Braidwood Calculation No. BRW-97-0798-M

Allowable Leakrate Calculation for Steam Generator Interim Plugging Criteria

Revision 1

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PREPARATION, REVIEW AND APPROVAL OF CALCULATIONS

CALCULATION TITLE PAGE

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BRAIDWOOD STATION UNITS 1&2

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PURPOSE AND OBJECTIVE:

The purpose of this calculation is to generate the maximum allowable primary to secondary steam generator tube leak rate during a postulated main steam line break using 24% plugging criteria design data. The evaluation was performed for both a pre-accident and accident initiated iodine spike. The release of iodine and the resulting thyroid dose at the Exclusion Area Boundary and Low Population Zone were considered in the leak rate determination. Whole body dose due to noble gas immersion is less limiting than thyroid dose as documented in UFSAR Table 15.0-11. Given the large margin to the 25 rem whole body dose limit, whole body dose was not re-evaluated.

METHODOLOGY AND ACCEPTANCE CRITERIA:

The Main Steam Line Break (MSLB) accident is considered the most limiting off-site dose accident because the event causes a sustained large pressure difference across the steam generator tubes providing a motive force for steam release. The Technical Specification limit for steam generator (SG) tube leakage is 150 gpd (0.1 gpm) for each SG. The dose attributed to a 1 gpm leak rate from the reactor coolant system was calculated. This value was then used to determine the allowable leak rate without exceeding the Standard Review Plan dose criteria.

The activity released to the environment due to a MSLB is analyzed in two distinct releases:

1. The release of the iodine activity that has been established in the secondary coolant prior to the accident, and

2. The release of the primary coolant iodine activity due to tube leakage.

The methodology used for calculating the Radiological Consequences of a MSLB with primary to secondary leakage is consistent with the Standard Review Plan (NUREG 0800), 15.1.5 Appendix A.

TID-14844 dose conversion factors were used to determine dose equivalent iodine concentrations, which is consistent with the Technical Specification definition of dose equivalent iodine. The TID values are based on ICRP 2, "Permissible Dose for Internal Radiation, 1959."

The off-site dose assessment uses ICRP 30, "Limits for Intakes of Radionuclides by Workers, 1979" dose conversion factors. ICRP 30 is also the basis for Federal Guidance Report No. 11, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," dated 1988. This report provides the dose conversion factors for the Station's Off-site Dose Calculation Manual for inhalation dose at the site boundary due to airborne effluents.

The dose Acceptance Criteria are based on the guidance of Standard Review Plan (NUREG-0800) Section 15.1.5, Appendix A. For a MSLB with a postulated pre-accident iodine spike, the calculated doses should not exceed the guideline values of 10CFR Part 100 Section 11. The numerical values used for these doses are 25 rem to the whole body and 300 rem to the thyroid from iodine exposure for 2 hours following the accident. For a MSLB with an accident initiated iodine spike, the calculated doses should not exceed a small fraction of the 10 CFR 100 guideline values, i.e. 2.5 rem and 30 rem respectively for the whole body and thyroid doses.

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ASSUMPTIONS:

1) The effect of boron on the RCS density is assumed to be negligible since the boron mass is less than 1% of the total RCS mass at the beginning of core life.

DESIGN INPUTS:

The following design inputs were transmitted in Reference 5.

1. The total volume of the RCS is 12,062 ft^3. (Reference 1)
2. The full power RCS temperature and pressure are 586.2 °F and 2250 psia. (Ref 1 and 2)
3. The RCS specific volume at full power is 0.02258 ft^3/lbm. (Ref. 3)
4. The iodine decay constant for I131 is 9.96E-7 sec^{-1} (Ref. 4)
5. The Purification System temperature and pressure are 130 °F and 2300 psia (Ref 1).
6. T..e Purification System specific volume is 0.01614 ft^3/lbm. (Ref. 3)
7. Breathing rate is 3.47E-4 m^3/sec. (Ref. 6)
8. Atmospheric Dilution Factors, X/Q, are taken from UFSAR Table 15.0-14. (Ref.7)
9. RCS iodine concentrations are based on UFSAR Table 11.1-2 without the 1% failed fuel contribution. (Ref. 8)
10. The initial steam release from the defective and intact steam generators are taken from UFSAR Table 15.1-3. (Ref. 9)
11. The secondary side faulted steam generator has a partition fraction of 1.0 and the intact steam generators have partition fraction of 0.1. (Reference 15)
12. The half life for I 131 is 8.04 days, I132 is 2.30 hrs, I 133 is 20.8 hrs, I 134 is 52.6 min, and I 135 is 6.61 hrs. (Ref.21)
13. The initial primary coolant activity dose equivalent iodine concentration is 60 μCi/g. (Ref. 14)
14. The initial secondary coolant activity is 0.1 μCi/g. (Ref. 14)
15. The duration of the spike is 2 hours. (Ref. 12)
16. No fuel failure attributable to the accident is assumed. (Ref. 12)
17. Iodine partition coefficients for all SGs are 1.0 for primary-to-secondary leakage. (Ref. 15)
18. Normal letdown purification flow is 75 gpm. (Ref 11)

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19. Letdown temperature is 130°F and 2300 psia. (Ref 11)

20. Specific volume of letdown is 0.01614 ft^3/lbm. (Ref 3)

21. Decon Factor, DF, for mixed bed demineralizer is 10. (Ref 13)

22. The iodine release rate spike factor is 500. (Ref 12)

REFERENCES:

1) B/B UFSAR Table 11.1-1, Revision 0

2) B/B UFSAR Table 5.1-1, Revision 0

3) ASME Steam Table, Fifth Edition

4) The Health Physics and Radiological Health Handbook, Revised Edition, Revised

5) BRW-DIT-97-278, Inputs into Offsite Dose Calculation to Support Unit 1 Reduced RCS DE I-131 Activity Limit

6) B/B UFSAR Table 15A-1, Revision 0

7) B/B UFSAR Table 15.0-14, Revision 0

8) B/B UFSAR Table 11.1-2, Revision 0

9) B/B UFSAR Table 15.1-3, Revision 6

10) Introductory Nuclear Physics by Kenneth S. Krane, 1988

11) B/B UFSAR Table 9.3-2, Revision 0

12) Standard Review Plan (NUREG 0800), 15.1.5 Appendix A

13) B/B UFSAR page 9.3-43, Revision 0

14) Technical Specifications 3.4.8 (Amendment 77), 3.7.1.4 (Original), 3.4.6.2 (Amendment 67)

15) WCAP 14046, "Braidwood 1 Technical Support for Cycle 5 Steam Generator Interim Plugging Criteria," dated May, 1994.

