# CALCULATION TITLE PAGE

CALCULATION NUMBER: PSAT 3019CF.QA.09

CALCULATION TITLE: Alternative Source Term Impact on NUREG-0737 Equipment Qualification, Vital Area Access, and Areas of Continuous Occupancy

| | ORIGINATOR Print/Sign/Date | CHECKER Print/Sign/Date | IND REVIEWER Print/Sign/Date |
|---|---|---|---|
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| REASON FOR REVISION: | Nonconformance Rpt |
|---|---|
| 0 - Initial Issue | N/A |

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**Purpose**

This calculation is prepared by Polestar Applied Technology, Inc. for Vermont Yankee (VY) to determine the impact of AST (Reference 1) on three aspects of NUREG-0737 (Reference 2) under Item II.B.2, Plant Shielding. These are:

Equipment Qualification,

Vital Area Access, and

Protection of Areas Requiring Continuous Occupancy (e.g., Control Room and Technical Support Center).

**Summary of Results**

1. Equipment Qualification can continue to be based on TID-14844.

2. Vital area access can continue to be based on TID-14844

3. The 30-day TSC dose is 3.5 rem TEDE. This is less than the 5 rem TEDE limit.

**Methodology**

The calculation is divided into three sections in order to address each of the three topics. The Equipment Qualification (EQ) section is, for the most part, qualitative since the NRC's position on the potential need for modifying EQ requirments has been made known (Reference 3), and Polestar agrees that no change in approach is warranted.

For vital area access, Polestar is providing a generic assessment of the dose potential for both shine and inhalation doses, comparing the AST (Reference 1) to the current licensing basis (CLB) for VY which is TID-14844 (Reference 4). It is shown that TID-14844 is inherently limiting, and that a change in source terms alone is not a basis for reassessing vital area access. If changes are needed for other reasons, it is acceptable to continue to use the TID-14844 source terms and to make changes within that context. For example, for Extended Power Uprate (EPU) it would be necessary to scale up the result by core inventory impact, but not to necessarily change the source term used in the analysis.

For the Technical Support Center (TSC), a reanalysis of the 30-day dose has been made based on the reanalysis of the Control Room 30-day dose in Reference 5. In Reference 5, the STARDOSE 1.01 code (Reference 6) was used only for independent verification; but in this analysis, it is used to generate the activities used for assessment of both the inhalation and the shine pathways for the TSC.

**Assumptions**

None other than those discussed in Reference 5.

**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. NUREG-0737, "Clarification of TMI Action Plan Requirements", November 1980

3. Memorandum from Jack Rosenthal (Safety Margins and Systems Analysis Branch Chief) to Ashok Thadani, Director of NRR (ADAMS Accession No. ML0112103480), April 30, 2001

4. J.J. DiNunno et al., "Calculation of Distance Factors for Power and Test Reactor Sites", USAEC TID-14844, US Atomic Energy Commission (now US NRC), 1962

5. PSAT 3019CF.QA.08, "Radiological Evaluation of a DBA-Loss of Coolant Accident", Revision 0

6. "STARDOSE Model Report", Polestar Applied Technology, Inc., PSAT C109.03 January 1997.

7. PSAT 3019CF.QA.03, "Design Database for Application of the Revised DBA Source Term to Vermont Yankee", Revision 2.

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

9. Memorandum to File from James Metcalf "Generalization of Spreadsheet Methodology for Comparing TID-14844 and AST Gamma Shine Dose Potential", July 27, 2003

10. MicroShield Version 5.03, 1995-1998, Grove Engineering

**Design Inputs**

Design Input Data (Reference 7 for all inputs except those taken from Reference 5, Item numbers given in parentheses):

| | | |
|---|---|---|
| Power level = 1950 MWt | | (Item 8.1) |
| Core inventories – see Reference 7 table | | (Item 1.1 – full core inventory at t = 0) |
| AST Release rates: | | |
| Fraction of core inventory, 0 – 120 seconds: | | (Item 2.1) |
| No Release | | |
| Fraction of core inventory, 120 – 1920 seconds: | | (Item 2.2) |
| Gases | Xe, Kr – 0.1/hr (0.05 total) | |
| | Elemental I – 4.9E-3/hr (2.4E-3 total) | |
| | Organic I – 1.5E-4/hr (7.5E-5 total) | |
| Aerosols | I, Br – 0.095/hr (0.0475 total) | |
| | Cs, Rb – 0.1/hr (0.05 total) | |
| Fraction of core inventory, 1920 – 7320 seconds: | | (Item 2.3) |
| Gases | Xe, Kr – 0.63/hr (0.95 total) | |
| | Elemental I – 8.1E-3/hr (1.2E-2 total) | |
| | Organic I – 2.5E-4/hr (3.8E-4 total) | |
| Aerosols | I, Br – 0.158/hr (0.2375 total) | |
| | Cs, Rb – 0.133/hr (0.2 total) | |
| | Te Group – 0.033/hr (0.05 total) | |
| | Ba, Sr – 0.013/hr (0.02 total) | |
| | Noble Metals – 1.7E-3/hr (2.5E-3 total) | |

La Group – 1.3E-4/hr (2E-4 total)
Ce Group – 3.3E-4/hr (5E-4 total)

Volume of Drywell – 131,470 $ft^3$ (max), 128,370 $ft^3$ (min) (Item 3.1)
Volume of Torus Airspace – 103,932 $ft^3$ (min) (Item 3.2)
Volume of Suppression Pool – 68,000 $ft^3$ (min), 70,000 $ft^3$ (max) (Item 3.3)
Volume of Main Condenser (MC) – 107,000 $ft^3$ (Item 3.5)
Reactor Building Volume (for TSC shine calc) – 1,786,049 $ft^3$ (Item 3.19)
Fraction of Reactor Building Volume above Refueling Floor – 0.33* (Item 3.20)
*584,406 $ft^3$/1,786,049 $ft^3$

Volumetric Leak Rate from Drywell (not including MSIVs) – 0.713 cfm (Item 3.6)
This represents 0.8% of the minimum DW volume per day (Item 3.1).
Volumetric Leak Rate from Torus Airspace – 0.577 cfm (Item 3.7)
This represents 0.8% of the torus airspace volume per day (Item 3.2).
Volumetric Flowrates for MSIV and Nitrogen Supply Bypass:
From Drywell, for Each of Two Main Steam Lines – 0.383 cfm
From Main Steam Lines, Combined Flow to Main Condenser – 3.91 cfm
From Main Steam Lines, Combined Bypass Flow – 0.032 cfm
From Main Condenser, to Environment – 2.05 cfm
Nitrogen Steam Supply Bypass – 0.031 cfm (Reference 5)
Reduction in Containment Leakage at 24 Hours – 50% (Reference 5)

ESF Leakage – 0.5 gpm analyzed as 1.0 gpm, assumed to start at t = 0 (Item 3.10)
Release Fraction of Radioiodine from ESF leakage – 10% (Item 4.3)

Lengths and Diameters of Nitrogen Supply Bypass Pathway - (Item 7.13)
4.67 ft (18") + 16 ft (1" horizontal coil) + 16.42 ft (1") + 22.75 ft (2")
Particulate Deposition Velocity in Nitrogen Supply Bypass Pathway = 5E-5 m/s (Reference 5)

Secondary Containment Drawdown Time, 0 minutes with all SGTS (Item 8.11)
10 minutes with one SGTS train failed**
**During the 10 minutes, the Reactor Building pressure is actually negative for at least four minutes (the Reactor Building begins at a negative pressure). Positive pressure will not occur beyond t = 10 minutes (accident time).

Drywell Spray Removal, t = 0.25 hours to t = 2.0667 hours
$\lambda$ for particulate and elemental = 20 per hour (Reference 5)
Drywell Spray Removal, t = 2.0667 hours to t = 720 hours
$\lambda$ for particulate and elemental = 2 per hour (Reference 5)

Nominal SGTS Single-Train Flow (with +/- 150 cfm) – 1500 cfm (Item 3.14)
Filter Efficiency – SGTS (Item 4.2)
For Particulate Iodine, Cesium and other Aerosols – 95%
For Elemental and Organic Iodine – 95%
For Noble Gases – 0%

Main Steam Line Removal Efficiencies (from Reference 5)

| | Aerosol Removal Efficiency | Elem Iodine Removal Efficiency |
|---|---|---|
| Steam Lines*, 62 scfh/Line | 38% | Assumed Negligible |
| Same, One MSIV Failed | 0% | 0% |
| ALT Volume** | 71% | 58% |
| Same, One MSIV Failed | Assumed No Change | Assumed No Change |
| Combined SL and ALT | 82% | 58% |
| Same, One MSIV Failed | 77% | Assumed No Change |
| Main Condenser | 95.1% | 99.8% |

*Between MSIVs
**Remainder of steam lines up to turbine stop valves

Volume of Control Room (CR) – 41,533.75 $ft^3$ (Item 3.4)
Volumetric Flowrate, Environment to CR (Pre-isolation Fresh Air Intake, Unfiltered) – 3700 cfm
Environment to CR (Post-Isolation, Unfiltered) – 3700 cfm (Items 3.8/3.18)
Time to Isolate CR Ventilation for DBA-LOCA – N/A# (Item 9.3)
#Transition to isolated condition not credited

Location of TSC Dose Point##: Elevation = 260.5' + 3' (6' person) = 263.5' (Item 10.1)
Elevation of TSC Overhead Shield = 272.5'
Distance from Reactor Building Centerline = 115' West
= 112' North
##maximum value identified as "Location 3" in reference calculation

Thickness of TSC Overhead (assumed to be ~150 lbm/ft3 concrete###) – 8" (Item 10.2)
###2.35 g/cc

