Braidwood Calculation No. BRW-97-0798-M

Allowable Leak Rate Calculation for Steam Generator Interim Plugging Criteria

Revision 4

12/10/97

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PREPARATION, REVIEW AND APPROVAL OF CALCULATIONS

CALCULATION TITLE PAGE

ComEd

BRAIDWOOD STATION UNITS 1&2

Calculation No: BRW-97-0798-M

DESCRIPTION CODE: R01

DISCIPLINE CODE: M

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TITLE: Allowable Leak Rate Calculation for Steam Generator Interim Plugging Criteria

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COMMONWEALTH EDISON COMPANY
CALCULATION REVISION PAGE

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

REVISION SUMMARIES

REV: 0

REVISION SUMMARY:

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CALCULATION REVISION PAGE

CALCULATION NO. BRW-97-0798-M	PAGE NO.: 2.1

REVISION SUMMARIES

REV: 2

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Corrected secondary side activities based on new information from Westinghouse. Also corrected typographical errors on page 12 and 23.

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REV: 3

REVISION SUMMARY:
Added secondary side releases to LPZ 0-2 hr dose. Clarified references, design inputs, and text. This revision completely supersedes all previous revisions.

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CALCULATION REVISION PAGE

CALCULATION NO. BRW-97-0798-M PAGE NO.: 2.2

REVISION SUMMARIES

REV: 4

REVISION SUMMARY:
Revised dose resulting from new end-of-cycle 7 leak rate. Pages affected: 2.2, 3, 6,23,24.

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Prepared by: W. J. Johnson/ [signature] 12/10/97
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The reviewer's signature indicates compliance with GES 320.10 and the verification of the following minimum items: correctness of math for hand calculations, appropriateness of input data, appropriateness of assumptions, and appropriateness of the calculation method.

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COMMONWEALTH EDISON COMPANY
CALCULATION TABLE OF CONTENTS

CALCULATION NO. BRW-97-0798-M	REV. NO. 4	PAGE NO. 3
SECTION	PAGE NO.	SUB-PAGE NO.
TITLE PAGE	1	
REVISION SUMMARY	2	2.1, 2.2
TABLE OF CONTENTS	3	
PURPOSE/OBJECTIVE	4	
METHODOLOGY AND ACCEPTANCE CRITERIA	4	
ASSUMPTIONS	5	
DESIGN INPUT	5	
REFERENCES	6	
CALCULATIONS	7	
SUMMARY AND CONCLUSIONS	24	
ATTACHMENTS	N/A	

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.

This calculation also determines the resulting thyroid dose at the Exclusion Area Boundary and Low Population Zone for the actual predicted end-of-cycle 7 steam generator tube leakage during a postulated Main Steam Line Break

METHODOLOGY AND ACCEPTANCE CRITERIA:

The Main Steam Line Break (MSLB) accident is evaluated because the event causes a sustained large pressure difference across the steam generator tubes providing a motive force for reactor coolant system (RCS) release. 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 for the RCS, which is 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.

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.

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:

1. The total volume of the RCS is 12,062 ft^3. (Ref. 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. (Deleted)

5. Letdown Purification System temperature and pressure are 130 °F and 2300 psig. (Ref. 1).

6. Letdown Purification System specific volume is 0.01613 ft^3/lbm. (Ref. 3)

7. Breathing rates are taken from UFSAR Table 15A-1. (Ref. 6)

8. Atmospheric Dilution Factors, X/Q, are the fifth percentile values taken from UFSAR Table 15.0-14. (Ref. 7)

9. RCS iodine concentrations are based on UFSAR Table 11.1-2. (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 coefficient of 1.0 and the intact steam generators have partition coefficient of 0.1. (Reference 15)

12. The half life for I-131 is 8.04 days, I-132 is 2.30 hrs, I-133 is 20.8 hrs, I-134 is 52.6 min, and I-135 is 6.61 hrs (λ_d = 0.693/half life). (Ref. 21)

13. The initial primary coolant activity for the pre-accident spike is 60 μCi/g DE I-131 and 1 μCi/g for the accident initiated spike. (Ref. 12 and 14)

14. The initial secondary coolant activity is 0.1 μCi/g DE I-131. (Ref. 12 and 14)

15. The duration of the spike is 2 hours. (Ref. 24)

16. No fuel failure attributable to the accident since DNB design basis is met. (Ref. 12 and 25)

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 1)

19. (Deleted)

20. (Deleted)

