IF(X.LE.1.0) E(I) = -ALOG(X) + A0+A1*X+A2*X2+A3*X3+A4*X4+A5*X5
      IF(X.GT.1.0) E(I) = (B0+B1*X+B2*X2+B3*X3+X4)/
     C                    (C0+C1*X+C2*X2+C3*X3+X4)/(X* EXP(X))
  250 CONTINUE
C**** COMPUTE INTEGRAND TERMS B(I) AND P(I)
      DO 300 I = 1, N
      Z = ZMIN + (I-1)*DZ
```

Figure F-2. Hamawi-Written Computer Listing

```
      G= EXP(-(Z+H)*(Z+H)/(2.0*SIGZ2)) +  EXP (-(Z-H)*(Z-H)/(2.0*SIGZ2))
      B(I) = G*E(I)
  300 P(I) = G* EXP(-MU*Z)
C**** PERFORM NUMERICAL INTEGRATION USING 9-POINT NEWTON-COTES FORMULA
      SUMB = 0.0
      SUMP = 0.0
      MM = M - 1
      KM = N - M + 1
      DO 350 K = 1,KM,MM
      SUMB = SUMB + D1*B(K)+D2*B(K+1)+D3*B(K+2)+D4*B(K+3)+D5*B(K+4)
     C                   +D6*B(K+5)+D7*B(K+6)+D8*B(K+7)+D9*B(K+8)
      SUMP = SUMP + D1*P(K)+D2*P(K+1)+D3*P(K+2)+D4*P(K+3)+D5*P(K+4)
     C                   +D6*P(K+5)+D7*P(K+6)+D8*P(K+7)+D9*P(K+8)
  350 CONTINUE
      DI=DZ*(SUMB+SUMP*ZK)/(D*2.828427*SIGZ)
      RETURN
      END
```

Figure F-2 (continued)

REFERENCES FOR APPENDIX F

1. "Meteorology and Atomic Energy 1968," D. H. Slade (ed.), USAEC Report TID-241090, 1968.
2. J. N. Hamawi, "A Method for Computing the Gamma-Dose Integrals $\bar{I}_1$ and $\bar{I}_2$ for the Finite-Cloud Sector-Average Model," Yankee Atomic Electric Company Report YAEC-1105, 1976.