Ameren MISSOURI

Callaway Plant

April 22, 2013

ULNRC-05985

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555-0001

40 CFR 190

Ladies and Gentlemen:

DOCKET NUMBER 50-483
CALLAWAY PLANT UNIT 1
UNION ELECTRIC CO.
FACILITY OPERATING LICENSE NPF-30
2012 ANNUAL RADIOACTIVE EFFLUENT RELEASE REPORT

Please find enclosed the 2012 Annual Radioactive Effluent Release Report for Callaway Plant. This report is submitted in accordance with Section 5.6.3 of the Callaway Plant Technical Specifications.

This letter does not contain new commitments.

If there are any questions, please contact Curtis Smith at (314) 225-1482.

Sincerely,

C D Smith

Curtis D. Smith
Radiation Protection Manager

EMP/nls

Enclosure

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Callaway Energy Center 2012 Annual Effluent Release Report

Facility Operating License NPF-30

Docket Number 50-483

Ameren MISSOURI | Callaway Energy Center

Callaway Energy Center 2012 Annual Radioactive Effluent Release Report

Facility Operating License NPF-30
Docket No. 50-483

Abstract

The Annual Radioactive Effluent Release Report covers the operation of the Callaway Energy Center during the year 2012. The report includes a summary of the quantities of radioactive liquid and gaseous effluents and solid waste released from the unit. The report also includes an annual summary of hourly meteorological data collected during the year and an assessment of radiation dose to the Member of the Public from liquid and gaseous effluents.

1. Introduction

This Annual Radioactive Effluent Release Report (ARERR) is submitted by Union Electric Co., dba Ameren Missouri, in accordance with the requirements of 10 CFR 50.36a and Callaway Energy Center Technical Specification 5.6.3. This report is for the period January 1, 2012 to December 31, 2012.

The doses to the Member of the Public from all liquid and gaseous effluents discharged during the reporting period were small fractions of the NRC and EPA regulatory limits and the Radiological Effluent Control limits in the Offsite Dose Calculation Manual.

To maximize consistency, aid in the review by Members of the Public, and to allow easier industry- wide comparison of the data, this report is presented in the format recommended by Regulatory Guide 1.21, revision 2, *insofar as is practicable*. Callaway is committed to revision

1 of Regulatory Guide 1.21, and some of the information is not readily available in the format recommended by revision 2.

2. Gaseous Effluents

The quantity of radioactive material released in gaseous effluents during the reporting period is summarized in Table A-1. The quarterly and annual sums of all radionuclides discharged in gaseous effluents are reported in Tables A-1A and A-1B. All gaseous effluent releases are considered to be ground level.

The quantity of ^{14}C released in gaseous effluents was calculated as described in EPRI Technical Report 1021106[1].

3. Liquid Effluents

The quantity of radioactive material released in liquid effluents during the reporting period is summarized in Table A-2. The quarterly and annual sums of all radionuclides discharged in liquid effluents are reported in Table A-2A. All liquid effluents were discharged in batch mode; there were no continuous liquid discharges for the reporting period. Dilution by the Missouri River, in the form of the near- field dilution factor, is utilized in the ODCM dose calculation methodology.

4. Solid Waste Storage and Shipments

The volume and activity of solid waste shipped for disposal is provided in Table A-3. Table A-3 is presented in the format of rev. 1 to Regulatory Guide 1.21 because the data is not readily available in the format recommended by rev. 2 to Regulatory Guide 1.21.

5. Dose Assessments

The annual evaluation of dose to the Member of the Public is calculated in accordance with the methodology and parameters in the ODCM and is reported in Tables A-4 and A-5.

5.1 Table A-4, Dose Assessments, 10 CFR 50, Appendix I

The dose assessments reported in Table A-4 were calculated using the methodology and parameters in the ODCM and demonstrate compliance with 10 CFR 50, Appendix I. The gamma air dose and beta air dose were calculated at the nearest Site Boundary location with the highest value of X/Q, as described in the ODCM. The maximum organ dose from gaseous effluents was calculated for the ingestion, inhalation, and ground plane pathways at the location of the nearest resident with the highest value of D/Q, as described in the ODCM. The organ dose does not include the dose from ^{14}C, which is listed separately.

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[1] *Estimation of Carbon- 14 in Nuclear Power Plant Gaseous Effluents*, Technical Report 1011106, Electric Power Research Institute, December, 2010.

5.2 Table A-5, EPA 40 CFR 190 Individual in the Unrestricted Area

The dose assessments reported in Table A-5 are the doses to the Member of the Public from activities within the Site Boundary plus the doses at the location of the Nearest Residence. A large portion of the residual land of the Callaway Site is managed by the State of Missouri Conservation Department as the Reform Wildlife Management Area. Pursuant to the guidance provided in Regulatory Guide 1.21, rev.2, the dose reported in Table A-5 is the sum of the dose from gaseous effluents (at the Nearest Resident location and within the Site Boundary), plus the dose contribution due to activities within the Site Boundary and the organ dose from inhalation of ^{14}C (at the Nearest Resident location and within the Site Boundary). The dose assessments in Table A-5 demonstrate compliance with 10 CFR 20.1301(e) and 40 CFR 190.

6. Supplemental Information

6.1 Abnormal Releases or Abnormal Discharges

There were no abnormal releases or abnormal discharges during the reporting period.

6.2 Non- routine Planned Discharges

There were no non- routine planned discharges during the reporting period.

6.3 Radioactive Waste Treatment System Changes

There were no major changes to the liquid or gaseous radwaste treatment system during the reporting period.

6.4 Annual Land Use Census Changes

There were no changes identified in the locations for dose calculation. Changes in sample locations identified in the Land Use Census are described in the Annual Radiological Environmental Operating Report.

6.5 Effluent Monitoring System Inoperability

There were no effluent radiation monitors out of service for periods in excess of the Limiting Condition for Operation and associated Action statements.

6.6 Offsite Dose Calculation Manual Changes

The Offsite Dose Calculation Manual (ODCM) was revised during the reporting period. Revision 19 was issued on August 7, 2012. A complete copy of the revised ODCM is attached. Revision 19 was a general revision with major formatting changes. For clarity and as an aid to the reviewer, the marks in the margins show only those areas of substantive change. Appendix B to the ODCM provides a description of the changes.

6.7 Process Control Program Changes

APA-ZZ-01011, "Process Control Program" was revised twice during the reporting period. Revision 11, issued on September 6, 2012, aligned the PCP change and approval process with

APA-ZZ-00101, "Processing Procedures, manuals, and Desktop Instructions" and FSAR-SP Specification 16.25, "Process Control Program (PCP). Revision 12, issued on October 8, 2012, was a minor change correcting the title of APA-ZZ-00101 as referenced in the procedure. Neither change resulted in a change in the formulas, sampling, analyses, tests or determinations relative to the processing and packaging of solid radioactive waste. Documentation relative to these changes is retained in the Callaway Energy Center records.

6.8 Corrections to Previous Reports

There are no corrections to previous reports.

6.9 Other Information Related to Radioactive Effluents

Meteorological Joint Frequency Tables for the monitoring period are attached as Appendix B.

Appendix A

Tables of Quantities Released in Liquid and Gaseous Radioactive Effluents and in Solid Radioactive Waste Shipments

Tables of Doses from the Discharge of Liquid and Gaseous Radioactive Effluents

Table A-1: Gaseous Effluents- Summation of All Releases

Summation of All Releases	Unit	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Total	Estimated Uncertainty (%)[2]
Fission & Activation Gases	Ci	3.04E+00	9.11E-01	2.45E-01	3.38E-01	4.53E+00	20
Avg Rel Rate	µCi/s	3.87E-01	1.16E-01	3.08E-02	4.25E-02	1.44E-01	
% of Limit	%	N/A	N/A	N/A	N/A	N/A	
^{131}Iodine	Ci	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	23
Avg Rel Rate	µCi/s	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
% of Limit	%	N/A	N/A	N/A	N/A	N/A	
Particulates	Ci	0.00E+00	0.00E+00	6.38E-07	0.00E+00	6.38E-07	30
Avg Rel Rate	µCi/s	0.00E+00	0.00E+00	8.02E-08	0.00E+00	2.01E-08	
% of Limit	%	N/A	N/A	N/A	N/A	N/A	
Gross Alpha	Ci	2.01E-07	5.24E-08	7.72E-08	8.92E-08	4.20E-07	
^{3}H	Ci	4.46E+00	8.05E+00	9.25E+00	6.31E+00	2.81E+01	14
Avg Rel Rate	µCi/s	5.68E-01	1.02E+00	1.16E+00	7.94E-01	8.86-01	
% of Limit	%	N/A	N/A	N/A	N/A	N/A	
^{14}C [3]	Ci	3.3	3.3	3.3	3.3	13.2	

[2] Safety Analysis calculation 87-063-00, January 6, 1988

[3] ^{14}C activity is estimated based on EPRI report TR-1021106, *Estimation of ^{14}C in Nuclear Power Plant Effluents*, December, 2010.

Table A-1A: Gaseous Effluents- Ground Level Release- Batch Mode						
Fission & Activation Gases	**Units**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Total for the year**
^{41}Ar	Ci	3.03E-02	1.04E-01	3.30E-02	3.80E-02	2.05E-01
^{133}Xe	Ci	0.00E+00	1.84E-03	3.56E-04	1.05E-03	3.25E-03
^{85}Kr	Ci	0.00E+00	1.31E-01	1.33E-01	0.00E+00	2.64E-01
^{131m}Xe	Ci	0.00E+00	0.00E+00	2.31E-05	0.00E+00	2.31E-05
Total	Ci	3.03E-02	2.37E-1	1.66E-01	3.90E-02	4.72E-01
Iodines & Halogens	**Units**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Total for the year**
Total	Ci	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Particulates	**Units**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Total for the year**
Total	Ci	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{3}H	Ci	2.92E-02	6.12E-01	2.39E-01	9.91E-02	9.79E-01
Gross α	Ci	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{14}C	Ci	5.41E-01	5.41E-01	5.41E-01	5.41E-01	2.16E+00

Table A-1B: Gaseous Effluents- Ground Level Release- Continuous Mode

Fission & Activation Gases	Units	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Total for the year
^{133}Xe	Ci	5.18E-01	5.79E-01	3.37E-02	2.87E-01	1.42E+00
^{135}Xe	Ci	1.01E-01	9.56E-02	4.52E-02	1.23E-02	2.54E-01
^{85}Kr	Ci	2.39E+00	0.00E+00	0.00E+00	0.00E+00	2.39E+00
Total	Ci	3.01E+00	6.75E-01	7.88E-02	2.99E-01	4.06E+00
Iodines & Halogens	**Units**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Total for the year**
^{133}I	Ci	5.33E-07	0.00E+00	0.00E+00	1.45E-06	1.98E-06
Total	Ci	5.33E-07	0.00E+00	0.00E+00	1.45E-06	1.98E-06
Particulates	**Units**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Total for the year**
^{99}Mo	Ci	0.00E+00	0.00E+00	3.19E-07	0.00E+00	3.19E-07
^{99m}Tc	Ci	0.00E+00	0.00E+00	3.19E-07	0.00E+00	3.19E-07
Total	Ci	0.00E+00	0.00E+00	6.38E-07	0.00E+00	6.38E-07
^{3}H	Ci	4.43E+00	7.44E+00	9.02E+00	6.21E+00	2.71E+01
Gross α	Ci	2.01E-07	5.24E-08	7.72E-08	8.92E-08	4.20E-07
^{14}C	Ci	2.76E+00	2.76E+00	2.76E+00	2.76E+00	1.10E+01

Table A-2: Liquid Effluents- Summation of All Releases

Summation of All Liquid Releases	Units	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Total	Estimated Uncert. (%)[4]
Fission and Activation Products[5]	Ci	6.11E-02	1.65E-02	7.67E-03	4.95E-03	9.02E-02	20
Avg Diluted Conc	µCi/ml	4.45E-07	1.18E-07	4.98E-08	2.96E-08	1.51E-07	
% of Limit	%	N/A	N/A	N/A	N/A	N/A	
^{3}H	Ci	5.80E+00	1.67E+01	7.89E+01	3.60E+02	4.61E+02	14
Avg Diluted Conc	µCi/ml	4.22E-05	1.20E-04	5.12E-04	2.15E-03	7.72E-04	
% of Limit	%	N/A	N/A	N/A	N/A	N/A	
Dissolved & Entrained Gases	Ci	0.00E+00	0.00E+00	0.00E+00	2.94E-06	2.94E-06	27
Avg Diluted Conc	µCi/ml	0.00E+00	0.00E+00	0.00E+00	1.76E-11	4.92E-12	
% of Limit	%	N/A	N/A	N/A	N/A	N/A	
Gross α	Ci	1.23E-03	1.53E-04	0.00E+00	6.50E-05	1.45E-03	29
Avg Diluted Conc	µCi/ml	8.95E-09	1.10E-09	0.00E+00	3.89E-10	2.42E-09	
Vol Liquid Effluent[6]	Liters	4.24E+06	4.24E+06	4.39E+06	4.24E+06	1.71E+07	
Dilution Volume[7]	Liters	1.33E+08	1.35E+08	1.50E+08	1.63E+08	5.81E+08	
Avg river flow[8]	m^3/s	2.00e+03	2.50E+03	1.32E+03	1.24E+03	1.77E+03	

[4] Safety Analysis calculation 87-063-00, January 6, 1988
[5] Excludes ^{3}H, noble gases, and gross alpha.
[6] Primary system liquid effluent plus secondary liquid effluent, prior to dilution.
[7] Does not include Missouri River dilution.
[8] Average Missouri River flow for the year at the Hermann, MO monitoring station as reported by the USGS.

Table A-2A: Liquid Effluents- Batch Mode

Fission & Activation Products	Units	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Total for the year
^{24}Na	Ci	5.02E-05	0.00E+00	0.00E+00	0.00E+00	5.02E-05
^{51}Cr	Ci	1.53E-03	2.56E-04	2.34E-05	0.00E+00	1.81E-03
^{54}Mn	Ci	4.96E-05	0.00E+00	0.00E+00	0.00E+00	4.96E-05
^{58}Co	Ci	0.00E+00	6.38E-06	4.11E-06	0.00E+00	1.05E-05
^{60}Co	Ci	1.09E-02	1.64E-03	2.52E-03	6.06E-04	1.57E-02
^{63}Ni	Ci	8.88E-04	5.51E-04	5.25E-04	6.37E-04	2.60E-03
^{134}Cs	Ci	9.24E-05	7.00E-05	3.86E-06	0.00E+00	1.66E-04
^{137}Cs	Ci	1.07E-03	9.81E-04	5.11E-04	7.05E-05	2.63E-03
^{138}Cs	Ci	1.99E-05	0.00E+00	0.00E+00	0.00E+00	1.99E-05
^{124}Sb	Ci	3.12E-03	2.26E-04	0.00E+00	0.00E+00	3.35E-03
^{125}Sb	Ci	4.33E-02	1.27E-02	4.07E-03	3.64E-03	6.37E-02
^{139}Ba	Ci	0.00E+00	0.00E+00	1.70E-05	0.00E+00	1.70E-05
^{95}Nb	Ci	0.00E+00	0.00E+00	2.80E-06	0.00E+00	2.80E-06
^{132}Te	Ci	1.50E-05	0.00E+00	0.00E+00	0.00E+00	1.50E-05
Total	Ci	6.10E-02	1.65E-02	7.68E-03	4.95E-03	9.01E-02

Table A-2A: Liquid Effluents- Batch Mode (continued)

Dissolved & Entrained Gases	Units	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Total for the year
^{135m}Xe	Ci	0.00E+00	0.00E+00	0.00E+00	2.94E-06	2.94E-06
Total	Ci	0.00E+00	0.00E+00	0.00E+00	2.94E-06	2.94E-06
^{3}H	Ci	5.80E+00	1.67E+01	7.89E+01	3.60E+02	4.61E+02
Gross α	Ci	1.23E-03	1.53E-04	0.00E+00	6.50E-05	1.45E-03

Table A-3: Solid Waste & Irradiated Fuel Shipments

A. SOLID WASTE SHIPPED OFFSITE FOR BURIAL OR DISPOSAL (Not Irradiated Fuel)

1. TYPE OF WASTE	Units	Period Jan – Jun	Period Jul - Dec	Est. Total Error (%)
Spent resins, filter sludges, evaporator bottoms, etc.	m^3 Ci	N/A N/A	4.67E+00 2.21E+00	± 25%
Dry compressible waste, contaminated equip., etc.	m^3 Ci	1.30E+02 6.39E-01	1.06E+02 1.78E-02	± 25%
Irradiated components, control rods, etc.	m^3 Ci	N/A N/A	N/A N/A	± 25%
Other (low level secondary resin, oily waste)	m^3 Ci	1.73E+01 4.29E-02	1.54E+01 2.07E-03	± 25%

2. ESTIMATE OF MAJOR NUCLIDE COMPOSITION (by Type of Waste)				
a. Spent resins, filters, evaporator bottoms, etc.				
Nuclide	% Abundance	Jan – Jun Ci	% Abundance	Jul – Dec Ci
^{137}Cs	N/A	N/A	69.35	1.54E+00
^{60}Co	N/A	N/A	8.82	1.95E-01
^{134}Cs	N/A	N/A	6.72	1.49E-01
^{55}Fe	N/A	N/A	5.30	1.17E-01
^{63}Ni	N/A	N/A	4.82	1.07E-01
b. Dry compressible waste, contaminated equipment, etc.				
^{60}Co	36.18	2.31E-01	36.10	6.42E-03
^{63}Ni	14.91	9.53E-02	14.88	2.65E-03
^{137}Cs	14.47	9.26E-02	14.46	2.57E-03
^{55}Fe	12.63	8.07E-02	12.59	2.24E-03
^{58}Co	5.58	3.56E-02	5.54	9.85E-04
^{51}Cr	3.90	2.49E-02	4.09	7.26E-04
^{95}Nb	3.69	2.36E-02	3.77	6.71E-04
^{95}Zr	2.48	1.59E-02	2.47	4.39E-04
^{134}Cs	2.20	1.40E-02	2.19	3.89E-04
^{54}Mn	1.88	1.20E-02	1.87	3.32E-04
c. Irradiated components, control rods, etc.				
None	N/A	N/A	N/A	N/A

Table A-3: Solid Waste & Irradiated Fuel Shipments (continued)

d. Other

Nuclide	% Abundance	Jan – Jun Ci	% Abundance	Jul – Dec Ci
^{144}Ce	72.44	3.10E-02	N/A	N/A
^{60}Co	10.61	4.55E-03	34.99	7.23E-04
^{63}Ni	N/A	N/A	14.36	2.97E-04
^{137}Cs	10.19	4.37E-03	13.96	2.89E-04
^{55}Fe	N/A	N/A	12.28	2.54E-04
^{58}Co	4.11	1.76E-03	6.07	1.25E-04
^{51}Cr	N/A	N/A	5.03	1.04E-04
^{95}Nb	N/A	N/A	4.50	9.30E-05
^{95}Zr	N/A	N/A	2.73	5.65E-05
^{134}Cs	2.65	1.14E-03	2.14	4.42E-05
^{54}Mn	N/A	N/A	1.86	3.84E-05

3. SOLID WASTE DISPOSITION

Number of Shipments	Mode of Transport	Destination	Class of Solid Waste Shipped	Type of Container
5	HITTMAN TRANSPORT	DURATEK SERVICES, INC.	A	INTERMODAL CONTAINER
2	HITTMAN TRANSPORT	DURATEK , INC./Gallaher Rd	A	INTERMODAL CONTAINER
1	HITTMAN TRANSPORT	DURATEK SERVICES, INC.	A	B-25 LSA Metal Boxes
1	HITTMAN TRANSPORT	DURATEK SERVICES, INC	A	CASK

*Sent to waste processors for volume reduction before burial.

4. SOLIDIFICATION AGENT

None used.

B. IRRADIATED FUEL SHIPMENTS (Disposition)

There were no shipments of irradiated fuel during the reporting period.

Table A-4: Dose Assessments, 10 CFR 50, Appendix I

	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Yearly total
Liquid Effluent Dose Limit, Total Body (mrem)	1.5	1.5	1.5	1.5	3
Total Body Dose (mrem)	3.32E-03	2.91E-03	1.58E-03	7.85E-04	8.55E-03
% Limit (%)	0.22%	0.19%	0.11%	0.05%	0.29%
Liquid Effluent Dose Limit, Maximum Organ (mrem)	5	5	5	5	10
Maximum Organ Dose (mrem)	4.88E-03	4.33E-03	2.31E-03	8.83E-04	1.23E-02
% Limit (%)	0.10%	0.09%	0.05%	0.02%	0.12%
Gaseous Effluent Dose Limit, Gamma Air (mrem)	5	5	5	5	10
Gamma Air Dose (mrad)	2.46E-05	4.78E-05	1.44E-05	2.46E-05	1.03E-04
% Limit (%)	0.00%	0.00%	0.00%	0.00%	0.00%
Gaseous Effluent Dose Limit, Beta Air (mrem)	10	10	10	10	20
Beta Air Dose (mrad)	1.95E-04	5.07E-05	1.81E-05	1.88E-05	2.79E-04
% Limit (%)	0.00%	0.00%	0.00%	0.00%	0.00%
Gaseous Effluent Dose Limit, Maximum Organ (mrem)	7.5	7.5	7.5	7.5	15
Maximum organ dose[9] (mrem)	8.72E-04	1.57E-03	1.81E-03	1.23E-03	5.49E-03
% Limit (%)	0.01%	0.02%	0.02%	0.02%	0.04%
^{14}C Maximum organ dose (mrem)[10]	2.53E-03	2.53E-03	2.53E-03	2.53E-03	1.01E-02

[9] Iodine, ^{3}H, and particulates with greater than an 8 day half- life.
[10] Not included in above totals

Table A-5: EPA 40 CFR 190 Individual in the Unrestricted Area			
	Whole Body	**Thyroid**	**Max Other Organ**
Dose Limit	25 mrem	75 mrem	25 mrem
Dose	7.71E-03	7.70E-03	1.61E-02
% Limit	0.03%	0.01%	0.06%

Appendix B

Joint Frequency Tables; Totals of Hours at Each Wind Speed & Direction for the period January 1, 2012- December 31, 2012

Dispersion Parameters for the Reporting Period

Nearest Resident

Direction: NNW

Distance: 2897 meters

X/Q, Undecayed and Undepleted:	7.340E-07 sec/m^3
X/Q Decayed and Undepleted:	7.298E-07 sec/m^3
X/Q Decayed and Depleted:	6.081E-07 sec/m^3
D/Q Deposition rate:	3.263E-09 m^{-2}

Site Boundary

Direction: NNW

Distance: 2200 meters

X/Q, Undecayed and Undepleted:	1.110E-06 sec/m^3
X/Q Decayed and Undepleted:	1.106E-06 sec/m^3
X/Q Decayed and Depleted:	9.433E-07 sec/m^3
D/Q Deposition rate:	5.114E-09 m^{-2}

Totals of Hours at Each wind Speed and Direction

January 1, 2012 - December 31, 2012

Stability Class A							
	Wind Speed at 10.00 Meter Level (MPH)						
	1-3	*4-7*	*8-12*	*13-18*	*19-24*	*>24*	*TOTAL*
N	0	10	18	5	0	0	33
NNE	0	10	8	0	0	0	18
NE	0	12	16	0	0	0	28
ENE	1	7	9	0	0	0	17
E	0	0	0	1	0	0	1
ESE	1	7	7	0	0	0	15
SE	0	8	7	1	0	0	16
SSE	0	6	22	2	0	0	30
S	0	6	12	5	0	0	23
SSW	0	5	34	4	3	0	46
SW	0	5	25	2	1	0	33
WSW	0	7	12	0	2	0	21
W	0	6	12	7	0	0	25
WNW	0	11	21	5	0	0	37
NW	0	10	36	3	0	0	49
NNW	0	7	22	1	0	0	30
Total	2	117	261	36	6	0	422
Hours of calm data: 1							
Hours of invalid data: 0							