X/Q values in sec/$m^3$:

| Building Releases | 0-2 hr | 0-1 hr | 1-2 hr | 2-8 hr | 8-24 hr | 1-4 day | 4-30 day |
|---|---|---|---|---|---|---|---|
| EAB ground (Item 5.1) | 1.7 E-3 for TB<br>1.476E-3 for RB | --- | --- | N/A | N/A | N/A | N/A |
| EAB stack (Item 5.1) | Fumigation:<br>2.03E-4 (0.5 hr)<br>Normal:<br>1.54E-4 (0.5 hr)<br>9.17E-5 (1.0 hr) | --- | --- | N/A | N/A | N/A | N/A |
| LPZ ground (Item 5.2) | --- | 2.74E-5<br>TB↑RB↓<br>5.253E-5 | 1.75E-5<br>TB↑RB↓<br>5.253E-5 | 8.01E-6<br>TB↑RB↓<br>2.227E-5 | 1.00E-6<br>TB↑RB↓<br>1.469E-5 | 5.80E-7<br>TB↑RB↓<br>5.948E-6 | 3.37E-7<br>TB↑RB↓<br>1.625E-6 |
| LPZ stack (Item 5.2) | --- | 2.55E-5 | 1.87E-5 | 1.01E-5 | 1.09E-6 | 6.90E-7 | 4.61E-7 |
| Control Room ground (Item 5.3) | --- | 4.66E-3<br>TB↑RB↓<br>2.25E-3* | 4.66E-3<br>TB↑RB↓<br>2.25E-3 | 3.46E-3<br>TB↑RB↓<br>8.18E-4 | 1.45E-3<br>TB↑RB↓<br>3.53E-4 | 1.09E-3<br>TB↑RB↓<br>2.77E-4 | 9.92E-4<br>TB↑RB↓<br>2.23E-4 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Control Room stack (Item 5.3) | Fumigation: 1.92E-5 (0.5 hr) Normal: 1.92E-5 (0.5 hr) 1.92E-5 (1.0 hr) | --- | --- | 8.28E-7 | 3.36E-7 | 3.08E-7 | 1.79E-7 |

*This is for the $N_2$ system sustained bypass. For short-term drawdown bypass, use 2.98E-3

Control Room breathing rates in $m^3/s$ (Item 5.4):
- 0-30 days 3.5E-4

EAB & LPZ breathing rates in $m^3/s$ (Item 5.4):
- 0-8 hr 3.5E-4
- 1-4 days 1.8E-4
- 4-30 days 2.3E-4

Control Room occupancy factors (Item 5.5):
- 0 – 24 hours 1.0
- 1-4 days 0.6
- 4-30 days 0.4

Dose Conversion Factors: Default FGR11&12.INP file from Reference 8

**Calculation**

*Section 1 – Impact of AST on Equipment Qualification*

1. Regulatory Guide 1.183 (Reference 1) states the following (Section 1.3.5):

   "Current environmental qualification (EQ) analyses may be impacted by a proposed plant modification associated with AST implementation. The EQ analyses that have assumptions or inputs affected by the plant modification should be updated to address these impacts. The NRC staff is assessing the effect of an increased cesium release on EQ doses to determine whether licensee action is warranted. Until such time as this generic issue is resolved, licensees may use either the AST or the TID14844 assumptions for performing the required EQ analyses. However, no plant modifications are required to address the impact of the difference in source term characteristics (i.e., AST vs TID14844) on EQ doses pending the outcome of the evaluation of the generic issue. The EQ dose estimates should be calculated using the design basis survivability period."

2. The generic issue (or more accurately, the candidate generic issue) was closed out on April 30, 2001 (ten months after the issuance of Regulatory Guide 1.183) with the issuance of a memorandum from Jack Rosenthal (Safety Margins and Systems Analysis Branch Chief) to Ashok Thadani, Director of NRR (ADAMS Accession No. ML0112103480). This memorandum states the following:

   "The panel has decided that the candidate generic issue should be dropped as having no significant chance of meeting the incremental risk thresholds for backfit as described in the MD 6.4 Handbook."

It is important to note, of course, that backfit criteria would not necessarily be applied in accepting or denying a voluntary licensing action. However, in this regard, one must note that the NRC, itself, tied the EQ requirements of Regulatory Guide 1.183 (by definition, a document dealing with voluntary licensing actions) to the outcome of the subject generic issue evaluation. Therefore, it is proper to consider the findings and conclusions of the generic issue evaluation as a way of clarifying the EQ requirements of this regulatory guide.

The generic issue evaluation further states the following:

"Sandia National Laboratories' letter report "*Evaluation of Radiological Consequences of Design Basis Accidents at Operating Reactors Using the Revised Source Term*, September 28, 1998 showed that, for equipment exposed to the containment atmosphere, the TID-14844 source term and the gap and in-vessel releases in the AST produce similar integrated doses. This report also showed that, for equipment exposed to sump water, the integrated doses calculated with the AST exceeded those calculated with TID-14844 after 42 days for a pressurized-water reactor (PWR) and 145 days for a boiling-water reactor (BWR) because of the 30% vs. 1% release of cesium."

With this finding in mind, the two key conclusions of this generic issue evaluation were (1) the determination that use of the AST is not a matter of compliance (10CFR50.49 is silent on the exact source term to be used, and Regulatory Guide 1.89 actually specifies TID-14844) and (2) it is not a matter of safety significance. In connection with this last point, the only issue even mentioned regarding safety significance is decay heat removal for PWRs (with the 42-day change in the bounding sump water source term). BWRs (and the 145-day change in the bounding sump water, or more exactly, suppression pool, source term) are not mentioned.

3. Polestar's view is that the long-term impact of cesium, particularly for a BWR, is a not significant and concurs with the position expressed in the NRC memorandum.

*Section 2 – Impact of AST on Vital Area Access*

To determine the accessibility of areas in the plant where post-accident actions must be taken, one must consider both the radiation levels and the airborne contamination levels in those areas. This, in combination with the duration of the post-accident operation being evaluated, determines the accessibility of the area.

**Proprietary Material Removed**

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*Section 3 – Technical Support Center (TSC) Habitability*

Continuous occupancy of the CR is covered in Reference 5. In Appendix B of Reference 5, a STARDOSE model is presented which calculates the CR dose. The same ventilation system which serves the CR also serves the TSC; and as with the CR, there is no filtration of the makeup air supply. Therefore, the TSC dose from activity brought into the ventilation system will be the same as that for the CR.

Where the assessment of TSC habitability differs from the assessment of CR habitability is in the area of external radiation effects. The TSC is not heavily shielded in the same manner as the CR. Therefore, some conservatisms in the RB drawdown bypass modeling and in the nitrogen supply RB bypass modeling that were included for the CR have been relaxed for the TSC. Therefore, this section has two parts: (1) a recalculation of the CR/TSC doses from activity brought in through the common ventilation system using the STARDOSE model (but with some of the bypass conservatisms relaxed and including holdup within the RB for consistency with the TSC external shine calculation), and (2) a recalculation of the TSC external shine using the RB activities as a function of time developed in the previous section (Attachment 1).

The case analyzed is the limiting case for the CR dose from Reference 5; i.e., failure of one SGTS train. This failure also maximizes the activity within the RB (as it was analyzed in the previous section).

<u>Dose from Activity Entering the CR/TSC Ventilation Supply for the DBA-LOCA</u>

The bypass refinements are as follows:

- Credit is taken for the fact that during the nominal 10-minute drawdown time, the RB is actually at a positive pressure for only six minutes (see Design Input). The six minutes of positive pressure are assumed to be at the end of the 10-minute period.

- Credit is taken for particulate deposition in a portion of the nitrogen supply leakage pathway leading from the PC to the south wall of the RB. This credit makes use of the same modeling as that used for the MSIVs.

To make this latter calculation, the nitrogen supply bypass pathway data from the Design Input section is used. A summary of the nitrogen supply bypass particulate removal calculation is as follows:

| | | | | | | |
|---|---|---|---|---|---|---|
| **Bypass Particulate Removal Efficiency** | | | | | | |
| Reference bypass leakage volumetric flow = | | | | **5** | scfh | |
| N2 bypass temp = | | **70** | F, DW temp and p = | **328** | F and | |
| | | | | **44** | psig | |
| Total volumetric N2 line flow from DW = | | | | 0.031 | cfm | |
| **Bypass Line Segment #:** | | **1** | | | | |
| D = | **18** | inches, A = | 1.77 | ft2 | | |
| Length = | **4.67** | feet for settling, V = | | 8.25 | ft3 | |
| Residence time = | | 99 | Min = | 1.65 | hours | |
| Settling velocity = | | **5.00E-05** | M/s, lambda = | 0.50 | per hour | |
| Eff = | 45% | | | | | |
| **Bypass Line Segment #:** | | **2** | | | | |
| D = | **1** | inches, A = | 0.01 | ft2 | | |
| Length = | **16** | feet for settling, V = | | 0.09 | ft3 | |
| Residence time = | | 1 | Min = | 0.02 | hours | |
| Settling velocity = | | **5.00E-05** | M/s, lambda = | 9.02 | per hour | |
| Eff = | 14% | | | | | |
| **Bypass Line Segment #:** | | **3** | | | | |
| D = | **1** | inches, A = | 0.01 | ft2 | | |
| Length = | **16.42** | feet for settling, V = | | 0.09 | ft3 | |
| Residence time = | | 1 | Min = | 0.02 | hours | |
| Settling velocity = | | **5.00E-05** | M/s, lambda = | 9.02 | per hour | |
| Eff = | 14% | | | | | |
| **Bypass Line Segment #:** | | **4** | | | | |
| D = | **2** | inches, A = | 0.02 | ft2 | | |
| Length = | **22.75** | feet for settling, V = | | 0.50 | ft3 | |
| Residence time = | | 6 | Min = | 0.10 | hours | |
| Settling velocity = | | **5.00E-05** | M/s, lambda = | 4.51 | per hour | |
| Eff = | 31% | | | | | |
| **Net Eff =** | 72% | | | | | |

The STARDOSE results for this case are as follows:

| | thyroid | wbody | skin | CEDE |
|---|---|---|---|---|
| Total dose: | 4.76E+001 | 6.08E-002 | 2.43E+000 | 2.22E+000 |
| Noble gas | 0.00E+000 | 5.70E-002 | 2.38E+000 | 0.00E+000 |
| Org iodine | 1.59E+001 | 1.69E-004 | 2.76E-003 | 4.86E-001 |
| Elem iodine | 2.12E+000 | 2.28E-004 | 2.77E-003 | 6.67E-002 |
| Part iodine | 2.88E+001 | 3.17E-003 | 3.86E-002 | 9.09E-001 |
| Cesium | 5.72E-001 | 2.36E-004 | 0.00E+000 | 6.39E-001 |
| Tellurium | 1.90E-001 | 2.37E-006 | 0.00E+000 | 9.30E-003 |
| Barium | 3.97E-004 | 3.16E-005 | 0.00E+000 | 1.59E-003 |
| Noble metal | 2.50E-004 | 0.00E+000 | 0.00E+000 | 1.49E-002 |

| | | | | |
|---|---|---|---|---|
| Lanthanides | 2.98E-005 | 0.00E+000 | 0.00E+000 | 3.01E-002 |
| Cerium | 1.40E-005 | 0.00E+000 | 0.00E+000 | 5.02E-002 |
| Strontinum | 8.33E-004 | 0.00E+000 | 0.00E+000 | 1.04E-002 |

The 30-day post-DBA-LOCA dose contribution from activity entering the TSC is 2.3 rem TEDE.

