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January 23, 2002
GO2-02-015

Docket No. 50-397

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

Gentlemen:

Subject: **COLUMBIA GENERATING STATION, OPERATING LICENSE NPF-21
LICENSE AMENDMENT REQUEST -- ALTERNATIVE SOURCE TERM
NON-PROPRIETARY VERSIONS OF PH AND MSLB CALCULATIONS**

Reference: Letter GO2-01-156, dated December 3, 2001, RL Webring (Energy Northwest) to
NRC, "License Amendment Request -- Alternative Source Term"

During a December 17, 2001, meeting the NRC requested that we provide copies of the suppression pool pH and main steam line break calculations in support of staff review of the referenced license amendment request.

Non-proprietary versions of the calculations are included as an enclosure. Proprietary versions of the calculations were submitted under separate cover.

Should you have any questions or desire additional information pertaining to this letter, please call Christina Perino at (509) 377-2075.

Respectfully,

DW Coleman, Manager
Performance Assessment and Regulatory Programs
Mail Drop PE20

Enclosure

cc: EW Merschoff - NRC RIV
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Pool

CALCULATION TITLE PAGE

CALCULATION NUMBER: PSAT 206CT.QA.01.05

CALCULATION TITLE: "Columbia Water Pool pH"

ORIGINATORPrint/SignDateCHECKERPrint/SignDateIND REVIEWERPrint/SignDate

REVISION: 0

1

2

REASON FOR REVISION:

Revision 0: Initial Issue

Revision 1:

1. Assume density of water is 0.993 g/cm³
2. Use mass of sodium pentaborate equal to 4,062.8 lbm per Rev. 2 of PSAT 206.QA.01.03

Revision 2:

1. Add justifications immediately following assumptions
2. Expand justification for Assumption 2
3. Assumptions 3 and 4 are combined to be more specific and the justification is expanded
4. Assumption 5 is deleted
5. Three new assumptions are included as Assumptions 4, 5 and 6
6. A new Section titled Design Inputs is included
7. Proprietary information deleted
- 8.
- 9.
- 10.

11.

12. A subsection is added under Calculation describing the determination of the minimum boron required to maintain $\text{pH} \geq 7$ over 30 days

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Purpose

The purpose of this calculation is to determine the pH of the Columbia Generating Station containment water pool as a function of time following a severe accident out to 30 days.

Methodology

1. Calculate the $[\text{HNO}_3]$ concentration in the water pool as function of time after reactor scram using the Radiolysis of Water model of the STARpH 1.04 code (Ref. 1).
2. Calculate the $[\text{HCl}]$ concentration in the water pool as a function of time using the Radiolysis of Cable model of the STARpH 1.04 code (Ref. 1).
3. Manually calculate the $[\text{H}^+]$ concentration added to the pool as a function of time from the results of the two previous calculations.
4. Calculate the pH of the water pool considering the concentration of sodium pentaborate in the pool and $[\text{H}^+]$ additions as a function of time using the Add Acid model of the STARpH 1.04 code (Ref. 1).

Assumptions

Assumption 1: Fission product inventory is 1.1 times the inventory given in item 1.3 of Reference 2.

Justification: The factor of 1.1 provides conservatism in the radiolytic production of nitric acid.

Assumption 2: Fraction of aerosol source term in water pool = 0.90

Justification: Previous Polestar QA calculations indicate that the fraction of the aerosol source term in an unsprayed drywell that settles in the sump pool is close to 90% (see for example Ref. 3 which calculates this fraction as 0.87 for the Perry drywell). Given that the spray will tend to wash any aerosol which deposits on elevated surfaces into the sump, the actual fraction of aerosol in the water pool is expected to be essentially 100%. Thus use of 90% is conservative since it will overestimate the radiation level in the drywell vapor space and thus overestimate the [HCl] from radiolysis of chloride-bearing insulation.

Assumption 3: The SLCS is actuated and the sodium pentaborate is injected into the pool within several hours of accident initiation.

Justification: A core damage event large enough to release the substantial quantities of fission products in the time frame considered for the alternate source term in Reference [4] will be very evident to the operators (e.g., core outlet temperature, radiation level in the drywell, pressure and temperature in the drywell, hydrogen level in the drywell) within minutes of the initiating event. Thus it is reasonable to assume for purposes of this calculation that the Columbia EOPs and SAMGs provide for SLCS actuation within ~1 hour of accident initiation.

If SLCS injection is into the pool (i.e., into the reactor vessel with the vessel communicating with the pool as in a recirculation line break), significant mixing will occur quickly, on the order of 1 hour based on a total RHR flow rate of about 7450 gpm and the pool volume of ~1E6 gallons per Reference 2.

If the reactor vessel is not immediately communicating with the pool, an additional few hours is assumed to transpire before the operators flood the vessel up to the break to assure communication with the pool or inject sodium pentaborate to the pool via an alternate pathway.

Assumption 4: The unbuffered pH of the pool should remain above 7 for at least several hours.

Justification: Proprietary information deleted

Assumption 5: The pH effect of the increased pool temperature from the accident is very small in a strongly buffered system such as Columbia and can be neglected.

Justification: Proprietary information deleted.

Proprietary information deleted

Assumption 6: Gamma radiation leakage from the containment is assumed to be equivalent to that from a BWR Mark I containment.

Justification: The factor (1- fractional gamma leakage), used in the STARpH 1.04 code is given for three different containment sizes in Reference 1. The containment size closest to Columbia ($3.45\text{E}5 \text{ ft}^3$) in Ref. 1 is that for a BWR Mark I ($2.83\text{E}5 \text{ ft}^3$). The

next closest size in Ref. 1 is for a BWR Mark III ($\sim 1\text{E}6\text{ ft}^3$). The slight increase in volume from $2.83\text{E}5\text{ ft}^3$ to $3.45\text{E}5\text{ ft}^3$ has a very small effect on the factor (1-fractional gamma leakage), and since gamma radiation is a much smaller contributor to HCl generation than is beta radiation, this assumption results in a negligible change in acid generated.

Design Inputs

1. Reactor power = 3556 MWt
2. Volume of water in wetwell = $137,262\text{ ft}^3$
3. RCS inventory = $6.59\text{E}5\text{ lbm}$
4. Pool initial pH = 5.3
5. Fission product inventory, see Assumption 1
6. Mass of Hypalon jacket = $2.777\text{E}6\text{ g}$
7. Density of Hypalon jacket = 1.1 g/cm^3
8. Thickness of Hypalon jacket = 0.06 inch
9. Cable OD = 0.75 inch
10. Drywell free volume = $200,540\text{ ft}^3$
11. Wetwell free volume = $144,184\text{ ft}^3$
12. Mass of sodium pentaborate available for injection = 4,062.8 lbm
13. Chemical formula for sodium pentaborate = $\text{Na}_2\text{O} \cdot 5\text{B}_2\text{O}_3 \cdot 10\text{H}_2\text{O}$
14. Boron enrichment in sodium pentaborate is natural

Items 1, 2, 4, and 6-14 are from Reference 2. Item 3 is from Reference 11, and Item 5 is from Assumption 1.

References

1. PSAT C107.02, STARpH Code Description and Validation and Verification Report, Revision 4, February 16, 2000.
2. PSAT 206.QA.01.03, Dose Calculation Data Base for Application of the Alternate Source Term to LOCA and Non-LOCA DBAs for Energy Northwest's Columbia Generating Station, Revision 5, August, 2001.
3. PSAT 04202H.12, Calculation of Fraction of Containment Aerosol Deposited in Water (Perry), April, 1996.
4. Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors, Regulatory Guide 1.183, July, 2000.
- 5.

- 6.
- 7.
8. Handbook of Chemistry and Physics, 77th Edition, CRC Press, 1996.
- 9.
- 10.
11. Columbia Generating Station Final Safety Analysis Report, Amendment 53, Table 6.2-4, "Initial Conditions Employed in Containment Response Analyses," November, 1998.
- 12.

Calculation

Calculation of $[\text{HNO}_3]$ in water pool as a function of time

The Radiolysis of Water model in the STARpH 1.04 code (Ref. 1) calculates the nitric acid concentration, $[\text{HNO}_3]$, in the containment water pool generated by radiolysis.

Inputs to the Radiolysis of Water model are: reactor power = 3556 MWt, initial pH = 5.3, fraction of aerosol in water = 0.90 (Assumption 2), water pool volume = $4.18\text{E}6$ L (calculated below), and core inventory of fission products (in Table 1 below) which, per Assumption 1, is 1.1 times the inventory provided in item 1.3 of Reference 2.

Table 1. Fission product inventory

<u>Group Title</u>	<u>Elements in Group</u>	<u>Core Inventory (Kg)</u>
I	I, Br	32.7
Cs	Cs, Rb	359
Te	Te, Sb, Se	68.9
Sr	Sr	94.3
Ba	Ba	158
Ru	Ru, Rh, Mo, Tc, Pd	981
Ce	Ce	1,342
La	La, Zr, Nd, Eu, Nb, Pm, Pr, Sm, Y	1,243

Containment water pool volume = water volume of wetwell + RCS volume

$$\begin{aligned}\text{Water volume of wetwell} &= 137,262 \text{ ft}^3 \cdot 2.83\text{E}1 \text{ L/ft}^3 \\ &= 3.88\text{E}6 \text{ L}\end{aligned}$$

$$\begin{aligned}\text{RCS volume} &= 6.59\text{E}5 \text{ lbm} \cdot 454 \text{ g/lbm} \cdot 1 \text{ cm}^3/0.989 \text{ g} \cdot 1 \text{ L/1E}3 \text{ cm}^3 \\ &= 3.03\text{E}5 \text{ L}\end{aligned}$$

where the density of water in the containment pool at 47 °C (see Assumption 5) is 0.989 g/cm³ (Ref. 8).

$$\text{Containment water pool volume} = 3.88\text{E}6 \text{ L} + 3.03\text{E}5 \text{ L} = 4.18\text{E}6 \text{ L}$$

The core inventory of fission products in the table above is entered in column F of the Radiolysis of Water model spread sheet and a burnup value of 33, 000 MWd/t is used in cell K2 so that the fission product inventory is not modified when calculating values for HI and CsOH.

The output of the calculation with the Radiolysis of Water model in the form of [HNO₃] as a function of time is provided as Exhibit 1.

Calculation of [HCl] in water pool as a function of time

The concentration of HCl in the water pool as a result of radiolysis of electrical cable insulation is calculated using the Radiolysis of Cable model of the STARpH 1.04 code (Ref. 1). The inputs to the Radiolysis of Cable model are: reactor power = 3556 MWt, water pool volume = 4.18E6 L (calculated above), aerosol fraction in pool = 0.90 (Assumption 2), mass of Hypalon jacketing = 6,117 lbm (calculated below), containment free volume = 9.76E9 cm³ (calculated below), and one minus fraction of gamma leakage = 0.068 (default value in Ref. 1 for BWR Mark I-sized containments, see Assumption 6).

$$\begin{aligned}\text{Containment free volume} &= \text{free volume of wetwell} + \text{free volume of drywell} \\ &= 144,184 \text{ ft}^3 + 200,540 \text{ ft}^3 \\ &= 344,724 \text{ ft}^3 \cdot (12 \text{ in/ft})^3 \cdot (2.54 \text{ cm/in})^3 \\ &= 9.76\text{E}9 \text{ cm}^3\end{aligned}$$

$$\text{Mass of Hypalon jacketing (defined as N lbm below)} = 2.777\text{E}6 \text{ g} / 454 \text{ g/lbm} = 6,117 \text{ lbm}$$

The constants R-gamma and R-beta, found in cells H2 and I2 of the spread sheet, were calculated as shown below to fit the geometry of the Columbia cable insulation.