21. Demineralizer Decon Factor, DF, for iodine is 10. (Ref 1)

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

23. Allowable primary to secondary leak rate is 150 gallons per day (0.1 gpm) per steam generator. (Ref. 14)

24. Dose conversion factors are based on ICRP 30 values using the significant digits from Federal Guidance Report No. 11. (Ref. 17 and 20)

25. Projected end-of-cycle 7 leak rate is 122 gpm based on room temperature and pressure. (Ref. 5)

REFERENCES:

1) B/B UFSAR Table 11.1-1, Revision 0, as amended in Reference 22

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

3) ASME Steam Table, Fifth Edition

4) (Deleted)

5) BRW-DIT-97-278, Inputs into Offsite Dose Calcula... o Support Unit 1 Reduced RCS DE I-131 Activity Limit, Rev. 2

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) (Deleted)

12) Standard Review Plan (NUREG 800), 15.1.5 Appendix A

13) (Deleted)

14) Technical Specifications 3.4.8 (Amendment 69), 3.7.1.4 (Original), 3.4.6.2 (Amendment 57)

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) J. P. Adams and C. L. Atwood, "The Iodine Spike Release Rate During a Steam Generator Tube Rupture," Nuclear Technology, Vol. 94, pp 361-371, June, 1991 and EGG NERD-8648 Technical Report "Probability of the Iodine Spike Release during an SGTR," September, 1989

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

22) "Primary Coolant Source Terms," Westinghouse letter CAE-97-185, CCE-97-225, dated September 19, 1997

23) TID-14844, "Calculation of Distance Factors for Power and Test Reactor Sites," March 23, 1962

24) B/B UFSAR Section 15.1.5.3, Revision 6

25) B/B UFSAR Section 15.1.5.1, Revision 4

VARIABLE AND CONSTANT DEFINITIONS:

M	RCS mass [g]
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]
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]
W_i	DCF-Weighted Activity [rem]
DE I-131	Dose Equivalent I-131

DEFINE UNITS:

Ci = 1 Curie
μCi = 1E-6 Ci
1 lbm = 454 g
1 ft^3 = 7.48 gal
1 min = 60 sec
1 Sv/Bq = 3.7E12 rem/Ci

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 (Design Input 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 (Design Input 10) 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 th[illegible] intact steam generators is 406,716 lbs (Design Input 10). The combined 2-8 hr steam release for [illegible] intact SGs is 939,604 lbs (Design Input 10). For the three intact SGs a partition coefficient o[illegible]sed (Design Input 11).

a. The iodine concentrations are obtained from UFSAR Table 15.0-9 as updated in Reference 22 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, Ref 22) [μCi/g]	Iodine Concentration, C_i, (Equation 1.a) [Ci/lb]
I-131	0.0645	2.93E-5
I-132	0.0723	3.28E-5
I-133	0.1032	4.69E-5
I-134	0.0155	7.04E-6
I-135	0.0567	2.57E-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) and then multiplied by the partition coefficient (1.0 for the faulted SG and 0.1 for the intact SGs) to obtain the curies released, R_i, for 0-2 hours.

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

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

TABLE 1.b

Nuclide	Activity Released from Faulted SG, R_i^{Faulted}, (Equation 1.b.1) [Ci]	Activity Released from Intact SGs (0-2 hrs), R_i^{intact}, (Equation 1.b.2) [Ci]
I-131	2.81E0	1.19E0
I-132	3.15E0	1.33E0
I-133	4.50E0	1.91E0
I-134	6.76E-1	2.86E-1
I-135	2.47E0	1.05E0

c. The activity released, R_i determined above, is multiplied by the ICRP-30 Dose Conversion Factor, DCF_i, (Design Input 24) for each iodine isotope and then summed separately for the faulted SG and intact SGs. The DCF-weighted activity released is:

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

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

TABLE 1.c

Nuclide	ICRP-30 Dose Conversion Factor, DCF_i, (Design Input 24) [rem/Ci]	Weighted Activity from Faulted SG, $W^{Faulted}$, (Equation 1.c.1) [rem]	Weighted Activity from Intact SGs, W^{Intact}, (0-2 hrs) (Equation 1.c.2) [rem]
I-131	1.08E6	3.03E6	1.29E6
I-132	6.44E3	2.03E4	8.57E3
I-133	1.80E5	8.10E5	3.44E5
I-134	1.07E3	7.23E2	3.06E2
I-135	3.13E4	7.73E4	3.29E4
	Total $\Sigma(R_i x DCF_i)$	3.94E6	1.68E6

The 0-2 hour weighted activity released from the faulted and the three intact SGs is 5.62E6 rem (3.94E6 + 1.68E6 rem). This total weighted activity can also be defined as $\Sigma_i(R_i x DCF_i)$.

