CALCULATION TITLE PAGE

CALCULATION NUMBER: PSAT 3019CF.QA.06

CALCULATION TITLE: Main Steam Line Break Accident Dose for Vermont Yankee

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0 - Initial Issue N/A

1 - Correct typos on page 11, NRC modeling discussion

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Purpose

This calculation analyzes the Main Steam Line Break (MSLB) Accident for Vermont Yankee including (1) both a quasi-steady and a "puff" X/Q and (2) both offsite and Control Room doses.

Summary of Results

Table 1 – MSLB Summary of Dose Results (TEDE in Rem*)

Case	Control Room**	EAB**	LPZ**
1. Turbine Building Ground-Level Release***	1.80/6.55	0.981/3.57	< 0.981/< 3.57
2. Turbine Building Puff Release****	0.55/2.00	0.981/3.57	< 0.981/< 3.57

*Limits as follows: Control Room - 5 rem TEDE; EAB/LPZ – 2.5 rem TEDE @ 1.1 μCi/gm DE I131, 25 rem TEDE @ 4.0 μCi/gm DE I131
**For Tech Spec coolant activity 1.1μCi/gm / 4.0 μCi/gm (i.e. 3.64 x Tech Spec coolant activity) DE I131
***Control Room X/Q calculated using ARCON96
****Control Room X/Q for hemispherical steam bubble crossing intake at maximum diameter

The offsite cases meet all of the applicable TEDE limits (2.5 rem EAB/LPZ at the normal Tech Spec coolant activity of 1.1 μCi/gm DE I131 and 25 rem EAB/LPZ at the pre-incident spike Tech

Spec coolant activity of 4.0 μCi/gm). For the Control Room, both cases meet the TEDE limit (5 rem for either Tech Spec coolant activity) for the normal Tech Spec coolant activity, but only Case 2 meets the Control Room TEDE limit for the pre-incident spike Tech Spec coolant activity.

This dose analysis fully complies with NRC Regulatory Guide 1.183 (Reference 1).

Methodology

The MSLB accident is initiated from hot stand-by conditions in order to conservatively maximize the mass of coolant released from the break and thus maximizing the activity released. Following accident initiation, the radionuclide inventory from the released coolant is assumed to reach the environment instantaneously (even though in the first case, a X/Q for a quasi-steady plume release is conservatively employed). Two cases are analyzed: Case 1 in which the XQ is for a quasi-steady plume release (as just noted, with the release assumed to be at the turbine stop valves and with no credit taken for Turbine Building holdup) and Case 2 in which the release is assumed to be an instantaneous "puff" that then crosses the Control Room air intake at its maximum dimension.

ARCON-96 (Reference 2) has been used to calculate the X/Q for Case 1. The "puff" X/Q for Case 2 has been calculated on the basis of a hemispherical steam cloud (or "bubble") of uniform density passing over the Control Room air intake. To demonstrate its conservatism, this result is compared to the NRC "puff" X/Q methodology outlined in Reference 3. The EAB X/Q corresponds to a ground-level release without plume rise, the worst-case offsite receptor (SSW sector, 188.2 m from the Turbine Building), and site-specific meteorology.

Releases account for:

1. Primary coolant activity being at the TS limit of 1.1 μCi/gm DE I131;
2. Pre-accident noble gas release rate to the atmosphere being at the TS limit of 0.16 Ci/sec;
3. Added case with 3.64 times these limits (coverin the 4.0 μCi/gm DE I131 24 hour TS limit)

The TEDE values obtained for these analyses are compared with the 2.5/25 rem MSLB TEDE limit for offsite doses and the 5 rem TEDE limit for the Control Room (Reference 1).

Assumptions

Assumption 1: There is no holdup in the Turbine Building.

Justification: Per Reference 1, there should be no holdup credited.

Assumption 2: In the calculation of the activity release, the entire released coolant mass is conservatively used (rather than just the liquid mass).

Justification: Reference 4

Assumption 3: There is no fuel damage. Therefore, there is no impact of Extendent Power Uprate or AST on the dose analysis other than the use of TEDE as the dose measure

Justification: Reference 4. Since there is no fuel damage, AST has no impact on the activity released. Extended Power Uprate has no impact because the analysis is conducted at zero power hot standby.

Assumption 4 An infinite exchange rate between the Control Room and the environment is assumed.