TSC Shine Calculation

The updated TSC shine calculation has been done with MicroShield MS5 (Reference 10). The limiting TSC dose point is identified in the Design Input section.

The modeling was developed using preliminary information (i.e., preliminary values for the RB activities as a function of time, building volume, dose point location , etc.). The development of the preliminary modeling is documented in a memo to file included as Attachment 2. The preliminary values for RB activities (analogous to Attachment 1 to this calculation) are included as an attachment to that memo to file. The use of MicroShield in the manner described in Attachment 2 has been independently verified in two ways. Not including the effects of skyshine was independently verified in a second memo to file (Attachment 3), and the use of MicroShield cylindrical geometry with a vertical annulus shield was independently verified using QADMOD-GP in a third memo to file (Attachment 4). While this work was conducted using preliminary information, the final inputs were very close to (and qualitatively the same as) the preliminary information used to qualify the approach. Therefore, verification of the final MicroShield analysis consisted of verifying that inputs from Attachment 1 and the Design Input section of this calculation were used.

The integrated 30-day shine dose for the TSC consists of two parts: the MicroShield analysis contribution of shine from activity within the RB and a contribution from the external cloud. From the Design Input section, the contribution from the external cloud is determined to be 15 times the whole body dose from sources internal to the TSC which is 15 x 0.062 rem or 0.93 rem. The integrated 30-day contribution from the MicroShield analysis (for the worst dose point identified in the Design Input section) is 0.27 rem. The total 30-day external shine dose is, therefore, 0.93 rem + 0.27 rem = 1.2 rem.

TSC Total 30-day Habitability Dose

The combined dose including the contribution from activity entering the TSC and from external shine is 3.5 rem TEDE. This is within the 5 rem TEDE limit for the TSC.

**Results**

*Section 1 – Impact of AST on Equipment Qualification*

No change is required in the basis for equipment qualification. Continued use of the TID-14844 source term as the basis for EQ is validated by the NRC generic dispositioning of the question of AST cesium impact on EQ programs. This is discussed further in the calculation section on this topic.

*Section 2 – Impact of AST on Vital Area Access*

- For doses from waterborne sources, TID-14844 will control dose rates for at least the first day and (with shielding considered) perhaps longer. The areas affected by waterborne souces will be controlled by access within the first day; and therefore, the TID-14844 dose rates will be greater than those of the AST.

- For doses from airborne sources (which are typically more controlling than waterborne sources in any case), the airborne dose rates will always be controlled by TID-14844 given that release pathways from the PC and/or the RB remain the same.

- For both waterborne and airborne cases, any increase in power level and/or burnup affecting the core inventory would need to be taken into account. However, the TID-14844 source term can remain as the basis.

*Section 3 – Technical Support Center (TSC) Habitability*

The 30-day dose for an occupant of the TSC (assuming the same occupancy as the CR) is 3.5 rem.TEDE.

**Conclusions**

The TID-14844 source term is generally more limiting than the AST. For EQ, a generic NRC/Sandia evaluation of the EQ implications of the AST (and the associated additional cesium release) concludes that the TID-14844 source term can continue to be used as the EQ basis. For vital area access, the TID-14844 source term produces more limiting dose rates than does the AST. For the TSC, the 30-day habitability dose for the DBA-LOCA is less than the 5 rem TEDE limit.