16) ICRP Publication 2, Report of Committee II on Permissible Dose for Internal Radiation, 1959

17) ICRP Publication 30, Limits for Intakes of Radionuclides by Workers, 1979

18) Adams and Atwood Report, "The Iodine Spike Release Rate During a Steam Generator Tube Rupture," October 16, 1990

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19) Westinghouse Letter CAE 97-171, dated July 21,1997, pertaining to the Reactor Coolant Water Density Used in Determining Byron and Braidwood Alternate Tube Plugging Limit.

20) Federal Guidance Report No.11, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors For Inhalation, Submersion, and Ingestion, 1988

21) NUREG/CR-1413, "A Radionuclide Decay Data Base – Index and Summary Table," 1980

VARIABLE AND CONSTANT DEFINITIONS:

M	RCS mass [lbm]
M_{stm}	Steam Generator steam release mass [lb]
V	RCS volume [ft^3]
v	RCS specific volume [ft^3/lbm]
λ_{lr}	RCS leak rate constant [sec^{-1}]
λ_{fuel}	Fuel Release constant [Ci/sec]
λ_d	Isotope Decay Constant [sec^{-1}]
λ_{LD}	Letdown Purification Removal Constant [sec^{-1}]
λ_t	Total Iodine Removal Rate [sec^{-1}]
t	Time [sec]
A_i	RCS Iodine activity [Ci]
C_i	Iodine Concentration [Ci/g or μCi/g]
C_o	Initial Iodine Concentration [Ci/g or μCi/g]
F_p	Letdown Purification Flow [g/sec]
Q_i	Activity Released of nuclide, i [Ci]
R_i	Activity Released of nuclide, i [Ci]
D	Thyroid Inhalation Dose [rem]
B	Breathing Rate [m^3/sec]
X/Q	Atmospheric Dilution Factor [sec/m^3]

DEFINE UNITS:

Ci = 1 Curie
μCi = 1E-6 Ci
1 lbm = 454 g
1 ft^3 = 7.48 gal
1 min = 60 sec

1. CALCULATION OF DOSE DUE TO STEADY STATE ACTIVITY IN SECONDARY SIDE

The first dose component to be calculated will be the dose from the secondary side. The secondary side activity is conservatively taken as the Technical Specification limit of 0.1 μCi/g (Reference 14). This value is the same for both the pre-accident and accident initiated events. The steam release for the faulted steam generator (SG) is 96,000 lbs (Reference 9) which is the entire initial SG water mass. The faulted SG is assumed to steam dry in 10-15 minutes so all of the iodine is available for release. The combined 0-2 hr steam release for the three intact steam generators is 406,716 lbs (Reference 9). The

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combined 2-8 hr steam release for the three intact SGs is 939,604 lbs (Reference 9). For the three intact SGs a partition factor of 0.1 is used (Design Input 11).

a. The iodine concentrations are obtained from UFSAR Table 15.0-9 and are converted to Ci/lb, since the steam release is defined in lbs.

$$C_i\left[\frac{Ci}{lb}\right] = C_o\left[\frac{\mu Ci}{g}\right] \times 454\left[\frac{g}{lb}\right] \times 1E-6\left[\frac{Ci}{\mu Ci}\right] \quad \text{Equation 1.a}$$

TABLE 1.a

Nuclide	Iodine Concentration, C_o (UFSAR Table 15.0-9) [μCi/g]	Iodine Concentration, C_i (Equation 1.a) [Ci/lb]
I-131	0.066	3.00E-5
I-132	0.024	1.09E-5
I-133	0.106	4.81E-5
I-134	0.016	7.26E-6
I-135	0.058	2.63E-5

b. The iodine concentration for each nuclide, C_i from Table 1.a, is multiplied by the mass of steam released (96,000 lbs for the faulted SG and 406,716 lbs for the three intact SGs) to obtain the total amount of curies available to be released, A_i, for 0-2 hours. The activity available for release in the intact SGs is then multiplied by the partition factor, 0.1, to determine the amount of activity actually released.

$$A_i^{faulted}[Ci] = C_i\left[\frac{Ci}{lb}\right] \times M_{stm}^{faulted}[lb] \times 1.0 \quad \text{Equation 1.b.1}$$

$$A_i^{intact}[Ci] = C_i\left[\frac{Ci}{lb}\right] \times M_{stm}^{intact}[lb] \times 0.1 \quad \text{Equation 1.b.2}$$

TABLE 1.b

Nuclide	Activity Released from Faulted SG, $A_i^{Faulted}$, (Equation 1.b.1) [Ci]	Activity Released from Intact SGs (0-2 hrs), A_i^{Intact}, (Equation 1.b.2) [Ci]
I-131	2.88E0	1.22E0
I-132	1.05E0	4.43E-1
I-133	4.62E0	1.96E0
I-134	6.97E-1	2.95E-1
I-135	2.52E0	1.07E0

c. The activity released, A_i determined above, is multiplied by the ICRP-30 Dose Conversion Factor, DCF_i, (Reference 17) for each iodine isotope and then summed separately for the faulted SG and intact SGs.