Justification: Conservative

References

1. "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors", US NRC Regulatory Guide 1.183, Revision 0, July 2000
2. J.V. Ramsdell Jr., et al., "Atmospheric Relative Concentrations in Building Wakes", NUREG/CR-6331 Revision 1 (PNNL-10521 Revision 1), May 1997
3. "Atmospheric Relative Concentrations for Control Room Radiological Habitability Assessments at Nuclear Power Plants", US NRC Regulatory Guide 1.194, Revision 0 June 2003
4. VY Calculation VYC-2064, "VY – Radiological Evaluation of a Main Steam Line Break Accident under Hot Standby Conditions", Revision 0
5. PSAT 3019CF.QA.03, "DESIGN DATA BASE FOR APPLICATION OF THE REVISED DBA SOURCE TERM TO VERMONT YANKEE", Revision 0
6. S. L. Humphries et al, "RADTRAD: A Simplified Model for Radionuclide Tansport and Removal and Dose Estimation", NUREG/CR-6604, Sandia National Laboratories, December 1997.
7. PSAT 3019CF.QA.05, "Fuel Handling Dose Analysis for Vermont Yankee", Revision 0

Design Inputs

Design Input Data (Reference 5 for all inputs except DCFs, Item numbers given in brackets)

Control Room Free Volume: 41,533.75 ft^3 [3.4]

X/Q values in sec/m^3:

EAB:	1.7E-3 (ground-level)	[5.1]
LPZ:	*	
CR (Case 1)	4.68E-3 (ground-level)	[5.3]

*LPZ dose not necessary since release is limited to two hours and EAB is more limiting

Breathing Rate in m^3/s (from start of release): 3.5E-4 [5.4]

Total mass of vapor and liquid released: 59,500 lbm [8.6]

Total mass of vapor only: 21,798 lbm [8.7]

Reference pressure for flashing: 1045 psia [8.8]

Activity Releases:

Isotope	Ci Released
Kr83m	3.711E-2
Kr85m	6.658E-2
Kr85	2.183E-4
Kr87	2.183E-1
Kr88	2.183E-1
Kr89	1.419
Kr90	3.056
Xe131m	1.637E-4
Xe133m	3.165E-4
Xe133	8.949E-2
Xe135m	2.838E-1
Xe135	2.401E-1
Xe137	1.637
Xe138	9.713E-1
I131	11.88
I132	113.4
I133	80.99
I134	216.0
I135	118.8

[2.13]

Dose Conversion Factors (DCFs from Reference 6 as documented in Reference 7)

Nuclide	WB	CEDE	TEDE*	CR TEDE**
Kr83m	1.49E-05	0	1.49E-05	5E-07
Kr85m	0.0277	0	0.0277	0.0009
Kr85	4.40E-04	0	4.40E-04	1E-05
Kr87	0.1524	0	0.1524	0.0047
Kr88	0.3774	0	0.3774	0.0117
Kr89	0.323	0	0.323	0.01
Xe131m	0.00149	0	0.00149	5E-05
Xe133m	0.00507	0	0.00507	0.0002
Xe133	0.00577	0	0.00577	0.0002
Xe135m	0.07548	0	0.07548	0.0023
Xe135	0.04403	0	0.04403	0.0014
Xe137	0.0303	0	0.0303	0.0009
Xe138	0.199	0	0.199	0.0062
I131	0.06734	32893	11.5799	11.515
I132	0.4144	381.1	0.54779	0.1462
I133	0.10878	5846	2.15488	2.0495
I134	0.481	131.35	0.52697	0.0609
I135	0.3069	1228.4	0.73684	0.4395

*Based on breathing rate of 3.5E-4 m^3/sec

**Based on CR volume of 41,533.75 ft^3

Calculation

The current VY MSLB dose calculation (Reference 4) can be readily benchmarked using a spreadsheet approach. The effective DCF in Table 2 below is the product of the CEDE DCF (rem/Ci) and the breathing rate of 3.5E-4 m^3/sec plus the whole body DCF (rem-m^3/Ci-sec). With the exception of Kr90, the DCFs are identified in the Design Input section. When multiplied by the activity release (Ci) (also identified in the Design Input section), one obtains the normalized TEDE impact (rem-m^3/sec). This value needs only to be multiplied by the X/Q (the inverse of the atmospheric dilution, sec/m3) to obtain the dose in rem TEDE.