## RB Activities vs. Time for TSC Shine Calculation

| Hours: | 1 | 2 | 4 | 8 | 16 | 24 | 48 | 72 | 96 | 120 | 240 | 720 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kr83m | 1.97E+02 | 9.76E+02 | 1.60E+03 | 8.01E+02 | 7.40E+01 | 4.87E+00 | 5.18E-04 | 6.09E-08 | 7.43E-12 | 9.20E-16 | 2.77E-35 | |
| Kr85m | 5.59E+02 | 3.44E+03 | 8.70E+03 | 1.04E+04 | 5.40E+03 | 2.01E+03 | 3.84E+01 | 8.12E-01 | 1.78E-02 | 3.98E-04 | 2.25E-12 | 2.36E-45 |
| Kr85 | 3.41E+01 | 2.46E+02 | 8.51E+02 | 1.91E+03 | 3.52E+03 | 4.63E+03 | 3.94E+03 | 3.69E+03 | 3.60E+03 | 3.56E+03 | 3.47E+03 | 3.19E+03 |
| Kr87 | 7.57E+02 | 3.16E+03 | 3.66E+03 | 9.20E+02 | 2.13E+01 | 3.52E-01 | 5.93E-07 | 1.10E-12 | 2.13E-18 | 4.16E-24 | 1.23E-52 | |
| Kr88 | 1.45E+03 | 8.15E+03 | 1.72E+04 | 1.43E+04 | 3.64E+03 | 6.62E+02 | 1.47E+00 | 3.62E-03 | 9.26E-06 | 2.40E-08 | 2.90E-21 | 6.25E-73 |
| Kr89 | 4.93E-03 | 7.51E-08 | 1.16E-18 | 5.28E-41 | 3.96E-86 | | | | | | | |
| Xe131m | 2.14E+01 | 1.54E+02 | 5.31E+02 | 1.18E+03 | 2.13E+03 | 2.75E+03 | 2.21E+03 | 1.96E+03 | 1.80E+03 | 1.68E+03 | 1.23E+03 | 3.58E+02 |
| Xe133m | 1.17E+02 | 8.35E+02 | 2.82E+03 | 6.01E+03 | 1.00E+04 | 1.19E+04 | 7.51E+03 | 5.21E+03 | 3.76E+03 | 2.75E+03 | 5.95E+02 | 1.32E+00 |
| Xe133 | 3.88E+03 | 2.79E+04 | 9.56E+04 | 2.10E+05 | 3.75E+05 | 4.76E+05 | 3.62E+05 | 3.04E+05 | 2.63E+05 | 2.29E+05 | 1.17E+05 | 7.83E+03 |
| Xe135m | 5.36E+01 | 2.69E+01 | 4.53E-01 | 2.39E-05 | 2.45E-14 | 1.79E-23 | 2.60E-51 | 4.17E-79 | | | | |
| Xe135 | 1.52E+03 | 1.02E+04 | 3.21E+04 | 5.94E+04 | 7.21E+04 | 6.02E+04 | 1.19E+04 | 2.31E+03 | 4.20E+02 | 7.29E+01 | 9.14E-03 | 1.76E-18 |
| Xe137 | 8.06E-02 | 1.37E-05 | 2.63E-14 | 1.84E-32 | 3.26E-69 | | | | | | | |
| Xe138 | 2.95E+02 | 1.84E+02 | 4.76E+00 | 5.96E-04 | 3.44E-12 | 1.41E-20 | 3.67E-46 | 1.05E-71 | 3.12E-97 | | | |
| I131Org | 1.53E+00 | 7.37E+00 | 2.29E+01 | 4.95E+01 | 8.80E+01 | 1.12E+02 | 8.92E+01 | 7.73E+01 | 6.94E+01 | 6.30E+01 | 4.01E+01 | 6.63E+00 |
| I132Org | 1.62E+00 | 5.81E+00 | 1.01E+01 | 6.69E+00 | 1.13E+00 | 1.37E-01 | 9.36E-05 | 6.98E-08 | 5.38E-11 | 4.20E-14 | 1.25E-29 | 1.00E-91 |
| I133Org | 3.01E+00 | 1.41E+01 | 4.14E+01 | 7.94E+01 | 1.11E+02 | 1.12E+02 | 4.37E+01 | 1.86E+01 | 8.22E+00 | 3.67E+00 | 6.68E-02 | 7.44E-09 |
| I134Org | 1.55E+00 | 3.36E+00 | 2.12E+00 | 1.87E-01 | 5.55E-04 | 1.18E-06 | 4.40E-15 | 1.78E-23 | 7.48E-32 | 3.18E-40 | 4.51E-82 | |
| I135Org | 2.61E+00 | 1.14E+01 | 2.92E+01 | 4.23E+01 | 3.39E+01 | 1.96E+01 | 1.43E+00 | 1.14E-01 | 9.44E-03 | 7.90E-04 | 3.32E-09 | 1.06E-30 |
| I131Elem | 8.94E+00 | 2.22E+01 | 4.17E+01 | 6.79E+01 | 1.05E+02 | 1.28E+02 | 1.53E+02 | 1.52E+02 | 1.42E+02 | 1.31E+02 | 8.45E+01 | 1.43E+01 |
| I132Elem | 1.07E+01 | 2.87E+01 | 5.75E+01 | 6.33E+01 | 4.21E+01 | 2.69E+01 | 7.27E+00 | 1.97E+00 | 5.34E-01 | 1.45E-01 | 2.12E-04 | 9.74E-16 |
| I133Elem | 1.76E+01 | 4.24E+01 | 7.52E+01 | 1.09E+02 | 1.32E+02 | 1.28E+02 | 7.52E+01 | 3.65E+01 | 1.68E+01 | 7.64E+00 | 1.41E-01 | 1.61E-08 |
| I134Elem | 9.06E+00 | 1.01E+01 | 3.84E+00 | 2.55E-01 | 6.60E-04 | 1.35E-06 | 7.56E-15 | 3.49E-23 | 1.53E-31 | 6.61E-40 | 9.50E-82 | |
| I135Elem | 1.53E+01 | 3.43E+01 | 5.30E+01 | 5.78E+01 | 4.03E+01 | 2.23E+01 | 2.46E+00 | 2.24E-01 | 1.93E-02 | 1.64E-03 | 7.01E-09 | 6.41E-28 |
| I131Part | 1.75E+02 | 4.34E+02 | 8.16E+02 | 1.33E+03 | 2.05E+03 | 2.50E+03 | 3.00E+03 | 2.97E+03 | 2.79E+03 | 2.57E+03 | 1.66E+03 | 2.80E+02 |
| I132Part | 1.85E+02 | 3.42E+02 | 3.58E+02 | 1.79E+02 | 2.63E+01 | 3.06E+00 | 3.15E-03 | 2.68E-06 | 2.16E-09 | 1.71E-12 | 5.17E-28 | 2.47E-56 |
| I133Part | 3.45E+02 | 8.31E+02 | 1.47E+03 | 2.13E+03 | 2.59E+03 | 2.50E+03 | 1.47E+03 | 7.16E+02 | 3.30E+02 | 1.50E+02 | 2.76E+00 | 3.15E-07 |
| I134Part | 1.78E+02 | 1.98E+02 | 7.53E+01 | 5.00E+00 | 1.29E-02 | 2.64E-05 | 1.48E-13 | 6.84E-22 | 3.00E-30 | 1.29E-38 | 1.86E-80 | |
| I135Part | 3.00E+02 | 6.73E+02 | 1.04E+03 | 1.13E+03 | 7.90E+02 | 4.36E+02 | 4.82E+01 | 4.39E+00 | 3.79E-01 | 3.22E-02 | 1.37E-07 | 4.47E-29 |
| Rb86 | 6.18E-01 | 1.13E+00 | 1.33E+00 | 1.14E+00 | 7.82E-01 | 5.37E-01 | 1.74E-01 | 5.65E-02 | 1.83E-02 | 5.95E-03 | 2.14E-05 | 3.59E-15 |
| Cs134 | 7.35E+01 | 1.34E+02 | 1.59E+02 | 1.37E+02 | 9.51E+01 | 6.61E+01 | 2.22E+01 | 7.49E+00 | 2.52E+00 | 8.47E-01 | 3.65E-03 | 1.26E-12 |
| Cs136 | 1.88E+01 | 3.43E+01 | 4.04E+01 | 3.45E+01 | 2.36E+01 | 1.61E+01 | 5.14E+00 | 1.64E+00 | 5.24E-01 | 1.67E-01 | 5.55E-04 | 6.74E-14 |
| Cs137 | 2.94E+01 | 5.38E+01 | 6.36E+01 | 5.47E+01 | 3.81E+01 | 2.65E+01 | 8.91E+00 | 3.00E+00 | 1.01E+00 | 3.40E-01 | 1.47E-03 | 5.17E-13 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sb127 | 1.62E+00 | 5.35E+00 | 6.93E+00 | 5.84E+00 | 3.83E+00 | 2.51E+00 | 7.07E-01 | 1.99E-01 | 5.60E-02 | 1.58E-02 | 2.79E-05 | 2.75E-16 |
| Sb129 | 3.81E+00 | 1.08E+01 | 1.03E+01 | 4.75E+00 | 9.26E-01 | 1.80E-01 | 1.33E-03 | 9.86E-06 | 7.29E-08 | 5.39E-10 | 1.19E-20 | 1.95E-49 |
| Te127m | 2.20E-01 | 7.32E-01 | 9.63E-01 | 8.35E-01 | 5.80E-01 | 4.02E-01 | 1.35E-01 | 4.50E-02 | 1.51E-02 | 5.04E-03 | 2.11E-05 | 6.54E-15 |
| Te127 | 1.54E+00 | 4.94E+00 | 6.47E+00 | 5.69E+00 | 3.95E+00 | 2.67E+00 | 7.79E-01 | 2.21E-01 | 6.23E-02 | 1.75E-02 | 3.11E-05 | 3.06E-16 |
| Te129m | 6.55E-01 | 2.17E+00 | 2.85E+00 | 2.47E+00 | 1.71E+00 | 1.18E+00 | 3.89E-01 | 1.28E-01 | 4.24E-02 | 1.40E-02 | 5.47E-05 | 1.28E-14 |
| Te129 | 3.03E+00 | 8.54E+00 | 1.12E+01 | 6.31E+00 | 1.29E+00 | 2.51E-01 | 1.86E-03 | 1.37E-05 | 1.01E-07 | 7.50E-10 | 1.65E-20 | 2.71E-49 |
| Te131m | 1.86E+00 | 6.05E+00 | 7.60E+00 | 6.02E+00 | 3.48E+00 | 2.01E+00 | 3.89E-01 | 7.53E-02 | 1.46E-02 | 2.82E-03 | 7.61E-07 | 4.07E-21 |
| Te132 | 1.74E+01 | 5.74E+01 | 7.41E+01 | 6.20E+01 | 4.02E+01 | 2.60E+01 | 7.05E+00 | 1.91E+00 | 5.18E-01 | 1.40E-01 | 2.06E-04 | 9.45E-16 |
| Ba137m | 2.85E+01 | 5.29E+01 | 6.36E+01 | 5.47E+01 | 3.81E+01 | 2.65E+01 | 8.91E+00 | 3.00E+00 | 1.01E+00 | 3.40E-01 | 1.47E-03 | 5.17E-13 |
| Ba139 | 5.79E+00 | 1.17E+01 | 5.64E+00 | 6.61E-01 | 8.40E-03 | 1.07E-04 | 2.19E-10 | 4.48E-16 | 9.19E-22 | 1.88E-27 | 6.80E-56 | 1.32E-90 |
| Ba140 | 9.17E+00 | 3.04E+01 | 3.98E+01 | 3.42E+01 | 2.34E+01 | 1.60E+01 | 5.10E+00 | 1.63E+00 | 5.19E-01 | 1.66E-01 | 5.47E-04 | 6.51E-14 |
| Mo99 | 1.18E+00 | 3.87E+00 | 4.98E+00 | 4.15E+00 | 2.66E+00 | 1.70E+00 | 4.47E-01 | 1.18E-01 | 3.09E-02 | 8.12E-03 | 1.02E-05 | 2.51E-17 |
| Tc99m | 9.61E-01 | 3.06E+00 | 4.14E+00 | 3.82E+00 | 2.72E+00 | 1.81E+00 | 4.91E-01 | 1.29E-01 | 3.40E-02 | 8.92E-03 | 1.12E-05 | 2.76E-17 |
| Ru103 | 1.14E+00 | 3.77E+00 | 4.95E+00 | 4.28E+00 | 2.97E+00 | 2.05E+00 | 6.79E-01 | 2.25E-01 | 7.43E-02 | 2.46E-02 | 9.75E-05 | 2.42E-14 |
| Ru105 | 7.74E-01 | 2.21E+00 | 2.14E+00 | 1.01E+00 | 2.09E-01 | 4.32E-02 | 3.79E-04 | 3.33E-06 | 2.93E-08 | 2.57E-10 | 1.35E-20 | 1.06E-61 |
| Ru106 | 6.39E-01 | 2.12E+00 | 2.79E+00 | 2.42E+00 | 1.68E+00 | 1.17E+00 | 3.94E-01 | 1.32E-01 | 4.45E-02 | 1.49E-02 | 6.41E-05 | 2.17E-14 |
| Rh105 | 8.13E-01 | 2.67E+00 | 3.46E+00 | 2.88E+00 | 1.77E+00 | 1.07E+00 | 2.27E-01 | 4.80E-02 | 1.01E-02 | 2.14E-03 | 8.98E-07 | 2.80E-20 |
| Y90 | 9.41E-03 | 4.39E-02 | 1.17E-01 | 2.14E-01 | 2.96E-01 | 3.00E-01 | 1.81E-01 | 8.18E-02 | 3.29E-02 | 1.25E-02 | 6.91E-05 | 2.63E-14 |
| Y91 | 7.49E-02 | 2.54E-01 | 3.58E-01 | 3.49E-01 | 2.77E-01 | 2.06E-01 | 7.34E-02 | 2.47E-02 | 8.24E-03 | 2.74E-03 | 1.12E-05 | 3.10E-15 |
| Y92 | 3.81E-01 | 2.60E+00 | 6.88E+00 | 6.14E+00 | 1.59E+00 | 2.94E-01 | 1.18E-03 | 4.03E-06 | 1.34E-08 | 4.45E-11 | 1.77E-23 | 2.10E-54 |
| Y93 | 8.22E-02 | 2.55E-01 | 2.92E-01 | 1.93E-01 | 7.74E-02 | 3.11E-02 | 2.01E-03 | 1.30E-04 | 8.40E-06 | 5.43E-07 | 6.13E-13 | 4.97E-35 |
| Zr95 | 8.63E-02 | 2.87E-01 | 3.77E-01 | 3.26E-01 | 2.26E-01 | 1.57E-01 | 5.23E-02 | 1.74E-02 | 5.80E-03 | 1.93E-03 | 7.91E-06 | 2.24E-15 |
| Zr97 | 8.24E-02 | 2.63E-01 | 3.19E-01 | 2.35E-01 | 1.18E-01 | 5.94E-02 | 7.53E-03 | 9.56E-04 | 1.21E-04 | 1.54E-05 | 5.05E-10 | 5.87E-28 |
| Nb95 | 8.65E-02 | 2.87E-01 | 3.78E-01 | 3.28E-01 | 2.28E-01 | 1.59E-01 | 5.34E-02 | 1.80E-02 | 6.05E-03 | 2.04E-03 | 8.75E-06 | 2.88E-15 |
| La140 | 1.29E-01 | 6.78E-01 | 2.06E+00 | 3.94E+00 | 5.42E+00 | 5.36E+00 | 2.96E+00 | 1.22E+00 | 4.53E-01 | 1.58E-01 | 6.12E-04 | 7.50E-14 |
| La141 | 7.17E-02 | 1.99E-01 | 1.84E-01 | 7.83E-02 | 1.31E-02 | 2.20E-03 | 1.04E-05 | 4.90E-08 | 2.31E-10 | 1.09E-12 | 2.55E-24 | 1.38E-67 |
| La142 | 5.33E-02 | 1.13E-01 | 5.97E-02 | 8.45E-03 | 1.56E-04 | 2.88E-06 | 1.82E-11 | 1.15E-16 | 7.21E-22 | 4.55E-27 | 4.51E-53 | 4.15E-89 |
| Pr143 | 8.21E-02 | 2.73E-01 | 3.61E-01 | 3.16E-01 | 2.24E-01 | 1.57E-01 | 5.32E-02 | 1.76E-02 | 5.76E-03 | 1.87E-03 | 6.40E-06 | 8.20E-16 |
| Nd147 | 3.34E-02 | 1.11E-01 | 1.45E-01 | 1.24E-01 | 8.49E-02 | 5.79E-02 | 1.83E-02 | 5.80E-03 | 1.84E-03 | 5.82E-04 | 1.85E-06 | 1.92E-16 |
| Am241 | 1.52E-05 | 5.06E-05 | 6.65E-05 | 5.78E-05 | 4.02E-05 | 2.80E-05 | 9.42E-06 | 3.17E-06 | 1.07E-06 | 3.60E-07 | 1.56E-09 | 5.52E-19 |
| Cm242 | 5.96E-03 | 1.98E-02 | 2.61E-02 | 2.26E-02 | 1.57E-02 | 1.09E-02 | 3.66E-03 | 1.23E-03 | 4.11E-04 | 1.38E-04 | 5.85E-07 | 1.89E-16 |
| Cm244 | 2.11E-03 | 7.01E-03 | 9.22E-03 | 8.01E-03 | 5.57E-03 | 3.88E-03 | 1.31E-03 | 4.40E-04 | 1.48E-04 | 4.98E-05 | 2.16E-07 | 7.57E-17 |
| Ce141 | 2.10E-01 | 6.98E-01 | 9.16E-01 | 7.93E-01 | 5.48E-01 | 3.79E-01 | 1.25E-01 | 4.11E-02 | 1.35E-02 | 4.46E-03 | 1.73E-05 | 3.97E-15 |
| Ce143 | 2.05E-01 | 6.66E-01 | 8.39E-01 | 6.68E-01 | 3.91E-01 | 2.29E-01 | 4.57E-02 | 9.14E-03 | 1.83E-03 | 3.66E-04 | 1.17E-07 | 1.23E-21 |
| Ce144 | 1.65E-01 | 5.49E-01 | 7.21E-01 | 6.26E-01 | 4.35E-01 | 3.03E-01 | 1.02E-01 | 3.42E-02 | 1.15E-02 | 3.85E-03 | 1.65E-05 | 5.55E-15 |
| Np239 | 3.35E+00 | 1.10E+01 | 1.41E+01 | 1.17E+01 | 7.36E+00 | 4.64E+00 | 1.16E+00 | 2.90E-01 | 7.26E-02 | 1.82E-02 | 1.78E-05 | 1.64E-17 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pu238 | 1.74E-03 | 5.78E-03 | 7.60E-03 | 6.60E-03 | 4.60E-03 | 3.20E-03 | 1.08E-03 | 3.62E-04 | 1.22E-04 | 4.11E-05 | 1.78E-07 | 6.26E-17 |
| Pu239 | 6.51E-05 | 2.16E-04 | 2.84E-04 | 2.47E-04 | 1.72E-04 | 1.20E-04 | 4.03E-05 | 1.36E-05 | 4.57E-06 | 1.54E-06 | 6.66E-09 | 2.37E-18 |
| Pu240 | 1.38E-04 | 4.58E-04 | 6.02E-04 | 5.22E-04 | 3.64E-04 | 2.53E-04 | 8.52E-05 | 2.87E-05 | 9.66E-06 | 3.25E-06 | 1.41E-08 | 4.98E-18 |
| Pu241 | 2.91E-02 | 9.67E-02 | 1.27E-01 | 1.10E-01 | 7.68E-02 | 5.34E-02 | 1.80E-02 | 6.06E-03 | 2.04E-03 | 6.87E-04 | 2.97E-06 | 1.04E-15 |
| Sr89 | 6.15E+00 | 2.04E+01 | 2.68E+01 | 2.32E+01 | 1.61E+01 | 1.12E+01 | 3.71E+00 | 1.23E+00 | 4.09E-01 | 1.36E-01 | 5.49E-04 | 1.47E-13 |
| Sr90 | 7.32E-01 | 2.43E+00 | 3.20E+00 | 2.78E+00 | 1.93E+00 | 1.34E+00 | 4.53E-01 | 1.52E-01 | 5.13E-02 | 1.73E-02 | 7.48E-05 | 2.63E-14 |
| Sr91 | 7.39E+00 | 2.28E+01 | 2.60E+01 | 1.69E+01 | 6.59E+00 | 2.57E+00 | 1.52E-01 | 9.04E-03 | 5.36E-04 | 3.18E-05 | 2.33E-11 | 7.79E-36 |
| Sr92 | 6.33E+00 | 1.62E+01 | 1.26E+01 | 3.82E+00 | 3.26E-01 | 2.78E-02 | 1.72E-05 | 1.07E-08 | 6.60E-12 | 4.09E-15 | 3.72E-31 | 6.86E-70 |