The DE I-131 activity released from the faulted and intact seam generators is the total weighted activity from Table 1.c divided by the I-131 dose conversion factor. Numerically this is 5.20 Ci DE I-131 (5.62E6 rem/1.08E6 rem/Ci)

d. The off-site thyroid inhalation dose at the exclusion area boundary, D_{EAB}, is calculated in accordance with UFSAR equation 15A-2. The LPZ doses for both the pre-accident and accident initiated iodine spike cases include the activity released from the secondary side and are calculated in steps 2.f and 3.f, respectively. The breathing rate is based on the 0-8 hour time period.

Exclusion Area Boundary Dose (0-2 hours) for Secondary Side Release

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

$$= 7.7E-4\left[\frac{\text{sec}}{\text{m}^3}\right] \times 3.47E-4\left[\frac{\text{m}^3}{\text{sec}}\right] \times 5.62E6[\text{rem}]$$

$$= 1.50\,[\text{rem}]$$

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 DE I-131. 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 DE I-131, 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 DE I-131. To obtain the total activity at 60 µCi/g DE I-131, each isotope activity is multiplied by 60.

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

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

$$\mathrm{DE\ I131}[\mathrm{Ci}] = \frac{\sum_i W_i[\mathrm{rem}]}{DCF_{I131}\left[\frac{\mathrm{rem}}{\mathrm{Ci}}\right]} = \frac{1.39\mathrm{E}9[\mathrm{rem}]}{1.48\mathrm{E}6\left[\frac{\mathrm{rem}}{\mathrm{Ci}}\right]} = 939.2\,[\mathrm{Ci}]$$

$$\text{Nuclide Concentration at } 1\frac{\mu\mathrm{Ci}}{\mathrm{g}}\text{ DE I-131} = \frac{A_i[\mathrm{Ci}]}{\mathrm{DE\ I131}[\mathrm{Ci}]} \quad \text{Equation 2.b.3}$$

$$\text{RCS Activity at } 1\frac{\mu\mathrm{Ci}}{\mathrm{g}}[\mathrm{Ci}] = \text{Equation 2.b.3} \times M[\mathrm{g}] \times 1\left[\frac{\mu\mathrm{Ci}}{\mathrm{g}}\right] \times \left[\frac{1\,\mathrm{Ci}}{1\mathrm{E}6\,\mu\mathrm{Ci}}\right] \quad \text{Equation 2.b.4}$$

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

TABLE 2.b

Nuclide	RCS Concent., C_o (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. 23)	Weighted Activity, W_i (Eq. 2.b.2) [rem]	Nuclide Concent., at 1 µCi/g (Eq. 2.b.3) [µCi/g]	RCS Total Activity at 1 µCi/g (Eq. 2.b.4) [Ci]	RCS Total Activity at 60 µCi/g (Eq. 2.b.5 [Ci])
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	0.566	137.3	8.23E3
			ΣW_i	1.39E9			

c. The two removal mechanisms for this accident are due to decay and leak rate 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).

$$\frac{dA(t)}{dt} = -\lambda_d A(t) - \lambda_{lr} A(t)$$

$$\int_{A_o}^{A} \frac{dA(t)}{A(t)} = \int_0^t \left(-\lambda_d - \lambda_{lr}\right) dt$$

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

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

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

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

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

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

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

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

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

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

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

TABLE 2.d

Nuclide	RCS Activity at 60 µCi/g (Table 2.b) [Ci]	Isotope Decay Constant, λ_d (Design Input 12) [sec^{-1}]	Activity Released, R_i (Equation 2.d) [Ci]
I-131	9.36E3	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 0-2 hour thyroid inhalation dose at the Exclusion Area Boundary (EAB) in accordance with UFSAR equation 15A-2.

TABLE 2.e

Nuclide	Activity Released, R_i (Table 2.d) [Ci]	ICRP-30 Dose Conversion Factor, DCF_i, (Design Input 24) [rem/Ci]	Weighted Activity Released, $R_i \times DCF_i$ [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 $\Sigma(R_i x DCF_i)_{EAB}$	1.72E7

The total DE I-131 activity released is the weighted activity from Table 2.e divided by the I-131 dose conversion factor. Numerically this is 15.9 Ci DE I-131 (1.72E7 rem/1.08E6 rem/Ci). The breathing rate is based on 0-8 hour time period.