The whole body DCF for Kr90 is not available in References 6 or 7. It has been developed in Appendix A.

Table 2 – Benchmark of VY CLB MSLB Activity Release and Normalized Dose Impact (EAB)

Isotope	Ci Released	CEDE DCF	WB DCF	Eff DCF	Norm TEDE Impact
Kr83m	3.71E-02	0	1.49E-05	0.0000	0.00
Kr85m	6.66E-02	0	0.0277	0.0277	0.00
Kr85	2.18E-04	0	4.40E-04	0.0004	0.00
Kr87	2.18E-01	0	0.1524	0.1524	0.03
Kr88	2.18E-01	0	0.3774	0.3774	0.08
Kr89	1.419	0	0.323	0.3230	0.46
Kr90	3.056	0	0.264	0.2640	0.81
Xe131m	1.64E-04	0	0.00149	0.0015	0.00
Xe133m	3.17E-04	0	0.00507	0.0051	0.00
Xe133	8.95E-02	0	0.00577	0.0058	0.00
Xe135m	2.84E-01	0	0.07548	0.0755	0.02
Xe135	2.40E-01	0	0.04403	0.0440	0.01
Xe137	1.637	0	0.0303	0.0303	0.05
Xe138	9.71E-01	0	0.199	0.1990	0.19
I131	11.88	32893	0.06734	11.5799	137.6
I132	113.4	381.1	0.4144	0.5478	62.1
I133	80.99	5846	0.10878	2.1549	174.5
I134	216.0	131.35	0.481	0.5270	113.8
I135	118.8	1228.4	0.3069	0.7368	87.5
				Total	577.2

To check these benchmarking results, the EAB X/Q of 1.694E-3 sec/m^3 from Reference 4 is multiplied by the sum of the normalized dose impact, 577.2 rem-m^3/sec. The result is 0.978 rem TEDE. The TEDE result from the VY CLB MSLB calculation (Reference 4) is 0.943 rem, 3.6% less than the benchmark projection. This result is well within the variation of DCFs (the DCFs used for Reference 4 are not stated in the reference).

The EAB X/Q identified in the Design Input section is 1.7E-3 sec/m^3, slightly different from the value used in Reference 4. The EAB dose for MSLB for this calculation is, therefore, increased from 0.978 rem TEDE to 0.981 rem TEDE to account for the slight increase in X/Q. This dose is well within the Reference 1 EAB TEDE limit of 2.5 rem.

If the coolant activity release were 3.64 times the data from Reference 4, Item 2.13 which corresponds to the Tech Spec coolant activity limit for iodine of 1.1 μCi/gm; (i.e., if it corresponded, instead, to the short-term, 24-hour Tech Spec coolant activity limit for iodine of 4.0 μCi/gm), the EAB dose would be about 3.64 times greater or 3.57 rem TEDE. This approach conservatively applies the 3.64 factor to both the noble gas and the iodine contribution to dose. Therefore, even using the short-term (24-hour) Tech Spec coolant activity (corresponding to a pre-existing iodine spike) and applying its impact conservatively, the EAB dose is well within the EAB TEDE limit of 25 rem for the pre-existing iodine spike. The conclusions reached for the EAB are conservative for the LPZ because of the greater distance to the Exclusion Area/LPZ boundary than to the EAB, itself.

To apply Table 2 to the control room, the normalized dose impact has to be adjusted for the finite volume of the control room. Since the control room has no filtration protection, and since the exchange rate is high (assumed to be infinite, see Assumption 4), no other corrections are needed.

To make the finite volume adjustment, the finite volume dose correction factor is applied to the WB DCFs and Table 2 is recalculated as Table 3. The finite volume dose correction factor is from Reference 1 and is equal to $V^{0.338}/1173$ where V is the Control Room volume in ft^3. Since the VY Control Room volume is 41,533.75 ft^3, the correction factor is 0.031, and the corrected table for Control Room use is:

Table 3 –MSLB Activity Release and Normalized Dose Impact for Control Room

Isotope	Ci Released	CEDE DCF	WB DCF	Eff DCF	Norm TEDE Impact
Kr83m	3.71E-02	0	4.62E-07	0.0000	0.00
Kr85m	6.66E-02	0	8.59E-04	0.0009	0.00
Kr85	2.18E-04	0	1.36E-05	0.0000	0.00
Kr87	2.18E-01	0	4.72E-03	0.0047	0.00
Kr88	2.18E-01	0	1.17E-02	0.0117	0.00
Kr89	1.419	0	1.00E-02	0.0100	0.01
Kr90	3.056	0	8.18E-03	0.0082	0.02
Xe131m	1.64E-04	0	4.62E-05	0.0000	0.00
Xe133m	3.17E-04	0	1.57E-04	0.0002	0.00
Xe133	8.95E-02	0	1.79E-04	0.0002	0.00
Xe135m	2.84E-01	0	2.34E-03	0.0023	0.00
Xe135	2.40E-01	0	1.36E-03	0.0014	0.00
Xe137	1.637	0	9.39E-04	0.0009	0.00
Xe138	9.71E-01	0	6.17E-03	0.0062	0.01
I131	11.88	32893	2.09E-03	11.5146	136.8
I132	113.4	381.1	1.28E-02	0.1462	16.6
I133	80.99	5846	3.37E-03	2.0495	166.0
I134	216	131.35	1.49E-02	0.0609	13.1
I135	118.8	1228.4	9.51E-03	0.4395	52.2
				Total	384.8

To apply this result to the VY Control Room, one must only calculate the X/Q and multiply the normalized dose impact value of 384.8 rem TEDE-m^3/sec by the X/Q value.

ARCON96 X/Q

The release is assumed to occur in the Turbine Building (Reference 5, Item 8.9) and lasts only 6.8 seconds (Reference 5, Item 8.7). Therefore, it is unlikely that the Control Room dose will result from a slow release of activity from the Turbine Building following the very rapid release from the main steam piping. In fact, Reference 1 requires consideration of an immediate release to the environment. However, a quasi-steady plume release X/Q is available for Turbine Building releases, and it is used here as one case for the MSLB dose analysis (Case 1).

Using the 384.8 rem TEDE-m^3/sec and the Turbine Building ARCON96 X/Q of 4.68E-3 sec/m^3, the Control Room dose becomes 1.80 rem TEDE. This dose is well within the Control Room TEDE limit of 5.0 rem. If the coolant activity release were 3.64 times the data from Reference 4, Item 2.13 (which corresponds to the Tech Spec coolant activity limit for iodine of 1.1 μCi/gm; i.e., if it corresponded, instead, to the short-term, 24-hour Tech Spec coolant activity limit for iodine of 4.0 μCi/gm representing a pre-existing iodine spike), the Control Room dose would be about 3.64 times greater or 6.55 rem TEDE. While this value exceeds the Reference 1 Control Room dose limit of 5.0 rem TEDE, it is not considered a valid case because of the slow-release, plume X/Q which is inconsistent with the other, more appropriate release characteristics (i.e., instantaneous release to the environment). A more reasonable Control Room dose for MSLB is discussed in the next section.

Puff X/Q

The puff X/Q will be calculated next. There are four steps to making this calculation: (1) evaluating the initial conditions of the steam release, (2) determining the volume and the diameter of the assumed hemispherical steam bubble, (3) evaluating the transit time for the bubble across the Control Room air intake and the associated X/Q, and (4) comparing this calculation to the NRC modeling described in Reference 3.

Evaluate Initial Conditions of Steam Release. The liquid-steam mixture is assumed to be instantaneous per Assumption 1 even though the actual release time is 6.8 seconds. The MSLB has a steam release of 21,798 lbm and a total (liquid+vapor) release of 59,500 lbm. The net liquid release is then, 37,702 lbm. The RCS pressure is 1045 psia. The temperature of the liquid-steam mixture at the time of the release to ambient is the saturation temperature corresponding to 1045 psia which is 550°F. Since the liquid is superheated at ambient pressure, some of this liquid will flash to steam. It is expected that the steam will form a "bubble", and the unflashed liquid will settle by gravity. Logically, the bulk of the activity would remain with the liquid, but by Assumption 2, all of the activity is assumed to be released with the steam. This is a conservative assumption in this analysis.