Memo to files Attachment 2 05/09/03
From: R. Sher
Comments added by J. Metcalf
Subject: Vermont Yankee TSC Integrated Dose Calculation

This memo describes the calculation of the integrated dose in the Technical Support Center (TSC) following a LOCA release to the Reactor Building (RB). The RB fission product activities as functions of time were supplied by Jim Metcalf and are shown in Attachment 1.

Dose rates as functions of time were calculated with MicroShield MS5. Following a suggestion by Jim Metcalf, an equivalent cylindrical geometry was employed. Figure 1 shows the equivalent cylindrical geometry in plan view. Figure 2 shows the geometry used in the MS5 calculations. Note that the estimated dose point location in Figure 1 (intended to represent "location 3" in the current VY TSC shine calculation) is 158' from the center of the assumed source in plan view, whereas in Figure 2, it is 127.7' from the center of the assumed source in plan view. This point will be revisited in what follows.

The MS5 geometry parameters for the top cylinder were H = 42', R = 72', Sh1 = 1' (air, density = 0.00122 g/cm$^3$), Sh2 = 54' (air), Sh3 = 0.667' (an 8" concrete shield placed vertically in the model, but actually oriented horizontally, density = 2.33 g/cm$^3$), X = 127.7', Y = 121', Z = 0'. The buildup factor for the 54' air "shield" was used, since it gave the largest dose rates. No credit has been taken for the sheet-metal wall of the upper compartment. The vertical placement of the concrete shield is a limitation of the code for this geometry and is discussed further below. The volume of the RB is actually based on a height of 139' since the dose point is approximately 18' above grade. However, this has no impact on the MS5 model geometry.

Sh1 represents a "transition region" which MS5 requires because the source is cylindrical but the shields are rectangular. X represents the horizontal distance from the origin of the coordinate system, which is at the center of the top of the cylinder, to the dose point. It is equal to 72'+1'+54'+0.667'+0.033' = 127.7'. 0.033' (1 cm) is the air gap at the dose point required by MS5. Y is the vertical distance from the origin to the dose point, equal to 42'+79' or 121'. The X axis is taken to be the horizontal line from the origin to the dose point, therefore Z = 0.

Since the center plane of the source volume is 100' above the dose point and the dose point is 128' from the centerline of the source volume, the angle of the ray from the center of the source volume to the dose point is 38 degrees above the horizontal. This means that the distance through the 8" vertical shield is actually a little more than 10". However, the actual distance through the 8" shield (were it able to be horizontally placed in the model) would be 13", and the dose would be lower than that calculated in this analysis. Moreover, this model is conservative because it places the dose point closer to the source than actually needed (128' to the center of the source rather than 158'). As the distance from the source increases, not only would the $1/r^2$ geometric effect decrease the dose, but air attenuation and a greater distance through the 8" shield would also decrease the dose.

It is interesting to note that given the vertical placement of the shield in the model, an opposite effect is observed for dose vs. distance up to a point. As the distance from the source increases, the angle of the ray above the horizontal becomes shallower, and the effectiveness of a vertical shield decreases rather than increases. Eventually the sensitivity of the effective shielding thickness with distance becomes small and geometric and air shielding effects become dominant, but for points near the source, the dose vs. distance actually increases (artificially) because of the vertical shield. For a dose point less than about 100' from the source in plan view, the angle of the ray above the horizontal becoming greater than 45 degrees; and this model would produce a non-conservative result using the vertical shield (i.e., the shielding effectiveness becomes overstated). But for angles above the horizontal less than 45 degrees, the model becomes increasingly conservative with distance.

The dose vs. distance *as calculated by the model* is shown on Figure 3, both with and without build-up (build-up is included in the dose results below). For r < 141' (where "r" is the distance from the center of the source to the dose point), the results are no longer conservative. Beyond r = 141' (and for a horizontal distance of 127.7', "r" is 162'), the dose becomes increasingly conservative. In this model (as shown on the figure), the dose decreases roughly as $1/r^3$ (the $1/r^2$ geometric effect plus air attenuation) beyond about r = 250'; but in actuality, it would be a much greater rate of decrease because of the shielding orientation.

To confirm that dose actually does vary as $1/r^2$ near the source, the thickness of the shield was varied to maintain a constant distance for the ray passing through the shield as the horizontal distance was varied from 100' to 300'. The results are shown on Figure 4, and there is good agreement between the actual doses and the estimated doses based on a $1/r^2$ dependency. The $1/r^2$ dependency is mentioned in Appendix A in terms of quantifying the impact of the portions of the assumed cylindrical source that are actually shielded by the lower concrete walls of the reactor building.

At each of the times up to 15 days that the source inventories were available, they were entered into the MS5 source file for that time. The full RB inventories were used. At the end of the calculation the dose obtained can be multiplied by the ratio of the free volume of the top compartment to the free volume of the whole RB (i.e., the volume used in the STARDOSE run that produced the source). A further correction to account for the portion of the upper compartment that is actually "seen" by the dose point is discussed below and in Appendix A.

The source inventory at 30 days was estimated by decaying the activities at 15 days by an additional 15 days. The code RADDECAY was used for this calculation. The 30-day activities may be overestimated since there is no removal by ventilation or purging flows included. However, the RB is in equilibrium with the containment by this point in time, so decay should effect both sources (containment) and sinks (RB exhaust flow) equally.