Totals of Hours at Each wind Speed and Direction

January 1, 2012 - December 31, 2012

Stability Class B

	Wind Speed at 10.00 Meter Level (MPH)						
	1-3	***4-7***	***8-12***	***13-18***	***19-24***	***>24***	***TOTAL***
N	0	13	19	1	0	0	33
NNE	0	11	12	1	0	0	24
NE	1	12	11	0	0	0	24
ENE	0	8	7	0	0	0	15
E	0	6	2	0	0	0	8
ESE	0	4	4	0	0	0	8
SE	0	14	16	3	0	0	33
SSE	1	11	23	2	0	0	37
S	0	8	18	5	1	0	32
SSW	0	7	24	6	2	0	39
SW	0	8	18	11	0	0	37
WSW	0	6	9	0	2	0	17
W	0	15	11	1	0	0	27
WNW	0	17	6	3	0	0	26
NW	0	9	18	1	0	0	28
NNW	0	8	18	2	0	0	28
Total	2	157	216	36	5	0	416
Hours of calm data: 0							
Hours of invalid data: 0							

Totals of Hours at Each wind Speed and Direction
January 1, 2012 - December 31, 2012

Stability Class C							
	Wind Speed at 10.00 Meter Level (MPH)						
	1-3	***4-7***	***8-12***	***13-18***	***19-24***	***>24***	***TOTAL***
N	0	20	22	0	0	0	42
NNE	1	15	17	1	0	0	34
NE	1	16	15	0	0	0	32
ENE	0	9	4	0	0	0	13
E	0	9	3	1	0	0	13
ESE	1	9	8	1	0	0	19
SE	0	17	13	2	0	0	32
SSE	0	20	24	3	0	0	47
S	0	16	29	17	0	0	62
SSW	0	18	25	11	1	0	55
SW	1	17	20	3	0	0	41
WSW	1	14	6	2	0	0	23
W	2	7	7	3	0	0	19
WNW	1	21	14	8	0	0	44
NW	0	16	16	3	0	0	35
NNW	1	24	18	0	0	0	43
Total	9	248	241	55	1	0	554
Hours of calm data: 1							
Hours of invalid data: 0							

Totals of Hours at Each wind Speed and Direction

January 1, 2012 - December 31, 2012

Stability Class D							
	Wind Speed at 10.00 Meter Level (MPH)						
	1-3	***4-7***	***8-12***	***13-18***	***19-24***	***>24***	***TOTAL***
N	12	98	87	17	0	0	214
NNE	17	114	60	4	0	0	195
NE	14	90	46	2	0	0	152
ENE	9	67	37	1	0	0	114
E	26	56	52	3	0	0	137
ESE	20	58	47	5	0	0	130
SE	14	105	88	12	0	0	219
SSE	14	113	113	29	0	0	269
S	18	82	124	75	4	0	303
SSW	11	54	72	40	3	0	180
SW	18	65	29	13	0	0	125
WSW	18	38	18	12	1	0	87
W	9	45	40	22	8	0	124
WNW	13	52	72	48	2	0	187
NW	15	77	74	19	0	0	185
NNW	19	103	109	18	0	0	249
Total	247	1217	1068	320	18	0	2870
Hours of calm data: 5							
Hours of invalid data: 0							

Totals of Hours at Each wind Speed and Direction
January 1, 2012 - December 31, 2012

Stability Class E							
	Wind Speed at 10.00 Meter Level (MPH)						
	1-3	***4-7***	***8-12***	***13-18***	***19-24***	***>24***	***TOTAL***
N	20	86	20	0	0	0	126
NNE	17	69	5	0	0	0	91
NE	23	56	4	0	0	0	83
ENE	20	58	5	0	0	0	83
E	16	70	13	0	0	0	99
ESE	17	97	20	0	0	0	134
SE	16	152	60	1	0	0	229
SSE	6	211	129	9	1	0	356
S	20	102	202	43	0	0	367
SSW	16	71	67	2	0	0	156
SW	19	73	25	3	0	0	120
WSW	27	47	11	1	0	0	86
W	18	61	15	2	0	0	96
WNW	32	54	21	0	0	0	107
NW	28	73	18	3	0	0	122
NNW	27	96	13	1	0	0	137
Total	322	1376	628	65	1	0	2392
Hours of calm data: 20							
Hours of invalid data: 0							

Totals of Hours at Each wind Speed and Direction
January 1, 2012 - December 31, 2012

Stability Class F							
	Wind Speed at 10.00 Meter Level (MPH)						
	1-3	4-7	8-12	13-18	19-24	>24	TOTAL
N	18	24	1	0	0	0	43
NNE	27	20	0	0	0	0	47
NE	40	15	1	0	0	0	56
ENE	38	13	0	0	0	0	51
E	29	7	0	0	0	0	36
ESE	29	25	0	0	0	0	54
SE	29	110	4	0	0	0	143
SSE	39	246	33	0	0	0	318
S	31	87	12	0	0	0	130
SSW	26	58	12	0	0	0	96
SW	26	64	7	0	0	0	97
WSW	29	21	1	0	0	0	51
W	17	23	0	0	0	0	40
WNW	41	21	0	0	0	0	62
NW	30	37	0	0	0	0	67
NNW	19	46	0	0	0	0	65
Total	468	817	71	0	0	0	1356
Hours of calm data: 26							
Hours of invalid data 0:							

Totals of Hours at Each wind Speed and Direction
January 1, 2012 - December 31, 2012

Stability Class G							
	Wind Speed at 10.00 Meter Level (MPH)						
	1-3	*4-7*	*8-12*	*13-18*	*19-24*	*>24*	*TOTAL*
N	42	20	0	0	0	0	62
NNE	47	10	0	0	0	0	57
NE	41	7	0	0	0	0	48
ENE	13	0	0	0	0	0	13
E	10	1	0	0	0	0	11
ESE	16	4	0	0	0	0	20
SE	15	12	2	0	0	0	29
SSE	54	71	3	0	0	0	128
S	35	12	1	0	0	0	48
SSW	12	15	0	0	0	0	27
SW	21	11	0	0	0	0	32
WSW	20	6	0	0	0	0	26
W	16	2	0	0	0	0	18
WNW	28	1	0	0	0	0	29
NW	29	24	0	0	0	0	53
NNW	50	27	0	0	0	0	77
Total	449	223	6	0	0	0	678
Hours of calm data: 42							
Hours of invalid data: 0							
Hours of good data: 8783=100% of total hours							

Totals of Hours at Each wind Speed and Direction

January 1, 2012 - December 31, 2012

Stability Class A							
	Wind Speed at 60.00 Meter Level (MPH)						
	1-3	***4-7***	***8-12***	***13-18***	***19-24***	***>24***	***TOTAL***
N	0	8	8	12	0	0	28
NNE	0	5	10	6	0	0	21
NE	0	5	20	0	0	0	25
ENE	0	4	4	5	0	0	13
E	0	1	0	0	1	0	2
ESE	0	7	7	0	0	0	14
SE	0	0	14	5	0	0	19
SSE	0	2	15	11	0	0	28
S	0	2	12	7	1	0	22
SSW	0	2	16	24	0	5	47
SW	0	0	13	19	2	0	34
WSW	0	0	8	9	1	2	20
W	0	2	12	7	9	0	30
WNW	0	3	14	14	7	1	39
NW	0	3	29	19	3	2	56
NNW	0	4	13	7	0	0	24
Total	0	48	195	145	24	10	422
Hours of calm data: 1							
Hours of invalid data: 0							

Totals of Hours at Each wind Speed and Direction

January 1, 2012 - December 31, 2012

Stability Class B							
	Wind Speed at 60.00 Meter Level (MPH)						
	1-3	*4-7*	*8-12*	*13-18*	*19-24*	*>24*	*TOTAL*
N	0	6	23	3	0	0	32
NNE	0	2	16	3	0	0	21
NE	1	4	12	3	0	0	20
ENE	0	4	13	1	0	0	18
E	0	3	5	0	0	0	8
ESE	0	2	4	0	0	0	6
SE	0	7	14	10	0	0	31
SSE	0	7	29	5	1	0	42
S	1	6	13	10	1	1	32
SSW	0	1	13	13	5	2	34
SW	0	3	15	14	9	2	43
WSW	0	2	4	4	1	2	13
W	0	3	18	6	2	0	29
WNW	0	6	13	6	3	1	29
NW	0	5	19	13	0	1	38
NNW	0	6	9	3	2	0	20
Total	2	67	220	94	24	9	416
Hours of calm data: 0							
Hours of invalid data: 0							

Totals of Hours at Each wind Speed and Direction
January 1, 2012 - December 31, 2012

Stability Class C							
	Wind Speed at 60.00 Meter Level (MPH)						
	1-3	***4-7***	***8-12***	***13-18***	***19-24***	***>24***	***TOTAL***
N	0	9	22	2	0	0	33
NNE	1	11	20	4	0	0	36
NE	0	14	14	3	0	0	31
ENE	0	8	7	1	0	0	16
E	0	6	3	1	0	0	10
ESE	0	3	10	2	0	0	15
SE	0	9	19	3	2	0	33
SSE	0	12	22	12	2	0	48
S	0	10	20	26	6	0	62
SSW	0	12	16	16	7	1	52
SW	0	13	21	9	2	1	46
WSW	1	6	10	5	0	2	24
W	0	8	6	2	3	0	19
WNW	0	11	17	8	9	3	48
NW	0	10	18	8	1	2	39
NNW	1	16	17	9	0	0	43
Total	3	158	242	111	32	9	555
Hours of calm data: 0							
Hours of invalid data: 0							

Totals of Hours at Each wind Speed and Direction
January 1, 2012 - December 31, 2012

Stability Class D							
	Wind Speed at 60.00 Meter Level (MPH)						
	1-3	*4-7*	*8-12*	*13-18*	*19-24*	*>24*	*TOTAL*
N	5	48	94	42	10	0	199
NNE	4	66	100	32	0	0	202
NE	6	67	67	10	1	0	151
ENE	10	34	48	13	1	0	106
E	10	31	51	19	6	0	117
ESE	8	33	61	27	3	1	133
SE	11	58	79	54	7	0	209
SSE	10	62	127	67	19	0	285
S	8	46	90	97	42	9	292
SSW	7	39	60	56	33	4	199
SW	7	37	50	22	13	2	131
WSW	3	25	27	15	9	7	86
W	6	20	33	32	14	24	129
WNW	5	27	49	67	38	30	216
NW	6	27	79	65	27	2	206
NNW	6	41	85	63	14	1	210
Total	112	661	1100	681	237	80	2871
Hours of calm data: 4							
Hours of invalid data: 0							

Totals of Hours at Each wind Speed and Direction

January 1, 2012 - December 31, 2012

Stability Class E							
	Wind Speed at 60.00 Meter Level (MPH)						
	1-3	*4-7*	*8-12*	*13-18*	*19-24*	*>24*	*TOTAL*
N	4	24	73	28	0	0	129
NNE	1	22	61	15	0	0	99
NE	0	16	62	5	0	0	83
ENE	2	22	56	6	0	0	86
E	1	17	57	9	1	0	85
ESE	6	14	100	28	0	0	148
SE	6	10	133	91	1	0	241
SSE	4	13	143	142	12	3	317
S	2	9	69	196	45	6	327
SSW	2	26	59	135	4	0	226
SW	4	16	59	60	5	0	144
WSW	0	14	34	23	4	0	75
W	4	13	48	41	2	1	109
WNW	2	11	46	49	6	0	114
NW	3	13	70	47	7	0	140
NNW	1	13	54	18	0	1	87
Total	42	253	1124	893	87	11	2410
Hours of calm data: 2							
Hours of invalid data: 0							

Totals of Hours at Each wind Speed and Direction

January 1, 2012 - December 31, 2012

Stability Class F							
	Wind Speed at 60.00 Meter Level (MPH)						
	1-3	*4-7*	*8-12*	*13-18*	*19-24*	*>24*	*TOTAL*
N	1	4	32	10	0	0	47
NNE	0	3	29	9	0	0	41
NE	0	6	28	4	0	0	38
ENE	0	12	38	3	0	0	53
E	3	12	44	2	0	0	61
ESE	3	8	48	5	0	0	64
SE	1	17	91	35	0	0	144
SSE	1	15	101	95	0	0	212
S	2	19	93	70	1	0	185
SSW	2	6	52	58	5	0	123
SW	3	11	34	76	2	0	126
WSW	2	5	32	18	1	0	58
W	2	9	30	12	1	0	54
WNW	2	8	28	20	1	0	59
NW	3	9	36	10	0	0	58
NNW	0	6	19	32	0	0	57
Total	25	150	735	459	11	0	1380
Hours of calm data: 2							
Hours of invalid data: 0							

Totals of Hours at Each wind Speed and Direction

January 1, 2012 - December 31, 2012

Stability Class G							
	Wind Speed at 60.00 Meter Level (MPH)						
	1-3	***4-7***	***8-12***	***13-18***	***19-24***	***>24***	***TOTAL***
N	4	5	18	19	0	0	46
NNE	2	7	23	13	0	0	45
NE	1	12	28	7	0	0	48
ENE	5	16	45	17	0	0	83
E	3	5	22	1	0	0	31
ESE	2	11	28	1	0	0	42
SE	3	7	9	1	0	0	20
SSE	0	16	21	14	0	0	51
S	3	9	42	19	0	0	73
SSW	6	13	29	9	0	0	57
SW	2	14	16	9	0	0	41
WSW	1	16	18	11	0	0	46
W	2	12	17	3	0	0	34
WNW	6	8	14	3	0	0	31
NW	1	17	13	8	0	0	39
NNW	3	10	5	14	0	0	32
Total	44	178	348	149	0	0	719
Hours of calm data: 1							
Hours of invalid data: 0							
Hours of good data: 8783=100% of total hours							

Appendix C

APA-ZZ-01003, Callaway Energy Center Offsite Dose Calculation Manual, rev. 19

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APA-ZZ-01003

OFF-SITE DOSE CALCULATION MANUAL

Revision 19

INFORMATION USE

August 2012

Contents

OFF-SITE DOSE CALCULATION MANUAL

1. Purpose and Scope

The Offsite Dose Calculation Manual (ODCM) describes the methodology and parameters used in the calculation of off-site doses resulting from radioactive gaseous and liquid effluents, in the calculation of gaseous and liquid effluent monitoring Alarm/Trip Setpoints, and in the conduct of the Radiological Environmental Monitoring Program. The ODCM also contains the Radioactive Effluent Controls and Radiological Environmental Monitoring Program required by T/S 5.5.4 and FSAR-SP Chapter 16.11.4, and descriptions of the information that should be included in the Annual Radiological Environmental Operating and Annual Effluent Release Reports required by T/S 5.6.2 and T/S 5.6.3

Compliance with the Radiological Effluent Controls limits demonstrates compliance with the limits of 10 CFR 20.1301.[1,2,3]

The ODCM consists of two parts: FSAR-SP Chapter 16.11 which contains the Radiological Effluent Controls (RECs), and APA-ZZ-01003, which contains the methodology and parameters used to implement the RECs.

2. Liquid Effluents

2.1. Liquid Effluent Monitors

Gross radioactivity monitors which provide for automatic termination of liquid effluent releases are present on the liquid effluent lines. Flow rate measurement devices are present on the liquid effluent lines and the discharge line (cooling tower blowdown). Setpoints, precautions, and limitations applicable to the operation of the Callaway Plant liquid effluent monitors are provided in the appropriate Plant Procedures. Setpoint values are calculated to assure that alarm and trip actions occur prior to exceeding ten times the Effluent Concentration Values (ECV) limits in 10 CFR Part 20 at the release point to the Unrestricted Area. The calculated alarm and trip action setpoints for the liquid effluent line monitors and flow measuring devices must satisfy the following equation:

$$\frac{cf}{F+f} \leq C$$

Eq. 1

Where:

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[1] Statements of Consideration, Federal Register, Vol. 56, No. 98, Tuesday, May 21, 1991, Subpart D, page 23374
[2] 10 CFR 50.36 a (b)
[3] Letter, F. J. Congel to J. F. Schmidt, dated April 23, 1991

C is the liquid effluent concentration value (ECV) implementing REC 16.11.1.1 for the site in µCi/ml;

c is the setpoint, in (µCi/ml), of the radioactivity monitor measuring the radioactivity concentration in the effluent line prior to dilution and subsequent release. The setpoint, which is inversely related to the volumetric flow of the effluent line and directly related to the volumetric flow of the dilution stream plus the effluent steam, represents a value, which, if exceeded, would result in concentrations exceeding ten times the values of 10 CFR Part 20 Appendix B, Table 2, Column 2, in the Unrestricted Area;

f is the undiluted waste flow rate as measured at the radiation monitor location, in volume per unit time, but in the same units as F, below; and

F is the dilution water flow rate setpoint as measured prior to the release point, in volume per unit time. If **F** is large compared to **f**, then $F + f \cong F$.[4]

If no dilution is provided then $c \leq C$.

The radioactive liquid waste stream is diluted by the plant discharge line prior to entry into the Missouri River. Normally, the dilution flow is obtained from the cooling tower blowdown, but should this become unavailable, the plant water treatment facility supplies the necessary dilution flow via a bypass line.

The limiting concentration which corresponds to the liquid radwaste effluent monitor setpoint is to be calculated using methodology from the expression above. Thus, the expression for determining the setpoint of the liquid radwaste effluent line monitor becomes:

$$c \leq \frac{C(F+f)}{f} (\mu Ci / ml)$$

Eq. 2

The alarm/trip setpoint calculations are based on the minimum dilution flow rate (corresponding to the dilution flow rate setpoint), the maximum effluent stream flow rate, and the actual isotopic analysis. Due to the possibility of a simultaneous release from more than one release pathway, a portion of the total site release limit is allocated to each pathway. The determination and usage of the allocation factor is discussed in Section 2.2. In the event the alarm/trip setpoint is reached, an evaluation will be performed using actual dilution and effluent flow values and actual isotopic analysis to ensure that REC 16.11.1.1 limits were not exceeded.

2.1.1. Continuous Liquid Effluent Monitors

The radiation detection monitor associated with continuous liquid effluent releases is:[5,6]

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[4] NUREG-0133, pages AA-1 thru AA-3
[5] FSAR-SP, Section 11.5.2.2.3.1
[6] FSAR-SP, Section 11.5.2.2.3.4

Monitor I.D.	Description
BM-RE-52	Steam Generator Blowdown Discharge Monitor

The Steam Generator Blowdown discharge is not considered to be radioactive unless radioactivity has been detected by the associated effluent radiation monitor or by laboratory analysis. The sampling frequency, minimum analysis frequency, and type of analysis performed are Per FSAR-SP Table 16.11-1.

2.1.2. Radioactive Liquid Batch Release Effluent Monitors

The radiation monitor associated with the liquid effluent batch release system is:[7]

Monitor I.D.	Description
HB-RE-18	Liquid Radwaste Discharge Monitor

This effluent stream is normally considered to be radioactive. The sampling frequency, minimum analysis frequency, and the type of analysis performed are per FSAR-SP Table 16.11-1.

2.2. Calculation of Liquid Effluent Monitor Setpoints

The dependence of the setpoint, **c**, on the radionuclide distribution, yields, calibration, and monitor parameters, requires that several variables be considered in setpoint calculations.[8]

2.2.1. Calculation of the ECV Sum

The isotopic concentration of the release(s) being considered must be determined. This is obtained from the analyses required per FSAR-SP Table 16.11-1, and is used to calculate an ECV sum (ECVSUM):

$$ECVSUM = \left(\sum (C_i)/(ECV_i)\right)$$
$$i = g, a, s, t, f$$

Eq. 3

Where:

$\mathbf{C_g}$ is the concentration of each measured gamma emitting nuclide observed by gamma-ray spectroscopy of the waste sample;

$\mathbf{C_a}$ is the concentration of ^{237}Np, ^{238}Pu, $^{239/240}$Pu, ^{241}Pu, ^{241}Am, ^{242}Cm, & $^{243/244}$Cm, in the quarterly composite sample based on previous composite sample analyses;

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[7] FSAR-SP, Section 11.5.2.2.3.2
[8] NUREG-0133, pages AA-1 thru AA-3

C_s is the measured concentrations of ^{89}Sr and ^{90}Sr as determined by analysis of the quarterly composite sample based on previous composite sample analyses;

C_t is the measured concentration of ^{3}H in the waste sample; and

C_f is the measured concentration of ^{55}Fe & ^{63}Ni as determined by analysis of the quarterly composite sample based on previous composite sample analyses.

ECV_g, ECV_s, ECV_a, ECV_f, and **ECV_t** are ten times the limiting concentrations of the appropriate radionuclides from 10 CFR 20, Appendix B, Table 2, Column 2. For dissolved or entrained noble gases, the concentration shall be limited to 2×10^{-4} μCi/ml total activity.

For the case ECVSUM ≤1, the monitor tank effluent concentration meets the limits of REC 16.11.1.1 without dilution and the effluent may be released at any desired flow rate. If ECVSUM > 1 then dilution is required to ensure compliance with the concentration limits of REC 16.11.1.1. If simultaneous releases are occurring or are anticipated, an allocation fraction, **N**, must be applied so that available dilution flow may be apportioned among simultaneous discharge pathways. The value of N may be any value between 0 and 1 for a particular discharge point, provided that the sum of the allocation fractions for all discharge points must be ≤1.

2.2.2. Calculation of the Maximum Permissible Liquid Effluent Discharge Flow Rate

The maximum permissible liquid effluent discharge flow rate is calculated by:

$$f_{max} \leq (F + f_p) \cdot SF \cdot N \div (ECVSUM)$$

Eq. 4

Where:

f_{max} is the maximum permissible liquid effluent discharge flow rate, (in gallons/minute);

f_p is the expected undiluted liquid effluent flow rate, in gpm;

N is the allocation fraction which apportions dilution flow among simultaneous discharge pathways (see discussion above); and

SF is the safety factor; an administrative factor used to compensate for statistical fluctuations and errors of measurements. This factor also provides a margin of safety in the calculation of the maximum liquid effluent discharge flow rate (f_{max}). The value of SF should be ≤ 1.

F and **ECVSUM** are previously defined.

The dilution water supply is furnished with a flow monitor which isolates the liquid effluent discharge if the dilution flow rate falls below its setpoint value.

In the event that f_{max} is less than f_p, then the value of f_{max} is substituted into the equation for f_p, and a new f_{max} value is calculated. This substitution is performed for three iterations in order to calculate the correct value of f_{max}.

2.2.3. Calculation of Liquid Effluent Monitor Setpoint

The liquid effluent monitors are NaI(Tl) based systems and respond primarily to gamma radiation. Accordingly, their setpoint is based on the total concentration of gamma emitting nuclides in the effluent:

$$c = 0.95 \cdot \left[bkg + \left[(\sum C_g) \div SF \right] \right]$$

Eq. 5

Where:

c is the monitor setpoint as previously defined, in µCi/ml;

bkg is the monitor background prior to discharge, in µCi/ml, adjusted for monitor response; and

0.95 is a factor for conservatism to ensure the monitor trips prior to exceeding the limits of REC 16.11.1.1

$\sum C_g$ and **SF** are as previously defined.

The monitor's background is controlled at an appropriate limit to ensure adequate sensitivity. Utilizing the methodology of ANSI N13.10-1974, the background must be maintained at a value of less than or equal to 9×10^{-6} µCi/ml (relative to ^{137}Cs) in order to detect a change of 4×10^{-7} µCi/ml of ^{137}Cs.[9]

In the event that there is no detectable gamma activity in the effluent or if the value of $\left\{ (\sum C_g) \div SF \right\}$ is less than the background of the monitor, then the monitor setpoint will be set at twice the current background of the monitor.

As previously stated, the monitor's response is dependent on the gamma emitting radionuclide distribution of the effluent. Accordingly, a database conversion factor is calculated for each release based upon the results of the gamma spectrometric analysis of the effluent sample and the measured response of the monitor to National Institute of Standards and Technology (NIST) traceable calibration sources:

$$DBCF_C = \left(\sum \left(C_g \right) \right) \div \left(CMR \right) x \left(ECF \right)$$

Eq. 6

$DBCF_c$ is the monitor data base conversion factor which converts count rate into concentration (µCi/ml);

CMR is the calculated response of the radiation monitor to the liquid effluent;

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[9] HPCI 96-005, "Calculation of Maximum Background Value for HB-RE-18"

ECF is the conversion factor for ^{137}Cs, which converts count rate into concentration (μCi/ml).

C_g is as previously defined.

The new value of the $DBCF_c$ is calculated and entered into the monitor data base prior to each discharge. A more complete discussion of the derivation and calculation of the CMR is given in HPCI 87-10.