Performing an energy balance to determine the flashing fraction,

$$mh = m_g h_g + m_f h_f$$

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_f = unflashed liquid mass (lbm)
h_f = 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

$$ff = m_g/m = [(mh - m_f h_f)/h_g]/m$$

$$= (h - m_f h_f/m)/h_g$$

Since

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

we have

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

Thus,

$$ff = (h - h_f)/(h_g - h_f) = (h - h_f)/h_{fg}$$

Using the steam tables,

$$h = h_f(550\text{ F}) = 549 \text{ Btu/lbm}$$

$$h_f(212\text{ F}) = 180 \text{ Btu/lbm}$$

$$h_g(212\text{ F}) = 1150 \text{ Btu/lbm}$$

$$h_{fg}(212\text{ F}) = 970 \text{ Btu/lbm}$$

Thus,

$$ff = (549 - 180)/970$$

$$= 0.38$$

Thus, the mass of flashed steam (e.g. liquid that instantaneously flashes) is $m_g = 0.38 \times 37{,}702 = 14{,}327$ lbm, and the total steam mass (i.e., initial bubble mass) is 21,798 + 14,327 = 36,125 lbm.

The temperature of the mixture of released steam at 550°F and flashed steam at 212°F is

$$T_b = (14{,}327 \times 212 + 21{,}798 \times 550)/36{,}125 = 416°F = 876 \text{ R}$$

Determine the Volume and Diameter of the Assumed Hemispherical Steam Bubble. The initial volume of the bubble is

$$V_i = 36{,}125 \text{ lbm}/\rho_s$$

where $\rho_s = 0.0284$ lbm/ft^3 (steam density at 876 R)
V_i = initial volume of steam bubble (pure steam)
Thus,

$$V_i = 1.272\text{E}6 \text{ ft}^3 = 3.6\text{E}4 \text{ m}^3$$

A spherical bubble of this volume has the radius

$$r_s = (3V_i/4\pi)^{1/3}$$

$$= 20.5 \text{ m}$$

A hemispherical bubble will have radius

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

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

$$r_h = 1.26 r_s$$

$$= 25.83 \text{ m}$$

and the diameter is 51.7 m.

Evaluate Bubble Transit Time across the Control Room Air Intake and Associated X/Q. The bubble transit time is based on a windspeed of 1.0 m/sec. The use of this value is explained in Appendix B. With a diameter of 51.7 m, the maximum bubble transit time across the control room air intake is 51.7 seconds at a windspeed of 1.0 m/sec.

As used in dose calculation models, the X/Q is the inverse of the dilution flow (units of m^3/sec) provided by atmospheric mixing. In this case, (Case 2) there is no atmospheric mixing; rather, dilution is provided only by the flashing and expansion of the steam carrying the activity. Therefore, one may assume that the release takes 6.8 seconds and that the "effective" dilution

flow (in order to produce a dilution volume of 3.6E4 m^3) is 5294 m^3/sec over that 6.8 seconds. The corresponding "effective" X/Q is 1/5294 = 1.89E-4 sec/m^3. However, there is an additional correction that must be applied.

The total activity in the coolant is released over the same 6.8 seconds as the steam, but the release duration must be assumed to be 51.7 seconds (the transit time for the plume) at the 6.8 second release rate. This is because the puff does not pass by the Control Room air intake at same rate that it is released from the Turbine Building. Therefore, the effective X/Q is actually larger than 1.89E-4 sec/m^3 by the ratio of the puff transit time divided by the release time; i.e., 51.7/6.8 or 7.6. Increasing the 1.89E-4 sec/m^3 by the factor of 7.6 gives the effective value of 1.44E-3 sec/m^3.

Comparison to the NRC Modeling. In Appendix B, the NRC puff model is shown to produce a X/Q of 1.16E-3 sec/m^3, about 1/5 less than the hemispherical model used in this section. Therefore, this model is conservative with respect to NRC's model. It is also shown in Appendix B that any consideration of air entrainment (which the NRC model does to a limited degree) tends to lower the effective X/Q.

Control Room Dose Calculation with the Puff X/Q for Case 2. Using the 384.8 rem TEDE-m^3/sec and the puff X/Q of 1.44E-3 sec/m^3, the Control Room dose becomes 0.55 rem TEDE. This dose is well within the Control Room TEDE limit of 5.0 rem. If the coolant activity release were 3.64 times the data from Reference 4, Item 2.13 (which corresponds to the Tech Spec coolant activity limit for iodine of 1.1 μCi/gm; i.e., if it corresponded, instead, to the short-term, 24-hour Tech Spec coolant activity limit for iodine of 4.0 μCi/gm), the Control Room dose would be about 3.64 times greater or 2.00 rem TEDE. This dose is also well within the Control Room TEDE limit of 5.0 rem.