$$D_i^{Faulted}[rem] = A_i^{Faulted}[Ci] \times DCF_i\left[\frac{rem}{Ci}\right] \quad \text{Equation 1.c.1}$$

$$D_i^{Intact}[rem] = A_i^{Intact}[Ci] \times DCF_i\left[\frac{rem}{Ci}\right] \quad \text{Equation 1.c.2}$$

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TABLE 1.c

Nuclide	ICRP-30 Dose Conversion Factor, DCF_{ii} (Reference 17) [rem/Ci]	Dose from Faulted SG, $D^{Faulted}$, (Equation 1.c.1) [rem]	Dose from intact SGs, D^{Intact}, (0-2 hrs) (Equation 1.c.2) [rem]
I-131	1.08E6	3.11E6	1.32E6
I-132	6.44E3	6.76E3	2.85E3
I-133	1.80E5	8.32E5	3.53E5
I-134	1.07E3	7.46E2	3.16E2
I-135	3.13E4	7.89E4	3.35E4
	Total ($\Sigma_i D_i x DCF_i$)	4.03E6	1.71E6

The 0-2 hour exclusion area boundary total dose released from the faulted and the three intact SGs is 5.74E6 rem (4.03E6 + 1.71E6 rem). This total dose can also be defined as $\Sigma_i D_i x DCF_i$.

The total DE I-131 activity released is the total dose from Table 1.c divided by the I-131 dose conversion factor. Numerically this is 5.31 Ci (5.74E6 rem/1.08E6 rem/ci)

d. The off-site thyroid inhalation dose at the exclusion area boundary, D_{EAB}, and at the low population zone, D_{LPZ}, are calculated in accordance with UFSAR equation 15A-2.

Exclusion Area Boundary Dose (0-2 hours)

$$D_{EAB}[rem] = \left(\frac{X}{Q}\right)_{EAB} \times B \times \sum_i D_i \times DCF_i \quad Equation\ 1.d.1$$

$$= 7.7E-4\left[\frac{sec}{m^3}\right] \times 3.47E-4\left[\frac{m^3}{sec}\right] \times 5.74E6[rem]$$

$$= 1.53\,[rem]$$

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2. **CALCULATION OF DOSE DUE TO PRIMARY-TO-SECONDARY LEAKAGE DURING PRE-ACCIDENT INITIATED SPIKE**

In accordance with Reference 12, the pre-accident case occurs when the reactor is operating at the maximum value permitted by the Technical Specifications prior to the postulated MSLB. The radioactive isotopes are assumed to be evenly distributed throughout the RCS. The iodine activity changes over time due to radioactive decay and the rate at which activity leaves the RCS due to primary-to-secondary tube leakage.

a. The RCS mass inventory, M, will be calculated given the hot full power volume and specific volume.

RCS Volume:	$V = 12062\ ft^3$	(design input 1)
RCS specific volume	$v = 0.02258\ ft^3/lbm$	(design input 3)

$$M[g] = \frac{V[ft^3]}{v\left[\frac{ft^3}{lbm}\right]} \times 454\left[\frac{g}{lbm}\right] \quad \text{Equation 2.a}$$

$$= \frac{12062[ft^3]}{0.02258\left[\frac{ft^3}{lbm}\right]} \times 454\left[\frac{g}{lbm}\right]$$

$$= 2.42E8\ [g]$$

b. The RCS activity needs to be calculated for 60 μCi/g. UFSAR Table 11.1-2 is used to obtain RCS activity, which is based on 1% fuel clad defects per UFSAR Table 11.1-1. The total initial RCS activity is calculated by multiplying the initial concentration by the RCS mass. The initial DE I-131 activity is then determined by multiplying each isotope's activity by its dose conversion factor, summing the values for each nuclide and dividing the sum by the I-131 dose conversion factor to normalize the activity to I-131. This DE I-131 activity is the contribution due to 1% fuel clad defects. To determine the activity at 1 μCi/g, the fraction of each isotopes contribution to the DE I-131 is calculated and then multiplied by the RCS mass to obtain the corrected total activity in the RCS at 1 μCi/g. To obtain the total activity at 60 μCi/g, each isotope activity is multiplied by 60.

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$$A_i[Ci] = C_e\left[\frac{Ci}{g}\right] \times M[g] \quad \text{Equation 2.b.1}$$

$$D_i[rem] = A_i[Ci] \times DCF_i\left[\frac{rem}{Ci}\right] \quad \text{Equation 2.b.2}$$

$$DE\ I131[Ci] = \frac{\sum_i D_i[rem]}{DCF_{I131}\left[\frac{rem}{Ci}\right]} = \frac{1.39E9[rem]}{1.48E6\left[\frac{rem}{Ci}\right]} = 939.2\ [Ci]$$

$$\text{Isotope Fraction at } 1\frac{Ci}{g} = \frac{A_i[Ci]}{DE\ I131[Ci]} \quad \text{Equation 2.b.3}$$

$$\text{RCS Activity at } 1\frac{Ci}{g}[Ci] = \text{Equation 2.b.3} \times M[g] \times 1\left[\frac{Ci}{g}\right] \times \left[\frac{1\ Ci}{1E6\ \ Ci}\right] \quad \text{Equation 2.b.4}$$

$$\text{RCS Activity at } 60\frac{Ci}{g} = \text{Equation 2.b.4}[Ci] \times 60 \quad \text{Equation 2.b.5}$$