<u>Exclusion Area Boundary Dose for 0-2 hours for a 1 gpm leak rate</u>

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

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

$$= 4.60\,[\mathrm{rem}]$$

f. Calculate the thyroid inhalation dose at the Low Population Zone (LPZ) using the equation from UFSAR Section 15A.4. The activity released during the accident from 2-40 hours was obtained from UFSAR Table 15.1-4 (as amended in Ref. 22). This activity includes the dose contribution from a 9.4 gpm primary-to-secondary leakage and the secondary side release.

TABLE 2.f.1

Nuclide	RCS Iodine Activity Released, R_i, (UFSAR Table 15.1-4) [Ci]	ICRP-30, Dose Conversion Factor, DCF_i, (Design Input 24) [rem/Ci]	2-40 Hour Weighted Activity Released, $R_i \times DCF_i$, [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 $\Sigma(R_i \times DCF_i)$	2.39E9

The total 2-40 hour weighted activity 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 weighted activity 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 Weighted Activity Released (Table 2.f.1) [rem]	Weighted Activity Released in Time Period [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		**Total Weighted Activity Released**	2.39E9

The atmospheric dilution factors (X/Q) for 0-8 hrs, 8-24 hrs, and 24-40 hrs 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 Section 15A.4.

$$D_{LPZ}[\text{rem}] = \left(\frac{\chi}{Q}\right)_{LPZ} \times B \times \sum (R_i \times DCF_i) \quad \text{Equation 2.f.1}$$

TABLE 2.f.3

Time Period	Atmos. Dispersion Factor, X/Q, (UFSAR Table 15.0-14) [sec/m^3]	Breathing Rate, B, (UFSAR Table 15A-1) [m^3/sec]	Weighted Activity Released, $\Sigma R_i x DCF_{Ii}$ (Table 2.f.2) [rem]	LPZ Dose, D_{LPZ}, w/ 9.4 gpm Leak Rate (Equation 2.f.1) [rem]
0-2 hr	7.1E-5	3.47E-4	1.67E8*	4.11
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
24-40	7.1E-6	2.32E-4	7.41E8	1.22
			Total LPZ Dose w/ 9.4 gpm Leak Rate [rem]	25.27

*From Tables 2.e and 1.c, [(1.72E7x9.4) + (3.94E6 + 1.68E6) = 1.67E8]

3. <u>CALCULATION OF DOSE DUE TO PRIMARY TO SECONDARY LEAKAGE DURING ACCIDENT INITIATED SPIKE</u>

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_t, through letdown purification and radioactive decay. Equation 2 of Reference 18 defines this total as:

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

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

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

$$F_p\left[\frac{g}{sec}\right] = 75\left[\frac{gal}{min}\right] \times \left[\frac{1\,ft^3}{7.48\,gal}\right] \times \left[\frac{1\,lb}{0.01613\,ft^3}\right] \times \left[\frac{454\,g}{lb}\right] \times \left[\frac{1\,min}{60\,sec}\right]$$

$$= 4704\left[\frac{g}{sec}\right]$$

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

$$\lambda_{LD}\left[sec^{-1}\right] = \frac{4704\left[\frac{g}{sec}\right]}{2.42E8[g]} \times \left(1 - \frac{1}{10}\right)$$

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

TABLE 3.a

Nuclide	Letdown Purif. Removal Constant, λ_{LD}, (Equation 3.a.2) $[sec^{-1}]$	Isotope Decay Constant, λ_d (Design Input 12) $[sec^{-1}]$	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 equilibrium fuel release rate, λ_{fuel}, is defined as the product of the RCS activity at 1 μCi/g DE I-131 (from Table 2.b) and the total iodine removal rate for each isotope:

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

Each equilibrium fuel release rate is multiplied by 500 (Design Input 22) to obtain the spiked release rate.

Table 3.