2.3. Liquid Effluent Concentration Measurements

Liquid batch releases are discharged as a discrete volume and each release is authorized based upon the sample analysis and the dilution flow rate existing in the discharge line at the time of release. To assure representative sampling, each liquid monitor tank is isolated and thoroughly mixed by recirculation of tank contents prior to sample collection. The methods for mixing, sampling, and analyzing each batch are outlined in applicable plant procedures. The allowable release rate limit is calculated for each batch based upon the pre-release analysis, dilution flow-rate, and other procedural conditions, prior to authorization for release. The liquid effluent discharge is monitored prior to entering the dilution discharge line and will automatically be terminated if the pre-selected alarm/trip setpoint is exceeded. Concentrations are determined primarily from the gamma isotopic and ^{3}H analyses of the liquid batch sample. For ^{89}Sr, ^{90}Sr, ^{55}Fe, ^{63}Ni, ^{237}Np, ^{238}Pu, $^{239/240}Pu$, ^{241}Pu, ^{241}Am, ^{242}Cm, & $^{243/244}Cm$, the measured concentrations from the previous quarterly composite analyses are used until laboratory results become available. Composite samples are collected for each batch release and analyzed in accordance with FSAR-SP Table 16.11-1.The dose from liquids discharged as continuous releases is calculated by utilizing the last measured values of samples in accordance with FSAR-SP Table 16.11-1.

2.4. Dose due to Liquid Effluents

2.4.1. The Maximum Exposed Individual

The cumulative dose determination considers the dose contributions from the maximum exposed individual's consumption of fish and potable water, as appropriate. Normally, the adult is considered to be the maximum exposed individual.[10]

The Callaway Plant's liquid effluents are discharged to the Missouri River. As there are no potable water intakes within 10 miles of the discharge point,[11,12] this pathway does not require routine evaluation. Therefore, the dose contribution from fish consumption is expected to account for more than 95% of the total man-rem dose from discharges to the Missouri River. Dose from recreational activities is expected to contribute the additional 5%, which is considered to be negligible.[13]

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[10] NUREG-0133, Section 4.3
[11] Environmental Report, OLS, Table 2.1-19
[12] FSAR-SP Section 11.2.3.3.4
[13] FSAR-SP, Section 11.2.3.4.3

2.4.2. Calculation of Dose from Liquid Effluents

The dose contributions for the total time period $\sum_{l=1}^{m} \Delta t_l$ are calculated at least once each 31 days and a cumulative summation of the total body and individual organ doses is maintained for each calendar quarter. Dose is calculated for all radionuclides identified in liquid effluents released to Unrestricted Areas using the following expression:[14]

$$D_\tau = \sum_i \left[A_{i\tau} \sum_{l=1}^{m} \Delta t_l \; C_{il} \; F_l \right]$$

Eq. 7

Where:

D_τ is the cumulative dose commitment to the total body or any organ, τ, from the liquid effluents for the total period $\sum_{l=1}^{m} \Delta t_l$ in mrem.

Δt_l is the length of the l^{th} time period over which $C_{i,l}$ and F_l are averaged for all liquid releases, in hours. Δt_l corresponds to the actual duration of the release(s).

$C_{i,l}$ is the average measured concentration of radionuclide, i, in undiluted liquid effluent during the time period Δt_l from any liquid release, in (μCi/ml).

$A_{i\tau}$ is the site- related ingestion dose commitment factor to the total body or any organ τ for each identified principal alpha, gamma and beta emitter listed in FSAR-SP Table 16.11-1,in (mrem/hr) per (μCi/ml). The calculation of the $A_{i\tau}$ values given in Table 1 are detailed in calculation 87-001-00.

F_l is the near field average dilution factor for C_{il} during any liquid effluent release:

$$F_l = \frac{f_{max}}{\left(F + f_{max}\right) \cdot 89.77}$$

Eq. 8

Where:

F_{max} is the maximum undiluted effluent flow rate during the release;

F is the average dilution flow; and

89.77 is site specific applicable factor for the mixing effect of the discharge structure.[15,16,17]

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[14] NUREG-0133, Section 4.3
[15] NEO-54
[16] UOTH 83-58

The term $C_{i,l}$ is the undiluted concentration of radioactive material in liquid waste at the common release point determined in accordance with REC 16.11.1.1, Table 16.11-1, "Radioactive Liquid Waste Sampling and Analysis Program". All dilution factors beyond the sample point(s) are included in the F_l term.

As there are currently no potable water intakes within 10 river miles of the discharge point, the drinking water pathway is not included in dose estimates to the maximally exposed individual. Should future potable water intakes be constructed within 10 river miles downstream of the discharge point, then this manual will be revised to include this pathway in dose estimates.[18]

2.4.3. Summary, Calculation of Dose Due to Liquid Effluents

The dose contribution for the total time period $\sum_{l=1}^{m} \Delta t_l$ is determined by calculation at least once per 31 days and a cumulative summation of the total body and organ doses is maintained for each calendar quarter. The projected dose contribution from liquid effluents for which radionuclide concentrations are determined by periodic composite and grab sample analysis may be approximated by using the last measured value. Dose contributions are determined for all radionuclides identified in liquid effluents released to Unrestricted Areas. Nuclides which are not detected in the analyses are reported as "less than" the Minimum Detectable Activity (MDA) and are not reported as being present at the Lower Limit of Detection (LLD) for that nuclide. The "less than" values are not used in the dose calculations.

2.5. Liquid Radwaste Treatment System

The Liquid Radwaste Treatment System is described in FSAR-SP Chapter 11.2.

The Operability of the Liquid Radwaste Treatment System ensures this system will be available for use when liquids require treatment prior to their release to the environment. Operability is demonstrated through compliance with REC 16.11.1.1. and 16.11.1.2.

Projected doses due to liquid releases to Unrestricted Areas are determined each 31 days. The prior 31 day period is used to calculate compliance. This may be modified as appropriate to account for changes in radwaste treatment which may have a significant effect on the projected doses.

2.6. Dose Factors

The dose conversion factors provided in Table 1 were derived from the appropriate dose conversion factors of Regulatory Guide 1.109, Table 2.2 and other sources as necessary.[19]

3. Gaseous Effluents

3.1. Gaseous Effluent Monitors

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[17] CAR 200700053- Attachments: Phase 1 final draft
[18] FSAR-SP, Section 11.2.3.3.4
[19] HPCI 04-06, rev. 1

Noble gas activity monitors are present on the containment building ventilation system, plant unit ventilation system, and radwaste building ventilation system.

The alarm/trip (alarm & trip) setpoint for any gaseous effluent radiation monitor is determined based on the instantaneous noble gas total body and skin dose rate limits of REC 16.11.2.1, at the Site Boundary location with the highest annual average X/Q value.

Each gaseous monitor channel is provided with a two level system which provides sequential alarms on increasing radioactivity levels. These setpoints are designated as alert setpoints and alarm/trip setpoints.[20]

The radiation monitor alarm/trip setpoints for each release point are based on the radioactive noble gases in gaseous effluents. It is not considered practicable to apply instantaneous alarm/trip setpoints to integrating radiation monitors sensitive to radioiodines, radioactive materials in particulate form and radionuclides other than noble gases. The exception is GL-RE-202. The only effluent released from the Laundry Decon Facility Dryer Exhaust is in the particulate form. Conservative assumptions may be necessary in establishing setpoints to account for system variables, such as the measurement system efficiency and detection capabilities during normal, anticipated, and unusual operating conditions, variability in release flow and principal radionuclides, and the time lag between alarm/trip action and the final isolation of the radioactive effluent.[21] FSAR-SP Table 16.11-6 provides the instrument surveillance requirements, such as calibration, source checks, functional tests, and channel checks.

3.1.1. Continuous Release Gaseous Effluent Monitors

The radiation detection monitors associated with continuous gaseous effluent releases are:[22,23]

Monitor I.D.	Description
GT-RE-21	Unit Vent
GH-RE-10	Radwaste Building Vent
GL-RE-202	Laundry Decon Facility Dryer Exhaust Monitor

Each of the above continuously monitors gaseous radioactivity concentrations downstream of the last point of potential influent, and therefore measures effluents and not inplant concentrations.

The unit vent monitor continuously monitors the effluent from the unit vent for gaseous radioactivity. The unit vent, via ventilation exhaust systems, continuously purges various tanks and sumps normally containing low-level radioactive aerated liquids that can potentially

[20] FSAR-SP Section 11.5.2.1.2
[21] NUREG- 0133, section 5.1.1
[22] FSAR-SP Section 11.5.2.3.3.1
[23] FSAR-SP Section 11.5.2.3.3.2

generate airborne activity. The exhaust systems which supply air to the unit vent are from the fuel building, auxiliary building, the access control area, the containment purge, and the condenser air discharge.

The unit vent monitor provides alarm functions only, and does not terminate releases from the unit vent.

The Radwaste Building ventilation effluent monitor continuously monitors for gaseous radioactivity in the effluent duct downstream of the exhaust filter and fans. The flow path provides ventilation exhaust for all parts of the building structure and components within the building and provides a discharge path for the waste gas decay tank release line. These components represent potential sources for the release of gaseous and air particulate and iodine activities in addition to the drainage sumps, tanks, and equipment purged by the waste processing system.

This monitor will isolate the waste gas decay tank discharge line upon a high gaseous radioactivity alarm.

The Laundry Decon Facility Dryer Exhaust Monitor continuously monitors the effluent of the dryer exhaust for particulate radioactivity during operation of the dryers. This effluent point is designed to release an insignificant quantity of radioactivity. The items to be placed in the dryers are typically washed before drying removing most of the radioactive material. The dryer effluent then passes through a HEPA filter before being sampled and released.

The Laundry Decon Facility Dryer Exhaust Monitor will secure the dryers and exhaust fans and isolate the dryer effluent upon a high radioactivity alarm or for a monitor failure.

The continuous Unit Vent and Radwaste Building Vent gaseous effluent monitor setpoints are established using the methodology described in Section 3.2. Since there are two continuous gaseous effluent release points, a fraction of the total dose rate limit (DRL) will be allocated to each release point. Neglecting the batch releases, the plant Unit Vent monitor has been allocated 0.7 DRL and the Radwaste Building Vent monitor has been allocated 0.3 DRL. These allocation factors may be changed as required to support plant operational needs, but shall not be allowed to exceed unity (i.e., 1.0). Therefore, a particular monitor reaching the setpoint would not necessarily mean the dose rate limit at the Site Boundary is being exceeded; the alarm only indicates that the specific release point is contributing a greater fraction of the dose rate limit than was allocated to the associated monitor, and will necessitate an evaluation of both systems.

For a loss of all isokinetic sampling and/or all heat tracing for the Unit Vent or Radwaste Building Vent grab samplers, one hour is allowed to restore a sampler to service. If sampling cannot be restored within one hour, all batch releases and ventilation not required for the operation of the plant should be secured. The best available sampling should be maintained during this period and normal sampling returned to service as soon as possible.

3.1.2. Batch Release Gaseous Effluent Monitors

The radiation monitors associated with batch release gaseous effluents are:[24,25,26]

Monitor I.D.	Description
GT-RE-22, GT-RE-33	Containment Purge System
GH-RE-10	Radwaste Building Vent

The Containment Purge System continuously monitors the containment purge exhaust duct during purge operations for gaseous radioactivity. The primary purpose of these monitors is to isolate the containment purge system on high gaseous activity via the ESFAS.

The sample points are located outside the containment between the containment isolation dampers and the containment purge filter adsorber unit.

The Radwaste Building Vent monitor was previously described.

A pre-release isotopic analysis is performed for each batch release to determine the identity and quantity of the principal radionuclides. The alarm/trip setpoint(s) is adjusted accordingly to ensure that the limits of REC 16.11.2.1 are not exceeded.

3.2. Gaseous Effluent Monitor Setpoints

The alarm/trip setpoint for the Unit Vent and Radwaste Building Vent gaseous effluent monitors is determined based on the more restrictive of the total body dose rate (Eq. 9) and skin dose rate (Eq. 11) as calculated for the Site Boundary .

The alarm/ trip setpoint for the Laundry Decon Facility Exhaust Monitor is set to less than or equal to 2,000 cpm above equilibrium background. The maximum allowed background is 2,000 cpm as discussed in HPCI 99-05.

3.2.1. Total Body Dose Rate Setpoint Calculations

To ensure that the limits of REC 16.11.2.1 are met, the alarm/trip setpoint based on the total body dose rate is calculated according to:

$$S_{tb} \le D_{tb} R_{tb} F_s F_a$$

Eq. 9

Where:

$\mathbf{S_{tb}}$ is the alarm/trip setpoint based on the total body dose rate (μCi/cc);

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[24] FSAR-SP Section 11.5.2.3.3.2
[25] FSAR-SP Section 11.5.2.3.2.3
[26] FSAR-SP Section 11.5.2.3.2.2

D_{tb} is the REC 16.11.2.1 dose rate limit of 500 mrem/yr, conservatively interpreted as a continuous release over a one year period;

F_s is the safety factor; a conservative factor used to compensate for statistical fluctuations and errors of measurement. (For example, F_S = 0.5 corresponds to a 100% variation.) Default value is F_S = 0.1.

F_a is the allocation factor which will modify the required dilution factor such that simultaneous gaseous releases may be made without exceeding the limits of REC 16.11.2.1.

R_{tb} is a factor used to convert dose rate to the effluent concentration as measured by the effluent monitor, in (μCi/cc) per (mrem/yr) to the total body, determined according to:

$$R_{tb} = C \div \left[\left(\overline{X/Q} \right) \sum_i (K_i Q_i) \right]$$

Eq. 10

Where:

C is the reading of a noble gas monitor corresponding to the sample radionuclide concentrations for the release. Concentrations are determined in accordance with FSAR-SP Table 16.11-4.The mixture of radionuclides determined via grab sampling of the effluent stream or source is correlated to a calibration factor to determine monitor response. The monitor response is based on concentration, not release rate, and is in units of (μCi/cc);

$\overline{X/Q}$ is the highest calculated annual average relative concentration for any area at or beyond the Site Boundary in (sec/m^3) (Table 10, Table 11, Table 12, and Table 13);

K_i is the total body dose factor due to gamma emissions for each identified noble gas radionuclide, in (mrem/yr) per (μCi/m^3) (Table 3); and

Q_i is the rate of release of noble gas radionuclide, i, in (μCi/sec).

Q_i is calculated as the product of the ventilation path flow rate and the measured activity of the effluent stream as determined by sampling.

3.2.2. Skin Dose Rate Setpoint Calculation

To ensure that the limits of REC 16.11.2.1 are met, the alarm/trip setpoint based on the skin dose rate is calculated according to:

$$S_s \leq D_s R_s F_s F_a$$

Eq. 11

Where:

F_s and F_a are as previously defined;

$\mathbf{S_s}$ is the alarm/trip setpoint based on the skin dose rate;

$\mathbf{D_s}$ is the REC 16.11.2.1 dose rate limit of 3000 mrem/yr, conservatively interpreted as a continuous release over a one year period; and

$\mathbf{R_s}$ is the factor used to convert dose rate to the effluent concentration as measured by the effluent monitor, in (μCi/cc) per (mrem/yr) to the skin, determined according to:

$$R_s = C \div \left[\left(\overline{X/Q}\right) \sum_i \left(L_i + 1.1M_i\right) Q_i \right]$$

Eq. 12

Where:

$\mathbf{L_i}$ is the skin dose factor due to beta emissions for each identified noble gas radionuclide, in (mrem/yr) per (μCi/m^3);

1.1 is a factor of units conversion; 1 mrad air dose = 1.1 mrem skin dose; and

$\mathbf{M_i}$ is the air dose factor due to gamma emissions for each identified noble gas radionuclide, in (mrad/yr) per (μCi/m^3).

C, $\overline{(X/Q)}$**, and** $\mathbf{Q_i}$ are previously defined.

3.3. Calculation of Dose and Dose Rate from Gaseous Effluents

3.3.1. Dose Rate from Gaseous Effluents

The following methodology is applicable to the location (Site Boundary or beyond) characterized by the values of the parameter X/Q which results in the maximum total body or skin dose rate. In the event that the analysis indicates a different location for the total body and skin dose limitations, the location selected for consideration is that which minimizes the allowable release values.[27]

The factors $\mathbf{K_i}$, $\mathbf{L_i}$, and $\mathbf{M_i}$ relate the radionuclide airborne concentrations to various dose rates, assuming a semi-infinite cloud model.

3.3.1.1. Dose Rate from Noble Gases

The release rate limit for noble gases is determined according to the following general relationships:[28]

$$D_{tb} = \sum_i \left[K_i Q_i \left(\left(\overline{X/Q}\right) \right) \right] \leq 500\ mrem/yr$$

Eq. 13

[27] NUREG-0133, Section 5.1.2
[28] NUREG-0133, Section 5.1.2

$$D_s = \sum_i \left[\left(L_i + 1.1\ M_i \right) \left(\left(\overline{X/Q} \right) Q_i \right) \right] \leq 3000\ mrem/yr$$

Eq. 14

Where:

Q_i is the release rate of noble gas radionuclides, i, in gaseous effluents, from all vent releases in (μCi/sec); and

1.1 is a factor of units conversion factor; 1 mrad air dose = 1.1 mrem skin dose.

L_i, M_i, K_i, $\left(\overline{X/Q}\right)$, D_{tb} and **D_s** are as previously identified.

3.3.1.2. Dose Rate from Radionuclides Other than Noble Gases

The release rate limit for ^{131}I and ^{133}I, for ^{3}H, and for all radioactive materials in particulate form with half-lives greater than 8 days is determined according to:[29]

$$D_o = \sum_i R_i \left[\overline{X/Q} \right] Q_i \leq 1500\ mrem/yr$$

Eq. 15

Where:

D_o is the dose rate to any critical organ, in (mrem/yr);

R_i is the dose parameter for radionuclides other than noble gases for the inhalation pathway for the child, based on the critical organ, in (mrem/yr) per (μCi/m^3); and

Q_i is the release rate of radionuclides other than noble gases, i, in gaseous effluents, from all vent releases in (μCi/sec).

$\left(\overline{X/Q}\right)$ is as previously defined.

The dose parameter (R_i) includes the internal dosimetry of radionuclide, i, and the receptor's breathing rate, which are functions of the receptor's age. The child age group has been selected as the limiting age group. All radiodines are assumed to be released in elemental form.[30]

R_i values were calculated according to:[31]

$$R_i = K'(BR)\ DFA_i$$

Eq. 16

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[29] NUREG-0133, Section 5.2.1
[30] NUREG-0133, Section 5.2.1
[31] NUREG-0133, Section 5.2.1.1

Where:

K' is a factor of units conversion factor: $1x10^6$ pCi/μCi;

BR is the breathing rate from Regulatory Guide 1.109, Table E-5 (m^3/yr);

DFA$_i$ is the maximum organ inhalation dose factor for the i^{th} radionuclide, in (mrem/pCi). The total body is considered as an organ in the selection of DFA$_i$.[32,33]

The results of periodic tritium, iodine and particulate samples of the Unit Vent and Radwaste Vent are used to verify the dose rate limit was not exceeded for the period during which the samples or composite samples were obtained.

3.3.2. Dose Due to Gaseous Effluents

3.3.2.1. Air Dose Due to Noble Gases

The air dose at the Site Boundary due to noble gases is calculated according to the following methodology:[34]

During any calendar quarter, for gamma radiation:

$$D_g = 3.17E\text{-}08 \sum_i \left[M_i \left(\overline{X/Q}\right) Q_i \right] \leq 5\ mrad$$

Eq. 17

During any calendar quarter, for beta radiation:

$$D_b = 3.17E\text{-}08 \sum_i \left[N_i \left(\overline{X/Q}\right) Q_i \right] \leq 10\ mrad$$

Eq. 18

During any calendar year, for gamma radiation:

$$D_g = 3.17E\text{-}08 \sum_i \left[M_i \left(\overline{X/Q}\right) Q_i \right] \leq 10\ mrad$$

Eq. 19

During any calendar year, for beta radiation:

$$D_b = 3.17E\text{-}08 \sum_i \left[N_i \left(\overline{X/Q}\right) Q_i \right] \leq 20\ mrad$$

Eq. 20

Where:

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[32] Regulatory Guide 1.109, Appendix E, Table E-9
[33] ZZ-48
[34] NUREG-0133, Section 5.3.1

D_g is the air dose in mrad, from gamma radiation due to noble gases released in gaseous effluent;

D_b is the air dose in mrad, from beta radiation due to noble gases released in gaseous effluents;

N_i is the air dose factor due to beta emissions for each identified noble gas radionuclide, i, in (mrad/yr) per (μCi/m^3);

Q_i is the releases of noble gas radionuclides, i, in gaseous effluents, for all gaseous releases in (μCi). Releases are cumulative over the calendar quarter or year as appropriate. Q_i is calculated as the product of the ventilation flow rate and the measured activity of the effluent stream as determined by sampling; and

3.17×10^{-8} is the inverse of the number of seconds per year.

$\overline{X/Q}$ & **M_i** are as previously defined.

3.3.2.2. Dose Due to Radionuclides Other than Noble Gases

The dose to a Member of the Public from ^{131}I and ^{133}I, for ^{3}H, and all radionuclides in particulate form with half-lives greater than 8 days in gaseous effluents released to areas at and beyond the Site Boundary, is calculated according to the following expressions:

During any calendar quarter:

$$\sum_j D_{I,j} \leq 7.5\ mrem$$

Eq. 21

During any calendar year:

$$\sum_j D_{I,j} \leq 15\ mrem$$

Eq. 22

For each pathway, j, (i.e., for inhalation, ground plane, meat, cow- milk, goat- milk, and vegetation) $D_{I,j}$ is calculated according to the expression:

$$D_{I,j} = 3.17E-8 \sum_i R_{I,i,j} \left[W_j Q_i \right]$$

Eq. 23

Where:

$D_{I,j}$ is the dose in mrem, to a Member of the Public from radionuclides other than noble gases, from pathway j, received by organ I (including total body);

$R_{I,i,j}$ is the dose factor for each identified radionuclide, i, in m^2 (mrem/yr) per (μCi/sec) or (mrem/yr) per (μCi/m^3) as appropriate, for the pathway $_j$, and exposed organ I, appropriate to the age group of the critical Member of the Public receptor;

$\mathbf{W_j}$ is the $\overline{X/Q}$ for the inhalation and tritium pathways, in sec/m^3 and is the $\overline{D/Q}$ for the food and ground plane pathways, in meters^{-2}.

$\overline{D/Q}$ is the average relative deposition of the effluent at or beyond the Site Boundary, considering depletion of the plume during transport;

$\mathbf{Q_i}$ is the release of radioiodines, radioactive materials in particulate form, and radionuclides other than noble gases, i, in gaseous effluents, for all gaseous releases in μCi. Releases are cumulative over the calendar quarter or year as appropriate. Q_i is calculated as the product of ventilation flow rate and the measured activity of the effluent stream as determined by sampling; and

$\mathbf{3.17x10^{-8}}$ is the inverse of the number of seconds per year.

$\overline{X/Q}$ is as previously defined. Refer to Table 10, Table 11,Table 12, and Table 13 for applicability;

Although the annual average relative concentration $\overline{X/Q}$ and the average relative deposition rate $\overline{D/Q}$ are generally considered to be at the approximate receptor location in lieu of the Site Boundary for these calculations, it is acceptable to consider the ingestion, inhalation, and ground plane pathways to coexist at the location of the nearest residence with the highest value of $\overline{X/Q}$.[35] The Total Body dose from ground plane deposition is added to the dose for each individual organ.[36]

3.4. Gaseous Radwaste Treatment System

The gaseous radwaste treatment system and the ventilation exhaust system are available for use whenever gaseous effluents require treatment prior to being released to the environment. The gaseous radwaste treatment system is designed to allow for the retention of all gaseous fission products to be discharged from the reactor coolant system. The retention system consists of eight (8) waste gas decay tanks. Normally, waste gases will be retained for at least 60 days prior to discharge. When practicable, waste gas decay tanks are discharged outside the growing season or at night such that ^{14}C released from the waste gas system will not be incorporated into the ingestion pathways and will result in a lower dose to the Member of the Public. For this purpose, the growing season is defined as April 1 through November 1.[37] These systems will provide reasonable assurance that the releases of radioactive materials in gaseous effluents will be kept ALARA.

The Operability of the gaseous radwaste treatment system ensures this system will be available for use when gases require treatment prior to their release to the environment. Operability is demonstrated through compliance with REC 16.11.2.1, 16.11.2.2, and 16.11.2.3.