TABLE 2.b

Nuclide	RCS Concent., C_i (UFSAR Table 11.1-2) [Ci/g]	RCS Activity, A_i (Eq. 2.b.1) [Ci]	ICRP-2 Dose Conversion Factor DCF_i [rem/Ci] (Ref. 16)	Total Dose, D_i (Eq. 2.b.2) [rem]	Isotope Fraction at 1 μCi/g (Eq. 2.b.3)	RCS Activity at 1 μCi/g (Eq. 2.b.4)	RCS Activity at 60 μCi/g (Eq. 2.b.5)
I 131	2.5E-6	605	1.48E6	8.95E8	0.645	156.1	9.36E3
I 132	2.8E-6	678	5.35E4	3.63E7	0.722	174.8	1.05E4
I 133	4.0E-6	968	4.00E5	3.87E8	1.032	249.7	1.50E4
I 134	6.0E-7	145	2.50E4	3.63E6	0.155	37.5	2.25E3
I 135	2.2E-6	532	1.24E5	6.60E7	0.567	137.3	8.23E3
			$\sum D_i$	1.39E9			

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c. The two removal mechanisms for this accident are due to decay and leakrate to the secondary side of 1 gpm. The time dependent activity after two hours with the removal constants can be calculated using the basic decay equation methodology (Reference 10).

$$\frac{dC(t)}{dt} = -\lambda_d C(t) - \lambda_{lr} C(t)$$

$$\int_{C_o}^{C} \frac{dC(t)}{C(t)} = \int_0^t \left(-\lambda_d - \lambda_{lr}\right) dt$$

$$C(t) = C_o e^{-t\left(\lambda_d + \lambda_{lr}\right)}$$

Where : $t = 2 \text{ hours} = 7200 \text{ sec}$

$$\lambda_{lr} = \frac{1 \text{ gpm}}{\text{Volume of RCS}}$$

$$\lambda_{lr} = \frac{1\left[\frac{gal}{min}\right]}{12062\left[ft^3\right]} \times \left[\frac{1\left[ft^3\right]}{7.48\left[gal\right]}\right] \times \left[\frac{1\left[min\right]}{60\left[sec\right]}\right]$$

$$= 1.85E-7\left[sec^{-1}\right]$$

d. Since the isotope concentration is assumed to remain evenly distributed throughout the RCS volume, then the rate at which the isotope concentration leaks from the RCS, R(t), is simply the RCS leakrate times the concentration. The total activity released during a given time interval is the integration of the release rate over that interval, in this case, 2 hours.

$$R(t) = \lambda_{lr} \times C(t)$$

$$R(t) = \lambda_{lr} \times C_o e^{-t(\lambda_d + \lambda_{lr})}$$

$$\int_0^t R(t)dt = \int_0^t \lambda_{lr} C_o e^{-t(\lambda_d + \lambda_{lr})} dt$$

$$= \frac{\lambda_{lr} C_o}{-\left(\lambda_d + \lambda_{lr}\right)} \int_0^t -\left(\lambda_d + \lambda_{lr}\right) e^{-t(\lambda_d + \lambda_{lr})} dt$$

$$R = \frac{\lambda_{lr} C_o}{\left(\lambda_d + \lambda_{lr}\right)}\left(1 - e^{-t(\lambda_d + \lambda_{lr})}\right) \quad \text{Equation 2.d}$$

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TABLE 2.d

Nuclide	RCS Activity at 60 µCi/g, C_o (Table 2.b) [Ci]	Isotope Decay Constant, λ_e (Reference 4) [sec^{-1}]	Activity Released, R (Equation 2.d) [Ci]
I-131	9.38E3	9.97E-7	1.24E1
I-132	1.05E4	8.37E-5	1.05E1
I-133	1.50E4	9.25E-6	1.93E1
I-134	2.25E3	2.20E-4	1.50E0
I-135	8.23E3	2.91E-5	9.88E0

e. Calculate the thyroid inhalation dose at the Exclusion Area Boundary (EAB) using the equation from UFSAR 15A.4.

Table 2.e

Nuclide	Activity Released, R_i (Table 2.d) [Ci]	ICRP-30 Dose Conversion Factor, DCF_i (Reference 17) [rem/Ci]	Exclusion Area Boundary, R_i x DCF_i [rem]
I-131	1.24E1	1.08E6	1.34E7
I-132	1.05E1	6.44E3	6.76E4
I-133	1.93E1	1.80E5	3.47E6
I-134	1.50E0	1.07E3	1.60E3
I-135	9.88E0	3.13E4	3.09E5
		Total $(\sum R_i x DCF_i)_{EAB}$	1.72E7

The total DE I-131 activity released is the total dose from Table 2.e divided by the I-131 dose conversion factor. Numerically this is 15.9 Ci (1.72E7 rem/1.08E6 rem/ci).

<u>Exclusion Area Boundary Dose for a 1 gpm Leakrate</u>

$$D_{EAB}[rem] = \left(\frac{X}{Q}\right)_{EAB} \times B \times \sum_i (R_i \times DCF_i)_{EAB} \quad Equation\ 2.e.1$$

$$= 7.7E-4\left[\frac{sec}{m^3}\right] \times 3.47E-4\left[\frac{m^3}{sec}\right] \times 1.72E7[rem]$$

$$= 4.60\,[rem]$$

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f. Calculate the thyroid inhalation dose at the Low Population Zone (LPZ) using the equation from UFSAR 15A.4. The activity released during the accident from 2-40 hours was obtained from UFSAR Table 15.1-4. This activity includes the dose contribution from a 9.4 gpm leak in the faulted SG.