Results

Two MSLB cases are analyzed. In Case 1, the X/Q is based on ARCON96. In Case 2, the X/Q is based on a puff release assumed to be hemispherical in shape, of uniform concentration, and not subject to dilution by air entrainment. In Appendix B this model is compared to an NRC model and is shown to be moderately conservative.

In both cases the results are based on an instantaneous release fully consistent with Reference 1. <u>The activity release is based on the Tech Spec coolant activity limit for continuous operation.</u>

The Case 1 results are EAB = 0.981 rem TEDE (conservative for the LPZ) and Control Room = 1.80 rem TEDE.

The Case 2 results are EAB = 0.981 rem TEDE (conservative for the LPZ) and Control Room = 0.55 rem TEDE.

Additional results were generated for an activity release based on the Tech Spec coolant activity limit for operation of not more than 24 consecutive hours. This activity level corresponds to a pre-existing iodine spike.

The Case 1 results are EAB = 3.57 rem TEDE (conservative for the LPZ) and Control Room = 6.55 rem TEDE.

The Case 2 results are EAB = 3.57 rem TEDE (conservative for the LPZ) and Control Room = 2.00 rem TEDE.

Conclusions

The MSLB doses are well within their Reference 1 limits except that the Control Room dose exceeds its limit slightly if both (1) a continuous release X/Q is used (and such a X/Q is not required by Reference 1) and (2) if the coolant activity is 3.64 times greater than the continuous operation Tech Spec limiting value of 1.1 μCi/gm DE I131 (i.e., if it is equal to the 24 hour maximum Tech Spec value of 4.0 μCi/gm DE I131).

Appendix A – Determination of Whole Body DCF for Kr90

Kr90 is a short-lived noble gas that has essentially no effect on radiation dose for any accident involving a time-dependent release. It is not included in the dose conversion factor library for RADTRAD (Reference A-1). For the MSLB accident, where the release to the environment is assumed to be instantaneous, the current analysis (Reference A-2) includes Kr90. The dose conversion factor can be readily determined from the average gamma energy using the expression from Reference A-3 (0.25 x the average photon energy in MeV to obtain the whole body DCF in rem-m^3/Ci-sec).

The following Table A-1 (based on Reference A-4) shows the photon energy distribution for gamma radiation from Kr90 decay. The average gamma energy is 1055 KeV per disintegration with that value being calculated as shown in the table. Columns A and B are data from Reference A-4 as well as the conversion factor for obtaining Column C from Columns A and B (i.e., multiplying the Relative Intensity by 0.038 to obtain the Absolute Intensity in MeV per 100 disintegrations, and then dividing by 100 and by the energies of the individual photons in each row to obtain the number of photons per disintegration for each photon energy). From Column C, Column D is a straightforward multiplication of C x A, and the average energy per disintegration is the sum of Column D.

The DCF is 0.025 times 1.055 MeV or 0.264 rem-m^3/Ci-sec.

Table A-1 – Relative Intensity of Gamma Radiation for Kr90

A. Photon Energy KeV	B. Relative Intensity	C. Photons/Dis (B*0.038)/100/(A/1000)	D. MeV/dis by energy (C x A)
539.5	17.3	1.22E-02	6.57E-03
578.06	15.9	1.05E-02	6.04E-03
655.17	202	1.17E-01	7.68E-02
707.05	1000	5.37E-01	3.80E-01
740.82	75	3.85E-02	2.85E-02
786.02	42	2.03E-02	1.60E-02
840.29	25	1.13E-02	9.50E-03
913.38	6.8	2.83E-03	2.58E-03
939.9	11.2	4.53E-03	4.26E-03
955.84	58	2.31E-02	2.20E-02
1123.37	13.1	4.43E-03	4.98E-03
1133.5	4.9	1.64E-03	1.86E-03
1233.21	110	3.39E-02	4.18E-02
1323.57	21	6.03E-03	7.98E-03
1344.76	13.5	3.81E-03	5.13E-03
1362.32	295	8.23E-02	1.12E-01
1396.16	25	6.80E-03	9.50E-03
1418.34	21	5.63E-03	7.98E-03
1440.21	8.5	2.24E-03	3.23E-03
1465.9	9.6	2.49E-03	3.65E-03
1486	14.7	3.76E-03	5.59E-03