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[35] NUREG-0133, Section 5.3.1
[36] Regulatory Guide 1.109, Appendix C, Section 1
[37] Hammer, Gregory, R., "Climate of Missouri", monograph available from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA), January, 2006.

Projected doses (gamma air, beta air, and organ dose) due to gaseous effluents at or beyond the Site Boundary are determined each 31 days. The prior 31 day period is used to calculate compliance. This may be modified as appropriate to account for changes in radwaste treatment which may have a significant effect on the projected doses.

3.5. Dose Factors

The dose conversion factors were derived from the appropriate dose conversion factors in Regulatory Guide 1.109 and other sources as necessary.[38,39] Particulate nuclides with a half-life of less than 8 days are not considered.[40] ^{90}Y, ^{140}La, and ^{144}Pr are included because the parent half-life is greater than 8 days, and equilibrium is assumed.

4. Dose and Dose Commitment from Uranium Fuel Cycle Sources

4.1. Calculation of Dose and Dose Commitment from Uranium Fuel Cycle Sources

The annual dose or dose commitment to a Member of the Public for Uranium Fuel Cycle Sources is determined as:

- Dose to the total body and internal organs due to gamma ray exposure from submersion in a cloud of radioactive noble gases, ground plane exposure, and direct radiation from the Unit , onsite storage of low-level radioactive waste, and outside storage tanks;
- Dose to skin due to beta radiation from submersion in a cloud of radioactive noble gases, and ground plane exposure;
- Thyroid dose due to inhalation and ingestion of radioiodines; and
- Organ dose due to inhalation and ingestion of radioactive material.

It is assumed that total body dose from sources of gamma radiation irradiates internal body organs at the same numerical rate.[41]

The dose from gaseous effluents is considered to be the summation of the dose at the individual's residence and the dose to the individual from activities within the Site Boundary.

Since the doses via liquid releases are very conservatively evaluated, there is reasonable assurance that no real individual will receive a significant dose from radioactive liquid release pathways. Therefore, only doses to individuals via airborne pathways and doses resulting from direct radiation are considered in determining compliance to 40 CFR 190.[42]

There are no other Uranium Fuel Cycle Sources within 8 km of the Callaway Plant.

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[38] ZZ-78
[39] ZZ-250
[40] Inspection Report 50-483/92002 (DRSS)
[41] NUREG-0543, Section III, page 8
[42] NUREG-0543, Section IV, page 9

4.1.1. Identification of the Member of the Public

The Member of the Public is considered to be a real individual, including all persons not occupationally associated with the Callaway Plant, but who may use portions of the plant site for recreational or other purposes not associated with the plant.[43] Accordingly, it is necessary to characterize this individual with respect to his utilization of areas both within and at or beyond the Site Boundary and identify, as far as possible, major assumptions which could be reevaluated if necessary to demonstrate continued compliance with 40 CFR 190 through the use of more realistic assumptions.[44,45]

The evaluation of Total Dose from the Uranium Fuel Cycle should consider the dose to two Critical Receptors: (a) The Nearest Resident, and (b) The Critical Receptor within the Site Boundary.

4.1.2. Total Dose to the Nearest Resident

The dose to the Nearest Resident is due to plume exposure from noble gases, ground plane exposure, and inhalation and ingestion pathways. It is conservatively assumed that each ingestion pathway (meat, milk, and vegetation) exists at the location of the Nearest Resident.

It is assumed that direct radiation dose from operation of the Unit and storage of radioactive material, and dose from gaseous effluents due to activities within the Site Boundary is negligible for the Nearest Resident. The total Dose from the Uranium Fuel Cycle to the Nearest Resident is calculated using the methodology discussed in Section 3, using concurrent meteorological data for the location of the Nearest Resident with the highest value of X/Q.

The location of the Nearest Resident in each meteorological sector is determined from the Annual Land Use Census conducted in accordance with the Requirements of REC 16.11.4.2.

4.1.3. Total Dose to the Critical Receptor within the Site Boundary

The Union Electric Company has entered into an agreement with the State of Missouri Department of Conservation for management of the residual lands surrounding the Callaway Plant, including some areas within the Site Boundary. Under the terms of this agreement, certain areas have been opened to the public for low intensity recreational uses (hunting, hiking, sightseeing, etc.) but recreational use is excluded in an area immediately surrounding the plant site (refer to Figure 4.1). Much of the residual lands within the Site Boundary are leased to area farmers by the Department of Conservation to provide income to support management and development costs. Activities conducted under these leases are primarily comprised of farming (animal feed), grazing, and forestry.[46,47,48]

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[43] NUREG-0133, Section 3.8
[44] NUREG-0543, Section IV, page 9
[45] NUREG-0543, section III, page 6
[46] Environmental Report, OLS, Section 2.1.2.3

Based on the utilization of areas within the Site Boundary, it is reasonable to assume that the critical receptor within the Site Boundary is a farmer, and that his dose from activities within the Site Boundary is due to exposure incurred while conducting his farming activities. The current tenant has estimated that he spends approximately 1100 hours per year working in this area[49]. Occupancy of areas within the Site Boundary is assumed to be averaged over a period of one year.

Any reevaluation of assumptions should consider only real receptors and real pathways using realistic assumption, and should include a reevaluation of the occupancy period at the locations of real exposure (e.g. a real individual would not simultaneously exist at each point of maximum exposure).

4.1.3.1. Total Dose to the Farmer from Gaseous Effluents

The Total Dose to the farmer from gaseous effluents is calculated for the adult age group using the methodology discussed in Section 3, utilizing concurrent meteorological data at the farmer's residence and historical meteorological data from Table 10 for activities within the Site Boundary. These dispersion parameters were calculated by assuming that the farmer's time is equally distributed over the areas farmed within the Site Boundary, and already have the total occupancy of 1100 hours/year factored into their value.[50]

As a first approximation, the farmer's residence is assumed to be at the location of the Nearest Resident as shown in Table 10 and Table 11. The gaseous effluents dose at the farmer's residence is due to plume exposure from Noble Gases and the ground plane, inhalation, and ingestion pathways. For conservatism, it is acceptable to assume that all of the ingestion pathways exist at this location.

It is assumed that food ingestion pathways do not exist within the Site Boundary, therefore the gaseous effluents dose within the Site Boundary is due to plume exposure from Noble Gases and the ground plane and inhalation pathways.

4.1.3.1.1. Direct Radiation Dose

The direct radiation dose to the Member of Public due to activities within the Site Boundary is insignificant.[51]

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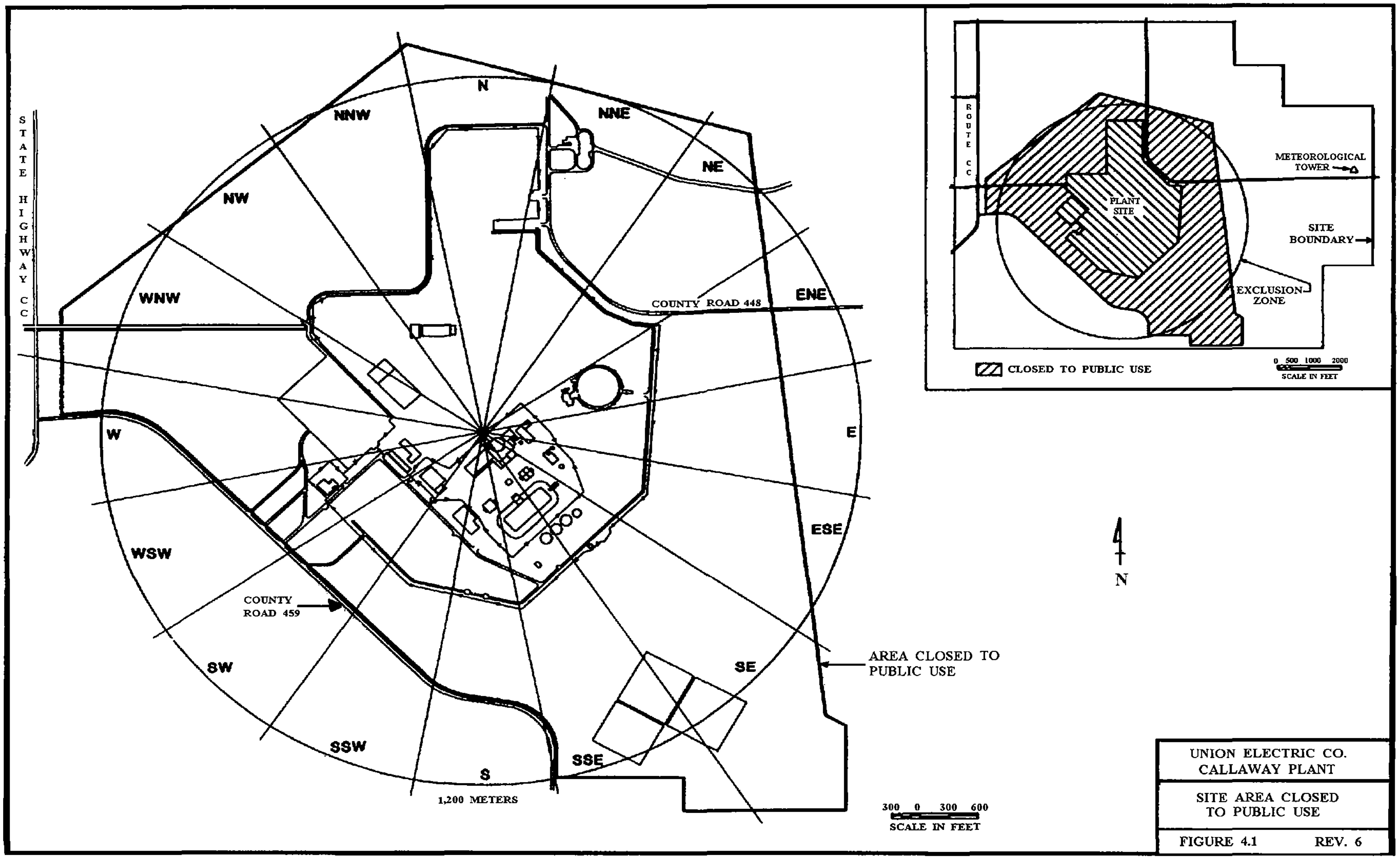
[47] Environmental Report, OLS, Section 2.1.3.3.4
[48] Management Agreement for the Public Use of Lands, Exhibit A.
[49] Private communication, H.C. Lindeman & B.F.Holderness, August 6, 1986
[50] ZZ-67
[51] HPCI 12-06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STATE HIGHWAY CC
COUNTY ROAD 448
COUNTY ROAD 459
AREA CLOSED TO PUBLIC USE
1,200 METERS
300 0 300 600
SCALE IN FEET
N
ROUTE CC
METEOROLOGICAL TOWER
PLANT SITE
SITE BOUNDARY
EXCLUSION ZONE
CLOSED TO PUBLIC USE
0 500 1000 2000
SCALE IN FEET
UNION ELECTRIC CO.
CALLAWAY PLANT
SITE AREA CLOSED TO PUBLIC USE
FIGURE 4.1
REV. 6

5. Radiological Environmental Monitoring

5.1. Description Of The Radiological Environmental Monitoring Program

The Radiological Environmental Monitoring Program is intended to act as a background data base for pre- operation and to supplement the radiological effluent release monitoring program during plant operation. Radiation exposure to the public from the various specific pathways and direct radiation can be adequately evaluated by this program.

Some deviations from the sampling frequency may be necessary due to seasonal unavailability, hazardous conditions, or other legitimate reasons. Efforts are made to obtain all required samples within the required time frame. Any deviation(s) in sampling frequency or location is documented in the Annual Radiological Environmental Operating Report.

REMP sampling locations that use meteorological sectors and or distance from the plant site were verified as described in HPCI 99-01.

Sampling, reporting, and analytical requirements are given in FSAR-SP Tables 16.11-7, 16.11-8, and 16.11-9.

Airborne, waterborne, direct radiation, and ingestion samples collected under the monitoring program are analyzed by an independent, third-party laboratory. With the exception of direct radiation, the laboratory is required to participate in an Interlaboratory Analyses Program per Reg. Guide 4.15.[52] The laboratory participates in an Interlaboratory crosscheck program administered by Environmental Resources Associates (ERA), Mixed Analyte Performance Evaluation Program (MAPEP), or equivalent program. This participation includes all of the determinations (sample medium - radionuclide combination) that are both offered by ERA and/or MAPEP and are also included in the environmental monitoring program.

5.2. Performance Testing Of Environmental Thermoluminescence Dosimeters

Dosimeters used for monitoring of direct radiation dose in the Radiological Environmental Monitoring Program are tested for accuracy and precision to demonstrate compliance with the applicable portions of Regulatory Guide 4.13.

6. Annual Average And Short Term Atmospheric Dispersion Parameters

6.1. Atmospheric Dispersion Parameters

The dispersion values presented in Table 10 and Table 11 were determined through the analysis of on-site meteorological data collected during the three year period of May 4, 1973 to May 5, 1975 and March 16, 1978 to March 16, 1979.

6.1.1. Dispersion Estimates

The variable trajectory plume segment atmospheric transport model MESODIF-II (NUREG/-CR-0523) and the straight-line Gaussian dispersion model XOQDOQ (NUREG/CR2919) were used for determination of the long-term atmospheric dispersion

[52] Regulatory Guide 4.15, rev. 1, section 6.3.2

parameters. A more detailed discussion of the methodology and data utilized to calculate these parameters can be found elsewhere.[53]

The Unit Vent and Radwaste Building Vent releases are at elevations of 66.5 meters and 20 meters above grade, respectively. Both release points are within the building wake of the structures on which they are located, and the Unit Vent is equipped with a rain cover which effectively eliminates the possibility of the exit velocity exceeding five times the horizontal wind speed. All gaseous releases are thus considered to be ground-level releases.[54]

6.1.2. Determination of Dispersion Estimates for Special Receptor Locations
Calculations utilizing the PUFF model were performed for 22 standard distances to obtain the desired dispersion parameters. Dispersion parameters at the Site Boundary and at special receptor locations were estimated by logarithmic interpolation according to:[55]

$$X = X_1 \left(d/d_1\right)^B$$

Eq. 24

Where:

$$B = \frac{ln\left(X_2/X_1\right)}{ln\left(d_2/d_1\right)}$$

Eq. 25

X_1, X_2 are the atmospheric dispersion parameters at distance **d_1** and **d_2**, respectively, from the source. The distances d_1 and d_2 were selected such that they satisfy the relationship $d_1<d<d_2$.

6.1.3. Atmospheric Dispersion Parameters for Farming Areas within the Site Boundary
The dispersion parameters for farming areas within the Site Boundary are intended for a narrow scope application; that of calculating the dose to the current farmer from gaseous effluents while he conducts farming activities within the Site Boundary.

For the purpose of these calculations, it was assumed that all of the farmer's time, approximately 1100 hours per year, is spent on croplands within the Site Boundary, and that his time is divided evenly over all of the croplands. Fractional acreage/time - weighted dispersion parameters were calculated for each plot as described in calculation ZZ-67. The weighted dispersion parameters for each plot were summed (according to type) in order to produce a composite value of the dispersion parameters which are presented in Table 10 and Table 11. These dispersion parameters therefore represent the distributed activities of the farmer within the Site Boundary and his estimated occupancy period.

6.2. Annual Meteorological Data Processing

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[53] FSAR-SA Section 2.3.5
[54] BLUE 1285
[55] FSAR-SA 2.3.5.2.1.2

The annual atmospheric dispersion parameters utilized in the calculation of doses for demonstration of compliance with the numerical dose objectives of 10 CFR 50, Appendix I, are determined using computer codes and models consistent with XOQDOQ.[56] These codes have been validated and verified by a qualified meteorologist prior to implementation. Multiple sensors are utilized to ensure 90% valid data recovery for the wind speed, wind direction, and ambient air temperature parameters as required by Regulatory Guide 1.23. The selection hierarchy is presented in Table 14.

The vertical height of the highest adjacent building, V, used to perform concurrent year annual average atmospheric dispersion X/Q calculations is 169.16 meters.

Meteorological Data is periodically verified to ensure valid data is being collected.

7. Reporting Requirements

7.1. Annual Radiological Environmental Operating Report

The reporting requirements for the Annual Radiological Environmental Operating Report (AREOR) have been relocated to FSAR-SP 16.11.5.1.

7.2. Annual Radioactive Effluent Release Report

The reporting requirements for the Annual Radioactive Effluent Release Report (ARERR) have been relocated to FSAR-SP 16.11.5.2. The application of atmospheric dispersion parameters in the ARERR is presented in Table 13.

8. Implementation of ODCM Methodology

The ODCM provides the mathematical relationships used to implement the Radioactive Effluent Controls. For routine effluent release and dose assessment, computer codes are utilized to implement the ODCM methodologies. These codes are evaluated in accordance with the requirements of plant operating procedures to ensure that they produce results consistent with the methodologies presented in the ODCM. Plant procedures implement the ODCM methodology.

9. Radioactive Effluent Controls (REC)

The Radioactive Effluent Controls have been relocated to FSAR-SP Chapter 16.11,"Offsite Dose Calculation Manual Radioactive Effluent Controls". The former ODCM REC numbers appear on each of the RECs in FSAR-SP Chapter 16.11, and may be used as a cross-reference between the previous and the current numbering system if necessary.

10. Administrative Controls

[56] NUREG/CR-2919

10.1. Major Changes to Liquid and Gaseous Radwaste Treatment Systems

A summary of Licensee-initiated major changes to the Radwaste Treatment Systems (liquid and gaseous) must be reported to the Commission in the Annual Radioactive Effluent Release Report (ARERR) for the period in which the evaluation was reviewed by the On-Site Review Committee (ORC). On site documentation must contain:

- A summary of the evaluation that led to the determination that the change could be made in accordance with 10 CFR 50.59;
- Sufficient detailed information to totally support the reason for the change without benefit of additional or supplemental information;
- A detailed description of the equipment, components and process involved and the interfaces with other plant systems;
- An evaluation of the change, which shows the predicted releases of radioactive materials in liquid and gaseous effluents that differ from those previously predicted in the License application and amendments thereto;
- An evaluation of the change, which shows the expected maximum exposures to a Member of the Public in the Unrestricted Area and to the general population that differ from those previously estimated in the License application and amendments thereto;
- A comparison of the predicted releases of radioactive materials, in liquid and gaseous effluents, to the actual releases for the period prior to when the changes are to be made;
- An estimate of the exposure to plant operating personnel as a result of the change; and
- Documentation of the fact that the change was reviewed and found acceptable by the ORC.

Changes to the Radwaste Treatment Systems shall become effective upon review and approval by the ORC.

10.2. Changes to the Offsite Dose Calculation Manual (ODCM)

All changes to the ODCM shall be performed pursuant to T/S AC 5.5.1

Review for each revision of the ODCM must include the Radiation Protection Department.

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Table 1: Ingestion Dose Commitment Values ($A_{iτ}$) for Adult Age Group

(mrem/hr) per (μCi/ml)

Nuclide	Bone	Liver	Total Body	Thyroid	Kidney	Lung	GI-LLI
^{3}H	0.00E+00	2.26E-01	2.26E-01	2.26E-01	2.26E-01	2.26E-01	2.26E-01
^{7}Be	1.31E-02	2.98E-02	1.45E-02	0.00E+00	3.15E-02	0.00E+00	5.17E+00
^{24}Na	4.07E+02	4.07E+02	4.07E+02	4.07E+02	4.07E+02	4.07E+02	4.07E+02
^{51}Cr	0.00E+00	0.00E+00	1.27E+00	7.61E-01	2.81E-01	1.69E+00	3.20E+02
^{54}Mn	0.00E+00	4.38E+03	8.35E+02	0.00E+00	1.30E+03	0.00E+00	1.34E+04
^{56}Mn	0.00E+00	1.10E+02	1.95E+01	0.00E+00	1.40E+02	0.00E+00	3.51E+03
^{55}Fe	6.58E+02	4.55E+02	1.06E+02	0.00E+00	0.00E+00	2.54E+02	2.61E+02
^{59}Fe	1.04E+03	2.44E+03	9.36E+02	0.00E+00	0.00E+00	6.82E+02	8.14E+03
^{57}Co	0.00E+00	2.09E+01	3.48E+01	0.00E+00	0.00E+00	0.00E+00	5.31E+02
^{58}Co	0.00E+00	8.92E+01	2.00E+02	0.00E+00	0.00E+00	0.00E+00	1.81E+03
^{60}Co	0.00E+00	2.56E+02	5.65E+02	0.00E+00	0.00E+00	0.00E+00	4.81E+03
^{63}Ni	3.11E+04	2.16E+03	1.04E+03	0.00E+00	0.00E+00	0.00E+00	4.50E+02
^{65}Ni	1.26E+02	1.64E+01	7.49E+00	0.00E+00	0.00E+00	0.00E+00	4.17E+02
^{64}Cu	0.00E+00	9.97E+00	4.68E+00	0.00E+00	2.51E+01	0.00E+00	8.50E+02
^{65}Zn	2.32E+04	7.37E+04	3.33E+04	0.00E+00	4.93E+04	0.00E+00	4.64E+04
^{69}Zn	4.93E+01	9.43E+01	6.56E+00	0.00E+00	6.13E+01	0.00E+00	1.42E+01
^{82}Br	0.00E+00	0.00E+00	2.27E+03	0.00E+00	0.00E+00	0.00E+00	2.60E+03
^{83}Br	0.00E+00	0.00E+00	4.04E+01	0.00E+00	0.00E+00	0.00E+00	5.82E+01
^{84}Br	0.00E+00	0.00E+00	5.24E+01	0.00E+00	0.00E+00	0.00E+00	4.11E-04
^{85}Br	0.00E+00	0.00E+00	2.15E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-15
^{86}Rb	0.00E+00	1.01E+05	4.71E+04	0.00E+00	0.00E+00	0.00E+00	1.99E+04
^{88}Rb	0.00E+00	2.90E+02	1.54E+02	0.00E+00	0.00E+00	0.00E+00	4.00E-09
^{89}Rb	0.00E+00	1.92E+02	1.35E+02	0.00E+00	0.00E+00	0.00E+00	1.12E-11
^{89}Sr	2.21E+04	0.00E+00	6.35E+02	0.00E+00	0.00E+00	0.00E+00	3.55E+03
^{90}Sr	5.44E+05	0.00E+00	1.34E+05	0.00E+00	0.00E+00	0.00E+00	1.57E+04
^{91}Sr	4.07E+02	0.00E+00	1.64E+01	0.00E+00	0.00E+00	0.00E+00	1.94E+03
^{92}Sr	1.54E+02	0.00E+00	6.68E+00	0.00E+00	0.00E+00	0.00E+00	3.06E+03
^{90}Y	5.76E-01	0.00E+00	1.54E-02	0.00E+00	0.00E+00	0.00E+00	6.10E+03
^{91m}Y	5.44E-03	0.00E+00	2.11E-04	0.00E+00	0.00E+00	0.00E+00	1.60E-02
^{91}Y	8.44E+00	0.00E+00	2.26E-01	0.00E+00	0.00E+00	0.00E+00	4.64E+03
^{92}Y	5.06E-02	0.00E+00	1.48E-03	0.00E+00	0.00E+00	0.00E+00	8.86E+02
^{93}Y	1.60E-01	0.00E+00	4.43E-03	0.00E+00	0.00E+00	0.00E+00	5.09E+03
^{95}Zr	2.40E-01	7.70E-02	5.21E-02	0.00E+00	1.21E-01	0.00E+00	2.44E+02
^{97}Zr	1.33E-02	2.68E-03	1.22E-03	0.00E+00	4.04E-03	0.00E+00	8.30E+02
^{95}Nb	4.47E+02	2.48E+02	1.34E+02	0.00E+00	2.46E+02	0.00E+00	1.51E+06
^{99}Mo	0.00E+00	1.03E+02	1.96E+01	0.00E+00	2.34E+02	0.00E+00	2.39E+02
^{99m}Tc	8.87E-03	2.51E-02	3.19E-01	0.00E+00	3.81E-01	1.23E-02	1.48E+01

Table 1: Ingestion Dose Commitment Values (A_{it}) for Adult Age Group

(mrem/hr) per (µCi/ml)