TABLE 2.f.1

Nuclide	RCS Iodine Activity, A_i (UFSAR Table 15.1-4a) [Ci]	ICRP-30, Dose Conversion Factor, DCF_i (Reference 17) [rem/Ci]	2-40 Hour Dose, $A_i \times DCF_i$, [rem]
I-131	1.9E3	1.08E6	2.05E9
I-132	3.8E1	6.44E3	2.45E5
I-133	1.8E3	1.80E5	3.24E8
I-134	3.7E0	1.07E3	3.96E3
I-135	3.8E2	3.13E4	1.19E7
		Total ($\Sigma A_i \times DCF_i$)	2.39E9

The total 2-40 hour dose calculated above in Table 2.f.1 is separated into specific time periods of 2-8 hrs, 8-24 hrs, 24-40 hrs. This is based on scaling the total 2-40 hour dose by the fraction of steam released during the same time period. The 2-40 hour steam release was obtained from UFSAR Table 15.1-3.

TABLE 2.f.2

Time Period	Steam Release, (UFSAR Table 15.1-3) [lb]	Fraction of Total Steam Release for Time Period	Total 2-40 Hr Dose (Table 2.f.1) [rem]	Fraction of Total 2-40 Hr Dose [rem]
2-8 hr	939,604	0.30	2.39E9	7.17E8
8-24 hr	1,234,515	0.39	2.39E9	9.32E8
24-40 hr	980,806	0.31	2.39E9	7.41E8
Total Steam Release	3,154,925			

The atmospheric dilution factors (X/Q) for 0-8 hrs, 8-24 hrs, and 24-40 hrs values were obtained from UFSAR Table 15.0-14. The breathing rates for 0-8 hrs, 8-24 hrs and 24-40 hrs were obtained from UFSAR Table15A-1. Calculate the thyroid inhalation dose at the Low Population Zone (LPZ) using the equation from UFSAR 15A.4.

$$D_{LPZ}\,[\text{rem}] = \left(\frac{X}{Q}\right)_{LPZ} \times B \times \sum A \times DCF \quad \text{Equation 2.f.1}$$

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TABLE 2.f.3

Time Period	Atmos. Dispersion Factor, X/Q, (UFSAR Table 15.0-13) [sec/m^3]	Breathing Rate, B, (UFSAR Table 15A-1) [m^3/sec]	Fractional Dose, ΣA×DCF, (Table 2.f.2) [rem]	Fractional LPZ Dose, D_{LPZ}, w/ 9.4 gpm Leakrate (Equation 2.f.1) [rem]
0-2 hr	7.1E-5	3.47E-4	1.62E8*	3.99
2-8 hr	7.1E-5	3.47E-4	7.17E8	17.66
8-24	1.4E-5	1.75E-4	9.23E8	2.28
24-48	7.1E-6	2.3E-4	7.41E8	1.21
			Total LPZ Dose w/ 9.4 gpm Leakrate [rem]	25.14

* From Table 2.e x 9.4

3. **CALCULATION OF DOSE DUE TO PRIMARY TO SECONDARY LEAKAGE DURING ACCIDENT INITIATED SPIKE**

The accident initiated spike model is the same as the pre-accident model except an additional iodine appearance rate term is added for fuel release rate into the RCS. In accordance with the Standard Review Plan, the reactor trip and/or primary system depressurization associated with the MSLB creates an iodine spike in the primary system. The spiking model assumes that the iodine release rate from the fuel rods to the primary coolant increases to a value 500 times greater than the Technical Specification limit. This factor adds an additional release rate factor for iodine activity, λ_{fuel}.

a. Calculate the total removal rate of iodine, λ_i, through letdown purification and radioactive decay. Equation 2 of Reference 18 defines this total as:

$$\lambda_i\left[sec^{-1}\right] = \lambda_{LD}\left[sec^{-1}\right] + \lambda_d\left[sec^{-1}\right] \quad \text{Equation 3.a.1}$$

$$\text{Where:} \quad \lambda_{LD}\left[sec^{-1}\right] = \frac{F_p\left[\frac{g}{sec}\right]}{M[g]} \times \left(1 - \frac{1}{DF}\right) \quad \text{Equation 3.a.2}$$

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The 75 gpm letdown purification flow, F_p, is converted from gpm to grams/sec at letdown operating parameters (Design Input 2 and 3 above).

$$F_p\left[\frac{g}{sec}\right] = 75\left[\frac{gal}{min}\right]\times\left[\frac{1\,ft^3}{7.48\,gal}\right]\times\left[\frac{1\,lb}{0.01614\,ft^3}\right]\times\left[\frac{454\,g}{lb}\right]\times\left[\frac{1\,min}{60\,sec}\right]$$

$$= 4701\left[\frac{g}{sec}\right]$$

Substituting the values of F_p, M and DF int o Equation 3.a.2 gives:

$$\lambda_{LD}\left[sec^{-1}\right] = \frac{4701\left[\frac{g}{sec}\right]}{2.42E8\left[g\right]}\times\left(1-\frac{1}{10}\right)$$

$$= 1.75E-5\left[sec^{-1}\right]$$

Values of λ_d for each isotope are obtained from Reference 4.

TABLE 3.a

Nuclide	Letdown Purif. Removal Constant, λ_{LD} (Equation 3.a.2) [sec^{-1}]	Isotope Decay Constant, λ_d (Ref. 4) [sec^{-1}]	Total Iodine Removal Rate, λ_t Equation 3.a.1 [sec^{-1}]
I 131	1.75E-5	9.97E-7	1.85E-5
I 132	1.75E-5	8.37E-5	1.01E-4
I 133	1.75E-5	9.25E-6	2.67E-5
I 134	1.75E-5	2.20E-4	2.38E-4
I 135	1.75E-5	2.91E-5	4.66E-5

b. The fuel release rate, λ_{fuel}, is defined as the product of the RCS activity and the total iodine removal rate for each isotope:

λ_{fuel} [Ci/sec] = A_i [Ci] × λ_t [sec^{-1}] Equation 3.b

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Each fuel release rate is multiplied by 500 (Design Input 5) to obtain the spiked release rate.