The integrated dose as a function of time was obtained from the dose rates by taking the linear average of the dose rate over a time interval, multiplying by the interval and summing. In this manner the 30-day integrated dose was obtained as 6.62 rad, assuming a volume ratio of 42/139 = 0.302 (same as the ratio of heights). An additional factor of 1.509 must be applied since the free volume of the RB is 1.5E6 $ft^3$, but the MS5 volume is 2.26E6 $ft^3$ (= $\pi \times 72^2 \times 139$).

A better way to average the dose rate is logarithmically (since the dose rate is diminishing approximately exponentially over a given time interval). Averaging logarithmically gave an integrated dose of about 6.1 rad. Figure 5 shows the integrated dose as a function of time, with both types of averaging. Note how much of the dose is accumulated in the first day. Therefore, while occupancy factors have not been credited, factors of less than unity after the first day would not have a significant effect.

These doses must be reduced further to account for the fact that the dose point "sees" only a portion of the source volume. In the original rectangular geometry, the fraction of the source volume that contributes to the dose is about 0.2, so without any dependence on "r", the integrated doses would be about 1.32 rad with linear averaging and about 1.22 rad with logarithmic averaging.

To consider the impact of r-dependence, an assessment was done using the assumed cylindrical geometry of the MS5 model. It was noted that the portion of the cylindrical model that can be seen above the concrete shielding of the lower RB would be the upper cylinder truncated by a conic section defined by the upper rim of the assumed cylindrical concrete shield. It was determined (see Appendix A) that the fraction of cylindrical volume that could be "seen" by the dose point is 0.19, almost identical to that found for the original rectangular geometry. However, it was also determined that the volume averaged "r" for the "retained" volume was smaller than that for the upper cylinder as a whole (about 139' vs. 187', the latter corresponding to a horizontal distance from the cylinder centerline to the dose point of 158'). Therefore, assuming a $1/r^2$ dose dependence, the "retained" volume would have about 1.8 times the impact of the cylindrical source as a whole on a per volume basis. This means the dose multiplier to relate the dose from the "retained" volume to that for the upper cylinder should be more like 0.34 rather than 0.19. This would yield a dose of about 2.2 rads for the linear averaging and 2.1 rads for the logarithmic averaging. More detail on the calculation of the view factors is given in Appendix A.

Finally, it should be noted that the above results are only for direct shine from the RB and do not include skyshine. On the other hand, these results do not include consideration of occupancy factor, either. Both of these would be small but not negligible effects. Taking both into account, it is anticipated that the shine contribution from the RB to the TSC can be shown to be less than 2.5 rads over 30 days, with most of the dose occurring within the first 24 hours.

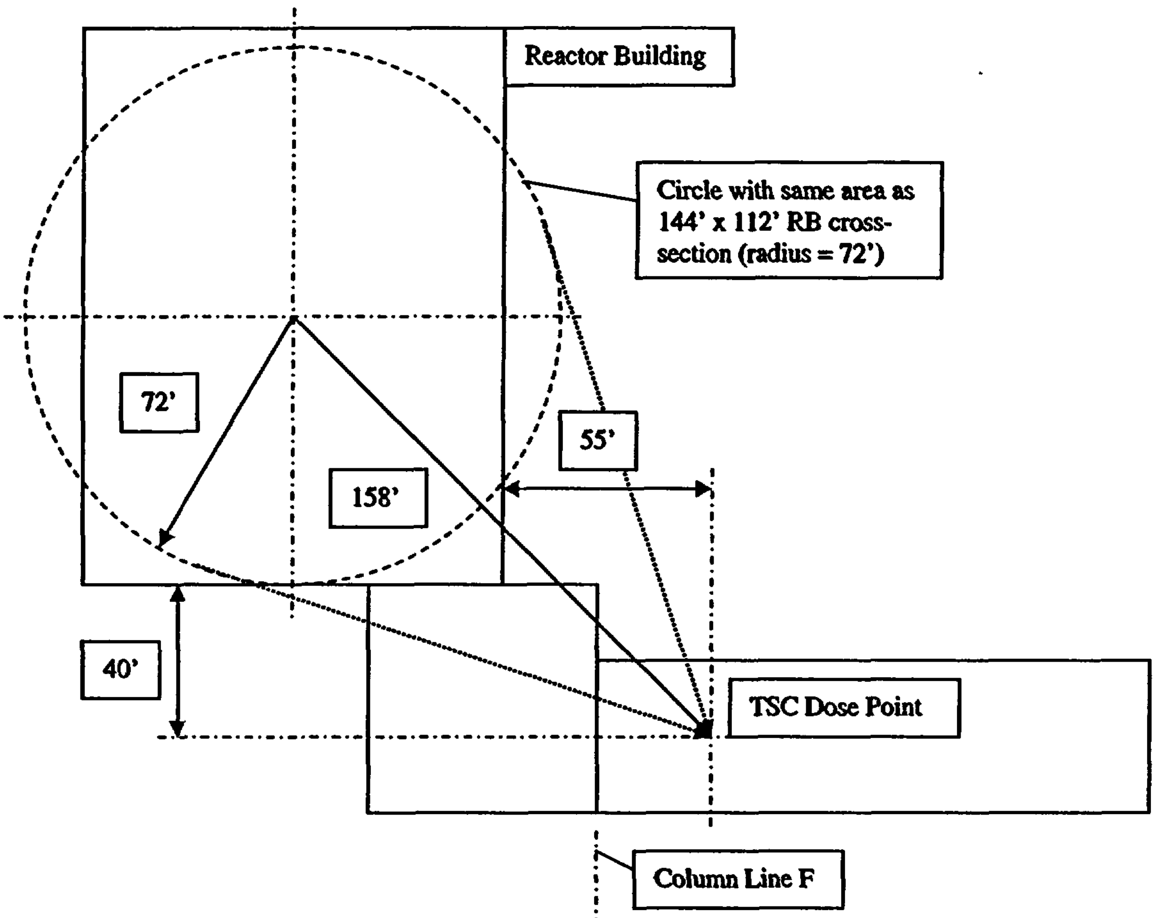



Figure 1. Equivalent Cylinder.

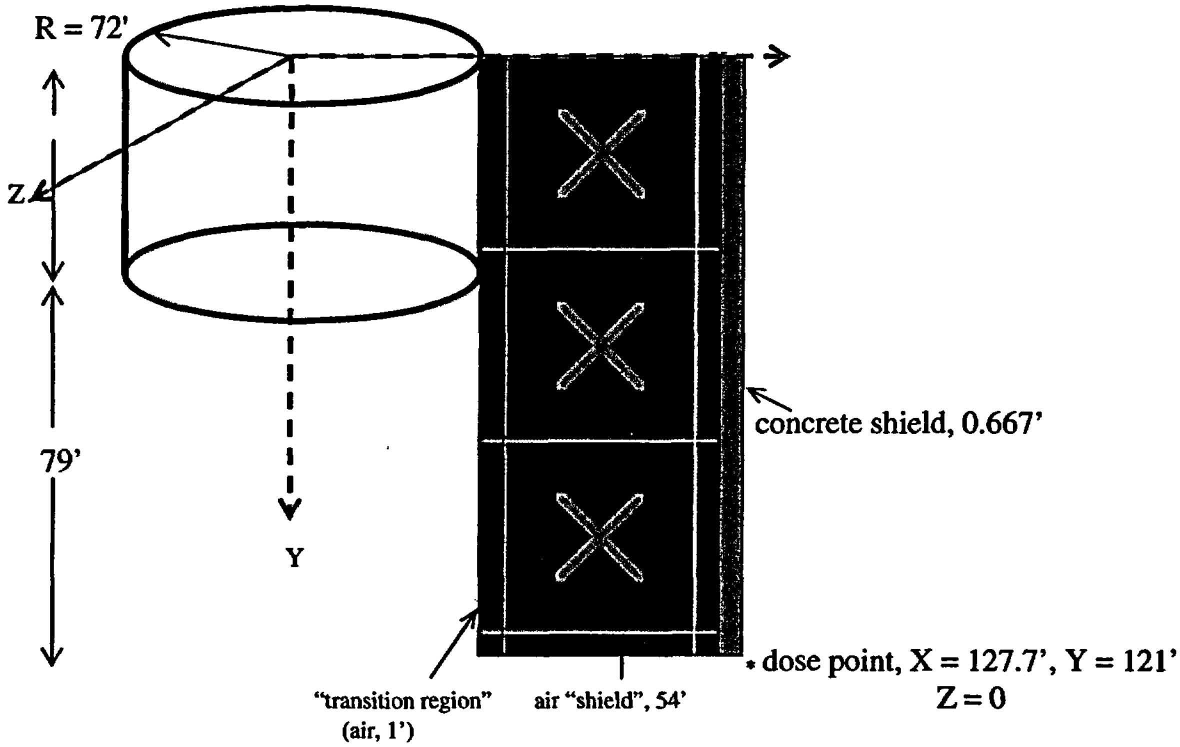



Figure 2. MS5 Geometry.