Proprietary information deleted.

Proprietary information deleted.

The output of the calculation with the Radiolysis of Cable model in the form of $[HCl]$ as a function of time is provided as Exhibit 2.

Proprietary information deleted.

Calculation of $[H^+]$ added to the pool

The net hydrogen ion concentration added to the pool is the sum of the Net $[OH^-]$ and $[HCl]$ shown as a function of time in Exhibit 1 and Exhibit 2, respectively. These data are combined in Table 2 below to give Net $[H^+]$ Added. The parenthetical values for Net $[H^+]$ Added mean that the values indicated are actually $[OH^-]$ since the amount of hydroxide in the Net $[OH^-]$ column exceeds the $[HCl]$. The Net $[OH^-]$ is taken from the first column of Exhibit 1, and is the $[OH^-]$ concentration in mol/L which results from the $[OH^-]$ from CsOH less the $[H^+]$ from initial pH, HI, and HNO_3 . Also shown in Table 2 is the hydrogen ion concentration, $[H^+]$ Added, due to $[HNO_3]$ and $[HCl]$ only (i.e., neglecting the $[OH^-]$ from CsOH).

Table 2. Calculation of $[H^+]$ added to pool

<u>Time</u>	<u>$[HNO_3]$</u>	Net <u>$[OH^-]$</u>	<u>$[HCl]$</u>	<u>$[H^+]$</u> <u>Added</u>	Net $[H^+]$ <u>Added</u>
1h	5.79E-6	1.17E-4	8.93E-6	1.47E-5	(1.08E-4)
2h	7.95E-6	1.15E-4	1.68E-5	2.48E-5	(9.82E-5)
5h	1.24E-5	1.11E-4	3.58E-5	4.82E-5	(7.52E-5)
12h	1.97E-5	1.03E-4	6.77E-5	8.74E-5	(3.53E-5)
1d	2.94E-5	9.37E-5	1.08E-4	1.37E-4	1.43E-5
3d	5.67E-5	6.63E-5	2.21E-4	2.78E-4	1.55E-4
10d	1.07E-4	1.56E-5	3.88E-4	4.95E-4	3.72E-4
20d	1.40E-4	(1.7E-5)	4.51E-4	5.91E-4	4.68E-4
30d	1.61E-4	(3.8E-5)	4.70E-4	6.31E-4	5.08E-4

Calculation of pH of the water pool

The inputs to the Add Acid model of the STARpH 1.04 code (Ref. 1) are the concentration in mol/L of the buffer, the dissociation constant of the buffer, and the starting pH.

Proprietary information deleted

The mass of sodium pentaborate in the SLCS is 4,062.8 lbm, or

$$454 \text{ g/lbm} \bullet 4,062.8 \text{ lbm} = 1.84E6 \text{ g.}$$

The molecular weight of sodium pentaborate ($Na_2O \bullet 5B_2O_3 \bullet 10H_2O$) with boron of natural enrichment is:

$$2 \times 22.990 + 10 \times 10.811 + 20 \times 1.008 + 26 \times 15.999 = 590 \text{ g/mol}$$

The moles of sodium pentaborate present are

$$1.84E6 \text{ g}/590 \text{ g/mol} = 3.12E3 \text{ mol.}$$

There are 10 moles of B per mole of sodium pentaborate, so there are

$$3.12E3 \times 10 = 3.12E4 \text{ mol of B.}$$

The concentration of B is

$$3.12\text{E}4 \text{ mol}/4.18\text{E}6 \text{ L} = 7.46\text{E}-3 \text{ mol/L}$$

where $4.18\text{E}6 \text{ L}$ is the volume of water in the containment pool.

Proprietary information deleted

For time points 1 hr and 2 hr, pH is indicated simply as >8.0 on the basis of Assumption 4. From 5 hours on, the effect of cesium is neglected and pH is obtained by applying the Table 2 $[\text{H}^+]$ Added column to Exhibit 3. The results are shown in Table 3.

Table 3. pH results vs. time

<u>Time</u>	<u>pH</u>
1h	>8.0
2h	>8.0
5h	8.6
12h	8.6
1d	8.5
3d	8.5
10d	8.4
20d	8.3
30d	8.3

Calculation of fraction of total boron necessary to maintain $\text{pH} \geq 7$

The Add Acid model was run in an iterative fashion to determine the fraction of total boron necessary to maintain $\text{pH} \geq 7$ over 30 days. Exhibit 4 is the STARpH result. It was found that 52% of the total boron available (i.e, a boron concentration (C1 on Exhibit 4) of $3.88\text{E}-3 \text{ mol/L}$) is necessary to maintain $\text{pH} \geq 7$ with the 30 day $[\text{H}^+]$ Added from Table 2 ($6.31\text{E}-4 \text{ mol/L}$).

Results and Conclusions

The pH of the containment water pool in the Columbia Generating Station decreases from 8.6 to 8.3 over 30 days following the release of fission products into the containment in a severe accident. However, 52% of the total boron available is necessary to maintain $\text{pH} \geq 7$ for 30 days.

Exhibit 1 Radiolysis of Water Input and Output

Input:

Output:

Exhibit 2 Radiolysis of Cable Input and Output

Input:

Output:

Exhibit 3 Add Acid Input and Output - Base Case

Input:

Output:

Exhibit 4 Add Acid Input and Output - Reduced Boron

Input:

Output:

CALCULATION TITLE PAGE

CALCULATION NUMBER: PSAT 206CT.QA.02.03

CALCULATION TITLE:

"Main Steam Line Break Accident Dose Analysis"

	<u>ORIGINATOR</u>		<u>CHECKER</u>		<u>IND REVIEWER</u>	
	<u>Print/Sign</u>	<u>Date</u>	<u>Print/Sign</u>	<u>Date</u>	<u>Print/Sign</u>	<u>Date</u>
REVISION: 0						
1						
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REASON FOR REVISION:

Nonconformance Rpt

0 - Initial Issue

N/A

1 – Revision 1:

N/A

1. Added Attachments 6 and 7 for dose from a trapped plume.
2. Added three additional purposes: one to clarify the dilution as a two-step process (initial expansion and entrainment followed by plume rise) and two others, one to treat releases from an intact turbine building (trapped plume) and the other to calculate offsite doses.
3. An outline of the trapped plume calculation and the offsite dose calculation was added to the Methodology section.
4. A discussion of a long-term (trapped plume) release case was added to Assumptions 7 and 8.
5. Assumption 11 was modified to refer to iodine spiking.
6. Added Assumption 13 and Reference 16.
7. A description of spiking was added to the CR Dose QA Calculation section.
8. Explanation of trapped activity fission product release was added.
9. STARDOSE model changed to use an intermediate control volume (ICV) explicitly and consistently (instead of using DW as surrogate).

10. Brief explanation of STARDOSE dose integration process added.
11. Explanation of trapped activity release and "puff" activity release (rising plume) added consistent with explanation of dose integration process.
12. Puff release X/Q changed from arbitrary $1\text{E-}2 \text{ sec/m}^3$ to $1.03\text{E-}4 \text{ sec/m}^3$ to be more physically realistic.
13. References [13] and [14] reversed to preserve order in which they are mentioned.
14. Attachment 6 explained in the section on the STARDOSE input file.
15. Attachment 7 and Table 3 added in section on CR Dose QA Results and Conclusions.
16. Statement added to clarify that no credit is being taken for filtered makeup or remote intakes.
17. Statement added to clarify that dose limit for CR is 5.0 rem TEDE.
18. Section on Offsite Dose QA Calculation and Offsite Dose QA Results and Conclusions added.
19. Misc editorial changes.

2 – Revision 2:

N/A

1. Attachment 7 eliminated
2. Moved trapped plume analysis from main body to Attachment 6.
3. Eliminated trapped plume analysis from purposes and other sections
4. Added Summary of Cases to Methodology section to clarify the various cases being addressed.
5. Modified assumptions to clarify that the primary case being calculated is direct release to environment and that the release via TBG is not appropriate for the licensing basis and is included for information only
6. Expanded Assumptions 1 and 2 to cover points specified in RG 1.183
7. Expanded Assumption 5 to clarify which CR intake is involved in the CR dose analysis
8. Added new assumption (Assumption 13) regarding CR isolation (and renumbered assumptions accordingly)
9. Modified Assumption 14 (formerly Assumption 13) to specify that the spiking factor of 20 is consistent with RG 1.183.
10. Made minor editorial corrections to references [5] and [9], renumbered references to reflect new order for reference [10], and eliminated reference [15] (now an assumption)
11. Added section on Design Input
12. Clarified flashing fraction equations
13. Divided subsection on Evaluate Bubble Rise into three subsections to further clarify and provide additional detail on the various cases being addressed
14. Provided bulleted format for explanation of Attachment 1 spreadsheet
15. Added a two bubble diameter calculation to Attachment 1, air entrainment in order to better allow illustration of the trend of the product of dilution and CR intake transit time
16. Clarified derivation of mixture gas constant
17. Added new Table (Table 1) to better illustrate the plume dilution results and the various cases being addressed
18. Included a parameter (product of dilution and transit time) which is a measure of dose and thus can be used to determine a bounding plume dilution and transit time for the QA dose calculation
19. Eliminated Table 3 with trapped dose results
20. Corrected Table 5 to show agreement with FSAR offsite dose

21. Corrected Tables 7 and 8 to reflect Table 5 result
22. Added last paragraph to show how RG 1.183 specifications for MSLB are satisfied

3 – Revision 3:

1. Footnote added to the design input table to indicate source of the breathing rate used to obtain the offsite doses.
2. New χ/Q values were obtained and used for the offsite dose calculations; they are $1.80\text{E-}04 \text{ sec/m}^3$ and $5.04\text{E-}05 \text{ sec/m}^3$ for the EAB and LPZ, respectively.
3. The offsite doses were recalculated using the new χ/Q values. Tables 7 and 8 were changed to include the results of the dose calculations.
4. Attachment 4 was changed to remove lines in STARDOSE input that implied that it was used to calculate offsite doses. In fact, no offsite doses were calculated with STARDOSE and no offsite doses are reported in Attachment 5.

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Attachment 1	Bubble Rise Velocity and Dilution for direct Atmosphere Release (2 pages)
Attachment 2	Bubble Rise Velocity and Dilution for Release via TGB (1 page)
Attachment 3	STARDOSE LIBFILE1 (1 page)
Attachment 4	Typical Plume Rise STARDOSE Input File (3 pages)
Attachment 5	STARDOSE Plume Rise Output File Excerpts (1 page)
Attachment 6	Analysis of MSLB CR Dose with Activity Trapped in Turbine Building – Two Hour Release (6 pages)
Appendix A	Non-Safety Calculation of Iodine Concentration at a Receptor from an MSLB Accident Using (Proprietary Information Deleted) (9 pages)
Appendix B	Non-Safety Computation of Iodine Concentration at a Receptor from an MSLB Accident Using (Proprietary Information Deleted) (12 pages)

Purpose

The purpose of this calculation is four-fold:

- (1) To perform a QA evaluation to determine the dilution in the superheated plume produced by the throttling of the steam released from the Columbia Generating Station main steam line break (MSLB) design basis accident (DBA) down to ambient;
- (2) To develop the QA dilution model further by adding dilution due to plume rise and expansion after a rapid release to the environment from the turbine-generator building (TGB);
- (3) To apply this dilution to control room (CR) dose and perform a QA dose analysis using Polestar's QA dose code STARDOSE; and
- (4) To perform a QA calculation of offsite doses.