Nuclide	Bone	Liver	Total Body	Thyroid	Kidney	Lung	GI-LLI
^{101}Tc	9.12E-03	1.31E-02	1.29E-01	0.00E+00	2.37E-01	6.72E-03	3.95E-14
^{103}Ru	4.43E+00	0.00E+00	1.91E+00	0.00E+00	1.69E+01	0.00E+00	5.17E+02
^{105}Ru	3.69E-01	0.00E+00	1.46E-01	0.00E+00	4.76E+00	0.00E+00	2.26E+02
^{106}Ru	6.58E+01	0.00E+00	8.33E+00	0.00E+00	1.27E+02	0.00E+00	4.26E+03
^{109}Cd	0.00E+00	5.55E+02	1.94E+01	0.00E+00	5.31E+02	0.00E+00	5.60E+03
^{110m}Ag	8.85E-01	8.18E-01	4.86E-01	0.00E+00	1.61E+00	0.00E+00	3.34E+02
^{113}Sn	5.67E+04	1.61E+03	3.26E+03	9.19E+02	0.00E+00	0.00E+00	1.69E+05
^{122}Sb	5.48E-01	1.12E-02	1.66E-01	7.73E-03	0.00E+00	2.94E-01	0.00E+00
^{124}Sb	6.70E+00	1.27E-01	2.66E+00	1.63E-02	0.00E+00	5.22E+00	1.90E+02
^{125}Sb	4.29E+00	4.79E-02	1.02E+00	4.36E-03	0.00E+00	3.30E+00	4.72E+01
^{127m}Te	6.48E+03	2.32E+03	7.90E+02	1.66E+03	2.63E+04	0.00E+00	2.17E+04
^{127}Te	1.05E+02	3.78E+01	2.28E+01	7.80E+01	4.29E+02	0.00E+00	8.31E+03
^{129m}Te	1.10E+04	4.11E+03	1.74E+03	3.78E+03	4.60E+04	0.00E+00	5.54E+04
^{129}Te	3.01E+01	1.13E+01	7.33E+00	2.31E+01	1.26E+02	0.00E+00	2.27E+01
^{131m}Te	1.66E+03	8.10E+02	6.75E+02	1.28E+03	8.21E+03	0.00E+00	8.04E+04
^{131}Te	1.89E+01	7.88E+00	5.96E+00	1.55E+01	8.26E+01	0.00E+00	2.67E+00
^{132}Te	2.41E+03	1.56E+03	1.47E+03	1.72E+03	1.50E+04	0.00E+00	7.38E+04
^{130}I	2.71E+01	8.01E+01	3.16E+01	6.79E+03	1.25E+02	0.00E+00	6.89E+01
^{131}I	1.49E+02	2.14E+02	1.22E+02	7.00E+04	3.66E+02	0.00E+00	5.64E+01
^{132}I	7.29E+00	1.95E+01	6.82E+00	6.82E+02	3.11E+01	0.00E+00	3.66E+00
^{133}I	5.14E+01	8.87E+01	2.70E+01	1.30E+04	1.55E+02	0.00E+00	7.97E+01
^{134}I	3.81E+00	1.03E+01	3.70E+00	1.79E+02	1.64E+01	0.00E+00	9.01E-03
^{135}I	1.59E+01	4.17E+01	1.54E+01	2.75E+03	6.68E+01	0.00E+00	4.70E+01
^{134}Cs	2.98E+05	7.09E+05	5.79E+05	0.00E+00	2.29E+05	7.61E+04	1.24E+04
^{136}Cs	3.12E+04	1.23E+05	8.86E+04	0.00E+00	6.85E+04	9.38E+03	1.40E+04
^{137}Cs	3.82E+05	5.22E+05	3.42E+05	0.00E+00	1.77E+05	5.89E+04	1.01E+04
^{138}Cs	2.64E+02	5.22E+02	2.59E+02	0.00E+00	3.84E+02	3.79E+01	2.23E-03
^{139}Ba	9.29E-01	6.62E-04	2.72E-02	0.00E+00	6.19E-04	3.75E-04	1.65E+00
^{140}Ba	1.94E+02	2.44E-01	1.27E+01	0.00E+00	8.30E-02	1.40E-01	4.00E+02
^{141}Ba	4.51E-01	3.41E-04	1.52E-02	0.00E+00	3.17E-04	1.93E-04	2.13E-10
^{142}Ba	2.04E-01	2.10E-04	1.28E-02	0.00E+00	1.77E-04	1.19E-04	2.87E-19
^{140}La	1.50E-01	7.54E-02	1.99E-02	0.00E+00	0.00E+00	0.00E+00	5.54E+03
^{142}La	7.66E-03	3.48E-03	8.68E-04	0.00E+00	0.00E+00	0.00E+00	2.54E+01
^{141}Ce	2.24E-02	1.52E-02	1.72E-03	0.00E+00	7.04E-03	0.00E+00	5.79E+01
^{143}Ce	3.95E-03	2.92E+00	3.23E-04	0.00E+00	1.29E-03	0.00E+00	1.09E+02
^{144}Ce	1.17E+00	4.88E-01	6.27E-02	0.00E+00	2.90E-01	0.00E+00	3.95E+02
^{143}Pr	5.51E-01	2.21E-01	2.73E-02	0.00E+00	1.27E-01	0.00E+00	2.41E+03

Table 1: Ingestion Dose Commitment Values ($A_{i\tau}$) for Adult Age Group

(mrem/hr) per (µCi/ml)

Nuclide	Bone	Liver	Total Body	Thyroid	Kidney	Lung	GI-LLI
^{144}Pr	1.80E-03	7.48E-04	9.16E-05	0.00E+00	4.22E-04	0.00E+00	2.59E-10
^{147}Nd	3.76E-01	4.35E-01	2.60E-02	0.00E+00	2.54E-01	0.00E+00	2.09E+03
^{154}Eu	3.68E+01	4.52E+00	3.22E+00	0.00E+00	2.17E+01	0.00E+00	3.28E+03
^{181}Hf	4.00E-02	1.94E-01	1.80E-02	0.00E+00	4.18E-02	0.00E+00	2.21E+02
^{187}W	2.96E+02	2.47E+02	8.65E+01	0.00E+00	0.00E+00	0.00E+00	8.10E+04
^{237}Np	3.28E+04	2.85E+03	1.33E+03	0.00E+00	9.86E+03	0.00E+00	1.90E+03
^{239}Np	2.85E-02	2.80E-03	1.54E-03	0.00E+00	8.74E-03	0.00E+00	5.75E+02
^{238}Pu	5.70E+03	8.03E+02	1.43E+02	0.00E+00	6.13E+02	0.00E+00	6.12E+02
^{239}Pu*	6.59E+03	8.88E+02	1.60E+02	0.00E+00	6.80E+02	0.00E+00	5.68E+02
^{241}Pu	1.38E+02	7.07E+00	2.78E+00	0.00E+00	1.28E+01	0.00E+00	1.17E+01
^{241}Am	4.90E+04	1.72E+04	3.24E+03	0.00E+00	2.44E+04	0.00E+00	4.44E+03
^{242}Cm	1.23E+03	1.26E+03	8.20E+01	0.00E+00	3.72E+02	0.00E+00	4.74E+03
^{243}Cm**	3.82E+04	1.44E+04	2.24E+03	0.00E+00	1.05E+04	0.00E+00	4.67E+03

*Includes Pu-240 contribution
**Includes Cm-244 contribution

Table 2: Bioaccumulation Factor (Bf_i) [a]

(pCi/kg) per (pCi/liter)

Element	Bf_i Fish (Freshwater)
H	9.0 E - 01
Be	2.0 E + 00
Na	1.0 E + 02
Cr	2.0 E + 02
Mn	4.0 E + 02
Fe	1.0 E + 02
Co	5.0 E + 01
Ni	1.0 E + 02
Cu	5.0 E + 01
Zn	2.0 E + 03
Br	4.2 E + 02
Rb	2.0 E + 03
Sr	3.0 E + 01
Y	2.5 E + 01
Zr	3.3 E + 00
Nb	3.0 E + 04
Mo	1.0 E + 01
Tc	1.5 E + 01
Ru	1.0 E + 01

Element	Bf_i Fish (Freshwater)
Rh	1.0 E + 01
Ag	2.3 E + 00
Cd	2.0 E + 02
Sn	3.0 E + 03
Sb	1.0 E + 00
Te	4.0 E + 02
I	1.5 E + 01
Cs	2.0 E + 03
Ba	4.0 E + 00
La	2.5 E + 01
Ce	1.0 E + 00
Pr	2.5 E + 01
Nd	2.5 E + 01
Eu	2.5 E + 01
Hf	3.3 E + 00
W	1.2 E + 03
Np	1.0 E + 01
Pu	3.5 E + 00
Am	2.5 E + 01
Cm	2.5 E + 01

[a] Values from Regulatory Guide 1.109, Rev. 1, Table A-1 and HPCI 04-06.

Table 3: Dose Factor for Exposure to a Semi- Infinite Cloud of Noble Gases

Radionuclide	Total Body Dose Factor K_i (mrem/yr) per (μCi/m^3)	Skin Dose Factor L_i (mrem/yr) per (μCi/m^3)	Gamma Air Dose Factor M_i (mrad/yr) per (μCi/m^3)	Beta Air Dose Factor Ni (mrad/yr) per (μCi/m^3)
^{83m}Kr	7.56 E-02	-----	1.93 E+01	2.88 E+02
^{85m}Kr	1.17E+03	1.46E+03	1.23 E+03	1.97 E+03
^{85}Kr	1.61 E+01	1.34 E+03	1.72 E+01	1.95 E+03
^{87}Kr	5.92 E+03	9.73 E+03	6.17 E+03	1.03 E+04
^{88}Kr	1.47 E+04	2.37 E+03	1.52 E+04	2.93 E+03
^{89}Kr	1.66 E+04	1.01 E+04	1.73 E+04	1.06 E+04
^{90}Kr	1.56 E+04	7.29 E+03	1.63 E+04	7.83 E+03
^{131m}Xe	9.15 E+01	4.76 E+02	1.56 E+02	1.11 E+03
^{133m}Xe	2.51 E+02	9.94 E+02	3.27 E+02	1.48 E+03
^{133}Xe	2.94 E+02	3.06 E+02	3.53 E+02	1.05 E+03
^{135m}Xe	3.12 E+03	7.11 E+02	3.36 E+03	7.39 E+02
^{135}Xe	1.81 E+03	1.86 E+03	1.92 E+03	2.46 E+03
^{137}Xe	1.42 E+03	1.22 E+04	1.51 E+03	1.27 E+04
^{138}Xe	8.83 E+03	4.13 E+03	9.21 E+03	4.75 E+03
^{41}Ar	8.84 E+03	2.69 E+03	9.30 E+03	3.28 E+03

Table 4: Ground Plane Pathway Dose Factors (R_i)

(m^2mrem/yr) per (µCi/sec)

Nuclide	Total Body	Skin
^{3}H	0.00E+00	0.00E+00
^{7}Be	2.24E+07	3.21E+07
^{51}Cr	4.66E+06	5.51E+06
^{54}Mn	1.39E+09	1.63E+09
^{55}Fe	0.00E+00	0.00E+00
^{59}Fe	2.73E+08	3.21E+08
^{57}Co	2.98E+08	4.37E+08
^{58}Co	3.79E+08	4.44E+08
^{60}Co	2.15E+10	2.53E+10
^{63}Ni	0.00E+00	0.00E+00
^{65}Zn	7.47E+08	8.59E+08
^{86}Rb	8.99E+06	1.03E+07
^{89}Sr	2.16E+04	2.51E+04
^{90}Sr	0.00E+00	0.00E+00
^{90}Y	5.36E+06	6.32E+06
^{91}Y	1.07E+06	1.21E+06
^{95}Zr	2.45E+08	2.84E+08
^{95}Nb	2.50E+08	2.94E+08
^{103}Ru	1.08E+08	1.26E+08
^{106}Ru	4.22E+08	5.07E+08
^{110m}Ag	3.44E+09	4.01E+09
^{109}Cd	3.76E+07	1.54E+08

Nuclide	Total Body	Skin
^{113}Sn	1.43E+07	4.09E+07
^{124}Sb	8.74E+08	1.23E+09
^{125}Sb	3.57E+09	5.19E+09
^{127m}Te	9.17E+04	1.08E+05
^{129m}Te	1.98E+07	2.31E+07
^{130}I	5.51E+06	6.69E+06
^{131}I	1.72E+07	2.09E+07
^{132}I	1.25E+06	1.47E+06
^{133}I	2.45E+06	2.98E+06
^{134}I	4.47E+05	5.31E+05
^{135}I	2.53E+06	2.95E+06
^{134}Cs	6.85E+09	8.00E+09
^{136}Cs	1.51E+08	1.71E+08
^{137}Cs	1.03E+10	1.20E+10
^{140}Ba	2.05E+07	2.35E+07
^{140}La	1.47E+08	1.66E+08
^{141}Ce	1.37E+07	1.54E+07
^{144}Ce	6.96E+07	8.04E+07
^{143}Pr	0.00E+00	0.00E+00
^{144}Pr	4.35E+07	5.00E+07
^{147}Nd	8.39E+06	1.01E+07
^{154}Eu	2.21E+10	3.15E+10
^{181}Hf	1.97E+08	2.82E+08

Table 6: Child Grass- Cow – Milk Pathway Dose Factors (R_i)

(m^2mrem/yr) per (µCi/sec)

Nuclide	Bone	Liver	Total Body	Thyroid	Kidney	Lung	GI-LLI
^{3}H	0.00E+00	1.57E+03	1.57E+03	1.57E+03	1.57E+03	1.57E+03	1.57E+03
^{7}Be	7.50E+03	1.28E+04	8.20E+03	0.00E+00	1.25E+04	0.00E+00	7.12E+05
^{51}Cr	0.00E+00	0.00E+00	1.02E+05	5.66E+04	1.55E+04	1.03E+05	5.40E+06
^{54}Mn	0.00E+00	2.10E+07	5.59E+06	0.00E+00	5.89E+06	0.00E+00	1.76E+07
^{55}Fe	1.12E+08	5.94E+07	1.84E+07	0.00E+00	0.00E+00	3.36E+07	1.10E+07
^{59}Fe	1.20E+08	1.95E+08	9.70E+07	0.00E+00	0.00E+00	5.64E+07	2.03E+08
^{57}Co	0.00E+00	3.84E+06	7.78E+06	0.00E+00	0.00E+00	0.00E+00	3.15E+07
^{58}Co	0.00E+00	1.21E+07	3.72E+07	0.00E+00	0.00E+00	0.00E+00	7.08E+07
^{60}Co	0.00E+00	4.32E+07	1.27E+08	0.00E+00	0.00E+00	0.00E+00	2.39E+08
^{63}Ni	2.97E+10	1.59E+09	1.01E+09	0.00E+00	0.00E+00	0.00E+00	1.07E+08
^{65}Zn	4.14E+09	1.10E+10	6.86E+09	0.00E+00	6.95E+09	0.00E+00	1.94E+09
^{86}Rb	0.00E+00	8.78E+09	5.40E+09	0.00E+00	0.00E+00	0.00E+00	5.65E+08
^{89}Sr	6.63E+09	0.00E+00	1.89E+08	0.00E+00	0.00E+00	0.00E+00	2.57E+08
^{90}Sr	1.12E+11	0.00E+00	2.84E+10	0.00E+00	0.00E+00	0.00E+00	1.51E+09
^{90}Y	3.38E+03	0.00E+00	9.05E+01	0.00E+00	0.00E+00	0.00E+00	9.62E+06
^{91}Y	3.91E+04	0.00E+00	1.04E+03	0.00E+00	0.00E+00	0.00E+00	5.20E+06
^{95}Zr	3.84E+03	8.43E+02	7.51E+02	0.00E+00	1.21E+03	0.00E+00	8.80E+05
^{95}Nb	3.72E+05	1.45E+05	1.03E+05	0.00E+00	1.36E+05	0.00E+00	2.68E+08
^{103}Ru	4.29E+03	0.00E+00	1.65E+03	0.00E+00	1.08E+04	0.00E+00	1.11E+05
^{106}Ru	9.25E+04	0.00E+00	1.15E+04	0.00E+00	1.25E+05	0.00E+00	1.44E+06
^{110m}Ag	2.09E+08	1.41E+08	1.13E+08	0.00E+00	2.63E+08	0.00E+00	1.68E+10
^{109}Cd	0.00E+00	3.86E+06	1.79E+05	0.00E+00	3.45E+06	0.00E+00	1.25E+07
^{113}Sn	6.11E+08	1.26E+07	3.48E+07	9.29E+08	0.00E+00	0.00E+00	4.32E+08
^{124}Sb	1.09E+08	1.41E+06	3.81E+07	2.40E+05	0.00E+00	6.03E+07	6.80E+08
^{125}Sb	8.71E+07	6.72E+05	1.83E+07	8.07E+04	0.00E+00	4.86E+07	2.08E+08
^{127m}Te	2.08E+08	5.61E+07	2.47E+07	4.98E+07	5.94E+08	0.00E+00	1.69E+08
^{129m}Te	2.72E+08	7.59E+07	4.22E+07	8.76E+07	7.98E+08	0.00E+00	3.31E+08

Table 6: Child Grass- Cow – Milk Pathway Dose Factors (R_i)

(m^2mrem/yr) per (μCi/sec)

Nuclide	Bone	Liver	Total Body	Thyroid	Kidney	Lung	GI-LLI
^{130}I	1.73E+06	3.50E+06	1.80E+06	3.85E+08	5.23E+06	0.00E+00	1.64E+06
^{131}I	1.30E+09	1.31E+09	7.46E+08	4.34E+11	2.15E+09	0.00E+00	1.17E+08
^{132}I	6.92E-01	1.27E+00	5.85E-01	5.90E+01	1.95E+00	0.00E+00	1.50E+00
^{133}I	1.72E+07	2.13E+07	8.05E+06	3.95E+09	3.54E+07	0.00E+00	8.57E+06
^{134}I	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{135}I	5.41E+04	9.74E+04	4.61E+04	8.63E+06	1.49E+05	0.00E+00	7.42E+04
^{134}Cs	2.27E+10	3.72E+10	7.84E+09	0.00E+00	1.15E+10	4.14E+09	2.00E+08
^{136}Cs	1.01E+09	2.78E+09	1.80E+09	0.00E+00	1.48E+09	2.21E+08	9.78E+07
^{137}Cs	3.23E+10	3.09E+10	4.56E+09	0.00E+00	1.01E+10	3.62E+09	1.93E+08
^{140}Ba	1.17E+08	1.03E+05	6.84E+06	0.00E+00	3.34E+04	6.12E+04	5.94E+07
^{140}La	1.78E+02	6.23E+01	2.10E+01	0.00E+00	0.00E+00	0.00E+00	1.74E+06
^{141}Ce	2.19E+04	1.09E+04	1.62E+03	0.00E+00	4.79E+03	0.00E+00	1.36E+07
^{144}Ce	1.62E+06	5.09E+05	8.67E+04	0.00E+00	2.82E+05	0.00E+00	1.33E+08
^{143}Pr	7.19E+02	2.16E+02	3.57E+01	0.00E+00	1.17E+02	0.00E+00	7.76E+05
^{144}Pr	5.04E+00	1.56E+00	2.53E-01	0.00E+00	8.24E-01	0.00E+00	3.35E+03
^{147}Nd	4.45E+02	3.61E+02	2.79E+01	0.00E+00	1.98E+02	0.00E+00	5.71E+05
^{154}Eu	9.43E+04	8.48E+03	7.75E+03	0.00E+00	3.73E+04	0.00E+00	1.97E+06
^{181}Hf	6.44E+02	2.35E+03	2.91E+02	0.00E+00	4.76E+02	0.00E+00	8.66E+05

Table 7: Child Grass- Goat – Milk Pathway Dose Factors (R_i)

(m^2mrem/yr) per (μCi/sec)

Nuclide	Bone	Liver	Total Body	Thyroid	Kidney	Lung	GI-LLI
^{3}H	0.00E+00	3.20E+03	3.20E+03	3.20E+03	3.20E+03	3.20E+03	3.20E+03
^{7}Be	9.00E+02	1.53E+03	9.84E+02	0.00E+00	1.50E+03	0.00E+00	8.55E+04
^{51}Cr	0.00E+00	0.00E+00	1.22E+04	6.79E+03	1.85E+03	1.24E+04	6.48E+05
^{54}Mn	0.00E+00	2.52E+06	6.71E+05	0.00E+00	7.06E+05	0.00E+00	2.11E+06
^{55}Fe	1.45E+06	7.72E+05	2.39E+05	0.00E+00	0.00E+00	4.36E+05	1.43E+05
^{59}Fe	1.56E+06	2.53E+06	1.26E+06	0.00E+00	0.00E+00	7.34E+05	2.64E+06
^{57}Co	0.00E+00	4.61E+05	9.33E+05	0.00E+00	0.00E+00	0.00E+00	3.78E+06
^{58}Co	0.00E+00	1.46E+06	4.46E+06	0.00E+00	0.00E+00	0.00E+00	8.50E+06
^{60}Co	0.00E+00	5.19E+06	1.53E+07	0.00E+00	0.00E+00	0.00E+00	2.87E+07
^{63}Ni	3.56E+09	1.91E+08	1.21E+08	0.00E+00	0.00E+00	0.00E+00	1.28E+07
^{65}Zn	4.97E+08	1.32E+09	8.23E+08	0.00E+00	8.34E+08	0.00E+00	2.32E+08
^{86}Rb	0.00E+00	1.05E+09	6.48E+08	0.00E+00	0.00E+00	0.00E+00	6.78E+07
^{89}Sr	1.39E+10	0.00E+00	3.97E+08	0.00E+00	0.00E+00	0.00E+00	5.39E+08
^{90}Sr	2.35E+11	0.00E+00	5.95E+10	0.00E+00	0.00E+00	0.00E+00	3.16E+09
^{90}Y	4.06E+02	0.00E+00	1.09E+01	0.00E+00	0.00E+00	0.00E+00	1.15E+06
^{91}Y	4.69E+03	0.00E+00	1.25E+02	0.00E+00	0.00E+00	0.00E+00	6.25E+05
^{95}Zr	4.60E+02	1.01E+02	9.01E+01	0.00E+00	1.45E+02	0.00E+00	1.06E+05
^{95}Nb	4.46E+04	1.74E+04	1.24E+04	0.00E+00	1.63E+04	0.00E+00	3.21E+07
^{103}Ru	5.14E+02	0.00E+00	1.98E+02	0.00E+00	1.29E+03	0.00E+00	1.33E+04
^{106}Ru	1.11E+04	0.00E+00	1.38E+03	0.00E+00	1.50E+04	0.00E+00	1.73E+05
^{110m}Ag	2.51E+07	1.69E+07	1.35E+07	0.00E+00	3.15E+07	0.00E+00	2.01E+09
^{109}Cd	0.00E+00	4.64E+05	2.15E+04	0.00E+00	4.14E+05	0.00E+00	1.50E+06
^{113}Sn	7.33E+07	1.51E+06	4.18E+06	1.11E+08	0.00E+00	0.00E+00	5.18E+07
^{124}Sb	1.30E+07	1.69E+05	4.57E+06	2.88E+04	0.00E+00	7.24E+06	8.16E+07
^{125}Sb	1.05E+07	8.06E+04	2.19E+06	9.68E+03	0.00E+00	5.83E+06	2.50E+07
^{127m}Te	2.50E+07	6.73E+06	2.97E+06	5.98E+06	7.13E+07	0.00E+00	2.02E+07
^{129m}Te	3.26E+07	9.10E+06	5.06E+06	1.05E+07	9.57E+07	0.00E+00	3.98E+07

Table 7: Child Grass- Goat – Milk Pathway Dose Factors (R_I)

(m^2mrem/yr) per (µCi/sec)