Table 3.b

Nuclide	Total Iodine Removal Rate, λ_{t} (Table 3.a) [sec^{-1}]	Fuel Release Rate, λ_{fuel} (Equation 3.b) [Ci/sec]	Spiked Release Rate $500 \times \lambda_{fuel}$ [Ci/sec]
I 131	1.85E-5	2.89E-3	1.45
I 132	1.01E-4	1.77E-2	8.85
I 133	2.67E-5	6.67E-3	3.34
I 134	2.38E-4	8.92E-3	4.46
I 135	4.66E-5	6.39E-3	3.20

c. Based on the data from Table 3.a and Table 3.b, it can be concluded that the fuel release rate is much larger than the effects of radioactive decay or leak rate removal, so λ_d and λ_lr are not considered in calculating the initial concentration of iodine in the RCS.

$$\frac{dC(t)}{dt} = -\lambda_d C(t) - \lambda_{lr} C(t) + \lambda_{fuel}$$

$$\int_{C_o}^{C} dC(t) = \int_0^t \lambda_{fuel} dt$$

$$C(t) = C_o + \lambda_{fuel} t \quad \text{Equation 3.c}$$

d. Since the isotope concentration, C(t) is assumed to remain evenly distributed throughout the RCS volume, then the rate at which the isotope concentration leaks from the RCS, R(t), is the RCS leak rate multiplied by the concentration determined by Equation 3.c. The total activity released during the event is calculated by integrating the release rate over the time interval.

$$R(t) = \lambda_{lr} C(t)$$

$$= \lambda_{lr}(C_o + \lambda_{fuel} t)$$

$$\int_0^t R(t)dt = \int_0^t \lambda_{lr}(C_o + \lambda_{fuel} t)dt$$

$$R = \lambda_{lr}\left(C_o t + \frac{\lambda_{fuel} t^2}{2}\right) \quad \text{Equation 3.d}$$

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TABLE 3.d

Nuclide	RCS Activity at 1 µCi/g, C_e (Table 2.b) [Ci]	Spiked Release Rate (Table 2.b) [Ci/sec]	Activity Released, R_i (Equation 3.d) [Ci]
I 131	156.1	1.45	7.16
I 132	174.8	8.85	4.27E1
I 133	249.7	3.34	1.63E1
I 134	37.5	4.46	2.14E1
I 135	137.2	3.20	1.55E1

e. Calculate the thyroid inhalation dose at the Exclusion Area Boundary and Low Population Zone using the equation from B/B UFSAR 15.A.4.

TABLE 3.e

Nuclide	Activity Released, R_i (Table 3.d) [Ci]	DCF_i [rem/Ci]	$R_i xDCF_i$ [rem]
I 131	7.16	1.08E6	7.73E6
I 132	4.27E1	6.44E3	2.75E5
I 133	1.63E1	1.80E5	2.93E6
I 134	2.14E1	1.07E3	2.29E4
I 135	1.55E1	3.13E4	4.85E5
		$\Sigma R_i xDCF$	1.14E7

The total DE I-131 activity released is the total dose from Table 3.e divided by the I-131 dose conversion factor. Numerically this is 10.6 Ci (1.14E7 rem/1.08E6 rem/ci).

<u>Exclusion Area Boundary Dose for a 1 gpm Leakrate:</u>

$$D_{EAB}[rem]=\left(\frac{X}{Q}\right)_{EAB}\times B\times\sum_i R_i\times DCF_i \quad Equation\ 3.e.1$$

$$=7.7E-4\left[\frac{sec}{m^3}\right]\times 3.47E-4\left[\frac{m^3}{sec}\right]\times 1.14E7[rem]$$

$$=3.05\,[rem]$$

f. Calculate the thyroid inhalation dose at the Low Population Zone (LPZ) using the equation from UFSAR 15A.4. The activity released during the accident from 2-40 hours was obtained from UFSAR Table 15.1-4. This activity includes the dose contribution from a 9.4 gpm leak in the faulted SG.

TABLE 3.f.1

Nuclide	RCS Iodine Activity, A_{ii} (UFSAR Table 15.1-4) [Ci]	ICRP-30, Dose Conversion Factor, DCF_{ii} (Reference 17) [rem/Ci]	2-40 Hour Dose, $A_{ii} \times DCF_{ii}$ [rem]
I-131	2.1E3	1.08E6	2.27E9
I-132	1.0E3	6.44E3	6.44E6
I-133	2.9E3	1.80E5	5.22E8
I-134	1.4E2	1.07E3	1.50E5
I-135	1.2E3	3.13E4	3.76E7
		Total ($\Sigma A_{ii} \times DCF_{ii}$)	2.84E9

The total 2-40 hour dose calculated above in Table 3.f.1 is separated into specific time periods of 2-8 hrs, 8-24 hrs, and 24-40 hrs. This is based on scaling the total 2-40 hour dose by the fraction of steam released during the same time period. The 2-40 hour steam release was obtained from UFSAR Table 15.1-3.

TABLE 3.f.2

Time Period	Steam Release (UFSAR Table 15.1-3) [lb]	Fraction of Total Steam Release for Time Period	Total 2-40 Hr Dose (Table 3.f.1) [rem]	Fraction of Total 2-40 Hr Dose [rem]
2-8 hr	939,604	0.30	2.84E9	8.52E8
8-24 hr	1,234,515	0.39	2.84E9	1.11E9
24-40 hr	980,806	0.31	2.84E9	8.80E8
Total Steam Release	3,154,925			

The atmospheric dilution factors (X/Q) for 0-8 hrs, 8-24 hrs, and 24-40 hrs values were obtained from UFSAR Table 15.0-14. The breathing rates for 0-8 hrs, 8-24 hrs and 24-40 hrs were obtained from UFSAR Table15A-1. Calculate the thyroid inhalation dose at the Low Population Zone (LPZ) using the equation from UFSAR 15A.4.