These calculations are being performed in accordance with references [1] and [2]. The source term in the MSLB steam plume is that from the fission products (noble gas and iodine) in the coolant. The source term (Ci/m^3) to which the CR is exposed (and which must be applied to the dose calculation) will be reduced as the plume is diluted.

Methodology

Plume Dilution. For the plume dilution QA calculation, a Safety-Related methodology has been defined to address the effects of plume buoyancy and air entrainment, yet provide a simple, conservative approach which is a relatively modest departure from the traditional assumption of an undiluted steam plume transiting horizontally across the CR intake with no rise. The steps in the plume dilution Safety-Related methodology are as follows:

- Use Energy Northwest provided parameters for the MSLB DBA (i.e., mass of liquid-steam mixture released, timing of release, temperature of the liquid-steam mixture, noble gas and iodine concentration in the release) to obtain the initial conditions of the released steam plume; noting that the steam plume is treated as a bubble with a given transit time up to and across the CR intake.
- Evaluate the bubble rise
(Proprietary information deleted)
Quantify the effect of this rise on dilution.
- Evaluate ranges of air entrainment (from the friction due to the bubble rise in air) and the effect of this entrainment on dilution.

In addition, two non-Safety-Related calculations were performed to provide a diverse check on the safety-related result. These non-Safety-Related calculations are documented in Appendices A and B. The purpose of the diverse calculations is to confirm the suitability of the Safety-Related methodology and provide confidence in the conservatism of the Safety-related Result.

CR Dose. For the QA CR dose calculation, the primary transport pathway, and the one upon which the calculation result is based, is direct release to the environment. For completeness, a second transport pathway via the TGB is also considered (see Assumptions 7 and 8 for further discussion). For each transport pathway, a spherical

bubble and a hemispherical bubble are treated. Plume dilution is considered for both transport pathways. The STARDOSE DBA computer code [3,4] is used to determine CR dose for the MSLB DBA source term release. A STARDOSE LIBFILE1 was created with the curie inventories for the Columbia MSLB. The iodine isotopic coolant concentrations given in the FSAR are used as the source term (but with consideration, also, of the potential for iodine spiking). Also, a STARDOSE input file was prepared to represent exposure to the CR operator equivalent to that provided by the passing plume. This equivalency is provided if the STARDOSE source term release rate (Ci/sec), release duration, and Chi/Q (sec/m^3) are determined so that the integrated curie concentration ($\text{Ci}\cdot\text{sec}/\text{m}^3$) at the CR intake in STARDOSE is the same as the integrated curie concentration of the plume at the CR intake.

Offsite Dose. For the QA calculation the iodine isotopic coolant concentrations given in the FSAR are used as the source term (but with consideration, also, of the potential for iodine spiking). It is conservatively assumed, as was in the FSAR, that the only transport pathway is a direct release to the environment. (Proprietary information deleted.) New values of Chi/Q are used for atmospheric dispersion of the cloud being transported to the exclusion area boundary (EAB) and the low population zone (LPZ) boundary (as compared to the Chi/Q values in the current update of the FSAR).

Summary of Cases. The various transport pathways, bubble geometries, and plume dilutions being considered in the main body of this calculation are summarized as follows:

Dose Calculation	Transport Pathway	Bubble Geometry	Plume Dilution
CR	Direct to envir. (primary case – used for licensing basis)	Hemispherical, spherical	Dilution due to plume rise only, (both with and without air entrainment)
CR	Via TGB (secondary case for information – not for licensing basis)	Hemispherical, spherical	Pre-dilution in TGB, and dilution due to plume rise (without air entrainment)
Offsite	Direct to envir.	N/A	N/A

Assumptions

Plume Dilution

1. Assumption

The main steam isolation valve (MSIV) closure time will not exceed 6 seconds. The release of steam resulting from the MSLB (through blowout panels in the steam tunnel) is instantaneous. The mass of coolant released is the amount in the steam line and connecting lines at the time of the break plus the amount passing through the valves prior to closure.

Justification

The Columbia FSAR [5] states that the MSLB steam and liquid discharge is based on MSIVs closing in 6 seconds. Since this is the basis for the MSLB radiological licensing evaluation, it is reasonable to assume that this is the maximum allowed closure time.

This time duration is small compared to the exposure time of interest for the CR, and in any event it is conservative to assume instantaneous release.

The FSAR evaluation of mass released in the MSLB is based on the 6 second closure time and states that a steam-water mixture flows from the break until the MSIV has closed.

2. Assumption

The steam from the liquid-steam release (including the flashed steam) forms a steam bubble at ground level. All activity partitions with the steam and is well-mixed throughout the bubble. The liquid (containing no activity – a very conservative assumption) settles by gravity. Two bubble shapes (geometries), spherical and hemispherical, are considered.

Justification

The steam, due to its lower molecular weight and high temperature, will tend to displace, and form a bubble in, the surrounding air.

Proprietary information deleted.

Since the iodine is in solution and nearly all of it will tend to stay with the liquid, it is conservative to assume that all of the iodine activity partitions with the steam and becomes airborne. It is also assumed that the noble gas becomes airborne.

The well-mixed assumption is conservative since, in reality, the steam plume will be Gaussian distributed with higher activity concentrations toward the center. (Proprietary information deleted.)

The released liquid consists of large droplets from the blowdown that will settle quickly.

Two bubble geometries are considered primarily to show that the results are not particularly sensitive to bubble shape. Bubble geometry affects the transit time up to and across the CR intake, and affects the bubble rise and associated dilution. The dilution and associated dose results will be determined in a manner that is bounding for both bubble shapes.

3. Assumption

Proprietary information deleted.

Justification

4. Assumption Proprietary information deleted.

Justification Proprietary information deleted.

5. Assumption The bubble elevation, and thus the dilution due to the swept volume, is based on the rise that occurs during the time required for the leading edge of the bubble to transit up to the CR intake plus the time for the bubble to transit across the CR intake (one diameter). This transit time is based on the bubble moving with a horizontal velocity of 1 m/s. The bubble transits across only 1 CR intake (the normal CR intake which is closest to the release location).

Justification As discussed further in Assumptions 6, 7, and 8, and in the calculation text, the MSLB steam release occurs at some distance from the CR intake. Thus, for CR exposure to occur, the bubble must transit to the point where the leading edge of the bubble is at the CR intake. Similarly, the CR intake will continue to be exposed to the air with the source term until the trailing edge of the bubble passes the CR intake.

A horizontal velocity of 1 m/s is used based on the minimum wind speed in the Pasquill diffusion categories in reference [6]. It is noted however, that the CR dose is determined by the integrated source term concentration (i.e., $C_i\text{-sec/m}^3$) which is essentially independent of this horizontal velocity (i.e., decreasing (increasing) the horizontal velocity causes a corresponding increase (decrease) in bubble rise and dilution such that the integrated source term concentration remains essentially constant).

There are three CR intakes at Columbia. Per reference [8], two of these are remote, located away from the power block (400 feet or more from the MSLB release location described in Assumption 7). The third is the normal intake which is contiguous with the CR building. This is the CR intake closest to the MSLB release location and thus it is assumed that the bubble translates directly to the normal CR intake. This minimizes the effect of plume rise and associated dilution. The bubble diameter for the primary transport pathway is a maximum of 200 feet. Thus the bubble will only transit across the normal CR intake.

6. Assumption The dilution to be used in the dose calculation is taken as the average of the dilution at the time that the leading edge of the bubble arrives at the CR intake and the dilution at the time that the trailing edge of the bubble leaves the CR intake.

Justification

Depending upon the MSLB release location, the bubble starts its horizontal movement at some distance away from the CR intake, and is assumed to transit toward the CR intake at 1 m/s. Thus some bubble rise, and associated dilution which is proportional to the vertically swept volume, will occur prior to the bubble arriving at the CR intake. The bubble will continue to rise, with associated dilution, as it transits across the CR intake (a distance of one bubble diameter). The average of the dilution at the time the bubble leading edge starts across the CR intake and the dilution at the time the bubble trailing edge just leaves the CR intake provides the effective dilution during the period of CR exposure.

7. Assumption

As noted in the CR Dose portion of the Methodology section, the primary release location (transport pathway), and that upon which the final QA results are based, is direct release to the environment. Release via the TGB (with brief confinement in the TGB) has also been considered.

Justification

Release directly to the environment is consistent with RG 1.183 which states that for MSLB, all the radioactivity in the released coolant should be assumed to be released to the atmosphere instantaneously. This is also consistent with what would be expected for the MSLB at Columbia based on the following.

Per reference [7], with the MSLB in the steam tunnel or tunnel extension (located in the reactor building (RB)), there are three blowout panels that are designed to vent to prevent overpressurization. Panels A and C at the north end of the tunnel vent into the TGB. Panel B at the east end vents directly to the atmosphere by way of another blow-out panel (Panel D). Thus there is roughly equal probability that the release will vent directly to the atmosphere on the east side of the RB (consistent with the assumption) or into the TGB.

Proprietary information deleted.

Release via the TGB with brief confinement has also been considered and is discussed further in Assumption 8. This is not, however, considered appropriate for the licensing basis and is included only for completeness.

8. Assumption

For release into the TGB, there are two cases considered in the main body of this calculation. One is that the TGB fails such that it in effect provides no confinement to the steam plume, similar to a release directly to the atmosphere. This is the primary release path

and is addressed by the release directly to the atmosphere noted in Assumption 7. The other case is where the TGB tends to briefly confine the plume, with release from the TGB at one or more specific failure locations. In this latter case, it is assumed that the steam plume mixes with the air in the TGB prior to release from the TGB.

Justification

Per the TGB outline on reference [8], the TBG is about $9.6E6 \text{ ft}^3$ in total volume. Assuming that the TGB remains largely intact and tends to briefly confine the steam plume as it is vented through blowout panels A and C, the plume will mix rapidly with the surrounding air in the TGB due to entrainment and density driven exchange. Thus the release to the atmosphere from the TGB will be a mixture of air and steam. To account for isolated volumes in the TGB and displacement of TGB air at the time of venting into the TGB, the mixing is assumed to involve only half of the TGB volume, i.e., the mixture released from the TGB is the steam volume plus approximately 50% of the TGB volume.

In addition to this brief confinement case, a third case for release into the TGB has been assessed in which the confinement is even longer and where the building failure occurs low in the structure, releasing air instead of steam and activity. In such a case, the trapped activity would be released at a lower rate, and the atmospheric dispersion would be characterized by normal atmospheric mixing without a steam bubble or plume rise. While this lower release case is viewed as extremely unlikely and (like the brief confinement case) is not considered appropriate for use in the licensing basis, it has been included for information in Attachment 6.

9. Assumption

For the air entrainment cases, the amount of air entrainment in the bubble is treated as a constant as the bubble rises.