Nuclide	Bone	Liver	Total Body	Thyroid	Kidney	Lung	GI-LLI
^{130}I	2.08E+06	4.20E+06	2.16E+06	4.62E+08	6.27E+06	0.00E+00	1.96E+06
^{131}I	1.57E+09	1.57E+09	8.95E+08	5.21E+11	2.58E+09	0.00E+00	1.40E+08
^{132}I	8.30E-01	1.53E+00	7.02E-01	7.08E+01	2.34E+00	0.00E+00	1.80E+00
^{133}I	2.06E+07	2.55E+07	9.66E+06	4.74E+09	4.25E+07	0.00E+00	1.03E+07
^{134}I	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{135}I	6.49E+04	1.17E+05	5.53E+04	1.04E+07	1.79E+05	0.00E+00	8.90E+04
^{134}Cs	6.80E+10	1.12E+11	2.35E+10	0.00E+00	3.46E+10	1.24E+10	6.01E+08
^{136}Cs	3.04E+09	8.35E+09	5.40E+09	0.00E+00	4.45E+09	6.63E+08	2.93E+08
^{137}Cs	9.68E+10	9.27E+10	1.37E+10	0.00E+00	3.02E+10	1.09E+10	5.80E+08
^{140}Ba	1.41E+07	1.23E+04	8.21E+05	0.00E+00	4.01E+03	7.35E+03	7.13E+06
^{140}La	2.14E+01	7.47E+00	2.52E+00	0.00E+00	0.00E+00	0.00E+00	2.08E+05
^{141}Ce	2.63E+03	1.31E+03	1.95E+02	0.00E+00	5.75E+02	0.00E+00	1.63E+06
^{144}Ce	1.95E+05	6.11E+04	1.04E+04	0.00E+00	3.38E+04	0.00E+00	1.59E+07
^{143}Pr	8.63E+01	2.59E+01	4.28E+00	0.00E+00	1.40E+01	0.00E+00	9.31E+04
^{144}Pr	6.05E-01	1.87E-01	3.04E-02	0.00E+00	9.89E-02	0.00E+00	4.03E+02
^{147}Nd	5.34E+01	4.33E+01	3.35E+00	0.00E+00	2.37E+01	0.00E+00	6.85E+04
^{154}Eu	1.13E+04	1.02E+03	9.29E+02	0.00E+00	4.47E+03	0.00E+00	2.37E+05
^{181}Hf	7.73E+01	2.81E+02	3.49E+01	0.00E+00	5.72E+01	0.00E+00	1.04E+05

Table 8: Child Meat Pathway Dose Factors (R_i)

(m^2mrem/yr) per (μCi/sec)

Nuclide	Bone	Liver	Total Body	Thyroid	Kidney	Lung	GI-LLI
^{3}H	0.00E+00	2.34E+02	2.34E+02	2.34E+02	2.34E+02	2.34E+02	2.34E+02
^{7}Be	7.38E+03	1.26E+04	8.07E+03	0.00E+00	1.23E+04	0.00E+00	7.00E+05
^{51}Cr	0.00E+00	0.00E+00	8.80E+03	4.88E+03	1.33E+03	8.92E+03	4.67E+05
^{54}Mn	0.00E+00	8.02E+06	2.14E+06	0.00E+00	2.25E+06	0.00E+00	6.73E+06
^{55}Fe	4.58E+08	2.43E+08	7.52E+07	0.00E+00	0.00E+00	1.37E+08	4.50E+07
^{59}Fe	3.77E+08	6.10E+08	3.04E+08	0.00E+00	0.00E+00	1.77E+08	6.35E+08
^{57}Co	0.00E+00	5.92E+06	1.20E+07	0.00E+00	0.00E+00	0.00E+00	4.85E+07
^{58}Co	0.00E+00	1.64E+07	5.03E+07	0.00E+00	0.00E+00	0.00E+00	9.59E+07
^{60}Co	0.00E+00	6.94E+07	2.05E+08	0.00E+00	0.00E+00	0.00E+00	3.84E+08
^{63}Ni	2.92E+10	1.56E+09	9.92E+08	0.00E+00	0.00E+00	0.00E+00	1.05E+08
^{65}Zn	3.76E+08	1.00E+09	6.23E+08	0.00E+00	6.31E+08	0.00E+00	1.76E+08
^{86}Rb	0.00E+00	5.77E+08	3.55E+08	0.00E+00	0.00E+00	0.00E+00	3.71E+07
^{89}Sr	4.82E+08	0.00E+00	1.38E+07	0.00E+00	0.00E+00	0.00E+00	1.87E+07
^{90}Sr	1.04E+10	0.00E+00	2.64E+09	0.00E+00	0.00E+00	0.00E+00	1.40E+08
^{90}Y	1.93E+05	0.00E+00	5.16E+03	0.00E+00	0.00E+00	0.00E+00	5.49E+08
^{91}Y	1.80E+06	0.00E+00	4.82E+04	0.00E+00	0.00E+00	0.00E+00	2.40E+08
^{95}Zr	2.67E+06	5.86E+05	5.22E+05	0.00E+00	8.39E+05	0.00E+00	6.11E+08
^{95}Nb	4.26E+06	1.66E+06	1.18E+06	0.00E+00	1.56E+06	0.00E+00	3.07E+09
^{103}Ru	1.55E+08	0.00E+00	5.96E+07	0.00E+00	3.90E+08	0.00E+00	4.01E+09
^{106}Ru	4.44E+09	0.00E+00	5.54E+08	0.00E+00	6.00E+09	0.00E+00	6.91E+10
^{110m}Ag	8.40E+06	5.67E+06	4.53E+06	0.00E+00	1.06E+07	0.00E+00	6.75E+08
^{109}Cd	0.00E+00	1.91E+06	8.84E+04	0.00E+00	1.70E+06	0.00E+00	6.18E+06
^{113}Sn	2.18E+09	4.48E+07	1.24E+08	3.31E+09	0.00E+00	0.00E+00	1.54E+09
^{124}Sb	2.93E+07	3.80E+05	1.03E+07	6.46E+04	0.00E+00	1.62E+07	1.83E+08
^{125}Sb	2.85E+07	2.20E+05	5.97E+06	2.64E+04	0.00E+00	1.59E+07	6.81E+07
^{127m}Te	1.78E+09	4.78E+08	2.11E+08	4.25E+08	5.07E+09	0.00E+00	1.44E+09
^{129m}Te	1.79E+09	5.00E+08	2.78E+08	5.78E+08	5.26E+09	0.00E+00	2.19E+09

Table 8: Child Meat Pathway Dose Factors (R_i)

(m^2mrem/yr) per (µCi/sec)

Nuclide	Bone	Liver	Total Body	Thyroid	Kidney	Lung	GI-LLI
^{130}I	3.06E-06	6.18E-06	3.18E-06	6.80E-04	9.23E-06	0.00E+00	2.89E-06
^{131}I	1.66E+07	1.67E+07	9.47E+06	5.51E+09	2.74E+07	0.00E+00	1.48E+06
^{132}I	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{133}I	5.70E-01	7.05E-01	2.67E-01	1.31E+02	1.17E+00	0.00E+00	2.84E-01
^{134}I	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{135}I	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
^{134}Cs	9.23E+08	1.51E+09	3.20E+08	0.00E+00	4.69E+08	1.68E+08	8.17E+06
^{136}Cs	1.62E+07	4.46E+07	2.89E+07	0.00E+00	2.38E+07	3.54E+06	1.57E+06
^{137}Cs	1.33E+09	1.28E+09	1.89E+08	0.00E+00	4.16E+08	1.50E+08	8.00E+06
^{140}Ba	4.39E+07	3.85E+04	2.56E+06	0.00E+00	1.25E+04	2.29E+04	2.22E+07
^{140}La	3.33E+02	1.17E+02	3.93E+01	0.00E+00	0.00E+00	0.00E+00	3.25E+06
^{141}Ce	2.22E+04	1.11E+04	1.65E+03	0.00E+00	4.86E+03	0.00E+00	1.38E+07
^{144}Ce	2.32E+06	7.27E+05	1.24E+05	0.00E+00	4.02E+05	0.00E+00	1.89E+08
^{143}Pr	3.34E+04	1.00E+04	1.66E+03	0.00E+00	5.43E+03	0.00E+00	3.61E+07
^{144}Pr	5.63E+02	1.74E+02	2.83E+01	0.00E+00	9.21E+01	0.00E+00	3.75E+05
^{147}Nd	1.17E+04	9.48E+03	7.34E+02	0.00E+00	5.20E+03	0.00E+00	1.50E+07
^{154}Eu	1.12E+07	1.01E+06	9.20E+05	0.00E+00	4.43E+06	0.00E+00	2.34E+08
^{181}Hf	4.77E+06	1.74E+07	2.15E+06	0.00E+00	3.53E+06	0.00E+00	6.41E+09

Table 9: Child Vegetation Pathway Dose Factors (R_i)

(m^2mrem/yr) per (μCi/sec)

Nuclide	Bone	Liver	Total Body	Thyroid	Kidney	Lung	GI-LLI
^{3}H	0.00E+00	4.01E+03	4.01E+03	4.01E+03	4.01E+03	4.01E+03	4.01E+03
^{7}Be	3.38E+05	5.76E+05	3.70E+05	0.00E+00	5.65E+05	0.00E+00	3.21E+07
^{51}Cr	0.00E+00	0.00E+00	1.17E+05	6.50E+04	1.78E+04	1.19E+05	6.21E+06
^{54}Mn	0.00E+00	6.65E+08	1.77E+08	0.00E+00	1.86E+08	0.00E+00	5.58E+08
^{55}Fe	8.01E+08	4.25E+08	1.32E+08	0.00E+00	0.00E+00	2.40E+08	7.87E+07
^{59}Fe	3.98E+08	6.43E+08	3.20E+08	0.00E+00	0.00E+00	1.87E+08	6.70E+08
^{57}Co	0.00E+00	2.99E+07	6.04E+07	0.00E+00	0.00E+00	0.00E+00	2.45E+08
^{58}Co	0.00E+00	6.44E+07	1.97E+08	0.00E+00	0.00E+00	0.00E+00	3.76E+08
^{60}Co	0.00E+00	3.78E+08	1.12E+09	0.00E+00	0.00E+00	0.00E+00	2.10E+09
^{63}Ni	3.95E+10	2.11E+09	1.34E+09	0.00E+00	0.00E+00	0.00E+00	1.42E+08
^{65}Zn	8.13E+08	2.17E+09	1.35E+09	0.00E+00	1.36E+09	0.00E+00	3.80E+08
^{86}Rb	0.00E+00	4.52E+08	2.78E+08	0.00E+00	0.00E+00	0.00E+00	2.91E+07
^{89}Sr	3.60E+10	0.00E+00	1.03E+09	0.00E+00	0.00E+00	0.00E+00	1.39E+09
^{90}Sr	1.24E+12	0.00E+00	3.15E+11	0.00E+00	0.00E+00	0.00E+00	1.67E+10
^{90}Y	3.01E+06	0.00E+00	8.04E+04	0.00E+00	0.00E+00	0.00E+00	8.56E+09
^{91}Y	1.86E+07	0.00E+00	4.99E+05	0.00E+00	0.00E+00	0.00E+00	2.48E+09
^{95}Zr	3.86E+06	8.48E+05	7.55E+05	0.00E+00	1.21E+06	0.00E+00	8.85E+08
^{95}Nb	7.48E+05	2.91E+05	2.08E+05	0.00E+00	2.74E+05	0.00E+00	5.39E+08
^{103}Ru	1.53E+07	0.00E+00	5.90E+06	0.00E+00	3.86E+07	0.00E+00	3.97E+08
^{106}Ru	7.45E+08	0.00E+00	9.30E+07	0.00E+00	1.01E+09	0.00E+00	1.16E+10
^{110m}Ag	3.21E+07	2.17E+07	1.73E+07	0.00E+00	4.04E+07	0.00E+00	2.58E+09
^{109}Cd	0.00E+00	2.45E+08	1.14E+07	0.00E+00	2.18E+08	0.00E+00	7.94E+08
^{113}Sn	1.58E+09	3.25E+07	9.00E+07	2.40E+09	0.00E+00	0.00E+00	1.12E+09
^{124}Sb	3.52E+08	4.57E+06	1.23E+08	7.77E+05	0.00E+00	1.95E+08	2.20E+09
^{125}Sb	4.99E+08	3.85E+06	1.05E+08	4.63E+05	0.00E+00	2.78E+08	1.19E+09
^{127m}Te	1.32E+09	3.56E+08	1.57E+08	3.16E+08	3.77E+09	0.00E+00	1.07E+09
^{129m}Te	8.41E+08	2.35E+08	1.31E+08	2.71E+08	2.47E+09	0.00E+00	1.03E+09

Table 9: Child Vegetation Pathway Dose Factors (R_I)

(m^2mrem/yr) per (μCi/sec)

Nuclide	Bone	Liver	Total Body	Thyroid	Kidney	Lung	GI-LLI
^{130}I	6.16E+05	1.24E+06	6.41E+05	1.37E+08	1.86E+06	0.00E+00	5.82E+05
^{131}I	1.43E+08	1.44E+08	8.17E+07	4.76E+10	2.36E+08	0.00E+00	1.28E+07
^{132}I	9.23E+01	1.70E+02	7.80E+01	7.87E+03	2.60E+02	0.00E+00	2.00E+02
^{133}I	3.53E+06	4.37E+06	1.65E+06	8.12E+08	7.28E+06	0.00E+00	1.76E+06
^{134}I	1.56E-04	2.89E-04	1.33E-04	6.65E-03	4.42E-04	0.00E+00	1.92E-04
^{135}I	6.26E+04	1.13E+05	5.33E+04	9.98E+06	1.73E+05	0.00E+00	8.59E+04
^{134}Cs	1.60E+10	2.63E+10	5.55E+09	0.00E+00	8.15E+09	2.93E+09	1.42E+08
^{136}Cs	8.24E+07	2.27E+08	1.47E+08	0.00E+00	1.21E+08	1.80E+07	7.96E+06
^{137}Cs	2.39E+10	2.29E+10	3.38E+09	0.00E+00	7.46E+09	2.68E+09	1.43E+08
^{140}Ba	2.77E+08	2.43E+05	1.62E+07	0.00E+00	7.90E+04	1.45E+05	1.40E+08
^{140}La	3.36E+04	1.18E+04	3.96E+03	0.00E+00	0.00E+00	0.00E+00	3.28E+08
^{141}Ce	6.56E+05	3.27E+05	4.86E+04	0.00E+00	1.43E+05	0.00E+00	4.08E+08
^{144}Ce	1.27E+08	3.98E+07	6.78E+06	0.00E+00	2.21E+07	0.00E+00	1.04E+10
^{143}Pr	1.46E+05	4.37E+04	7.23E+03	0.00E+00	2.37E+04	0.00E+00	1.57E+08
^{144}Pr	7.88E+03	2.44E+03	3.97E+02	0.00E+00	1.29E+03	0.00E+00	5.25E+06
^{147}Nd	7.15E+04	5.79E+04	4.48E+03	0.00E+00	3.18E+04	0.00E+00	9.17E+07
^{154}Eu	1.66E+08	1.50E+07	1.37E+07	0.00E+00	6.57E+07	0.00E+00	3.48E+09
^{181}Hf	4.90E+05	1.79E+06	2.21E+05	0.00E+00	3.63E+05	0.00E+00	6.59E+08

Table 10: Highest Annual Average Atmospheric Dispersion Parameters Unit Vent

Location[b]	Meteorological Sector	Distance (meters)	X/Q Undecayed/ undepleted (sec/m^3)	X/Q Decayed/ Undepleted (sec/m^3)	X/Q Decayed/ Depleted (sec/m^3)	D/Q (m^{-2})
Site Boundary[a]	NNW	2200	1.0E-6	9.9E-7	8.5E-7	4.3E-9
Nearest Residence [c] [d]	NNW	2897	6.7E-7	6.6E-7	5.6E-7	2.6E-9
Farming Areas within the Site Boundary[c] [e]	N/A	N/A	2.6E-7	2.6E-7	2.4E-7	1.3E-9

(a) Values given are from FSAR-SA Table 2.3-82

(b) Data from 2002 Land Use Census

(c) Values derived[57] from FSAR-SA Table 2.3-83, using the methodology presented in Eq. 24

(d) All pathways are assumed to exist at the location of the nearest resident.

(e) These values were derived for a narrow scope application. Extreme caution should be exercised when determining their suitability for use in other applications.

Building Shape Parameter (C) = 0.5[58]

Vertical Height of Highest Adjacent Building (V) = 66.45 meters[59]

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57 Calculation ZZ-67

58 BLUE 1232

59 BLUE 1232

Table 11: Highest Annual Average Atmospheric Dispersion Parameters Radwaste Vent and Laundry/Decon Facility Dryer Exhaust

Location[(b)]	Meteorological Sector	Distance (meters)	X/Q Undecayed/ undepleted (sec/m^3)	X/Q Decayed/ Undepleted (sec/m^3)	X/Q Decayed/ Depleted (sec/m^3)	D/Q (m^{-2})
Site Boundary[(a)]	NNW	2200	1.3E-6	1.3E-6	1.1E-6	4.3E-9
Nearest Residence[(c) (d)]	NNW	2897	8.5E-7	8.5E-7	7.1E-7	2.6E-9
Farming Areas Within Site Boundary[(c) (e)]	N/A	N/A	3.5E-7	3.5E-7	3.2E-7	1.3E-9

(a) Values given are from FSAR-SA Table 2.3-84

(b) Data from 2002 Land Use Census

(c) Values derived [60] from FSAR-SA Table 2.3-81, using the methodology presented in Eq. 24

(d) All pathways are assumed to exist at the location of the nearest resident.

(e) These values were derived for a narrow scope application. Extreme caution should be exercised when determining their suitability for use in other applications.

Building Shape Parameter (C) = 0.5[61]

Vertical Height of Highest Adjacent Building (V) = 19.96 meters[62]

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[60] Calculation ZZ-67
[61] BLUE 1232
[62] BLUE 1232

Table 12: Application of Atmospheric Dispersion Parameters for Release Permits

Dose Pathway	Dispersion Parameter	Controlling Age Group	REC	Controlling Location
Noble Gas, Beta Air & Gamma Air	X/Q, decayed/undepleted (2.26 day half-life)	N/A	16.11.2.2	Site Boundary
Noble Gas, Total Body & Skin	X/Q, decayed/undepleted (2.26 day half-life)	N/A	16.11.2.1	Site Boundary
Inhalation	X/Q, decayed/depleted (8 day half-life)	Child	16.11.2.1 16.11.2.3	Nearest Resident Site Boundary
Ground Plane Deposition	D/Q	N/A	16.11.2.3	Nearest Resident
Ingestion pathways	D/Q*	Child	16.11.2.3	Nearest Resident

*For ^{3}H, X/Q decayed/depleted is used instead of D/Q.[63]

[63] Regulatory Guide 1.109, Appendix C, Section 3.a

Table 13: Application of Atmospheric Dispersion Parameters Annual Radioactive Effluent Release Report

Dose Pathway	Dispersion Parameter	Controlling Age Group	Dispersion Values	Controlling Location
Noble Gas, Beta Air & Gamma Air Dose	X/Q, decayed/undepleted (2.26 day half-life)	N/A	Concurrent	Site Boundary Nearest Resident
Noble Gas, Total Body & Skin Dose	X/Q, decayed/undepleted (2.26 day half-life)	N/A	Concurrent	Site Boundary Nearest Resident
			Concurrent Historical	Farmer's Residence Inside Site Boundary
Ground Plane Deposition Dose	D/Q	N/A	Concurrent	Site Boundary Nearest Resident
			Concurrent Historical	Farmer's Residence Inside Site Boundary
Inhalation Dose	X/Q, decayed/depleted (8 day half-life)	Child	Concurrent	Site Boundary Nearest Resident
		Adult	Concurrent Historical	Farmer's Residence Inside Site Boundary
Ingestion Dose Pathways	D/Q*	Child	Concurrent	Site Boundary Nearest Resident

* For H^3, X/Q, decayed/depleted is used instead of D/Q.[64]

The applicability of atmospheric dispersion parameters to the calculation of dose from ^{14}C is described in Appendix A.

[64] Regulatory Guide 1.109, Appendix C, Section 3.a

Table 14: Meteorological Data Selection Hierarchy

Parameter	Primary	First Alternate	Second Alternate	Third Alternate
Wind Speed	10m A	10m B	60m A	60m B
Wind Direction	10m A	10m B	60m A	60m B
Air Temperature	10m A	10m B		
Wind Variability	10m A	10m B	60m A	60m B
Temp Difference	60-10m A	60-10m B		
Dew point/Relative Humidity	10m A	60m B		
Precipitation	1m			

(a) 'A' indicates Alpha train meteorological instrumentation.

(b) 'B' indicates Bravo train meteorological instrumentation.

Appendix A: Methodology for Calculating Dose from ^{14}C in Gaseous Effluents

The purpose of this Appendix is to provide methodology and parameters for calculating (1) the quantity of ^{14}C released in gaseous effluents, (2) the dose to the Member of the Public at the nearest receptor location due to ^{14}C released in gaseous effluents, and (3) the dose from ^{14}C released in gaseous effluents to the Member of the Public due to activities within the Site Boundary.

The quantity of ^{14}C discharged can be estimated[65] by sample measurements, or by use of a normalized ^{14}C source term and scaling factors based on power generation,[66] or by use of the GALE code,[67] or by use of the EPRI site specific or proxy methodologies.[68] *Any of these methodologies is acceptable for estimating the ^{14}C discharged in gaseous effluents.*

Assumptions

1. The total quantity of ^{14}C produced during the year is assumed to be released during the year in which it was produced.
2. For conservatism, it is assumed that all ^{14}C produced is released in gaseous effluents.
3. The dose contribution of ^{14}C from liquid effluents is much less than that contributed by gaseous effluents, therefore evaluation of ^{14}C in liquid effluents is not required.[69]
4. The dose to the Member of the Public is determined in accordance with the methodology and parameters in Regulatory Guide 1.109.
5. ^{14}C has a long half- life with respect to the transit time. ^{14}C is discharged as CH_4 or CO_2 gas and does not deplete or undergo chemical change before it reaches the receptor location. Therefore the appropriate dispersion parameter is X/Q (undecayed and undepleted).
6. The inhalation pathway is assumed to exist at the Nearest Residence location with the highest value of X/Q as determined by the annual Land Use Census.
7. The ingestion pathways are assumed to exist at the nearest receptor location with the highest value of X/Q as determined by the annual Land Use Census.
8. ^{14}C is not a gamma- emitting nuclide; therefore the ground plane pathway is negligible.
9. It is assumed that the child age group exists at the Nearest Residence and ingestion pathway locations.
10. Only $^{14}CO_2$ discharged during the period of photosynthesis is considered for the ingestion pathways.
11. All of the ^{14}C produced is assumed to contribute to the inhalation dose pathway, regardless of chemical form.

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[65] Regulatory Guide 1.21, rev. 2, Section 1.9
[66] NCRP Report 81
[67] NUREG- 0017
[68] EPRI TR-1021106, Section 4.
[69] Regulatory Guide 1.21, rev. 2, Section 1.9

Applicable Dose Limits

10 CFR 50, Appendix I, states, "The calculated annual total quantity of all radioactive iodine and radioactive material in particulate form above background to be released from each light-water-cooled nuclear power reactor in effluents to the atmosphere will not result in an estimated annual dose or dose commitment from such *radioactive iodine and radioactive material in particulate form* for any individual in an unrestricted area from all pathways of exposure in excess of 15 millirems to any organ."[70] Radiological Effluent Control (REC) 16.11.2.3 limits the annual dose to the Member of the Public from *^{131}I, ^{133}I, ^{3}H, and particulates* with half-lives greater than 8 days released in gaseous effluents to 15 mrem to any organ.[71] ^{14}C is released as a gas in the form of CH_4 or CO_2 and is not a radioiodine, tritium, or particulate, therefore the design objectives in 10 CFR 50, Appendix I and the limits of REC 16.11.2.3 do not apply to ^{14}C.

10 CFR 20.1301(a)(1) limits the annual TEDE dose to the Member of the Public to 100 mrem.

40 CFR 190.10(a) limits the total annual dose from the uranium fuel cycle to the Member of the Public to 25 mrem to the whole body or any organ. 40 CFR 190 is implemented by REC 16.11.3.1. This limit includes dose from the release of gaseous effluents to areas at or beyond the Site Boundary, the dose from gaseous effluents due to activities within the Site Boundary, and the dose from direct radiation. The methodology for calculating the total annual dose from the uranium fuel cycle is provided in Section 4.

Estimation of ^{14}C in Gaseous Effluents

^{14}C exists in all PWR systems, and any location or system that contains tritium most likely also will contain ^{14}C in some chemical form. Measurements of ^{14}C concentrations in various liquid systems have been performed, and some of the reported data are included in EPRI TR-1021106.[72] As a general rule, ^{14}C in the primary coolant is essentially all organic with a significant fraction as a gaseous species. If the RCS liquid or gas is exposed to an oxidizing environment, such as during the forced oxidation during the shutdown evolution and during refueling outages, a slow transformation from an organic to an inorganic chemical form can occur.