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$$D_{LPZ}[rem] = \left(\frac{X}{Q}\right)_{LPZ} \times B \times \sum A \times DCF \quad \text{Equation 3.f.1}$$

TABLE 3.f.3

Time Period	Atmos. Dispersion Factor, X/Q, (UFSAR Table 15.6-14) [sec/m³]	Breathing Rate, B, (UFSAR Table 15A-1) [m³/sec]	Fractional Dose, ΣAxDCF (Table 3.f.2) [rem]	Fractional LPZ Dose, D_{LPZ}, w/ a 9.4 gpm Leakrate (Equation 3.f.1) [rem]
0-2 hr	7.1E-5	3.47E-4	1.07E8*	2.64
2-8 hr	7.1E-5	3.47E-4	8.52E8	20.99
8-24	1.4E-5	1.75E-4	1.11E9	2.27
24-40	7.1E-6	2.3E-4	8.80E8	1.4
			Total LPZ Dose w/ a 9.4 Leakrate [rem]	27.79

* From Table 3.e x 9.4

4. **CALCULATION OF SITE ALLOWABLE LEAKRATE**

a. Results of the Pre-Accident Initiated Iodine Spike Model

The EAB dose for a 9.4 gpm leakrate is 43.14 rem (4.60 X 9.4). The total LPZ dose calculated in Table 2.f.3 is 25.14 rem. Therefore, the EAB dose is more limiting.

The thyroid dose due to the release of activity in the secondary side of all four steam generators is 1.53 rem. The dose due to 1 gpm primary to secondary leakage in 4 steam generators with a concentration of 60 μCi/g is 4.60 rem. Given that the dose limit in the Standard Review Plan is 300 rem for the pre-accident model, the maximum allowable leak rate without exceeding 300 rem is:

$$\text{Allowable Leak Rate} = \left(\frac{300\ rem - 1.53\ rem}{4.60\ \frac{rem}{gpm}} \right)$$

$$= 64.88\ gpm$$

Consequently, the total EAB dose due to a 64.88 gpm leak during a MSLB is 300 rem. Allowing 0.1 gpm per each of the three intact steam generators leaves 64.58 gpm (64.88-0.3) for the faulted loop.

Note that the 64.88 gpm allowable leakrate is calculated at RCS operating conditions. Should the allowable leakrate be desired to be expressed at room temperature conditions, the 64.88 gpm must be divided by 1.406 (Reference 19) to account for RCS density differences. Therefore, the room temperature allowable leak rate is 46.14 gpm.

b. Results of the Accident Initiated Iodine Spike Model

The EAB dose for a 9.4 gpm leakrate is 28.67 rem (3.05 x 9.4). The total LPZ dose calculated in Table 3.f.3 is 27.79 rem. Therefore, the EAB dose is more limiting.

The thyroid dose due to the release of activity in the secondary side of all four steam generators is 1.53 rem. The dose due to 1 gpm primary to secondary leakage in 4 steam generators with a concentration of 1 μCi/g is 3.05 rem. Given that the dose limit in the Standard Review Plan is 30 rem for the accident initiated spike model, the maximum allowable leak rate without exceeding 30 rem is:

$$Allowable\ Leak\ Rate = \left(\frac{30\ rem - 1.53\ rem}{3.05\ \frac{rem}{gpm}} \right)$$

$$= 9.33\ gpm$$

Consequently, the total EAB dose due to a 9.33 gpm leak during a MSLB is 30 rem. Allowing 0.1 gpm per each of the three intact steam generators leaves 9.03 gpm (9.33-0.3) for the faulted loop.

Note that the 9.33 gpm allowable leakrate is calculated at RCS operating conditions. Should the allowable leakrate is desired to be expressed at room temperature conditions, the 9.33 gpm must be divided by 1.406 (Reference 19) to account for RCS density differences. Therefore, the room temperature allowable leak rate is 6.63 gpm.

5. **CALCULATION OF END-OF-CYCLE 7 PREDICTED DOSES**

In accordance with the requirements for Braidwood Unit 1 voltage based repair criteria (IPC) for outer diameter stress corrosion cracking at tube support plates, the potential tube leakage during a MSLB event with containment bypass must be predicted at the end of the next operating period. In addition to the predicted IPC leakage, the MSLB leakage contribution from circumferential cracking at the top of the tubesheet must also be factored into the end of cycle assessment. This combined predicted leakrate must be compared to and shown to be less than the maximum site allowable leakrate determined in Section 4 above.

Braidwood Station is currently preparing a request for Technical Specification change to lower the RCS Dose Equivalent Iodine –131 limit to 0.1 μCi/g. As documented in Section 3, the site allowable leakrate of 6.63 gpm is based on an RCS DE I131 limit of 1 μCi/g. The site allowable leakrate can be increased proportional to a reduction in RCS DE I131. Therefore by reducing the RCS DE I131 limit to 0.1 μCi/g, the allowable leakrate is increased to 66.3 gpm (6.63 gpm/0.1).

The predicted end-of-cycle 7 IPC leakrate 57.1 gpm based on room temperature conditions (Reference 5). To this is added 5 gpm to account for the contribution from circumferential cracking at the top of the tube sheet and operational leakage from three steam generators (0.1 gpm per steam generator) for a total leakrate of 62.4 gpm. This is bounded by the requested 66.3 gpm site allowable leakrate limit.