Justification

In reality, the bubble is a transient, puff problem and will entrain increasing amounts of air as it is released and as it rises. This is addressed in Appendices A and B which are non-Safety-Related calculations that model the puff release in a detailed, mechanistic manner. For the purpose of the QA calculation, treating the amount of air entrainment as a constant is acceptable since the purpose of the air entrainment evaluation is simply to establish in the QA calculation that for increasing initial air entrainment the effective dilution increases.

10. Assumption

The steam-air mixture may be treated as a perfect gas.

Justification

The perfect gas assumption is very reasonable for low pressure, high temperature gases where there are minimal interaction forces between gas molecules. This is the case for the steam-air mixture.

CR Dose

11. Assumption

The fission product inventory available for release is based on the equilibrium activity in the coolant which is allowed by the

Columbia Technical Specification. For this calculation, this equilibrium level is increased by a factor of 20.

Justification

Per reference [9], the only activity available for release from the MSLB is that present in the reactor coolant and steam lines prior to the break. This is consistent with the Technical Specifications as stated in reference [9]. However, consistent with reference [10], an increase by a factor of 20 will be included to take into account iodine spiking. This differs from the analysis presented in reference [9].

12. Assumption

The fission product release and other input parameters in STARDOSE are determined such that the integrated activity concentration at the CR intake is equal to the integrated activity concentration of the passing plume.

Justification

If the STARDOSE integrated activity concentration ($C_i\text{-sec/m}^3$) at the CR intake is equal to the actual integrated activity concentration which results from the MSLB release together with the plume dilution calculation, then the CR operators will be exposed to the correct source term.

13. Assumption

For the CR MSLB dose calculation, no credit is taken for isolation and filtration of CR supply air.

Justification

The bubble transit time could be less than 1 minute. While the CR would be expected to be isolated in less than 1 minute for an MSLB, for conservatism no credit has been taken for isolation and filtration. Only unfiltered inleakage is considered.

Offsite Dose

14. Assumption

The fission product inventory available for release is based on the equilibrium activity in the coolant which is allowed by the Columbia Technical Specification. For this calculation, this equilibrium level is increased by a factor of 20.

Justification

Per reference [9], the only activity available for release from the MSLB is that present in the reactor coolant and steam lines prior to the break. This is consistent with the Technical Specifications as stated in reference [9]. However, an increase by a factor of 20 will be included to take into account iodine spiking. While this differs from the analysis presented in reference [9], it is consistent with the latest NRC guidance for MSLB associated with AST in reference [10].

15. Assumption

Offsite dose assumes a direct unfiltered release to the environment and does not consider the effects of plume dilution due to buoyancy.

Justification

This is based on the FSAR methodology which assumes a direct unfiltered release to the environment. The FSAR also does not consider the effects of plume dilution due to buoyancy. Both of

these assumptions are conservative, and simplify the analysis.
Resulting doses have significant margin to dose limits.

References

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3. Polestar Applied Technology, Inc. "STARDOSE Validation Report," PSAT CI09.05, Rev. 0.
4. Polestar Applied Technology, Inc. "STARDOSE Users Manual," PSAT CI09.06, Rev. 0.
5. Columbia Generating Station Final Safety Analysis Report (WNP-2 FSAR), Amendment 53, Section 15.6.4.4 (page 15.6-7), November, 1998.
6. U.S. NRC, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Boiling Water Reactors," Regulatory Guide 1.3, Rev. 2, June, 1974.
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8. Columbia Generating Station, Chi/Q Values for Control Room Intake Using ARCON 96, File No. 19030-M-06, Rev. 1, Page 12.
9. Columbia Generating Station FSAR, Amendment 53, Section 15.6.4.5, November 1998.
10. U.S. NRC, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors," Regulatory Guide 1.183, July, 2000.
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15. K. Eckerman et al, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion", Federal Guidance Report No. 11, DE89-011065, Oak Ridge National Laboratory, Oak Ridge, TN, 1988, page 136.

Design Input

The Columbia design input used for this calculation is as follows:

Columbia Design Input Parameter	Parameter Value	Basis
Maximum time for MSIV closure	6 sec	Ref. [5]
Approx. volume of TGB	9.5E5 ft ³	Ref. [8]
Liquid release from MSLB	105,000 lbm	Ref. [5]
Steam release from MSLB	25,000 lmb	Ref. [5]
RCS pressure	1060 psia (552 F)	Ref. [5]
Blowout panel locations for MSLB	Panels A and C (N. end of tunnel) and B and D (E. end of tunnel)	Ref. [7]
Dist. from MSLB release point to CR intake for Panels B and D	300 ft	Ref. [8]
Dist. from MSLB release point to CR intake for Panels A and C	200 ft	Ref. [8]
Bubble transit velocity	1 m/s	Ref. [6]
Approx. TGB perimeter	1080 ft.	Ref. [8]
Approx. perpendicular dist. of CR intake from TGB	50 ft.	Ref. [8]
Coolant iodine inventories	See Table 2	Ref. [9]
Iodine spiking factor	20	Ref. [10]
Noble gas inventories	See Attachment 3	Ref. [9]
Radioactivity release rate to environment	Instantaneous	Ref. [10]
Vol. of CR	214,000 ft ³	Ref. [14]
CR occupancy factor	1	Ref. [14]
CR unfiltered inleakage	4 cases per Table 3	Ref. [14]
CR Breathing Rate	3.5E-4	Ref. [14]
EAB distance	1950 m	Ref. [9]
LPZ distance	4827 m	Ref. [9]
Chi/Q, EAB	1.7E-4 sec/m ³	Ref. [14]
Chi/Q, LPZ	5.6E-5 sec/m ³	Ref. [14]
Offsite Breathing Rate*	3.47E-4 m ³ /s	Ref. [6]
Dose Conversion Factors	See Table 6	Ref. [10]

*This breathing rate is used in lieu of the value in Reference 10 because the offsite dose results are scaled from the current Reference 6-based values.

Plume Dilution QA Calculation

Evaluate Initial Conditions of Steam Release Per reference [5], the liquid-steam mixture is released over a period of ~6 seconds (assumed to be instantaneous per Assumption 1), 105,000 lbm as liquid and 25,000 lbm as steam, and the RCS pressure is 1060 psia. The temperature of the liquid-steam mixture at the time of the release to ambient is the saturation temperature corresponding to 1060 psia which is 552 F. Since the liquid is superheated at ambient pressure, some of this liquid will flash to steam. Per Assumption 2, the steam will form a bubble, and the unflashed liquid will settle by gravity.

Performing an energy balance to determine the flashing fraction,

$$mh = m_g h_g + m_l h_l$$

where m = initial liquid mass (lbm)
 h = initial liquid enthalpy (Btu/lbm)
 m_g = flashed steam mass (lbm)
 h_g = flashed steam enthalpy (Btu/lbm)
 m_l = unflashed liquid mass (lbm)
 h_l = unflashed liquid enthalpy (Btu/lbm)

and the unflashed liquid and flashed steam are at atmospheric pressure and saturation temperature corresponding to atmospheric pressure (212 F).

The flashing fraction, ff , is

$$\begin{aligned} ff &= m_g/m = (mh - m_l h_l)/m/h_g \\ &= (h - m_l h_l/m)/h_g \end{aligned}$$

Since

$$m_l/m = (m - m_g)/m = 1 - ff$$

we have

$$ff = (h - (1 - ff)h_l)/h_g$$

Thus,

$$ff = (h - h_l)/(h_g - h_l)$$

Using the steam tables,

$$h(552 \text{ F}) = 552 \text{ Btu/lbm}$$

$$h_l(212 \text{ F}) = 180.2 \text{ Btu/lb}$$

$$h_g(212 \text{ F}) = 1150.5 \text{ Btu/lb}$$

Thus,

$$ff = (552 - 180.2)/(1150.5 - 180.2)$$

$$= 0.383$$

Thus, the mass of flashed steam is $m_g = 0.383 \times 105,000 = 4.02\text{E}4$ lbm, and the total steam mass (i.e., initial bubble mass) is $25,000 + 4.02\text{E}4 = 6.52\text{E}4$ lbm.

The temperature of the mixture of released steam at 552 F and flashed steam at 212 F is

$$T_b = (4.02\text{E}4 \times 212 + 25000 \times 552) / 6.52\text{E}4 = 342 \text{ F}$$

$$= 802 \text{ R}$$

The initial volume of the bubble (pure steam) is

$$V = 6.52\text{E}4 \text{ lbm} / \rho_s \quad (1)$$

where $\rho_s = 0.0311 \text{ lbm/ft}^3$ (steam density at 802 R). Thus,

$$V = 2.1\text{E}6 \text{ ft}^3 = 5.95\text{E}4 \text{ m}^3$$

Per Assumption 2, two bubble geometries (spherical and hemispherical) are considered here to provide confidence that the result is not particularly sensitive to bubble geometry. A hemispherical bubble will have radius

$$r_h^3 = 2r_s^3$$

where r_s = radius of a sphere of equivalent volume. Thus,

$$r_h = 1.26r_s \quad (2)$$

Use of these radii is discussed further below.

Evaluate Bubble Rise – Release Direct to Environment, No Air Entrainment. The spreadsheet shown in Attachment 1 is to evaluate bubble upward velocity and associated plume dilution for the CR dose calculation with transport pathway direct to environment. The release direct to environment is the primary case for this QA calculation as discussed in Assumption 7. Both no air entrainment and air entrainment cases are considered in Attachment 1. The no air entrainment cases (first two rows) are discussed here. The air entrainment cases bottom 20 rows) are discussed below.

The bubble rise is caused by buoyancy. The expression for buoyancy force, due to the density difference between ambient air and the hot bubble (all steam for the no air entrainment rows), is taken from reference [11] and is

$$F_b = 144 p V (1 / R_a T_a - 1 / R_b T_b) \quad (3)$$

where p = ambient pressure (psia)

V = bubble volume (ft^3)

R_a = gas constant for air

T_a = temperature of ambient air (R)

R_b = gas constant for gas in bubble

T_b = temperature of bubble (R)

Proprietary information deleted.

The dilution due to bubble rise is based on Assumptions 4 and 5. The swept volume as the bubble rises is just a cylinder with the diameter of the bubble and a height equal to bubble elevation. The dilution D (actually the reciprocal of dilution) is expressed as the initial (pure steam) bubble volume divided by the swept volume, i.e.,

$$D = (6.52E4/\rho_s)/(\pi r^2 vt) \quad (5)$$

where v = bubble rise velocity
 t = bubble transit time.