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. Neglecting the loss terms (radiodecay, leakage and letdown), the time dependent RCS activity due to the accident initiated iodine spike may be written as:

$$\frac{dA(t)}{dt} = 500\lambda_{fuel}$$

$$\int_{A_o}^{A} dA(t) = \int_{0}^{t} 500\lambda_{fuel}\,dt$$

$$A(t) = A_o + 500\lambda_{fuel}t \quad \text{Equation 3.c}$$

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

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

$$= \lambda_{lr}\left(A_o + 500\lambda_{fuel}t\right)$$

$$\int_{0}^{t} R(t)dt = \int_{0}^{t} \lambda_{lr}\left(A_o + 500\lambda_{fuel}t\right)dt$$

$$R = \lambda_{lr}\left(A_o t + \frac{500\lambda_{fuel}t^2}{2}\right) \quad \text{Equation 3.d}$$

TABLE 3.d

Nuclide	RCS Activity at 1 μCi/g, A_o (Table 2.b) [Ci]	Spiked Release Rate (Table 3.b) [Ci/sec]	0-2 Hour 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	137.3	3.20	1.55E1

e. Calculate the thyroid inhalation dose at the Exclusion Area Boundary and Low Population Zone in accordance with UFSAR equation 15A-2.

TABLE 3.e

Nuclide	0-2 Hour Activity Released, R_i (Table 3.d) [Ci]	DCF_i [rem/Ci]	R_ixDCF_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
		$\Sigma(R_i$x$DCF_i)$	1.14E7

The total DE I-131 activity released in 0-2 hours is the total weighted activity released, $\Sigma(R_i$x$DCF_i)$, from Table 3.e divided by the I-131 dose conversion factor. Numerically this is 10.6 Ci DE I-131 released in the first two hours (1.14E7 rem/1.08E6 rem/Ci). The breathing rate is based on the 0-8 hour time period.

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

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

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

$$= 3.05\,[\text{rem}]$$

f. Calculate the thyroid inhalation dose at the Low Population Zone (LPZ) using the equation from UFSAR Section 15A.4. The activity released during the accident from 2-40 hours was obtained from UFSAR Table 15.1-4 (as amended in Ref. 22). This activity includes the dose contribution from a 9.4 gpm primary-to-secondary leakage and the secondary side release.

TABLE 3.f.1

Nuclide	RCS Iodine Activity Released, R_i, (UFSAR Table 15.1-4) [Ci]	ICRP-30, Dose Conversion Factor, DCF_i, (Design Input 24) [rem/Ci]	2-40 Hour Weighted Activity Released, R_i x DCF_i, [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 $\Sigma(R_i \times DCF_i)$	2.84E9

The total 2-40 hour weighted activity released 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 weighted activity released 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 Weighted Activity Released (Table 3.f.1) [rem]	Weighted Activity Released in Time Period [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		**Total Weighted Activity Released**	2.84E9

The atmospheric dilution factors (X/Q) for 0-8 hrs, 8-24 hrs, and 24-40 hrs 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 Section 15A.4.

$$D_{LPZ}[\mathrm{rem}] = \left(\frac{\chi}{Q}\right)_{LPZ} \times B \times \sum (R_i \times DCF_i) \quad \text{Equation 3.f.1}$$

TABLE 3.f.3

Time Period	Atmos. Dispersion Factor, X/Q, (UFSAR Table 15.0-14) [sec/m^3]	Breathing Rate, B, (UFSAR Table 15A-1) [m^3/sec]	Weighted Activity Released, $\Sigma(R_i x DCF_i)$, (Table 3.f.2) [rem]	LPZ Dose, D_{LPZ}, w/ a 9.4 gpm Leak Rate (Equation 3.f.1) [rem]
0-2 hr	7.1E-5	3.47E-4	1.13E8*	2.78
2-8 hr	7.1E-5	3.47E-4	8.52E8	20.99
8-24	1.4E-5	1.75E-4	1.11E9	2.72
24-40	7.1E-6	2.32E-4	8.80E8	1.45
			Total LPZ Dose w/ a 9.4 Leak Rate [rem]	27.94

*From Tables 3.e and 1.c [(1.14E7x9.4) + (3.94E6 + 1.68E+6) = 1.13E8]

4. <u>CALCULATION OF SITE ALLOWABLE LEAK RATE</u>

a. Results of the Pre-Accident Iodine Spike Model

The EAB dose for a 9.4 gpm leak rate is 44.74 rem (4.60 X 9.4+1.50). The total LPZ dose calculated in Table 2.f.3 is 25.27 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 1.50 rem (page 10). 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 (page14). 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:

$$\text{Allowable Leak Rate} = \left(\frac{300\ \text{rem} - 1.50\ \text{rem}}{4.60\ \dfrac{\text{rem}}{\text{gpm}}}\right)$$

$$= 64.89\ \text{gpm}$$

Consequently, the total EAB dose due to a 64.89 gpm leak during a MSLB is 300 rem. Allowing 0.1 gpm room temperature leakage per each of the three intact steam generators leaves 64.47 gpm (64.89-0.3x1.406) for the faulted loop.