1542.2	35	8.62E-03	1.33E-02
1610.8	59	1.39E-02	2.24E-02
1625.11	44	1.03E-02	1.67E-02
1828.9	10.7	2.22E-03	4.07E-03
1836.49	38	7.86E-03	1.44E-02
1888.79	14.7	2.96E-03	5.59E-03
2002.9	6.7	1.27E-03	2.55E-03
2024.1	11.6	2.18E-03	4.41E-03
2040.79	21	3.91E-03	7.98E-03
2073	4	7.33E-04	1.52E-03
2105.7	15	2.71E-03	5.70E-03
2121.2	9.8	1.76E-03	3.72E-03
2172.9	3.4	5.95E-04	1.29E-03
2297.1	7.4	1.22E-03	2.81E-03
2318.6	28	4.59E-03	1.06E-02
2411.8	11.4	1.80E-03	4.33E-03
2433.09	26	4.06E-03	9.88E-03
2543.93	7.7	1.15E-03	2.93E-03
2612.2	14.6	2.12E-03	5.55E-03
2665.4	8.9	1.27E-03	3.38E-03
2682.6	12.2	1.73E-03	4.64E-03
2730.5	44	6.12E-03	1.67E-02
2763.9	5	6.87E-04	1.90E-03
2801	9.1	1.23E-03	3.46E-03
2864.1	31	4.11E-03	1.18E-02
2987.1	29	3.69E-03	1.10E-02
3022.3	6.2	7.80E-04	2.36E-03
3116.7	9.9	1.21E-03	3.76E-03
3231.3	89	1.05E-02	3.38E-02
3318.5	31	3.55E-03	1.18E-02
3505.8	6.5	7.05E-04	2.47E-03
3669.1	7.3	7.56E-04	2.77E-03
3949	9.4	9.05E-04	3.57E-03
3955	8.4	8.07E-04	3.19E-03
4023.1	6.7	6.33E-04	2.55E-03
4290.9	17	1.51E-03	6.46E-03
4297.2	16.7	1.48E-03	6.35E-03
4320.9	9.1	8.00E-04	3.46E-03
4367.3	16.1	1.40E-03	6.12E-03
4372.8	14.1	1.23E-03	5.36E-03
4495.1	8.8	7.44E-04	3.34E-03
4762.3	6.8	5.43E-04	2.58E-03
4787.4	5.7	4.52E-04	2.17E-03
5154	2.8	2.06E-04	1.06E-03
5221.6	7.9	5.75E-04	3.00E-03
		MeV/dis =	1.055E+00

References

A-1 S. L. Humphries et al, "RADTRAD: A Simplified Model for Radionuclide Tansport and Removal and Dose Estimation", NUREG/CR-6604, Sandia National Laboratories, December 1997

A-2 VY Calculation VYC-2064, "VY – Radiological Evaluation of a Main Steam Line Break Accident under Hot Standby Conditions", Revision 0

A-3 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

A-4 Evaluated Nuclear Structure Data File (ENSDF), http://www.nndc.bnl.gov/nndc/ensdf/ensdfindex.html, Brookhaven National Laboratory, May 14, 2003

Appendix B – Comparison of the Calculated Puff X/Q to Preliminary NRC Methods

In Reference B-1, the NRC presents a model for a puff X/Q. The model has the following features:

1. The puff is released at ground-level as is assumed to pass the control room air intake at the maximum puff dimension.

2. It is a spherical puff.

3. The puff is allowed to entrain air and to expand slightly as it moves downwind.

4. Activity within the puff is normally distributed, and the integration of the puff activity concentration as it crosses the control room air intake must be from -3σ to $+3\sigma$ (unless the release point is closer than 3σ to the control room air intake in which case the integration begins at x).

This can be compared to the hemispherical model described in the main body of the calculation as follows (point by point):

1. Same.

2. Hemispherical rather than spherical with a nominal diameter 1.26 times greater than the NRC spherical puff. However, for the NRC model, $3\sigma = (3.429 \text{ x Volume})^{1/3}$ instead of $r_h = (0.478 \text{ x Volume})^{1/3}$; and this means that the integration time is 1.93 times greater for the NRC model dispite the greater diameter of the hemisphere (relative to that of a sphere) in the model presented in the main body of the calculation.