The transit time up to the CR intake (first no air entrainment row) is

$$t = d/(1 \text{ m/s} * 3.28 \text{ ft/m}) \text{ seconds} \quad (6)$$

where d = distance from leading edge of bubble at release location to CR intake (ft)

To evaluate d , the two plume release locations of Assumption 7 have been considered. For release directly to the atmosphere (Attachment 1), the release could be either from Panels B and D eastward from the RB or could be northward from Panels A or C based on the TGB not remaining intact and providing little or no plume confinement (see Assumption 7). If upon release the edge of the bubble were to be tangent to the eastward release point, from reference [8] the distance from the bubble leading edge to the CR intake would be ~300 feet. Also, if upon release the edge of the bubble were to be tangent to the northward release point, from reference [8] the distance from the bubble leading edge to the CR intake would be of the order of 200 ft. Thus one bubble diameter is used to provide a conservative (small) value of d in Attachment 1 for transit of the leading edge of the bubble up to the CR intake. Thus, we have

$$d = 2 \times \text{bubble radius}$$

and from equation (6), the first no air entrainment row has hemispherical bubble transit time of

$$t = 2 \times 100/3.28 = 61 \text{ sec} \quad (6a)$$

Also from equation (6), the first no air entrainment row has spherical bubble transit time of

$$t = 2 \times 79.4/3.28 = 48 \text{ sec} \quad (6b)$$

Based on Assumption 6, the transit time up to and across the CR intake (second no air entrainment row) must be determined. This is

$$t = (4 \times \text{bubble radius}) / (1 \text{ m/s} \times 3.28 \text{ ft/m}) \text{ seconds} \quad (7)$$

since the total distance of bubble travel is equal to

$$d + \text{one bubble diameter} = 4 \times \text{bubble radius}$$

Thus, from equation (7), the second no air entrainment row has hemispherical bubble transit time of

$$t = 4 \times 100/3.28 = 122 \text{ sec} \quad (7a)$$

Also from equation (7), the first no air entrainment row has spherical bubble transit time of

$$t = 4 \times 79.4/3.28 = 97 \text{ sec} \quad (7b)$$

Thus, the columns of the Attachment 1 no air entrainment cases are as follows:

- Column 1 is the bubble volume multiplier to account for the effect of air entrainment on bubble volume. The bubble volume multiplier in column 1 is unity for the Attachment 1 no air entrainment cases (pure steam bubble).
- Column 2, the bubble volume, is equal to the volume from equation (1) multiplied by the column 1 volume multiplier.
- Column 3 is the bubble radius, assuming a spherical shape.
- Column 4 is the bubble radius assuming a hemispherical shape. This radius is calculated per equation (2).
- Column 5 is the mole fraction of steam, and is unity for the no air entrainment cases and is just the ratio of initial (pure steam) volume to total volume for the air entrainment cases.
- Column 6 is the bubble temperature, and is 802 R as calculated above.
- Column 7 is the gas constant, and is just that of steam for the no air entrainment cases.
- Column 8 is the product of temperature and gas constant.
- Column 9 calculates the buoyancy force based on equation (3).
- Column 10 calculates velocity based on equation (4) for a hemispherical bubble.

- Column 11 is the hemispherical bubble transit time, and is based on equations (6a) and (7a).
- Column 12 is the dilution due to bubble rise for the hemispherical bubble based on equation (5).
- Column 13 calculates velocity based on equation (4) for a spherical bubble.
- Column 14 is the spherical bubble transit time, and is based on equations (6b) and (7b).
- Column 15 is the dilution due to bubble rise for the spherical bubble based on equation (5).

Evaluate Bubble Rise – Release Direct to Environment, With Air Entrainment. In the Attachment 1 air entrainment cases (i.e., the bottom 20 rows), per Assumption 9 the effect of air entrainment is approximated by adding an amount of air to the bubble and determining the dilution. With air entrainment, the bubble upward velocity is reduced (due to cooling of and additional weight in the bubble from the air) thus reducing the bubble elevation and associated dilution. On the other hand, the entrained air increases bubble volume which tends to compensate for the reduced elevation.

In Attachment 1, progressively increasing amounts of air entrainment have been considered in the successive rows as evident from column 1. For example, the first row in the Air Entrainment Cases increases bubble volume by 10% (i.e., the bubble is 10 parts steam (by volume) at 802 R and 1 part air at 528 R). Since mole fraction is just equal to volume fraction, the mole fraction steam shown in column 5 is just

$$2.10\text{E}6/(1.1*2.10\text{E}6) = 0.91$$

The second row increases bubble volume by 20% (i.e., the bubble is 10 parts steam (by volume) at 802 R and 2 parts air at 528 R). Since mole fraction is just equal to volume fraction, the mole fraction steam is just

$$2.10\text{E}6/(1.2*2.10\text{E}6) = 0.83$$

These increases continue down through the 20th air entrainment row where volume is increased to 10 parts steam and 20 parts air, and the steam mole fraction is

$$2.10\text{E}6/(3*2.10\text{E}6) = 0.33$$

Note that columns 2, 3, and 4 for the air entrainment rows are based on the same equations as for the no air entrainment rows.

The evaluation of columns 6 to 8 for the air entrainment rows is based on treating the steam-air mixture as a perfect gas (Assumption 10). The mixture temperature may be calculated from the equation of state for a perfect gas:

$$PV = n\mathcal{R}T$$

where P = pressure
 V = volume
 n = number of moles of gas
 \mathcal{R} = universal gas constant
 T = temperature

With a mixture of two gases,

$$P = P_1 + P_2 = (n_1 \mathcal{R}T_1 + n_2 \mathcal{R}T_2)/V = n\mathcal{R}T/V$$

or

$$T = (n_1 T_1 + n_2 T_2)/n \quad (8)$$

Thus the mixture temperature is the mole-weighted temperature. Equation (8) is the expression used in column 6.

The mixture gas constant may be calculated as follows:

$$PV = n\mathcal{R}T$$

Noting that $R = \mathcal{R}/M$ where R is the gas constant for a particular gas and M is the molecular weight for this gas, we have

$$P = nMRT/V$$

Noting that the mass of the gas is nM , we have

$$\rho = nM/V$$

$$P/\rho = RT$$

$$\rho = P/(RT)$$

where ρ = gas density

With a mixture of two gases,

$$\rho = \rho_1 + \rho_2 = (n_1 M_1 + n_2 M_2)/V$$

Thus

$$nM/V = (n_1 M_1 + n_2 M_2)/V$$

and

$$nM = n_1 M_1 + n_2 M_2$$

$$M = n_1 M_1/n + n_2 M_2/n$$

Noting that $R = \mathcal{R}/M$, we have

$$R = \mathcal{R}/(n_1 M_1/n + n_2 M_2/n) \quad (9)$$

Thus the mixture gas constant is the universal gas constant divided by the mole-weighted molecular weight. Equation (9) is the expression used in column 7. Column 8 is just the product of columns 6 and 7.

Columns 9 to 15 for the air entrainment rows are based on the same equations as the no air entrainment rows.

Evaluate Bubble Rise – Release Via TGB The spreadsheet shown in Attachment 2 is to evaluate bubble upward velocity and associated plume dilution for the CR dose calculation with transport pathway via the TGB. There is brief holdup and mixing in the TGB as noted in Assumption 8. That is, it is assumed that the vented steam mixes with the TGB air prior to release from the TGB itself. Thus the release via the TGB is pre-diluted (see Methodology section). There is also dilution due to plume rise as in Attachment 1, but no air entrainment is assumed for the release via TGB. As noted in the Methodology section and discussed in Assumption 7, this transport pathway evaluation is provided for completeness and is not considered appropriate for use in the licensing basis.

In Attachment 2, there are two rows: one for transit up to the CR intake, and one for transit up to and across the CR intake. The columns of Attachment 2 use similar input and equations as the last air entrainment row of Attachment 1:

- The bubble volume multiplier in column 1 is based on Assumption 8. That is, the bubble volume is

$$0.5 \times 9.6\text{E}6 \text{ ft}^3 + 2.1\text{E}6 \text{ ft}^3 = 6.9\text{E}6 \text{ ft}^3$$

Thus the bubble volume multiplier is

$$\text{Vol multiplier} = 6.9\text{E}6 / 2.1\text{E}6 = \sim 3.0$$

This is identical to the last row of the Attachment 1 air entrainment case which has a bubble volume multiplier of 3.

- Columns 2 to 10 and column 13 in Attachment 2 are identical to Columns 2 to 10 and column 13 in the last air entrainment row of Attachment 1.
- To obtain column 11 (hemispherical bubble transit times), it is assumed that there is brief confinement of the plume in the TGB prior to failure of the TGB and release to the environment. In this case, the TGB overpressure failure location is judged equally likely at any point around the perimeter of the TGB. From reference [8], the closest location on the TGB perimeter to the CR intake would be the west half of the south side. Noting that the TGB perimeter is approximately $2 \times 310 + 2 \times 230 = 1080 \text{ ft}$. and taking the 10% of the TGB perimeter (i.e., $\sim 108 \text{ ft}$) that is closest to the CR intake, and noting from reference [8] that the CR intake is a distance of $\sim 50 \text{ ft}$ on the perpendicular from the TGB wall, the distance d will be

$$d = \sqrt{50^2 + 54^2} = 73.6 \text{ ft}$$

Thus there is 90% confidence that $d \geq 73.6 \text{ ft}$., and 73.6 ft . is taken as a reasonably conservative value for d . From equation (6), the first row in Attachment 2 (transit of leading edge of the bubble up to CR intake) has transit time (column 11) of

$$t = 73.6 / 3.28 = 22 \text{ seconds}$$

The transit time for the second row in Attachment 2 (transit of bubble up to and across CR intake) is the sum of d and $2 \times$ bubble radius and for the hemisphere is

$$t = (d + 2 \times 144.3) / 3.28 = 110 \text{ seconds}$$

To obtain column 14 (spherical bubble transit times), the same approach as above is used except bubble radius is 118 ft. Thus for transit of leading edge of the bubble up to CR intake (first row), the transit time is

$$t = 73.6/3.28 = 22 \text{ seconds}$$

For transit of leading edge of the bubble up to and across the CR intake (second row), the transit time is

$$t = (d + 2 \times 114.5)/3.28 = 92 \text{ seconds}$$

- Columns 12 and 15, hemispherical and spherical bubble dilution respectively, use the same equations as Attachment 1.

Plume Dilution QA Results

The plume dilution results for D (see equation (5)) are calculated in the dilution columns of Attachments 1 and 2 (columns 12 (hemispherical bubble) and 15 (spherical bubble)). Based on Assumption 6, the value of plume dilution to be used in the dose calculation is the average of the two values for transit of the leading edge up to the CR intake, and transit of the leading edge up to and across the CR intake.

It is also noted that per Assumption 12, the maximum integrated activity concentration at the CR intake ($C_i\text{-sec}/\text{m}^3$) will give the maximum dose. Given a fixed amount of activity released, this integrated activity concentration is just proportional to the product of the plume dilution and the bubble transit time across the CR intake. Thus this number is a measure of what the dose would be using the associated plume dilution and transit time.

From Attachments 1 and 2, the results are given in Table 1. Based on the Methodology section and Assumption 7, the licensing basis is to be based on the direct release to environment. As is evident from Table 1, the first row (no air entrainment) is the most conservative direct release case. A plume dilution of 0.1 will be applied to the QA dose calculation which provides some margin for this case. In addition, the maximum bubble transit time (61 sec) for the direct release, no air entrainment case will be used. This gives a product of 6.1 which will yield a dose result that bounds all cases from Table 1.