Note that the 64.89 gpm allowable leak rate is calculated at RCS operating conditions. Should the allowable leak rate be desired to be expressed at room temperature conditions, the 64.89 gpm must be divided by 1.406 (Reference 19) to account for RCS density differences. Therefore, the room temperature allowable leak rate is 46.15 gpm.

b. Results of the Accident Initiated Iodine Spike Model

The EAB dose for a 9.4 gpm leak rate is 30.17 rem (3.05 x 9.4+1.5). The total LPZ dose calculated in Table 3.f.3 is 27.94 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 1.50 rem (page 10). 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 (page 19). 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:

$$\text{Allowable Leak Rate} = \left(\frac{30\ \text{rem} - 1.50\ \text{rem}}{3.05\ \dfrac{\text{rem}}{\text{gpm}}} \right)$$

$$= 9.34\ \text{gpm}$$

Consequently, the total EAB dose due to a 9.34 gpm leak during a MSLB is 30 rem. Allowing 0.1 gpm room temperature leakage per each of the three intact steam generators leaves 8.92 gpm (9.34-0.3x1.406) for the faulted loop.

Note that the 9.34 gpm allowable leak rate is calculated at RCS operating conditions. Should the allowable leak rate be desired to be expressed at room temperature conditions, the 9.34 gpm must be divided by 1.406 (Reference 19) to account for RCS density differences. Therefore, the room temperature allowable leak rate is 6.64 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. This predicted leak rate must be compared to and shown to be less than the maximum site allowable leak rate 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 0.05 μCi/g. As documented in Section 3, the site allowable leak rate of 6.64 gpm at room temperature conditions is based on an RCS DE I131 limit of 1 μCi/g. The site allowable leak rate can be increased proportional to a reduction in RCS DE I131. Therefore by reducing the RCS DE I131 limit to 0.05 μCi/g, the allowable leak rate at room temperature conditions is increased to 132.8 gpm (6.64 gpm/0.05).

The predicted end-of-cycle 7 leak rate is 122 gpm based on room temperature conditions (Design Input 25). To this is added operational leakage from three steam generators (0.1 gpm per steam generator) for a total leak rate of 122.3 gpm at room temperature conditions. This is bounded by the requested 132.8 gpm site allowable leak rate limit at room temperature conditions.

This section of the calculation determines the EAB and LPZ thyroid dose for the predicted end-of-cycle leak rate of 122.3 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 (page 22). This dose limit corresponds to an allowable leak rate of 6.64 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 132.8 gpm because RCS DE I-131 is decreased by a proportional amount. The EAB dose, X_{EAB}, due to current cycle projected leakage of 122.3 gpm is calculated by performing a ratio of calculated values to projected values.

$$\frac{122.3\ \text{gpm}}{132.8\ \text{gpm}} = \frac{X_{EAB}}{30\ \text{rem}}$$

$$X_{EAB} = \frac{122.3\ \text{gpm}}{132.8\ \text{gpm}} 30\ \text{rem}$$

$$X_{EAB} = 27.63\ \text{rem at a } 0.05\ \mu\ \text{Ci/g RCS DE I131 concentration}$$

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 27.94 rem per Section 3.f (page 21). This dose limit corresponds to an allowable leak rate of 6.64 gpm at an RCS DE I-131 concentration of 1 μCi/g, which again remains the same under the proposed allowable leak rate of 132.8 gpm because RCS DE I-131 is reduced to 0.05 μCi/g DE I-131. The LPZ dose for projected end-of-cycle conditions, X_{LPZ}, is calculated by performing a ratio of calculated values to projected values.

$$\frac{122.3\ \text{gpm}}{132.8\ \text{gpm}} = \frac{X_{LPZ}}{27.94\ \text{rem}}$$

$$X_{LPZ} = \frac{122.3\ \text{gpm}}{132.8\ \text{gpm}} 27.94\ \text{rem}$$

$$X_{LPZ} = 25.73\ \text{rem at a } 0.05\ \mu\text{Ci/g RCS DE I-131 concentration}$$

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

SUMMARY AND CONCLUSIONS

It is concluded from Section 4 that the accident initiated spike is more limiting, therefore the maximum site allowable SG leak rate 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 0.05 μCi/g RCS DE I-131 limit, are 27.63 rem and 25.73 rem, respectively, which are less than the 30 rem limit for the limiting accident initiated spike case.

- FINAL -