Dissolved nitrogen gas and ammonia in the RCS could contribute to the ^{14}C source term. The dissolved nitrogen could become significant in the latter stages of the fuel cycle due to the introduction of increased quantities of non-borated water for boron dilution. Callaway maintains a hydrogen gas overpressure on the RCS which effectively eliminates dissolved nitrogen gas and ammonia in the RCS, therefore the RCS ammonia concentration is assumed to be 0.

In general, ^{14}C is produced in light water moderated nuclear power reactors by $^{14}N(n,p)^{14}C$ reactions with nitrogen impurities in the coolant and by $^{17}O(n,\alpha)^{14}C$ reactions in the coolant. ^{14}C produced in a nuclear power reactor can be released directly to the environment from the coolant in a gaseous form or in much smaller quantities as liquid effluents.[73] Kunz estimated the fraction of ^{14}C in liquid and solid wastes at

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[70] 10 CFR 50, Appendix I, section II, paragraph C
[71] NUREG-1301, REC 3.11.2.3
[72] EPRI TR-1021106, Section 4.1
[73] IAEA Report 421, Section 3.1.3

<5% of that in gaseous discharges[74]. Regulatory Guide 1.21 states that the dose contribution from ^{14}C in liquid discharges is insignificant and evaluation of ^{14}C released in liquid effluents is not required.[75]

The release and removal pathways from the primary coolant include VCT venting, boron dilution, inventory buildup on the letdown demineralizers and filters, and reactor coolant leakage. Letdown system removal is approximately 1 Ci/yr.[76] The ^{14}C production balance is shown in Figure 1.

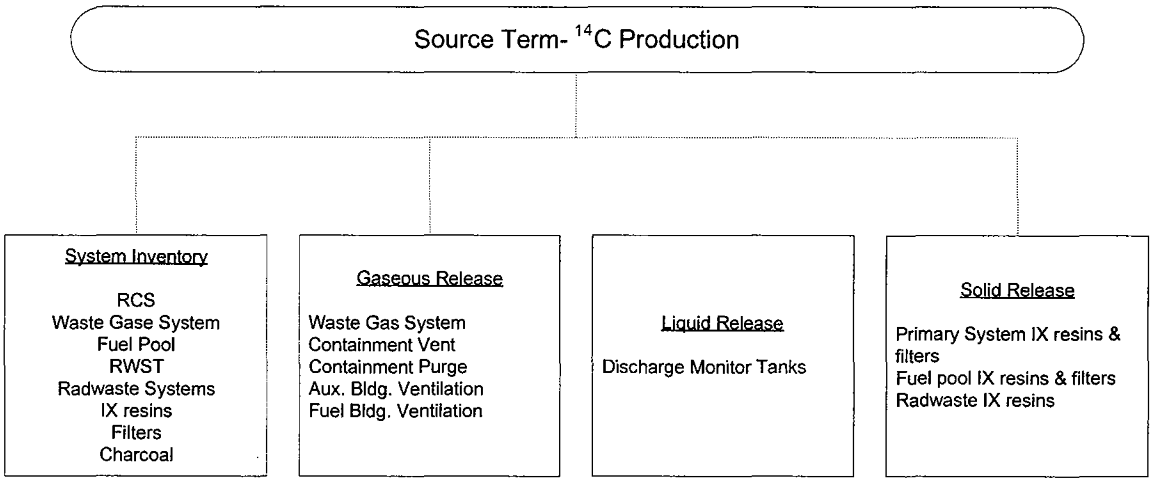

Figure 1: ^{14}C Production Balance

Chemical Form of ^{14}C in Gaseous Effluents

Since the PWR operates with a reducing chemical environment, most, if not all, of the ^{14}C species initially produced are in the reduced, i.e., organic, form and contain only a single carbon atom. Possible species include methane ($^{14}CH_4$), methanol ($^{14}CH_3OH$), formaldehyde ($H_2{}^{14}C{=}O$ or the *gem*-diol $H_2{}^{14}C(OH)_2$), and formic acid ($H^{14}COOH$). In theory, the only ionic species produced will be formic acid ($H^{14}CO_2H$) , and some or all of the formic acid will be removed by the letdown demineralizers. Formaldehyde is soluble in water and may partially be chemisorbed on the ion exchange resin. A quasi-equilibrium is established in the coolant between the initially produced species and other possible species in the reactor coolant. The most chemically reduced species and probably the most prevalent species is $^{14}CH_4$ which partitions between the liquid and gas phases in the VCT and pressurizer.[77] The airborne ^{14}C released from PWRs is predominantly hydrocarbons (75–95%), mainly methane (CH_4), with only a small fraction in the form of CO_2.[78,79] Regulatory Guide 1.21 states that ^{14}C releases in PWRs occur primarily as a mix of organic carbon and CO_2 in gaseous waste from the waste gas system.[80] NUREG-0017[81]

[74] Kunz, 1985
[75] Regulatory Guide 1.21, rev. 2, section 1.09
[76] EPRI TR-1021106, Section 4.1
[77] EPRI TR-1021106, Section 4.1
[78] IAEA Report 421, Section 3.1.3
[79] Neeb, section 4.2.4
[80] Regulatory Guide 1.21, rev. 2, section 1.09
[81] NUREG-0017, Section 2.2.25.2

concludes that 16.4% of the ^{14}C produced in a PWR will be released via the waste gas processing system, and the remainder, 83.6%, from the Reactor Building and the Auxiliary Building.

Due to the presence of high temperature hydrogen recombiners in the Callaway waste gas system, 100% of the ^{14}C released through the waste gas system is assumed to be released from the waste gas decay tanks in the oxidized, i.e., inorganic form as CO_2. The ^{14}C released from the unit vent is assumed to be in the reduced (organic) form as CH_4, therefore 16.4% of the ^{14}C produced is released through the Waste Gas Decay tanks (WGDT) as CO_2, and 83.6% is released via the Unit Vent as CH_4.

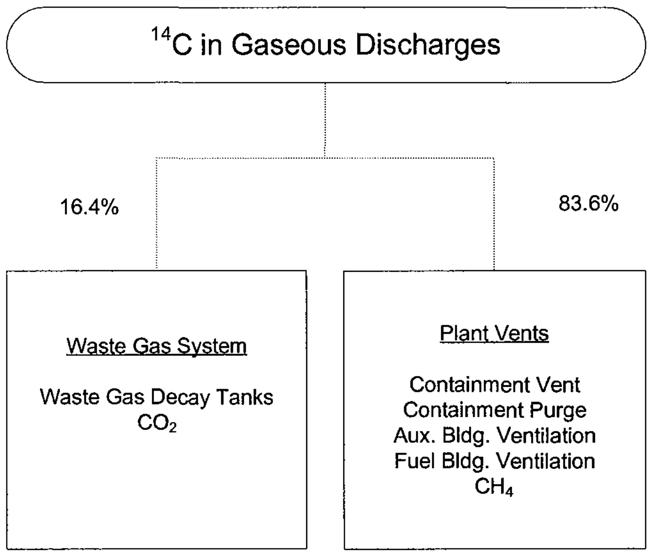

Figure 2: ^{14}C Gaseous Discharge Balance

^{14}C Source Term Estimation

The neutron absorption cross section for the $^{17}O(n,\alpha)^{14}C$ reaction is shown in Figure 3. The $^{17}O(n,\alpha)^{14}C$ reaction has a 1/v region and a significant high energy neutron cross section. Given a constant neutron flux and target concentration, the rate of production of a species, N_a, in atoms per second is given by:

$$N_a = N_T \bullet \{(\sigma_t \bullet \varphi_t) + (\sigma_e \bullet \varphi_e) + (\sigma_f \bullet \varphi_f)\}$$

Where:

N_a is the rate of production, atoms/sec

NT is the number of ^{17}O or ^{14}N target atoms per kg of coolant

σ_t is the effective neutron cross section for thermal neutron absorption, cm^2

φ_t is the thermal neutron flux, n/cm^2-sec

σ_e is the effective neutron cross section for epithermal energy neutron absorption, cm^2

φ_e is the epithermal neutron flux, n/cm^2-sec

σ_f is the effective neutron cross section for fast neutron absorption, cm^2

φ_f is the fast neutron flux, n/cm^2-sec

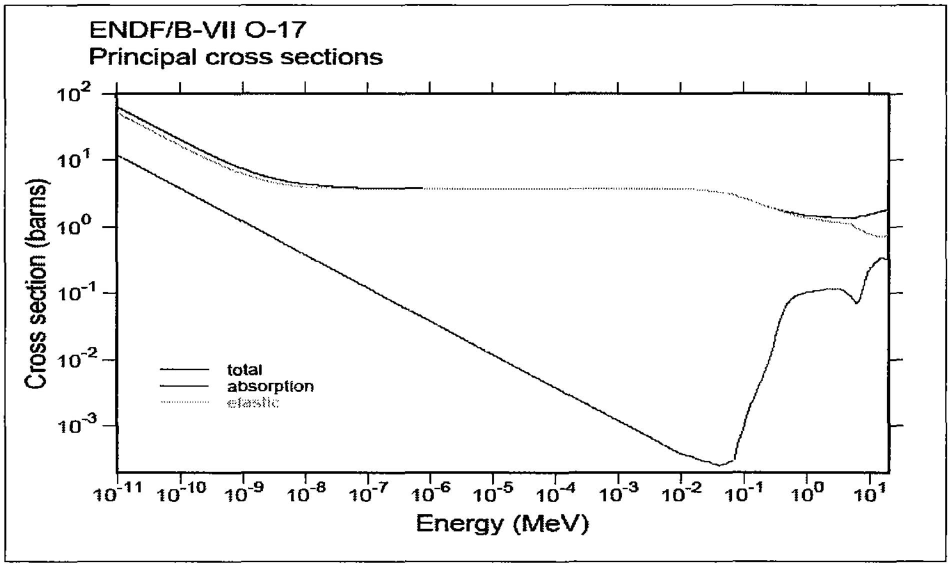

Figure 3: ENDF/B VII Cross Sections for ^{17}O

Table 15: Effective Cross Section for the $^{17}O(n,\alpha)^{14}C$ Reaction in the PWR as a Function of Neutron Energy[82]		
Neutron Group	Group Energy	Effective Cross Section
Thermal	≤0.625 eV	0.121 barns
Epithermal (E)	>0.625 eV - <1 MeV	0.0291 barns
Fast (F)	≥1 MeV	0.1124 barns

The source term of each species A_i, is given by:

$$A_a\,(dps) = N_a \cdot \lambda_a$$

$$A_a(\mu Ci) = \frac{N_a \cdot \lambda_a}{3.7E4}$$

Where A_a is the activity of species a, N_a is the number of atoms of species a, λ_a is the decay constant of species a, in seconds. The ^{14}C production rate from the $^{17}O(n,\alpha)^{14}C$ reaction is calculated for the three group flux distribution according to:[83]

[82] EPRI TR-1021106, Section 4.3.2.2
[83] EPRI TR-1021106, Section 4.3.2.1

$$^{14}C\ production\ rate = \frac{(1E\text{-}24 \cdot \lambda \cdot N \cdot \{(\sigma_t \varphi_t) + (\sigma_e \varphi_e) + (\sigma_f \varphi_f)\}}{3.7E4}$$

Where:

^{14}C Production rate is ^{14}C rate of production, µCi/sec- kg

N is the number of target atoms per unit mass of coolant (1.27E22 atoms ^{17}O/ kg H_2O);

σ_t is the effective neutron cross section for thermal neutron absorption, in barns;

φ_t is the thermal neutron flux, n/cm^2-sec;

σ_e is the effective neutron cross section for epithermal energy neutron absorption, in barns;

φ_e is the epithermal neutron flux, n/cm^2-sec;

σ_f is the effective neutron cross section for fast neutron absorption, in barns;

φ_f is the fast neutron flux, n/cm^2-sec;

1.0E-24 is a units conversion factor, 1.0E-24 cm^2/barn;

λ is the ^{14}C decay constant, 3.833E-12/sec; and

3.7E4 is a units conversion factor, 3.7E4 d/(sec- µCi).

The activity of ^{14}C produced is thus the product of the production rate, the coolant mass in the active core region, and time:

$$A_C = \text{Production rate} \bullet \text{coolant mass} \bullet \text{time}$$

Where:

A_C is the activity of ^{14}C produced, in µCi;

The ***coolant mass*** is the mass of water in the active core region, in kg, corrected for core average temperature and pressure;

The ***time*** is the time period of reactor operation, in sec;

Site Specific Parameters for ^{14}C Source Term Estimation

The Callaway reactor is a Westinghouse Model F, four loop Pressurized Water Reactor (PWR) rated at 3565 MW_{th}. The fuel is Westinghouse Vantage+ OFA with 193 fuel assemblies. The mass of coolant in the active core region is 12,925 kg.[84] The hydrogen gas overpressure in the Volume Control Tank (VCT) effectively eliminates N_2 and NH_3 in the RCS, therefore ^{14}C production from the $^{14}N(n,p)^{14}C$ reaction is insignificant.

The core average neutron flux, the Effective Full Power Years (EFPY), and the fuel burnup are specific to the reactor operation for the period.

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[84] Westinghouse Calculation Note CN-TA-02-135, "Callaway (SCP) RSG IGOR/RETRAN Base Deck", May 16, 2003

Inhalation Dose at the Nearest Residence Location from ^{14}C

The child age group is the critical age group for an airborne release of ^{14}C due to higher inhalation dose factors and higher ingestion dose factors.[85] The inhalation dose for the child age group, D, is calculated according to the expression[86]:

$$D_j = 3.17E4 \cdot R_a \cdot DFA_j \cdot Q_i \cdot X/Q$$

Where:

D is the dose in mrem, to a member of the public from ^{14}C, from the inhalation pathway, received by organ j;

3.17 E4 is the number of pCi/Ci divided by the number of sec/yr;

$\boldsymbol{R_a}$ is the breathing rate for the child age group (3700 m^3/yr);[87]

$\boldsymbol{DFA_j}$ is the ^{14}C inhalation pathway dose factor for organ *j*, appropriate to the child age group (mrem/pCi). For ^{14}C, the limiting organ is the bone. The DFA_{bone} for the child age group is 9.70E-6 mrem/pCi, and the $DFA_{total\ body}$ for the child age group is 1.82E-6;[88]

$\boldsymbol{Q_i}$ is the quantity of ^{14}C produced during the year (Ci/yr); and

X/Q is the highest calculated annual average concentration at the nearest receptor location (sec/m^3).

The inhalation dose to the bone for the child age group at the Nearest Residence location is:

$$D_{bone} = 1138 \cdot Q_i \cdot X/Q$$

The inhalation dose to the total body for the child age group at the Nearest Residence location is:

$$D_{total\ body} = 213 \cdot Q_i \cdot X/Q$$

Concentration of ^{14}C in Vegetation

The concentration of ^{14}C in leafy vegetation is calculated by assuming that the ^{14}C ratio to the natural carbon in the vegetation is the same as the ratio of ^{14}C to natural carbon in the atmosphere surrounding the vegetation.[89]

Only ^{14}C released in the oxide form (CO or CO_2) is incorporated into the plant material.[90] All ^{14}C released from the waste gas decay tanks is assumed to be in the organic form, as CO_2. The inorganic form, e.g., CH_4, is not incorporated into plant material, therefore, only the organic form, e.g., CO_2 contributes to the ingestion dose pathway. $^{14}CO_2$ released outside the growing season or at night is not incorporated into plant material and does not contribute to the dose from the ingestion pathway. $^{14}CO_2$ released during the growing season in the daytime is assumed to be incorporated into the plant material

[85] Regulatory Guide 1.109, Table E-9, and Table E-13
[86] Regulatory Guide 1.109, equations C-3 and C-4.
[87] Regulatory Guide 1.109, Table E-5
[88] Regulatory Guide 1.109, Table E-9.
[89] Regulatory Guide 1.109, Appendix C
[90] Regulatory Guide 1.109, Appendix C

and contributes to the ingestion dose pathway. The growing season in mid- Missouri is approximately April 1- November 1.[91]

The concentration of ^{14}C in leafy vegetation is given by:[92]

$$Conc_v = \frac{3.17E7 \cdot Q_i \cdot X/Q \cdot 0.11}{0.16}$$

Where:

$Conc_V$ is the concentration of ^{14}C in leafy vegetation grown at the nearest receptor location (pCi/kg);

3.17E7 is equal to (1E12pCi/C)(1E3g/kg)/(3.15E7 sec/yr);

Q_i is the quantity of ^{14}C released as CO_2 during periods of photosynthesis (Ci/yr);

X/Q is the highest calculated annual average concentration at the nearest receptor location (sec/m^3);

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

0.16 is the concentration of natural carbon in the atmosphere (g/m^3).

Substitution of constants yields:

$$Conc_v = 2.2E7 \cdot Q_i \cdot X/Q$$

Dose from ^{14}C in Fresh Leafy Vegetation

The leafy vegetation ingestion dose for the Child age group at the nearest receptor location is given by:[93]

$$D = DFI \cdot f_l \cdot U_a \cdot Conc_v$$

Where:

D is the annual dose to the bone or total body for the child age group from ingestion of fresh leafy vegetation, (mrem/yr);

DFI is the ingestion dose conversion factor for the maximum exposed organ. For the child age group, the bone is the maximum exposed organ. The **DFI_{bone}** is 1.21E-5 mrem/pCi ingested and the **$DFI_{total\ body}$** is 2.42E-6 mrem/pCi ingested;[94]

f_l is the fraction of leafy vegetation grown in the garden at the nearest receptor location. f_l = 1.0;[95] and

U_a is the ingestion rate of leafy vegetation. For the child age group, U_a = 26 kg/yr.[96]

Concentration of ^{14}C in Milk

[91] Hammer, G. R.
[92] Regulatory Guide 1.109, equation C-8
[93] Regulatory Guide 1.109, equation C-13
[94] Regulatory Guide 1.109, Table E-13
[95] Regulatory Guide 1.109, Table E-15
[96] Regulatory Guide 1.109, Table E-5

The concentration of ^{14}C in milk is determined as[97]:

$$Conc_{milk} = F_m \cdot Conc_v \cdot Q_F \cdot e^{-\lambda t_f}$$

Where:

$Conc_{milk}$ is the concentration of ^{14}C in milk, in pCi/L;

F_m is the average fraction of the animal's daily intake of ^{14}C which appears in each liter of milk, in days/L. For cow milk, F_m is 1.2E-2 days/L.[98] For goat milk, F_m is 0.10 days/L;[99]

$Conc_V$ is the concentration of ^{14}C in leafy vegetation grown at the receptor location (pCi/kg), as described above;

Q_F is the amount of feed consumed by the animal per day, in kg/day. For cows, Q_F is equal to 50 kg/day and for goats Q_F is equal to 6 kg/day;[100]

t_f is the average transport time of the ^{14}C from the feed into the milk and to the receptor (a value of 2 days is assumed): and

λ is the radiological decay constant for ^{14}C, 3.32E-7 $days^{-1}$.

Dose from ^{14}C in Milk

The dose from ^{14}C in milk is determined as:

$$D = DFI \cdot U_a \cdot Conc_{milk}$$

Where:

D is the annual dose to the bone or total body for the child age group from milk ingestion, (mrem/yr);

DFI is the ingestion dose conversion factor for the maximum exposed organ. For the child age group, the bone is the maximum exposed organ. The **DFI_{bone}** is 1.21E-5 mrem/pCi ingested and the **$DFI_{total\ body}$** is 2.42E-6 mrem/pCi ingested;[101] and

U_a is the ingestion rate for milk. For the child age group, U_a =330 L/yr (for both cow and goat milk).[102]

[97] Regulatory Guide 1.109, equation C-10
[98] Regulatory Guide 1.109, Table E-1
[99] Regulatory Guide 1.109, Table E-2
[100] Regulatory Guide 1.109, Table E-3
[101] Regulatory Guide 1.109, Table E-13
[102] Regulatory Guide 1.109, Table E-5

Concentration of ^{14}C in Meat

The concentration of ^{14}C in meat is determined as[103]:

$$Conc_{meat} = 3.1E\text{-}2 \cdot Conc_v \cdot 50 \cdot e^{-(20 \cdot 3.32E-7)}$$

Where:

$Conc_{meat}$ is the concentration of ^{14}C in meat, in pCi/kg;
3.1E-02 is the stable element transfer factor, in days/kg, for beef[104]
$Conc_V$ is the concentration of ^{14}C in leafy vegetation grown at the receptor location (pCi/kg), as described above;
50 kg/day is the amount of feed consumed by the beef animal per day;[105]
20 days is the average time from slaughter to consumption[106]: and
3.32E-7 days^{-1} is the radiological decay constant for ^{14}C.

Dose from ^{14}C in Meat

The dose from ^{14}C in meat is determined as:

$$D = DFI \cdot U_a \cdot Conc_{meat}$$

Where:
D is the annual dose to the bone or total body for the child age group from milk ingestion, (mrem/yr);
DFI is the ingestion dose conversion factor for the maximum exposed organ. For the child age group, the bone is the maximum exposed organ. The **DFI_{bone}** is 1.21E-5 mrem/pCi ingested and the **$DFI_{total\ body}$** is 2.42E-6 mrem/pCi ingested;[107] and
U_a is the ingestion rate for meat. For the child age group, U_a =41 kg/yr.[108]

Dose to the Member of the Public from Activities within the Site Boundary

The Member of the Public performing activities within the Site Boundary is described in Section 4. The ingestion dose pathways do not exist within the Site Boundary. ^{14}C is not a gamma- emitting nuclide; therefore the ground plane pathway is negligible.

The inhalation dose to the farmer, D, is calculated according to the expression[109]:

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[103] Regulatory Guide 1.109, equation C-12
[104] Regulatory Guide 1.109, Table E-1
[105] Regulatory Guide 1.109, Table E-3
[106] Regulatory Guide 1.109, Table E-15
[107] Regulatory Guide 1.109, Table E-13
[108] Regulatory Guide 1.109, Table E-5
[109] Regulatory Guide 1.109, equations C-3 and C-4

$$D_j = 3.17E4 \cdot R_a \cdot DFA_j \cdot Q_i \cdot X/Q \cdot 1.26E\text{-}1$$

Where:

D is the dose in mrem, to a member of the public from ^{14}C, from the inhalation pathway, received by organ j;

3.17 E4 is the number of pCi/Ci divided by the number of sec/yr;

R_a is the breathing rate for the adult age group (8000 m^3/yr);[110]

DFA_j is the ^{14}C inhalation pathway dose factor for organ *j*, appropriate to the adult age group (mrem/pCi). For ^{14}C, the limiting organ is the bone. The DFA_{bone} for the adult age group is 2.27E-6 mrem/pCi, and the $DFA_{total\ body}$ and $DFA_{thyroid}$ is 4.26E-7 mrem/pCi.[111]

Q_i is the quantity of ^{14}C produced during the year (Ci/yr)

X/Q is the highest calculated annual average concentration for activities within the Site Boundary, 2.6E-7 sec/m^3.

1.26E-1 is the fraction of the year the farmer performs activities within the Site Boundary (1100 hrs/8760 hrs), dimensionless

The inhalation dose to the bone for the adult age group from activities within the Site Boundary is:

$$D_{bone} = 1.89E\text{-}5 \cdot Q_i$$

The inhalation dose to the total body for the adult age group from activities within the Site Boundary is:

$$D_{total\ body} = 3.54E-6 \cdot Q_i$$

The inhalation dose to the thyroid for the adult age group from activities within the Site Boundary is:

$$D_{thyroid} = 3.54E-6 \cdot Q_i$$

110 Regulatory Guide 1.109, Table E-5
111 Regulatory Guide 1.109, Table E-7

Comparison of EPRI Site Specific Methodology with Regulatory Guide 1.21

Regulatory Guide 1.21 states that the following methods are acceptable for estimating the production of ^{14}C:[112]

- Sampling and analysis of effluent streams
- Use of normalized ^{14}C source term and scaling factors based on power generation, e.g., NCRP Report 81[113]
- Use of the PWR GALE code[114]

Callaway Plant effluents have not been sampled for ^{14}C. NCRP Report 81, Table 3.3 states that the total ^{14}C production rate for a PWR without reactor coolant nitrogen is 6 Ci/GW_e-yr. Assuming a conversion of 0.34 GW_e/GW_{th}, the expected ^{14}C production rate is 2 Ci/GW_{th}-yr or 7.2 Ci/EFPY for Callaway. The PWR GALE code does not calculate the quantity of ^{14}C produced, but instead assigns a value of 7.3 Ci/yr for every PWR without regard for power level, reactor coolant nitrogen concentration, or waste gas system design and operation. Using the EPRI methodology and the neutron flux distribution for Cycle 18, the ^{14}C production for Callaway is 13.2 Ci/EFPY.[115] The ^{14}C production calculated using the EPRI methodology is therefore conservative with respect to the ^{14}C production calculated using NCRP Report 81 and the PWR GALE code.