Table 1 Results of Plume Dilution Calculation

	Plume Dilution (a)		Bubble Transit Time (b)		(a) x (b)	
	Hemisph. Bubble	Spher. Bubble	Hemisph. Bubble	Spher. Bubble	Hemisph. Bubble	Spher. Bubble
Direct Rel. to Environment, no air entrainment (average of rows 1 and 2, Attach. 1)	0.05	0.08	61 s.	48 s.	3.1	3.8
Direct Rel. to Environment, with air entrainment (based on first row of Attach. 1 air entrainment cases with bubble vol. multiplier of 1.1)	0.045	0.075	63 s.	50 s.	2.8	3.75
Direct Rel. to Environment, with air entrainment (based on Attach. 1 air entrainment cases with bubble vol. multiplier of 2)	0.03	0.045	77 s.	61 s.	2.3	2.7
Release via TGB (average of rows 1 and 2, Attach. 2)	0.065	0.085	88 s.	70 s.	5.7	5.9

CR Dose QA Calculation

Fission Product Inventory The fission product inventory available for release for the MSLB DBA is determined from the section in the Columbia FSAR addressing the radiological consequences of the MSLB [9]. Based on Assumption 11, the curie inventories for the iodine isotopes are the product of the Technical Specification coolant activity concentration and the coolant liquid release from the break (105,000 lbm). Thus the coolant fission product inventories may be calculated as activity in $\mu\text{Ci/gm} \times 105,000 \text{ lbm} \times 454 \text{ gm/lbm}$. The resulting coolant isotopic activities (Ci) appear to be ~2% less than the reference [9], Table 15.6-7 numbers. (Note: it is assumed in this work that the FSAR Table 15.6-7 exponents for iodine isotopes are in error and that the total iodine release is 177 Ci. This would be 9.5 Ci I-131 equivalent ($0.2 \mu\text{Ci/gm} \times 105,000 \text{ lbm} \times 454 \text{ gm/lbm}$), although each iodine isotope is explicitly considered in STARDOSE so the I-131 dose equivalent is not used.)

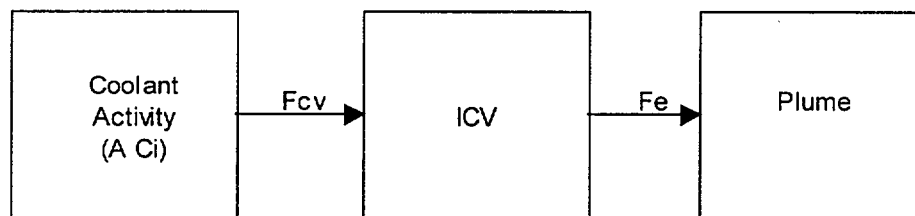
As noted in Assumption 14, there is a point of departure in this calculation relative to the calculation reported in reference [9], and that is the issue of iodine spiking. Reference [10] requires that iodine spiking be considered for analysis of MSLB dose at a value 20 times greater than the $0.2 \mu\text{Ci/gm}$ value from reference [9]. While the offsite dose limits from reference [10] for MSLB without iodine spiking are a factor of 10 lower than the corresponding limits with spiking, the factor of 20 increase in activity outweighs the more favorable offsite dose limits by a factor of two. Moreover, for the CR dose, the limit for both cases is the same. Therefore, it is clear that the case with spiking is more limiting than the case without spiking, and only the spiking case will be analyzed here. The Table 15.6-7 numbers multiplied by a factor of 20 (for iodine only, equivalent to $4 \mu\text{Ci/gm}$) will be used for conservatism and are listed in Table 2.

Table 2 Coolant Iodine Inventories for STARDOSE Calculation

Iodine Isotope	Coolant Activity ($\mu\text{Ci/gm}$)	Coolant F.P. Inventory (Ci)
I-131	0.08×20	78
I-132	0.74×20	720
I-133	0.55×20	534
I-134	1.50×20	1434
I-135	0.80×20	780

The coolant fission product inventories for noble gases are taken from Table 15.6-7 of reference [9] and, along with the above iodine inventories, are listed in the STARDOSE LIBFILE1 file (Attachment 3).

Fission Product Release The purpose of this subsection is to determine the STARDOSE model for fission product release which will provide a release equivalent to that from the diluted plume in terms of STARDOSE inputs. The results of this subsection are then used in the subsequent subsection to define the STARDOSE input file. STARDOSE fission product release is determined based on Assumption 12 and is illustrated in Figure 1 below. The STARDOSE input file (typical for four values of control room unfiltered inleakage as specified in reference [14], item 3.15) is Attachment 4 for cases involving buoyant plume rise. The MSLB release (100% of the coolant activity) is defined in the input file block called "core" and is released to an intermediate control volume (ICV). An intermediate volume is used in STARDOSE as a means of transporting the fission product activity from the "core" to the environment (i.e., the plume). Thus in the STARDOSE input file, leakage from ICV to the environment creates the plume.

Figure 1 STARDOSE Model for Fission Product Release

In the STARDOSE code (as in most dose codes), the release is assumed to be continuous from a given start time to a given end time (a "time-step"). The concentration at the receptor over the same time step is assumed to be instantaneously equal to the product of the source rate, S_e , times the Chi/Q (the dispersion parameter). The time-integrated activity concentration at that receptor location is then simply the concentration times the length of the time-step.

To model what is in effect a "puff" release to the environment, the release period must be extended to cover the duration of the plume passage over the control room. The dilution

is determined from the initial volume of the bubble and the minimum factor of ten greater dilution due to plume rise (see Plume Dilution QA Results section). Also as noted in this section, 61 sec is used for bubble transit time across the CR intake. Therefore, the effective dilution rate (Q/Chi) is

$$Q/Chi = (V = 5.95E4 \text{ m}^3)(10)/61 \text{ seconds} = 9754 \text{ m}^3/\text{sec}$$

$$\text{And } Chi/Q = 1.03E-4 \text{ sec/m}^3.$$

Based on Assumption 12,

$$S_e Chi/Q = C_p D Ci/m^3 \quad (10)$$

where S_e = source from ICV to the environment (Ci/sec)

$Chi/Q = Ci/m^3$ at the CR intake per Ci/sec released (sec/m³)

C_p = fission product concentration in the plume with no dilution (Ci/m³)

D = dilution of the plume (i.e., fission product concentration in diluted plume is $D \times C_p$)

With the given value for Chi/Q , one can let equation (10) determine S_e . Thus,

$$Chi/Q = 1.03E-4 \text{ sec/m}^3 \quad (11)$$

and

$$S_e = 9754 C_p D \text{ Ci/sec}$$

Defining A as the total coolant activity and F_e as the fraction of total coolant activity released to the environment per second, we have

$$F_e = S_e/A = 9754 (C_p/A) D \text{ sec}^{-1} \quad (12)$$

where C_p/A is the fraction of total coolant activity per unit volume in the plume without dilution. Since 100% of the coolant activity is released to the environment essentially instantaneously,

$$C_p/A = 1/V \text{ m}^{-3} \quad (13)$$

where V = plume (bubble) volume (m³)

To achieve a given value of F_e released from the ICV in the STARDOSE calculation, F_e is expressed in terms of STARDOSE input parameters. Assuming activity A in volume ICV, we have

$$S_e = AF_e = A\dot{V}_{CV} / V_{CV} / 60 \text{ Ci/sec}$$

where V_{CV} = ICV volume (ft³)

\dot{V}_{CV} = Volumetric flow from the ICV (cfm)

The parameters V_{CV} and \dot{V}_{CV} are STARDOSE inputs. Thus we have

$$F_e = \dot{V}_{CV} / V_{CV} / 60 \text{ sec}^{-1} \quad (14)$$

To maintain activity level A in the ICV in the STARDOSE calculation for the duration of plume transit across the CR intake, a source into the ICV must be defined. This source consists of two parts: (1) a puff which loads the ICV with A Ci essentially instantaneously, and (2) a constant source $F_{CV} \text{ sec}^{-1}$ which maintains activity level A Ci for the 61 second duration of the plume transit across the CR intake. Since the ICV is being depleted at a rate $F_e \text{ sec}^{-1}$, $F_{CV} = F_e$.

We can arbitrarily select a value for V_{CV} and let equation (14) determine \dot{V}_{CV} . Thus,

$$V_{CV} = 1 \text{ ft}^3 \quad (15)$$

and

$$\dot{V}_{CV} = 60 F_{CV} \text{ cfm} \quad (16)$$

STARDOSE Input File Referring now to the STARDOSE input file, Attachment 4, the source into the ICV is defined in the input block entitled "core". The puff is represented by a fractional release of 6000 hr^{-1} for a period of $1.667\text{E-}4 \text{ hr}$ (0.6 sec); i.e.,

$$(6000)(1.667\text{E-}4) = 1.0.$$

Since $F_{CV} = F_e$, the constant source F_{CV} can be determined from equations (12) and (13). Using the result of $D = 0.1$ from the plume dilution result above, and noting from the plume dilution calculation section that the plume volume is $5.95\text{E}4 \text{ m}^3$,

$$\begin{aligned} F_{CV} &= 9754 \times (1/5.95\text{E}4) \times 0.1 \\ &= 0.0164 \text{ sec}^{-1} \\ &= 59 \text{ hr}^{-1} \end{aligned}$$

This source exists for the duration of the transit time of the plume across the CR intake. The ICV input block has air volume from equation (15). The CR input block has air volume from reference [14], item 3.5. Per reference [14], item 3.17, the CR recirculation filter system is not credited. The ICV to environment junction has a flow from equation (16),

$$\dot{V}_{CV} = 60 F_{CV} = 0.984 \text{ cfm}$$

As is the case for the source, this flow exists from the time of the puff until the end of the transit time (61 seconds). The CR Chi/Q is $1.03\text{E-}4$ per equation (11). The environment to CR junctions are defined per reference [14], items 3.15 and 4.2. Per Assumption 13, CR isolation does not occur for the MSLB accident.

CR Dose QA Results and Conclusions

Attachment 5 contains the STARDOSE CR dose results for the QA plume dilution and transit time. A range of CR unfiltered inleakages have been considered per reference [14], item 3.15. No credit is taken for filtered makeup. Dose conversion factors are based

on reference [15] which is consistent with reference [10]. The results are summarized in Table 3.

The doses in Table 3 include the effect of iodine spiking. To obtain non-spiking doses, the results may be divided by a factor of 20. While dividing by 20 will understate the noble gas contribution, the noble gas contribution is small even to the whole body dose (less than one percent, typically) and is essentially zero to the TEDE.

Table 3 CR Dose Results – Plume Rise – Spiking Considered

CR unfiltered inleakage (cfm)	Whole Body (rem)	CEDE (rem)	TEDE (rem)	Regulatory Limit (rem TEDE)
300/150	2E-3	2.79E-1	2.8E-1	5.0
300/200	2E-3	2.35E-1	2.4E-1	5.0
300	1E-3	1.80E-1	1.8E-1	5.0
350/200	2E-3	2.72E-1	2.7E-1	5.0

The relatively low doses in Table 3 are due to the plume rise dilution. It is noted that neither filtered makeup nor use of the remote intake(s) is credited in these results.

The conclusion from these results is that the MSLB CR doses are well below the 5.0 rem TEDE regulatory limit for control room operator exposure given in reference [10] for BWR MSLB. This is true for all the control room unfiltered inleakage values included in this study.

Non-Safety-Related Plume Dilution Results

Proprietary information deleted.

It is concluded from the Appendix A and B non-safety diverse plume dilution calculations that the QA plume dilution result of 0.1 is very conservative.