   Helping to counteract this effect is the fact that the effective volume for the NRC puff is 14.35 times greater (i.e., 2 x 3.429/0.478), so the average concentration is 14.35 times less for the NRC model than for the model presented in the main body of the calculation. However since the maximum radial and maximum cross-wind concentration is used in the NRC model (i.e., the integration is done as the center of the puff moves across the air intake), the benefit of the distributed concentration is limited, since the peak concentration in the cross-wind and vertical directions will be 2.39 times greater than the average (i.e., $6/(2\pi)^{1/2}$. This means that the benefit of the greater effective volume of the NRC model is reduced from the value of 14.35 to a value of $(14.35/2.39^2) = 2.51$. Then, taking into consideration the longer integration time (NRC model 1.93 times greater), the net benefit of the NRC model is reduced to $2.51/1.93 = 1.3$.

3. No air entrainment. Air entrainment provides dilution, but it also increases the diameter of the puff and, therefore, the integration time at whatever windspeed is assumed. However, a volume of air assumed to be entrained in the puff decreases the concentration

linearly while it increases the diameter (and, therefore, the integration time) by the cube root of the volume. Ignoring air entrainment is, therefore, conservative.

To evaluate the degree of conservatism introduced by ignoring air entrainment in the model presented in the main body of the calculation, one must know the distance traversed by the NRC's puff before the control room air intake is encountered (the uniform concentration model in the main body of the calculation does not require that information). If one assumes that the distance traversed is 33 meters for the center of the puff (the distance assumed in the ARCON96 modeling – see Reference B-2) and then refers to Figure 3 of Reference B-1 assuming Stability Class F (as suggested by Reference B-1), the one-sigma puff expansion in the down-wind and cross-wind direction is about 1.7 m. It is assumed to be zero in the vertical direction

The spherical radius of the initial puff (3σ before expansion) would be 2.43 times that calculated in the main body of the calculation for the nominal sphere; i.e., 49.8 m. Increasing this radius by 2 x 1.7 m in both the down-wind and cross-wind directions only increases the effective volume by about a factor of 1.14. However, it also increases the diameter by a factor of 1.07 (and the associated integration time). Therefore, the net benefit of expansion due to entrainment in the NRC model is about a factor of 1.07.

4. Uniform concentration assumed, and therefore, no activity excluded from the integration. For the NRC model, integration from -3σ to +3σ creates essentially the same degree of completeness.

It is clear that the model described in the main body of the calculation is the same or conservative on all points.

The overall conservatism of the hemispherical, uniform concentration model in the main body of the calculation is 1.3 for the assumed hemispherical vs. spherical configuration (and uniform vs. distributed concentration), and 1.07 for the constant volume (no air entrainment). Multiplying these contributions, the overall conservatism is 1.39. Since the X/Q developed for the model presented in the main body of the calculation is 1.44E-3 sec/m^3, the NRC model would be expected to give a result of 1.04E-3 sec/m^3. This can be checked by actually calculating the NRC result (assuming a -3σ to +3σ integration).

In Referece B-1, Section 5, the guidance is to use F-Stability and a windspeed of 1.0 m/sec. Therefore, these are the values that are appropriate for use in the main body of the calculation. However, stability does not enter into the hemispherical, uniform concentration model because air entrainment is not considered; and thus, only the windspeed of 1.0 m/sec (based on References B-1 and B-3) is actually used.

The integration may be carried out on a spreadsheet assuming the expression for $\sigma_{x,y}$ is $0.08x^{0.875}$ (based on a fit of the Reference B-1 figure between x = 10 and 100 m). The result is a X/Q of 1.16E-3 sec/m^3, about 11% greater than the estimate of 1.04E-3 sec/m^3 given above. The value in the main body of the calculation is still bounding.

References

B-1 "Atmospheric Relative Concentrations for Control Room Radiological Habitability Assessments at Nuclear Power Plants", US NRC Regulatory Guide 1.194, Revision 0, June 2003

B-2 VY Calculation VYC-1967, "Control Room Atmospheric Dispersion Factors for Releases via the Turbine Building" R0

B-3 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