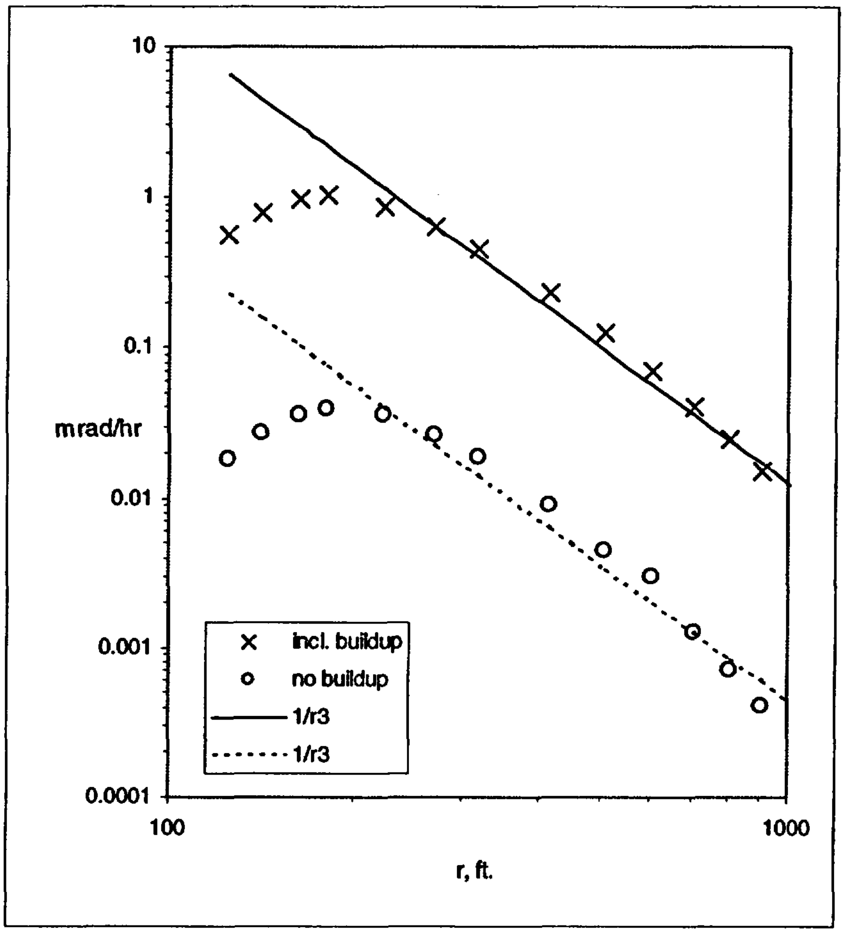



Figure 3. Dose vs. Distance.

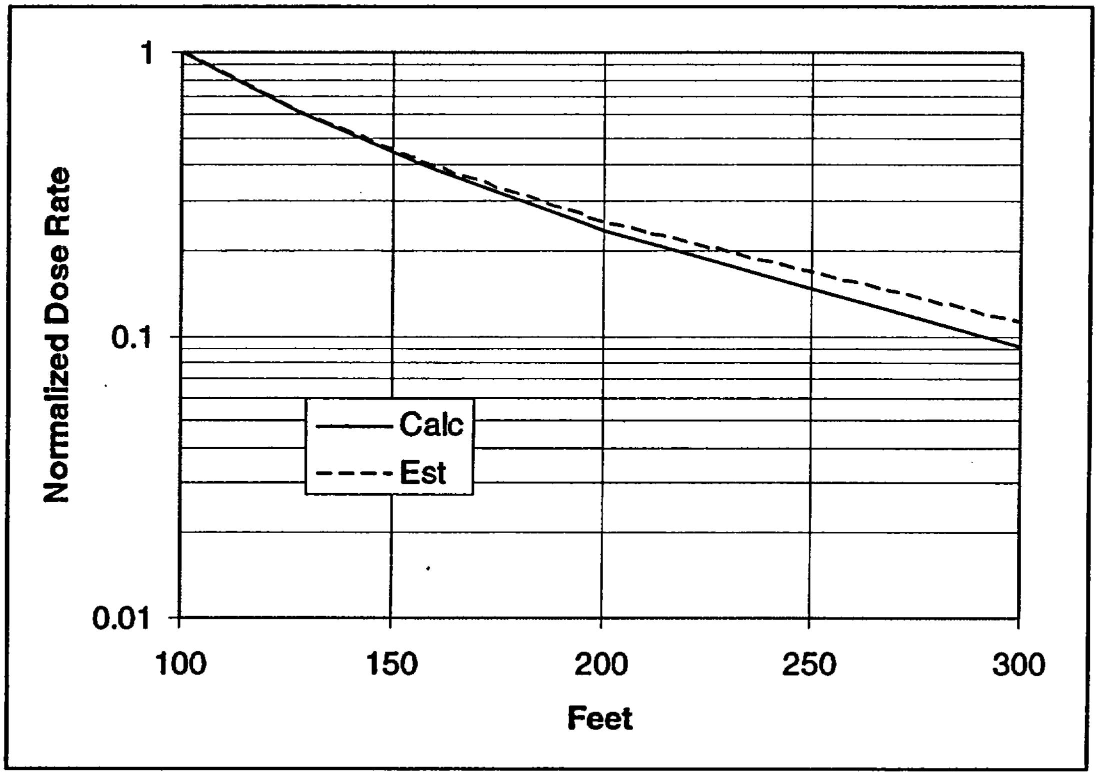



Figure 4. Dose vs. Distance.

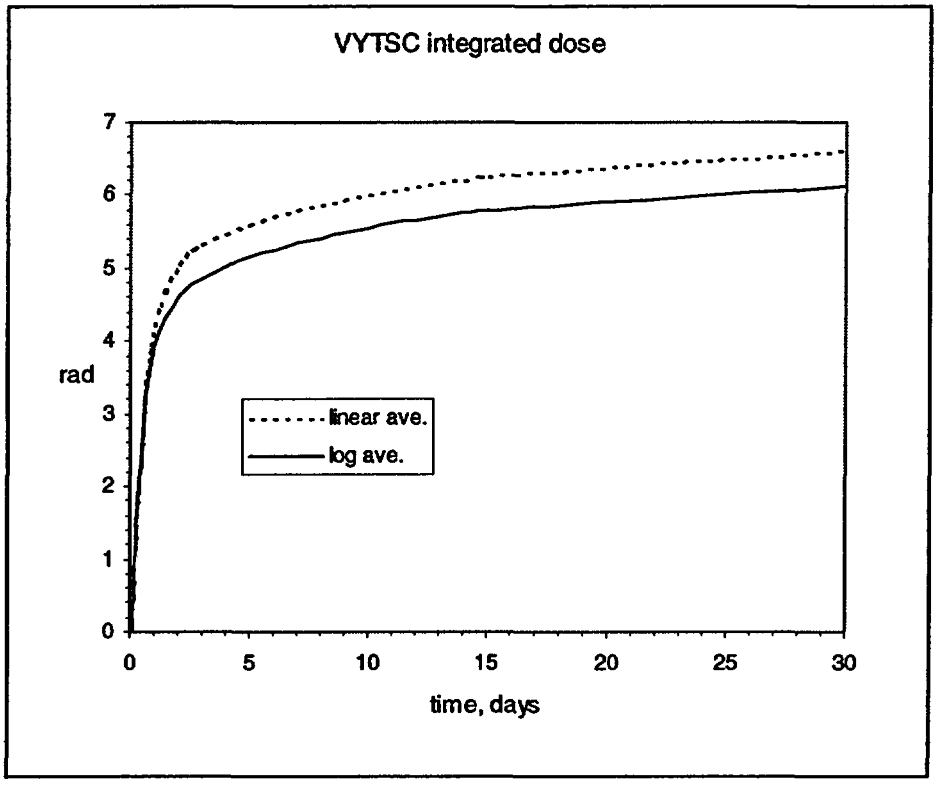
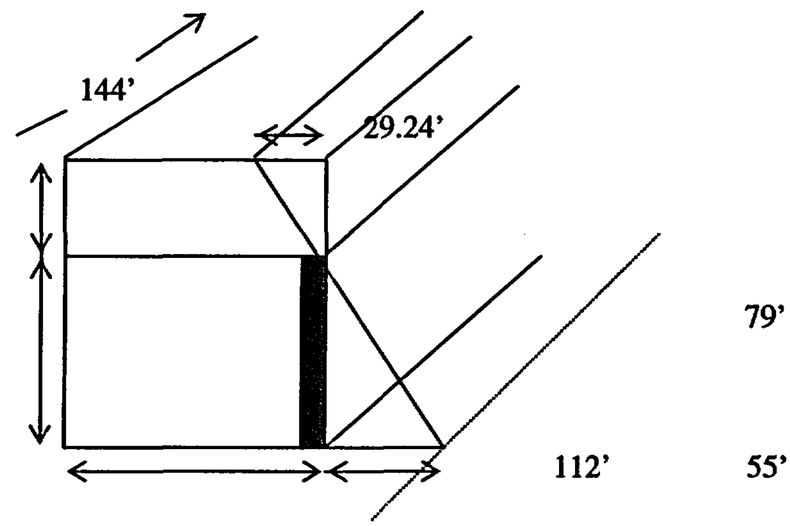



Figure 5. Integrated Dose (rad).

## Appendix A – Calculation of the View Factor.

The figure shows the geometry that determines the view factor in rectangular geometry.




The portion of the upper compartment that is seen from the dose point is the wedge whose volume is (42 x 29.24 x 144)/2 = 88422 $ft^3$. (29.24 = 42 x 55/79.) The total volume of the upper compartment is 42 x 112 x 144 = 677376 $ft^3$.

Similarly, from the other face of the upper compartment, the portion of the upper volume that is seen from the dose point is the wedge whose volume is (42 x 21.27 x 112)/2 = 50027 $ft^3$. (21.27 = 42 x 40/79; the offset in this direction is 40' rather than 55'.)