Offsite Dose QA Calculation

The Columbia Generating Station FSAR [9] includes a calculation of doses at the exclusion area boundary (EAB) and at the low population zone (LPZ) boundary. For the FSAR calculation, the coolant iodine inventories listed above in Table 2 (divided by 20) were used, along with the dispersion data listed in Table 4. It is not clear from the calculation what values were used for isotopic exposure-to-dose conversion factors, and for the breathing rate for the first eight hours.

Table 4 Dispersion Data Used in the FSAR Calculations

Dispersion Data	Values
Distance to EAB, m	1950
Distance to LPZ Boundary, m	4827
χ/Q for Total Dose at EAB, sec/m ³	2.62E-04
χ/Q for Total Dose at LPZ, sec/m ³	1.06E-04

The results obtained in the FSAR calculation are shown on Table 5. Also shown are results of a new calculation of the thyroid doses made for purposes of comparison, using the iodine isotope inventories in the coolant listed in Table 2 (divided by 20) and the χ/Q values shown in Table 4. For the new calculation, the exposure-to-dose conversion factors for the iodine isotopes inhaled and deposited in the thyroid were taken from reference [15], and are listed on Table 6. Note that Sv/Bq is converted to mrem/ μ Ci by multiplying by 3.7E9. The breathing rate for the first eight hours was taken from Regulatory Guide 1.3 [6] to be 3.47E-04 m³/sec. The agreement is good.

To make the new calculations, the simple expression for inhalation dose was used; i.e.,

$$\text{Dose} = \text{Activity Release} \times \chi/Q \times \text{Breathing Rate} \times \text{Dose Conversion Factor}$$

No new calculations were made for the whole body doses using the old χ/Q values, so the FSAR values are retained.

**Table 5 Offsite Doses From FSAR and From a New Calculation,
Using FSAR Values for χ/Q**

Quantities	Original FSAR Doses	New Doses
Whole Body Dose at EAB, rem	0.023	0.023
Thyroid Dose at EAB, rem	0.959	0.959
Whole Body Dose at LPZ Boundary, rem	0.00932	0.00932
Thyroid Dose at LPZ Boundary, rem	0.388	0.388

**Table 6 Exposure-to-Dose Conversion Factors for Iodine
Isotope Inhalation and Deposition in the Thyroid**

Iodine Isotope	Thyroid Dose per Unit Intake, (Sv/Bq)
I-131	2.92E-07
I-132	1.74E-09
I-133	4.86E-08
I-134	2.88E-10
I-135	8.46E-09

Offsite Dose QA Results and Conclusions

Since the FSAR was completed, new χ/Q values have been obtained; they are 1.80E-04 sec/m³ and 5.04E-05 sec/m³ for the EAB and LPZ, respectively [14]. Using these values, the offsite doses were recalculated by multiplying the Table 4 results by the new-to-old χ/Q ratios. The results are shown on Table 7.

Table 7 Offsite Doses Using New Values for χ/Q

Quantities	Doses
Whole Body Dose at EAB, rem	0.0158
Thyroid Dose at EAB, rem	0.659
Whole Body Dose at LPZ Boundary, rem	0.00443
Thyroid Dose at LPZ Boundary, rem	0.185

To make these doses current, the thyroid doses must be increased by a factor of 20 to account for iodine spiking (4 vs. 0.2 $\mu\text{Ci/gm}$), and the thyroid doses must also be converted to CEDE by multiplying the thyroid dose by the ratio of CEDE-to-thyroid dose from reference [15] (approximately 0.03). One can also multiply the whole body doses

by a factor of 20 even though some contribution to the whole body dose comes from noble gas. (It is conservative to assume that all of the whole body dose comes from iodine and must be increased to account for spiking). The offsite TEDE results (the sum of the whole body dose and the CEDE) are shown on Table 8.

Table 8 Offsite Doses Using New Values for χ/Q and Including Spiking

Quantities	Doses
Whole Body Dose at EAB, rem	0.316
Thyroid Dose at EAB, rem	13.2
TEDE at EAB, rem	0.71
Whole Body Dose at LPZ Boundary, rem	0.09
Thyroid Dose at LPZ Boundary, rem	3.70
TEDE at LPZ Boundary, rem	0.20

The conclusion from these results is that the MSLB offsite doses are well below the 25 rem TEDE regulatory limit from reference [10] for BWR MSLB with spiking. In fact, these results are less than the 2.5 rem TEDE regulatory limit for BWR MSLB without spiking considered. Clearly, the Columbia MSLB is not of concern for offsite dose.

To obtain non-spiking doses, these results may be divided by a factor 20.

It is noted that the QA results from this calculation are consistent with design input from Appendix D of reference [10]. This is evident from the following:

- The iodine concentration (with spiking) from the FSAR corresponds to 4.0 $\mu\text{Ci/g}$ DE I-131.
- The activity released from the fuel is assumed to mix homogeneously in the reactor coolant, and noble gases are assumed to enter the steam phase instantaneously.
- Per Assumption 1, the MSIV closure time (6 seconds) is assumed to be the maximum allowed time.
- Per Assumption 1, total mass of coolant released is the amount in the steam line and connecting lines at the time of the break plus the amount that passes through the valves prior to closure.
- All radioactivity in the released coolant is assumed to be released to the atmosphere instantaneously (Assumption 1).
- All radioactivity in the released coolant is assumed to be released as a ground-level release (Assumption 2).
- No credit is taken for plateout, holdup, or dilution within facility buildings for the primary case used as the basis for the final QA results (Assumption 7).
- All iodine is assumed to partition with the gas (Assumption 2) which is very conservative relative to what would occur with the reference [10], Appendix D, paragraph 4.4 specification.

Attachment 1 Bubble Rise Velocity and Dilution for Direct Atmosphere Release

Steam Initial Conditions

Mass (lbm) 6.52E+04
Temp(Rankine) 802
Rho (lbm/ft3) 3.11E-02
Volume (ft3) 2.10E+06

Air Initial Conditions

Temp(Rankine) 528
Rho,air(lbm) 0.077

Other parameters

Proprietary information deleted
Bubble transit velocity (m/s) 1

Bubble Vol Multiplier	Bubble Vol (ft3)	BubbleRad Sphere(ft)	BubbleRad Hemisph.(ft)	Mole Frac. Steam	Tb (Rankine)	Rb	RbTb	Fb (lb)	Hemisph. Bubble Vel(ft/s)	Hemisph. Bubble Tran- sit Time (s)	Hemisph. Bubble Dilution	Sph. Bubble Vel(ft/s)	Sph. ubble Tran- sit Time (s)	Sph. Bubble Dilution
No air entrainment:														
Transit of leading edge of bubble up to CR intake (one bubble diameter):														
1	2.1E+06	79.4	100.0	1.0	802.0	85.8	6.9E+04	9.3E+04	16.0	61	0.07	20.2	48.4	0.11
Transit of bubble up to and across CR intake (two bubble diameters):														
1	2.1E+06	79.4	100.0	1.0	802.0	85.8	6.9E+04	9.3E+04	16.0	122	0.03	20.2	96.8	0.05
Air entrainment cases (one bubble diameter):														
1.1	2.3E+06	81.9	103.2	0.9	777.1	81.3	6.3E+04	9.6E+04	15.8	63	0.06	19.9	50.0	0.10
1.2	2.5E+06	84.4	106.3	0.8	756.3	77.9	5.9E+04	9.9E+04	15.5	65	0.06	19.6	51.4	0.09
1.3	2.7E+06	86.6	109.2	0.8	738.8	75.2	5.6E+04	1.0E+05	15.3	67	0.05	19.3	52.8	0.09
1.4	2.9E+06	88.8	111.9	0.7	723.7	73.1	5.3E+04	1.0E+05	15.1	68	0.05	19.0	54.1	0.08
1.5	3.1E+06	90.9	114.5	0.7	710.7	71.3	5.1E+04	1.1E+05	14.9	70	0.05	18.7	55.4	0.08
1.6	3.4E+06	92.8	117.0	0.6	699.3	69.8	4.9E+04	1.1E+05	14.7	71	0.05	18.5	56.6	0.07
1.7	3.6E+06	94.7	119.4	0.6	689.2	68.6	4.7E+04	1.1E+05	14.5	73	0.04	18.2	57.8	0.07
1.8	3.8E+06	96.6	121.7	0.6	680.2	67.5	4.6E+04	1.1E+05	14.3	74	0.04	18.0	58.9	0.07
1.9	4.0E+06	98.3	123.9	0.5	672.2	66.6	4.5E+04	1.1E+05	14.1	76	0.04	17.8	59.9	0.06
2	4.2E+06	100.0	126.0	0.5	665.0	65.7	4.4E+04	1.1E+05	14.0	77	0.04	17.6	61.0	0.06
2.1	4.4E+06	101.7	128.1	0.5	658.5	65.0	4.3E+04	1.1E+05	13.8	78	0.04	17.4	62.0	0.06
2.2	4.6E+06	103.2	130.1	0.5	652.5	64.4	4.2E+04	1.1E+05	13.7	79	0.04	17.2	63.0	0.06
2.3	4.8E+06	104.8	132.0	0.4	647.1	63.8	4.1E+04	1.2E+05	13.5	81	0.04	17.0	63.9	0.06
2.4	5.0E+06	106.3	133.9	0.4	642.2	63.3	4.1E+04	1.2E+05	13.4	82	0.03	16.8	64.8	0.05
2.5	5.2E+06	107.7	135.7	0.4	637.6	62.8	4.0E+04	1.2E+05	13.2	83	0.03	16.7	65.7	0.05
2.6	5.4E+06	109.2	137.5	0.4	633.4	62.4	4.0E+04	1.2E+05	13.1	84	0.03	16.5	66.6	0.05
2.7	5.7E+06	110.5	139.3	0.4	629.5	62.0	3.9E+04	1.2E+05	13.0	85	0.03	16.4	67.4	0.05
2.8	5.9E+06	111.9	141.0	0.4	625.9	61.6	3.9E+04	1.2E+05	12.9	86	0.03	16.2	68.2	0.05
2.9	6.1E+06	113.2	142.6	0.3	622.5	61.3	3.8E+04	1.2E+05	12.7	87	0.03	16.1	69.0	0.05
3	6.3E+06	114.5	144.3	0.3	619.3	61.0	3.8E+04	1.2E+05	12.6	88	0.03	15.9	69.8	0.05