EPRI Proxy PWR Methodology

The average ^{14}C production rate for Westinghouse PWRs is 3.4 Ci/ GW_{th}- yr[116]. Callaway is rated at 3.565 GW_{th} (3565 MW_{th}), therefore, the ^{14}C production rate based on the proxy PWR is 12.1 Ci/ EFPY. The ^{14}C production calculated using the EPRI proxy methodology is therefore conservative with respect to the ^{14}C production calculated using NCRP Report 81 and the PWR GALE code.

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[112] Regulatory Guide 1.21, Section 1.9
[113] NCRP Report 81
[114] NUREG-0017
[115] HPCI 11-02
[116] EPRI TR-1021106, Section 4.8 and Appendix D

Appendix B: Record of Revisions[117]

Rev. No. 0 Date: March 1983

Rev. No. 1 Date: November, 1983

Revised to support the current RETS submittal and to incorporate NRC Staff comments.

Rev. No. 2 Date: March, 1984

Revised to incorporate NRC Staff comments

Rev. No. 3 Date: June, 1985

Revised to incorporate errata identified by ULNRC00803 and changes to the Environmental Monitoring Program. Incorporate results of 1984 Land Use Census.

Rev. No. 4 Date: February, 1987

Minor clarifications, incorporated 31-day projected dose methodology. Change in the utilization of areas within the Site Boundary.

Rev. No. 5 Date: January, 1988

Minor clarifications, revised descriptions of liquid and gaseous rad monitors, revised liquid setpoint methodology to incorporate monitor background, revised dose calculations for 40CFR190 requirements, Revised Table 6 and Figures 5.1A and 5.1B to refine descriptions of environmental TLD stations, incorporated description of environmental TLD testing required by Reg. Guide 4.13, revised Tables 1, 2, 4 and 5 to add additional nuclides, deleted redundant material from Chapter 6.

Rev. No. 6 Date: May, 1989

Revised methodology for calculating maximum permissible liquid effluent discharge rates and liquid effluent discharge rates and liquid effluent monitor setpoints, provided methodology for calculating liquid effluent monitors response correction factors, provided an enhanced description of controls on liquid monitor background limits, provided additional liquid and gaseous dose conversion factors and bioaccumulation factors (Tables 1, 2, 4 & 5), provided description of the use of the setpoint required by Technical Specification 4.9.4.2 during Core Alterations, added discussion of gaseous and liquid monitor setpoint selection in the event that the sample contains no detectable activity, added minimum holdup requirements for Waste Gas Decay tanks, revised dispersion parameters and accompanying description per FSAR Change Notice 88-42.

APA-ZZ-01003

Rev. No. 0 Date: August, 1989

Radiological Effluent Technical Specifications were moved from the Callaway Plant Technical Specifications to Section 9.0, Radioactive Effluent Controls, of the ODCM per NRC Generic Letter 89-01. At the same time, in order to formalize control of the entire ODCM, it was converted to APA-ZZ-01003, Offsite Dose Calculation Manual.

Rev. No. 1 Date: October, 1990

Revise Action 41 of Table 9.2-A to allow continued purging for 24 hours per Amendment 20 to operating license, issued 4/10/87.

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[117] Section numbers, table numbers, etc. refer to the numbering schema used in the particular revision.

Rev. No. 2 Date: May, 1991

Section 2.4.2: Changed gross alpha analysis frequency from "each batch" to a monthly composite per Table 9.3-A, and the Callaway Plant NPDES permit (reissued March 15, 1991).

Rev. No. 3 Date: June, 1993

Deleted HF-RE-45 and LE-RE-59 as effluent monitors. Revised table numbering for consistency with those in Section 9.0, deleted redundant material, incorporated 1992 Land Use Census results, moved LLD description to Attachment 1, moved REC Bases to Attachment 2. Deleted reporting requirements for solid radwaste, which are described in APA-ZZ-01011, Process Control Program. Addressed compliance with 10 CFR 20.1301. Revised the dilution flow rate to allow values other than 5000 gpm, based on dilution flow monitor setpoint. Revised "MPC" terminology to "ECV". Added Action 46 to REC 9.2 to clarify actions for inoperable mid and high range WRGM Channels. Revised references to be consistent with the revised 10 CFR 20. Added Appendix A. Revised Action 41 of Rec 9.2 and the operability requirements of GT-RE-22/33. Incorporated the revised R_i values in Tables 3.2 and 3.3. Added Section 6.2 and Table 6.5.

Rev. No. 4 Date: September, 1994

Increased the minimum channels OPERABLE requirement of REC 9.2 for GT-RE-22 & 33 from 1 channel to 2 channels. Revised Action 41 and the Bases for REC 9.2 accordingly. Incorporated the operability requirements from Tech Spec 3.9.9 into the Action statement for clarity. (Refer to CARS 199401176).

Rev. No. 5 Date: February, 1995

Removed the REMP station locations. Removed particulate nuclides with a half-life of less than 8 days from Tables 3.2-3.4 and removed ^{14}C, ^{32}P, ^{63}Ni, and ^{125m}Te from Tables 2.1, 2.2, 3.2, 3.3, and 3.4. Changed the reporting frequency of the Effluent Release Report from semiannual to annual. Removed the meat, milk and vegetable pathway dispersion parameters from Tables 6.1, 6.2, and 6.3, and clarified the applicability of the dispersion parameters and dose locations in Table 6.4. Relocated REC 9.1 and 9.2 to the FSAR. Revised footnotes 3 and 7 of Table 16.11-4 to require additional sampling of the Unit Vent in the event of a reactor power transient, only if the Unit Vent noble gas activity increases by a factor of 3 or greater. Added Section 4.1.3.1.3 for determination of dose due to the on-site storage of low level radioactive waste.

Rev. No. 6 Date September, 1996

Section 2: Added dose factors ($A_{i\tau}$)for ^{110m}Ag, ^{237}Np, ^{238}Pu, $^{239/240}Pu$, ^{241}Pu, ^{241}Am, ^{242}Cm, and $^{234/244}Cm$ to Table 2.1, and Bioaccumulation Factors (Bf_i) for Ag, Pu, Am, and Cm to Table 2.2 due to a change in the liquid radwaste treatment process. Revised the description of the methodology for performing the 31 day dose projection in Section 2.5. Revised the maximum allowable background for HB-RE-18. Section 3: Eliminated ^{91m}Y and ^{99m}Tc from Table 3.4 (Meat Pathway) due to a half-life of < 8 days. Substituted the phrase “more restrictive” in lieu of “lesser” in Section 3.2. Revised the definition of F_a in equation 3.1. Added description of use of samples to verify dose rates in Section 3.3.1.2. Augmented the definition of q_i in Section 3.3.2.1. Edited equations 3.13 and 3.14 and added equation 3.15 to clarify dose calculations. Revised the methodology for performing the 31 day dose projection in Section 3.4. Section 4: Strengthened the discussion of the reevaluation of assumptions in Section 4.1.3. Section 6: Added new Table 6.6 to describe the selection and use of dispersion parameters during the preparation of the Effluent Release Report. Updated Tables 6.1 and 6.2 to reference the 1995 Land Use Census. There were no changes in the receptor locations. Section 8: Replaced the reference to HDP-ZZ-04500 to a more generic reference to the plant operating procedures, due to change in organizational structure and responsibilities. Section 9: (1) Eliminated 9.0.1 and 9.0.2 due to redundancy with Technical Specifications 3.0.1 and 3.0.2;
(2) Revised Table 9.3-A to incorporate sampling and analysis requirements for TRU nuclides in liquid effluents;
(3) Eliminated sampling of Fuel Building Exhaust from Table 16.11-4 and the associated footnotes due to

redundancy with Unit Vent sampling; revised the continuous sampling requirements for the gaseous batch release points consistent with plant design; revised the ^{3}H analysis frequency for Purges from weekly to "prior to each purge"; and, (4) Revised the air sampling station location criteria on Table 9.11-A and footnote # 1, and eliminated footnote #3 in order to be less generic and more descriptive of the parameters used in determining the station locations (See CARS 199502280).Revised the location requirements for milk and vegetables. Revised description of use of baseline samples to trigger gamma isotopic analysis in footnote #4, revised requirement for location of downstream sample station in footnote #6. Revised Surveillance Requirement 9.10.2.1 to eliminate liquid effluents from the surveillance. (5) Revised REC 9.5 and REC 9.9 to eliminate exceptions for partially tested effluents being released in excess of the respective limit. Section 11: Added reference 11.14.13.Attachment 2: Revised the Bases for REC 9.10 to support the elimination of liquid effluents from Surveillance 9.10.2.1.The remaining changes are editorial in nature and have no technical impact.(This revision implements CARS 199502055, CARS 199600167, CARS 199600961, CARS 199502280, and CARS 199600986).

Rev. No. 7 Date February, 1997

Section 9: (1) REC 9.5, "Liquid Radwaste Treatment System", Action statement: Eliminated reference to COMN 1161. (2) Table 9.11-A, items 4a (milk) and 4c (vegetation): revised to required control stations in the least prevalent wind direction. (See CARS 199700166) Appendix A: revised the discussion relative to the appropriate gross alpha Effluent Concentration Value.

Rev. No. 8 Date May, 1997

Section 1: The Purpose and Scope was revised to describe the split of the ODCM into two sections Per FSAR Change Notice 95-058. Section 2: Sections 2.2 and 2.3 were revised to clarify the use of nuclide- specific alpha activity vice gross alpha activity for setpoint determination. Section 2.5 was revised to delete the description of the Liquid Radwaste Treatment System. Section 6: Tables 6.1, 6.2, and 6.3 were revised to reflect the results of the 1996 Annual Land Use Census. Section 7: The reporting requirements for the Annual Radiological Environmental Operating Report and the Effluent Release Report were relocated to the FSAR Per FSAR Change Notice 95-058. Section 9: REC's and the supporting Attachments 1 and 2 were relocated to the FSAR Per FSAR Change Notice 95-058. Appendix A: Appendix A was deleted. Editorial changes were made throughout the ODCM reflecting the relocation of the REC's to the FSAR.

Rev. No. 9 Date March, 1998

Section 2.5: Revised projected liquid dose calculation to use previous 31 day cumulative doses.
Section 3.1.1: Added GL-RE-202, Laundry Decon Facility Dryer Exhaust Monitor. Added action to be taken when the particulate and/or iodine grab sampler is not operable. Section 3.2: Added setpoint calculation for GL-RE-202.
Section 3.2.1 and 3.3.2.2: Changes were made to correct typographical errors and have no technical impact.
Section 3.4: Revised projected gas dose calculation to use previous 31 day cumulative doses. Section 3.5: Removed the word secular from "secular equilibrium" since the equilibrium mode could be secular or transient depending on the isotope. Table 6.2: Added Laundry Decon Facility Dryer Exhaust to title of table since these will be the dispersion factors used for this release point.

Rev. No. 10 Date December 20, 1999

Section 3.1: Added explanation that GL-RE-202 only monitors particulate. Section 3.2: Changed Laundry Decon Facility Exhaust Monitor setpoint to less than or equal to 2000 cpm above equilibrium background with a maximum allowed background of 2000 cpm as calculated in HPCI 99-05. Tables 6.1, 6.2, 6.3: Updated values as calculated in HPCI 99-02. Section 5.1: Defined how REMP sample locations were determined. Removed reference to Plant Operating manual since it no longer exists.

Rev. No. 11 Date December 22, 1999

Changes required to go from old Technical Specifications to Improved Technical Specifications (ITS). Technical Specification 4.9.4.2 changed to FSAR 16.11.2.4.1. Technical Specification 6.8.4.F changed to FSAR 16.11.4. Technical Specification 6.8.1.F changed to Improved Technical Specification 5.4.1. Technical Specification 6.14 changed to Improved Technical Specification 5.5.1. Technical Specification 6.8.4.E changed to Improved Technical Specification 5.5.4. Technical Specification 6.9.1.6 changed to Improved Technical Specification 5.6.2. Technical Specification 6.9.1.7 changed to Improved Technical Specification 5.6.3. Changed name of Annual Radiological Effluent Release Report to Effluent Release Report as stated in ITS. Added liquid releases are limited to 10 times the Appendix B, Table 2, Column 2 limits Per FSAR CN 98-041 supporting implementation of ITS.

Rev. No. 12 Date December 01, 2000

Section 2.1 and 2.2.1: Updated 10CFR20, Appendix B, Table II, Column 2 reference to the new 10CFR20 format. Corrected typo for "f", flow setpoint should be undiluted waste flow rate. Section 3.2.1: Corrected typo, default value for safety factor should be 0.1. Section 5.1: Updated crosscheck program used to EML since EPA program is no longer available. Section 6.2: Added vertical height of highest adjacent building used to perform concurrent year annual average atmospheric dispersion (X/Q) calculations and reference for this value. This information should be documented in the ODCM. Added responsibility for validation of meteorological data, since responsibility has changed from engineering to HPTS. Section 10.1.1: Revised to require a summary of Major Radwaste System changes to be included in the annual report. This was done to be consistent with FSAR 16.11.5.2.Several changes were made throughout the procedure to correct typographical errors and have no technical impact.

Rev. No. 13 Date September 19, 2002

Section 3.2: Revised to implement the approved OL 1218, Rev. 1; License Amendment no. 152 allowing equipment hatch and emergency air lock to remain open during refueling activities (FSAR CN-01-030 and CN-02-049). The amendment eliminated FSAR 16.11.2.4.1B and subsequently deleted the core alteration setpoint value 5.0 E-3 μCi/cc for Containment Purge Monitors GT-RE-22 and GT-RE-33. The alarm setpoints for the Containment Purge Monitors will be based on the methodology described in Section 3 of the ODCM.

Rev. No. 14 Date June 17, 2003

Revised Table 2.1 (Ingestion Dose Commitment Factor for Adult Age Group) to include dose factors for Pr-144. (CARS 200303251).Revised Section 4.1.3.1 to adjust the Farmer's residence (critical receptor) from 3830 meters in the SE sector to 2897 meters in the NNW sector. The Farmer's residence (critical receptor) was changed in 2002 to a location directly across the street from the Nearest residence. For conservatism and ease in calculation, Table 6.1 and 6.2 were revised making the distances and dispersion parameters for the Farmer's residence (critical receptor) and the Nearest residence the same. Revised section 7.2 to reference Table 6.6. Revised section 10.2.2 to remove the requirement for QA department review of the ODCM for reach revision (CARS 200304509). Added a reference to 11.14.14, Calculation HPCI 03-004 (Rev. 0), "Calculation of Liquid Effluent Dose Commitment factor for Pr-144 (A_{iT}) for the Adult Age Group", June, 2003.

Rev. No. 15 Date December 9, 2004

Reformatted references to FSAR-SP Chapter 16.11 in section 1, 2.1.1, 2.1.2, 2.2.1, 2.3, 2.4.2, 2.5, 2.6, 3.1, 3.2.1, 3.5, 5.1, 7.1, 7.2, and 9. References to ^{63}Ni were added to section 2.2.1 for the calculation of ECVSUM, section 2.3, and described in section 2.6 since it is an exception to non- gamma emitters not listed in FSAR-SP Table 16.11-1. ^{63}Ni was added to the ODCM based on previous 10 CFR 61 sample results and 2nd quarter liquid composite analyses. Consolidated references listed in section 2.4.2 and 2.6 for the site related ingestion dose commitment factors (A_{iT} of Table 2.1 into HPCI 04-06, Revision 1. References to HPCIs 95-004 (Ref: 11.14.13) and 03-004 (Ref: 11.14.14) were deleted and replaced with HPCI 04-06, Revision 1 which is now listed as Ref: 11.14.13. Added ^{63}Ni and ^{122}Sb to Table 2.1- INGESTION DOSE COMMITMENT FACTOR (A_{iT}) FOR ADULT AGE GROUP. Revised the reference for Table 2.1 to 11.14.13. Corrected a typo in section 3.1.2 referring to the Radwaste Building Vent

system designator as GT vs. GH (CAR 200406851). References 11.19 and 11.20 were deleted in section 4.1.3.1.1. Reference 11.18 was changed to MICROSHIELD (Grove Engineering, Inc.) vs. ISOSHLD. Reference 11.24 in section 4.1.3.1.3 was corrected to 11.18. Section 5.1 and 5.2 were revised to indicate that the Radiological Environmental Monitoring Program TLDs will be processed and provided by a vendor laboratory beginning in the first quarter of 2005. Section 5.2 was revised to delete reference 11.14.10 which refers to HPCI 88-08, "Performance Testing of the Environment TLD System at Callaway Plant", August 1989. Reference 11.14.7 was corrected with HPCI 87-10 vs. 88-10. Revised Table 6.1, Note (c) to reference FSAR Table 2.3-83 vs. Table 2.3-82. Revised Table 6.1 and 6.2 Note (b) to reference data is from the 2002 Land Use Census. Changed and/or corrected the Skin dose factor (L_i) units in Table 3.1 (Dose Factor for exposure to a Semi-Infinite Cloud of Noble Gases) to mrem/yr per uCi/m^3. Revised section 3.3.1.2: Added units for the term BR in m^3/yr. Removed paragraph in section 3.3.2.2 that describes actions for implementing the use of appropriate $R_{I,i,j}$ values. This paragraph was taken directly from section 5.3.1 of NUREG 0133, U.S. Nuclear Regulatory Commission, "Preparation of Radiological Effluent Technical Specification for Nuclear Power Plants", USNRC NUREG-0133, Washington, D.C. 20555, October, 1978. This paragraph does not apply since the use of pathways is already considered as described in sections 4.1.2 and 4.1.3.1. Revised note (c) of Table 6.1 to reference FSAR-SA Table 2.3-83. Revised note (a) from Table 6.1 to reference FSAR-SA Table 2.3-82. In addition, revised Note (b) from Table 6.1 to reference data taken from the 2002 Land Use Census. Revised Notes (a) and (c) from Table 6.2 to reference FSAR-SA Table 2.3-84 and 2.3-81 respectively. Added a 0.95 conservatism factor to section 2.2.3 *Calculation of Liquid Effluent Monitor Setpoint*. This will conservatively reduce the liquid monitor setpoint to further ensure the section 4.4.1 of NUREG 0133, U.S. Nuclear Regulatory Commission, "Preparation of Radiological Effluent Technical Specification for Nuclear Power Plants", USNRC NUREG-0133, Washington, D.C. 20555, October, 1978 which states the alarm and trip setpoints for each instrument channel listed in Table 3.3-11 should be provided and should correspond to a value(s) which represents a safe margin of assurance that the instantaneous liquid release limit of 10 CFR Part 20 is not exceeded. A determination was made IAW T/S 5.5.1 that the associated changes with Revision 15 maintain the levels of radioactive effluent control required by 10 CFR 20.1302, 40 CFR 190, 10 CFR 50.36a, and 10 CFR 50 Appendix I, and not adversely impact the accuracy or reliability of effluent, dose, or setpoint calculations.

Rev. No. 16 Date December 1, 2005

Section 5.1 was revised to remove an invalid requirement that a third-party laboratory performing analysis specifically state the Interlaboratory Comparison (crosscheck) requirements for the Radiological Environmental Monitoring Program (REMP) contract lab. Reference 11.14.14 to Reg. Guide 4.15, Quality Assurance for Radiological Monitoring Programs (Normal Operations)- Effluent Streams and the Environment, was added to provide supporting documentation for contract lab Interlaboratory Comparison requirements. Additional information on REMP contract lab participation in Interlaboratory Comparisons was also added in section 5.1. (CAR 200500891) Revised reference 11.14.7 by adding normalization and standardization factors for radionuclides listed in Table 2.1 of the ODCM that were not included in the original calculation. Added section 4.1.3.1.4 to describe direct dose to a Member of the Public from the Old Steam Generator Storage Facility (OSGSF). Reworded step 4.1.2 to describe the sources of direct radiation from "outside storage tanks" to "storage of radioactive material". Revised section 4.1.3.1.2 to include and describe direct dose calculations in support of Modification 03-1008, Equipment Hatch Platform and Missile Shield Modification. Reference 11.14.10 was added to reference direct dose calculation to the Member of the Public from Modification 03-1008. Revised section 4.1.3.1.3 to include and describe direct dose calculations from the Radwaste Yard RAM storage and Stores II. Reference 11.19 and 11.20 were added to reference direct dose calculations to the Member of the Public from RAM storage at Stores II and the Radwaste Yard. A determination was made IAW T/S 5.5.1 that the associated changes with Revision 16 maintain the levels of radioactive effluent control required by 10 CFR 20.1302, 40 CFR 190, 10 CFR 50.36a, and 10 CFR 50 Appendix I, and not adversely impact the accuracy or reliability of effluent, dose, or setpoint calculations.

Rev. No. 17 Date March 14, 2007

Section 2.4.1 was revised Per CAR 200701309 to state that no potable water intakes exist within 10 miles of the plant discharge point. This is due to the fact that the Annual Land Use Census ensures no newly developed potable water intakes within 10 miles of the plant discharge Per FSAR-SP Chapter 16.11.4.2c. Section 2.4.2 was revised to add reference 11.6.18 to CAR 200700053 which provides documentation of an evaluation of the site specific mixing factor for liquid effluents. Modification 06-0061 reconfigured the plant discharge terminus at the Missouri River. The modification was completed in January 2007.

Rev. No. 18 Date October 11, 2007

Revised Table 6.5 was revised to reflect upgrade/replacement of the primary meteorological tower instrumentation as per Modification Package 04-1020. Section 2.4.2 was revised to remove the discussion of the nearest municipal potable water intake downstream from the liquid effluent discharge point as being located near the city of St. Louis, Missouri, approximately 78 miles downstream. Since the Land Use Census annually verifies no potable water intakes within 10 miles – this discussion was deemed inappropriate in describing methodology for calculating dose to the public from liquid effluents. In addition, the distance referenced as not having potable water intakes downstream of the plant discharge was changed for consistency with section 2.4.1 and the Land Use Census.

Rev. No. 19 Date August, 2012

Converted to Word 2010, including appropriate formatting changes and cross- referencing for the conversion. Deleted all references to the obsolete Commitment Tracking System (COMN) and all hidden text for the obsolete hidden text referencing system. Added level of use. (CAR 201104163, Action 1) Section 3.4- Added dose reduction controls for discharge of ^{14}C from the waste gas system and defined the growing season. Section 3.5- Deleted statement that non- gamma emitting nuclides not listed in the FSAR-SP Table 16.11.4 are not considered in dose calculations. Eliminated Sections 4.1.3.1.1, 4.1.3.1.2, 4.1.3.1.3, and 4.1.3.1.4- direct radiation dose is negligible; refer to HPCI 12-06. Section 5.2- changed to allow use of dosimeters other than TLDs. Section 6.1- Deleted discussion of short- term X/Q processing and the slope factor and deleted the associated table of 'S' factors. Section 6.2- Deleted designation of responsibilities for met data review. (CAR 201104163, Action 1) Section 10.2- changed to align with T/S 5.5.1. CAR 201104163, Action 2) Corrected the department title to align with organizational structure. (CAR 201104163, Action 1). Table 10 and Table 11- The dispersion parameters for the Farmer's residence were removed. As a first approximation, the dispersion parameters for the Nearest Residence will be used for the Farmer's residence. Appendix A- Appendix A was added to describe the calculation of the production of ^{14}C and the calculation of dose from ^{14}C in gaseous effluents. (CAR 201104163) ^{63}Ni was added to the gaseous effluent inhalation pathway and ingestion pathways dose factor tables. Values for ^{63}Ni are from APA-ZZ-01003, rev. 4. (CAR 201104197). Adult ingestion dose factors removed. Ingestion dose pathway removed from Table 13 for activities inside the Site Boundary.