This section of the calculation determines the EAB and LPZ thyroid dose for the predicted end-of-cycle leakrate of 62.4 gpm to validate that the current operating conditions are bounded by existing calculations. The EAB and LPZ dose is bounded by Section 3 of this document, which showed that the accident initiated spike is the limiting accident.

a. The most restrictive EAB thyroid dose limit is 30 rem per section 4.b. This dose limit corresponds to an allowable leakrate of 6.63 gpm at an RCS DE I-131 concentration of 1 μCi/g. The calculated EAB dose remains the same when allowable leakage is increased to 66.3 gpm because RCS DE I-131 is decreased by a proportional amount. To calculate the EAB dose due to current cycle projected leakage of 66.3 gpm, X_{EAB}, determine the fraction of projected leakage compared to allowable leakage.

$$\frac{62.4\text{ gpm}}{66.3\text{ gpm}} = \frac{X_{EAB}}{30\text{ rem}}$$

$$X_{EAB} = \frac{62.4\text{ gpm}}{66.3\text{ gpm}} 30\text{ rem}$$

$$X_{EAB} = 28.2\text{ rem at a } 0.1\,\mu\text{ Ci/g RCS DE I131 concentration}$$

Therefore, the end-of-cycle 7 predicted EAB dose is within the 30 rem dose limit under end-of-cycle 7 operating conditions.

b. The LPZ calculated thyroid dose is 27.79 rem per Section 3.f. This dose limit corresponds to an allowable leakrate of 6.63 gpm at an RCS DE I-131 concentration of 1 μCi/g, which again remains the same under the proposed allowable leakrate of 66.3 gpm because RCS DE I-131 is proportionally reduced. The LPZ dose for projected end-of-cycle conditions, X_{LPZ}, is calculated by performing a ratio of calculated values to projected values.

$$\frac{62.4\ \text{gpm}}{66.3\ \text{gpm}} = \frac{X_{LPZ}}{27.79\ \text{rem}}$$

$$X_{LPZ} = \frac{62.4\ \text{gpm}}{66.3\ \text{gpm}} 27.79\ \text{rem}$$

$$X_{LPZ} = 26.16\ \text{rem at a}\ 0.1\ \mu\text{Ci/g RCS DE I131 concentration}$$

Therefore, the end-of-cycle 7 predicted LPZ dose is bounded by Section 3.f.

SUMMARY AND CONCLUSIONS

It is concluded from Section 4 that the accident initiated spike is more limiting, therefore the maximum site allowable SG leakrate during a postulated MSLB is 9.3 gpm at RCS operating conditions (6.6 gpm at room temperature) with a RCS DE I-131 concentration of 1 µCi/g. This value includes the 0.1 gpm contribution from each of the three intact SGs.

Section 5 determined that the Unit 1 end-of-cycle 7 predicted MSLB tube leakage results in off-site thyroid doses that are less than a small fraction (10%) of 10CFR100 limits. The resulting EAB and LPZ doses, with a 0.1 µCi/g RCS DE I-131 limit, are 28.2 rem and 27.79 rem, respectively, which are less than the 30 rem limit for the limiting accident initiated spike case.

- FINAL -

PREPARATION, REVIEW AND APPROVAL OF CALCULATIONS

CALCULATION TITLE PAGE

ComEd

BRAIDWOOD STATION UNITS 1&2

Calculation No: BRW-97-0798-M

DESCRIPTION CODE: R02

DISCIPLINE CODE: M

SYSTEM CODE: RC, MS

TITLE: Allowable Leakrate Calculation for Steam Generator Interim Plugging Criteria

X Safety Related ______ Augmented Quality ______ Non-Safety Related

REFERENCE NUMBERS

Type	Number	Type	Number

COMPONENT EPN:

EPN	Compt Type

DOCUMENT NUMBERS:

Doc Type/SubType	Document Number

REMARKS:

REV. NO.	REVISING ORGANIZATION	APPROVED PRINT/SIGN	DATE
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CALCULATION REVISION PAGE

CALCULATION NO. BRW-97-0798-M PAGE NO.: 2

REVISION SUMMARIES

REV: 0

REVISION SUMMARY:

Original issue, pages 1-23

Electronic Calculation Data Files:
(Program Name, Version, File name ext/size/date/hour/: min)

None

Prepared by: W. J. Johnson/[signature] 8/29/97
Print/Sign Date

Reviewed by: R. G. Chow/ [signature] 8/29/97
Print/Sign Date

Type of Review
[X] Detailed [ ] Alternate [ ] Test

DO ANY ASSUMPTIONS IN THIS CALCULATION REQUIRE LATER VERIFICATION [ ] YES [X] NO

Tracked by:__________

REV: 1

REVISION SUMMARY:

Corrected typographical error on page 24.

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Print/Sign Date

Type of Review
[X] Detailed [ ] Alternate [ ] Test

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proportionally reduced. The LPZ dose for projected end-of-cycle conditions, X_{LPZ}, is calculated by performing a ratio of calculated values to projected values.

$$\frac{62.4\ \text{gpm}}{66.3\ \text{gpm}} = \frac{X_{LPZ}}{27.79\ \text{rem}}$$

$$X_{LPZ} = \frac{62.4\ \text{gpm}}{66.3\ \text{gpm}} 27.79\ \text{rem}$$

$$X_{LPZ} = 26.16\ \text{rem at a } 0.1\ \mu\text{Ci/g RCS DE I131 concentration}$$

Therefore, the end-of-cycle 7 predicted LPZ dose is bounded by Section 3.f.

SUMMARY AND CONCLUSIONS

It is concluded from Section 4 that the accident initiated spike is more limiting, therefore the maximum site allowable SG leakrate during a postulated MSLB is 9.3 gpm at RCS operating conditions (6.6 gpm at room temperature) with a RCS DE I-131 concentration of 1 μCi/g. This value includes the 0.1 gpm contribution from each of the three intact SGs.

Section 5 determined that the Unit 1 end-of-cycle 7 predicted MSLB tube leakage results in off-site thyroid doses that are less than a small fraction (10%) of 10CFR100 limits. The resulting EAB and LPZ doses, with a 0.1 μCi/g RCS DE I-131 limit, are 28.2 rem and 26.16 rem, respectively, which are less than the 30 rem limit for the limiting accident initiated spike case.

- FINAL -