Bubble Vol Multiplier	Bubble Vol (ft3)	BubbleRad Sphere(ft)	BubbleRad Hemisp.(ft)	Mole Frac. Steam	Tb (Rankine)	Rb	RbTb	Fb (lb)	Hemisph. Bubble Vel(ft/s)	Hemisph. Bubble Tran- sit Time (s)	Hemisph. Bubble Dilution	Sph. Bubble Vel(ft/s)	Sph. ubble Tran- sit Time (s)	Sph. Bubble Dilution
Air entrainment cases (two bubble diameters):														
1.1	2.30E+06	81.9	103.2	0.91	777	81.3	6.32E+04	9.61E+04	15.8	126	0.03	19.9	100	0.05
1.2	2.51E+06	84.4	106.3	0.83	756	77.9	5.89E+04	9.88E+04	15.5	130	0.03	19.6	103	0.05
1.3	2.72E+06	86.6	109.2	0.77	739	75.2	5.56E+04	1.01E+05	15.3	133	0.03	19.3	106	0.04
1.4	2.93E+06	88.8	111.9	0.71	724	73.1	5.29E+04	1.03E+05	15.1	136	0.03	19.0	108	0.04
1.5	3.14E+06	90.9	114.5	0.67	711	71.3	5.07E+04	1.05E+05	14.9	140	0.02	18.7	111	0.04
1.6	3.35E+06	92.8	117.0	0.63	699	69.8	4.88E+04	1.07E+05	14.7	143	0.02	18.5	113	0.04
1.7	3.56E+06	94.7	119.4	0.59	689	68.6	4.73E+04	1.08E+05	14.5	146	0.02	18.2	116	0.04
1.8	3.77E+06	96.6	121.7	0.56	680	67.5	4.59E+04	1.10E+05	14.3	148	0.02	18.0	118	0.03
1.9	3.98E+06	98.3	123.9	0.53	672	66.6	4.47E+04	1.11E+05	14.1	151	0.02	17.8	120	0.03
2.0	4.19E+06	100.0	126.0	0.50	665	65.7	4.37E+04	1.12E+05	14.0	154	0.02	17.6	122	0.03
2.1	4.40E+06	101.7	128.1	0.48	658	65.0	4.28E+04	1.13E+05	13.8	156	0.02	17.4	124	0.03
2.2	4.61E+06	103.2	130.1	0.45	653	64.4	4.20E+04	1.14E+05	13.7	159	0.02	17.2	126	0.03
2.3	4.82E+06	104.8	132.0	0.43	647	63.8	4.13E+04	1.15E+05	13.5	161	0.02	17.0	128	0.03
2.4	5.03E+06	106.3	133.9	0.42	642	63.3	4.06E+04	1.16E+05	13.4	163	0.02	16.8	130	0.03
2.5	5.24E+06	107.7	135.7	0.40	638	62.8	4.00E+04	1.17E+05	13.2	166	0.02	16.7	131	0.03
2.6	5.45E+06	109.2	137.5	0.38	633	62.4	3.95E+04	1.18E+05	13.1	168	0.02	16.5	133	0.03
2.7	5.66E+06	110.5	139.3	0.37	629	62.0	3.90E+04	1.19E+05	13.0	170	0.02	16.4	135	0.02
2.8	5.87E+06	111.9	141.0	0.36	626	61.6	3.86E+04	1.19E+05	12.9	172	0.02	16.2	136	0.02
2.9	6.08E+06	113.2	142.6	0.34	622	61.3	3.82E+04	1.20E+05	12.7	174	0.01	16.1	138	0.02
3.0	6.29E+06	114.5	144.3	0.33	619	61.0	3.78E+04	1.21E+05	12.6	176	0.01	15.9	140	0.02

Attachment 2 Bubble Rise Velocity and Dilution for Release via TGB

Steam Initial Conditions						Air Initial Conditions				Other parameters				
Mass (lbm)						Temp(Rank				Proprietary information deleted				
Temp(Rankine						Rho,air(lbm				Bubble transit				
Rho (lbm/ft3)										velocity (m/s)				
Volume (ft3)										1				
Bubble Vol Multiplier	Bubble Vol (ft3)	BubbleRad Sphere(ft)	BubbleRad Hemisph.(ft)	Mole Frac. Steam	Tb (Rankine)	Rb	RbTb	Fb (lb)	Hemisph. Bubble Vel(ft/s)	Hemisph. Bubble Tran- sit Time (s)	Hemisph. Bubble Dilution	Sph. Bubble Vel(ft/s)	Sph. ubble Tran- sit Time (s)	Sph. Bubble Dilution
Transit of leading edge of bubble up to CR intake (74 ft)														
3	6.3E+06	114.5	144.3	0.33	619.33	61.0	3.78E+04	1.21E+05	12.63	22.44	0.11	15.92	22.44	0.14
Transit of bubble up to and across CR intake (74 ft + one bubble diameter):														
3	6.3E+06	114.5	144.3	0.33	619.33	61.0	3.8E+04	1.2E+05	12.63	110.39	0.02	15.92	92.24	0.03

STARDOSE LIBFILE1.TXT

Proprietary information deleted.

STARDOSE INPUT.DAT File for Plume Rise Case 300/150 CFM Inleakage
(Note: This input file was revised (to Rev. 2) as part of Rev. 3 of the main calc., but the change did not affect the output, so Attachment 5 is still Rev. 1)

Proprietary information deleted.

STARDOSE INPUT.DAT File for Plume Rise Case 300/150 CFM Inleakage
(Note: This input file was revised (to Rev. 2) as part of Rev. 3 of the main calc., but the change did not affect the output, so Attachment 5 is still Rev. 1)

Proprietary information deleted.

STARDOSE INPUT.DAT File for Plume Rise Case 300/150 CFM Inleakage

(Note: This input file was revised (to Rev. 2) as part of Rev. 3 of the main calc., but the change did not affect the output, so Attachment 5 is still Rev. 1)

Proprietary information deleted.

STARDOSE Output File Excerpts for Plume Rise Cases

Control_Room (unfiltered inleakage 300/150 cfm @ 0.5 hr)

	thyroid	wbody	skin	CEDE
Total dose:	8.74E+000	1.68E-003	1.54E-002	2.79E-001
Noble gas	0.00E+000	1.07E-004	2.53E-003	0.00E+000
Org iodine	0.00E+000	0.00E+000	0.00E+000	0.00E+000
Elem iodine	8.74E+000	1.57E-003	1.29E-002	2.79E-001
Part iodine	0.00E+000	0.00E+000	0.00E+000	0.00E+000

Control_Room (unfiltered inleakage 300/200 cfm @ 0.5 hr)

	thyroid	wbody	skin	CEDE
Total dose:	7.32E+000	1.55E-003	1.39E-002	2.35E-001
Noble gas	0.00E+000	8.78E-005	2.07E-003	0.00E+000
Org iodine	0.00E+000	0.00E+000	0.00E+000	0.00E+000
Elem iodine	7.32E+000	1.46E-003	1.18E-002	2.35E-001
Part iodine	0.00E+000	0.00E+000	0.00E+000	0.00E+000

Control_Room (unfiltered inleakage 300 cfm)

	thyroid	wbody	skin	CEDE
Total dose:	5.58E+000	1.37E-003	1.17E-002	1.80E-001
Noble gas	0.00E+000	6.29E-005	1.47E-003	0.00E+000
Org iodine	0.00E+000	0.00E+000	0.00E+000	0.00E+000
Elem iodine	5.58E+000	1.30E-003	1.02E-002	1.80E-001
Part iodine	0.00E+000	0.00E+000	0.00E+000	0.00E+000

Control_Room (unfiltered inleakage 350/200 cfm @ 0.5 hr)

	thyroid	wbody	skin	CEDE
Total dose:	8.48E+000	1.80E-003	1.61E-002	2.72E-001
Noble gas	0.00E+000	1.02E-004	2.40E-003	0.00E+000
Org iodine	0.00E+000	0.00E+000	0.00E+000	0.00E+000
Elem iodine	8.48E+000	1.70E-003	1.37E-002	2.72E-001
Part iodine	0.00E+000	0.00E+000	0.00E+000	0.00E+000

Analysis of MSLB Control Room Dose with Activity Trapped in Turbine Building -
Two Hour Release

Purpose:

The purpose of the analysis contained in this attachment is to determine the control room dose for a set of physically inconsistent assumptions to ensure that the control room dose limit of Regulatory Guide 1.183 (Reference 6-1, 5 rem TEDE) would be met even for that set of assumptions.

Assumptions:

1. Iodine spiking occurs immediately before the MSLB such that activities in the coolant are equal to Table 1 (of the main calculation) values for radioiodine. Noble gas activities are also equal to those used in the main calculation.
2. This activity is released to the environment uniformly over a two-hour period.
3. Normal make-up remains unfiltered for one-half hour after the MSLB occurs. Per Reference 6-2, the normal make-up is 1800 cfm for 0.5 hours and 900 cfm after 0.5 hours. After 0.5 hours, all iodine is filtered with an efficiency of 94% (Reference 6-2).
4. The unfiltered inleakage is assumed to be 300 cfm for the first 0.5 hours and 150 cfm after that. This is the worst case from the main calculation.
5. The dose calculation is continued for 10 hours after the end of the release. With a purge rate of 1050 cfm after 0.5 hours and a control room volume of $2.14\text{E}5 \text{ ft}^3$ (Reference 6-2), this yields approximately a three-volume control room purge after the end of the release and provides for a fully accumulated control room operator dose.
6. During the first 0.5 hours, the X/Q is $3.17\text{E}-3 \text{ sec/m}^3$ for both make-up and unfiltered inleakage (no credit for remote intakes). Between 0.5 hours and the end of the release at two hours, the 900 cfm make-up is assumed to experience a X/Q of $6.13\text{E}-4 \text{ sec/m}^3$ and the 150 cfm unfiltered inleakage is assumed to continue to experience the X/Q of $3.17\text{E}-3 \text{ sec/m}^3$. Refer to Reference 6-2 for a definition of X/Q values.

References:

6-1 "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors", US NRC Regulatory Guide 1.183, Revision 0, July 2000

6-2 PSAT 206.QA.01.03, "Dose Calculation Data Base for Application of Alternate Source Term to LOCA and Non-LOCA DBAs for Energy Northwest's Columbia Generating Station", Revision 5, 08/30/01

**6-3 "STARDOSE Model Report", Polestar Applied Technology, Inc., PSATCI09.03,
January 1997**

Calculation:

Proprietary information deleted.

Proprietary information deleted.

Proprietary information deleted.

Proprietary information deleted.

Results:

An excerpt of the control room data block for the 12-hour edit is as follows:

edit time 12.000000
Control_Room

	thyroid	wbody	skin	CEDE
Total dose:	1.18E+002	4.17E-002	3.16E-001	3.86E+000
Noble gas	0.00E+000	7.33E-004	1.69E-002	0.00E+000
Org iodine	0.00E+000	0.00E+000	0.00E+000	0.00E+000
Elem iodine	1.18E+002	4.10E-002	2.99E-001	3.86E+000
Part iodine	0.00E+000	0.00E+000	0.00E+000	0.00E+000
Cesium	0.00E+000	0.00E+000	0.00E+000	0.00E+000
Tellurium	0.00E+000	0.00E+000	0.00E+000	0.00E+000
Barium	0.00E+000	0.00E+000	0.00E+000	0.00E+000
Noble metal	0.00E+000	0.00E+000	0.00E+000	0.00E+000

Lanthanides	0.00E+000	0.00E+000	0.00E+000	0.00E+000
Cerium	0.00E+000	0.00E+000	0.00E+000	0.00E+000
Strontinum	0.00E+000	0.00E+000	0.00E+000	0.00E+000

The results are, therefore, as follows: whole body dose = 0.04 rem
CEDE = 3.86 rem
 TEDE = 3.90 rem

Conclusions:

This calculation illustrates that even for an incredible case wherein the major steam line rupture occurs, and the blowdown enters and pressurizes the turbine building; but the turbine building then releases the activity at a uniform rate over two hours, the control room doses are acceptable (i.e., less than 5 rem TEDE). This case also includes a pre-accident iodine spike and no filtered make-up to the control room for one-half hour after the accident.

Appendix A to PSAT 206.QA.02.03

Proprietary information deleted.

Appendix B to PSAT 206.QA.02.03

Proprietary information deleted.