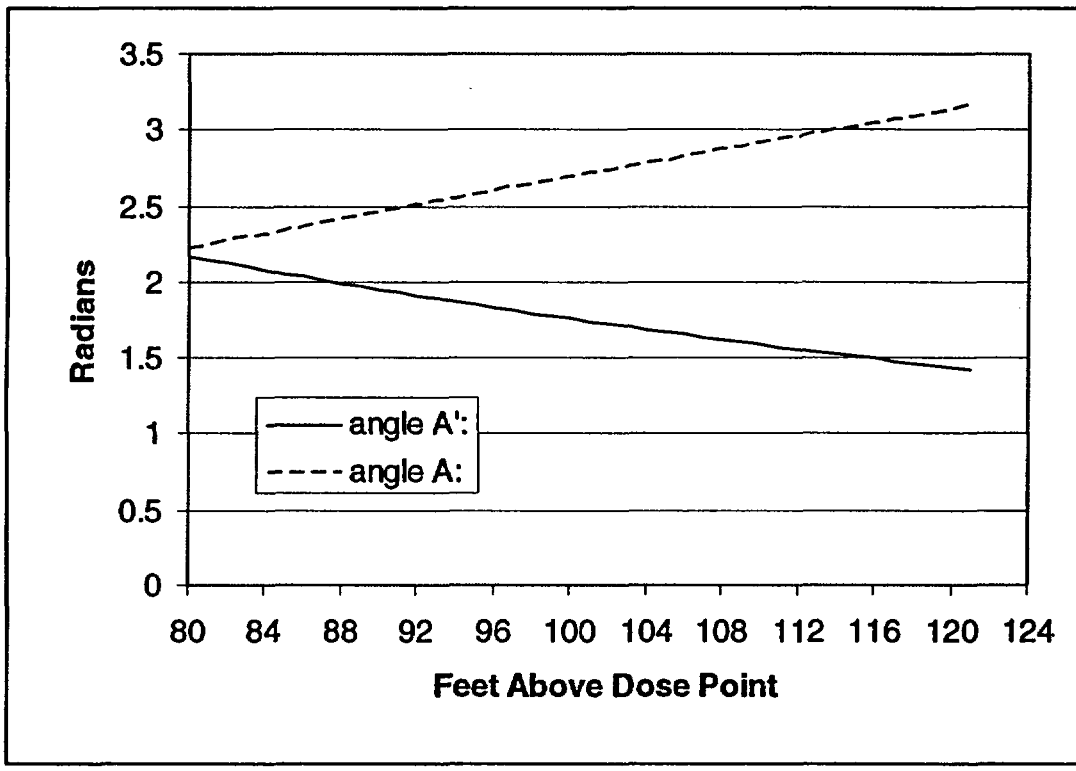
Thus the fraction of the upper compartment that is seen at the dose point is (88422 + 50027 – 0.5 x $V_{int}$)/677376.

$V_{int}$ is the volume of the prism formed by the intersecting volumes of the two wedges and is equal to (29.24 x 21.27 x 42)/2 = 13061 $ft^3$.

Finally, the view factor is (88422 + 50027 – 0.5 x 13061)/677376 = 0.2.

The view factor can also be determined by examining the cylindrical geometry. Looking from the dose point towards the cylinder representing the reactor building, the top rim of the concrete shielding surrounding the lower compartment casts an elliptical "shadow" on any imaginary horizontal plane above the rim of the concrete shielding. The leading edge of this "shadow" (i.e., the point closest to the dose point) is set back a distance of about 1.1 feet from the surface of the upper compartment for each foot of height assuming the dose point is 158' from the centerline of the cylinder (and, therefore, 86' from the surface in the horizontal plane) and 79' below the rim of the concrete shielding. At the top of the upper compartment (42' above the rim of the concrete), the setback is about 46'.

Assuming the leading edge of the "shadow" can be treated as circular over the relatively small arc of its intersection with the circle defined by the assumed cylindrical surface of the upper compartment, the area of the "retained" volume (i.e., that outside the "shadow") for each horizontal slice through the cylindrical upper compartment is based on two intersecting circles with the "shadow" always having a larger radius than the constant 72' radius of the upper compartment. The angle subtended by the chord joining the intersection of these two circles decreases with elevation for the "shadow" circle (angle A, below) as its radius increases and increases for the circle defined by the upper compartment cylinder (angle A', below). As one can see, the chord joining the intersection becomes essentially the diameter of the upper compartment cylinder at the top elevation of the upper compartment (angle A' equals π).




The fraction of the circular area included in the "retained" volume at each elevation increases from zero at 79' to 34% at 121' (the top of the upper compartment). The integrated volume is 19% of the total upper compartment volume. This is essentially the same fraction as that calculated for the original rectangular geometry discussed previously.

An area-weighted average distance from the center of the "retained" area at each elevation to the dose point was calculated to be 139'. The distance from the center of the upper compartment to the dose point is 187'. Therefore, if one assumes that dose impact varies as $1/r^2$, on a per volume basis, the "retained volume would have an impact $(187/139)^2 = 1.8$ times greater than the upper compartment taken as a whole.

Attachment 1 to R. Sher Memo of 5/9/03 (2 pages)

| Ci in RB<br>Hours: | 0 | 1 | 2 | 4 | 8 | 16 | 24 | 48 | 72 | 96 |
|---|---|---|---|---|---|---|---|---|---|---|
| Kr83m | 0.00E+01 | 1.72E+02 | 8.49E+02 | 1.37E+03 | 6.70E+02 | 5.89E+01 | 3.73E-00 | 3.48E-04 | 3.98E-08 | 4.85E-12 |
| Kr85m | 0.00E+01 | 4.71E+02 | 2.89E+03 | 7.20E+03 | 8.35E+03 | 4.15E+03 | 1.48E+03 | 2.48E+01 | 5.12E-01 | 1.12E-02 |
| Kr85 | 0.00E+01 | 3.14E+01 | 2.25E+02 | 7.71E+02 | 1.68E+03 | 2.96E+03 | 3.74E+03 | 2.78E+03 | 2.55E+03 | 2.48E+03 |
| Kr87 | 0.00E+01 | 6.26E+02 | 2.60E+03 | 2.98E+03 | 7.28E+02 | 1.61E+01 | 2.55E-01 | 3.76E-07 | 6.81E-13 | 1.32E-18 |
| Kr88 | 0.00E+01 | 1.19E+03 | 6.68E+03 | 1.39E+04 | 1.13E+04 | 2.73E+03 | 4.76E+02 | 9.30E-01 | 2.23E-03 | 5.68E-06 |
| Kr89 | 0.00E+01 | 4.00E-03 | 6.07E-08 | 9.29E-19 | 4.11E-41 | 2.94E-86 | | | | |
| Xe131m | 0.00E+01 | 2.37E+01 | 1.70E+02 | 5.79E+02 | 1.25E+03 | 2.16E+03 | 2.67E+03 | 1.88E+03 | 1.62E+03 | 1.49E+03 |
| Xe133m | 0.00E+01 | 1.15E+02 | 8.14E+02 | 2.72E+03 | 5.63E+03 | 8.96E+03 | 1.02E+04 | 5.64E+03 | 3.82E+03 | 2.75E+03 |
| Xe133 | 0.00E+01 | 3.68E+03 | 2.63E+04 | 8.91E+04 | 1.91E+05 | 3.24E+05 | 3.95E+05 | 2.64E+05 | 2.16E+05 | 1.87E+05 |
| Xe135m | 0.00E+01 | 5.34E+01 | 2.67E+01 | 4.43E-01 | 2.28E-05 | 2.22E-14 | 1.56E-23 | 1.99E-51 | 3.11E-79 | |
| Xe135 | 0.00E+01 | 1.44E+03 | 9.72E+03 | 3.02E+04 | 5.45E+04 | 6.36E+04 | 5.14E+04 | 9.24E+03 | 1.75E+03 | 3.13E+02 |
| Xe137 | 0.00E+01 | 7.95E-02 | 1.35E-05 | 2.55E-14 | 1.73E-32 | 2.92E-69 | | | | |
| Xe138 | 0.00E+01 | 2.77E+02 | 1.72E+02 | 4.39E-00 | 5.36E-04 | 2.94E-12 | 1.16E-20 | 2.64E-46 | 7.37E-72 | 2.19E-97 |
| I131Org | 0.00E+01 | 1.49E-00 | 7.15E-00 | 2.20E+01 | 4.62E+01 | 7.82E+01 | 9.58E+01 | 6.69E+01 | 5.66E+01 | 5.06E+01 |
| I132Org | 0.00E+01 | 1.58E-00 | 5.65E-00 | 9.64E-00 | 6.25E-00 | 1.01E-00 | 1.17E-01 | 7.03E-05 | 5.11E-08 | 3.93E-11 |
| I133Org | 0.00E+01 | 2.86E-00 | 1.34E+01 | 3.87E+01 | 7.22E+01 | 9.65E+01 | 9.33E+01 | 3.20E+01 | 1.33E+01 | 5.85E-00 |
| I134Org | 0.00E+01 | 1.47E-00 | 3.18E-00 | 1.98E-00 | 1.70E-01 | 4.81E-04 | 9.86E-07 | 3.22E-15 | 1.28E-23 | 5.33E-32 |
| I135Org | 0.00E+01 | 2.53E-00 | 1.10E+01 | 2.78E+01 | 3.92E+01 | 3.00E+01 | 1.66E+01 | 1.07E-00 | 8.31E-02 | 6.85E-03 |
| I131Elem | 0.00E+01 | 8.00E-00 | 2.08E+01 | 3.92E+01 | 6.20E+01 | 9.18E+01 | 1.08E+02 | 1.20E+02 | 1.15E+02 | 1.06E+02 |
| I132Elem | 0.00E+01 | 9.37E-00 | 2.39E+01 | 4.26E+01 | 4.06E+01 | 2.28E+01 | 1.27E+01 | 2.41E-00 | 4.59E-01 | 8.76E-02 |
| I133Elem | 0.00E+01 | 1.54E+01 | 3.88E+01 | 6.89E+01 | 9.68E+01 | 1.13E+02 | 1.05E+02 | 5.76E+01 | 2.70E+01 | 1.23E+01 |
| I134Elem | 0.00E+01 | 7.91E-00 | 9.24E-00 | 3.52E-00 | 2.28E-01 | 5.64E-04 | 1.11E-06 | 5.79E-15 | 2.58E-23 | 1.12E-31 |
| I135Elem | 0.00E+01 | 1.36E+01 | 3.20E+01 | 4.95E+01 | 5.26E+01 | 3.52E+01 | 1.87E+01 | 1.92E-00 | 1.69E-01 | 1.44E-02 |
| I131Part | 0.00E+01 | 1.23E+02 | 3.28E+02 | 6.71E+02 | 1.14E+03 | 1.75E+03 | 2.09E+03 | 2.35E+03 | 2.25E+03 | 2.08E+03 |
| I132Part | 0.00E+01 | 1.31E+02 | 2.59E+02 | 2.94E+02 | 1.54E+02 | 2.25E+01 | 2.56E-00 | 2.47E-03 | 2.03E-06 | 1.61E-09 |
| I133Part | 0.00E+01 | 2.37E+02 | 6.13E+02 | 1.18E+03 | 1.78E+03 | 2.16E+03 | 2.03E+03 | 1.13E+03 | 5.29E+02 | 2.40E+02 |
| I134Part | 0.00E+01 | 1.22E+02 | 1.46E+02 | 6.04E+01 | 4.18E-00 | 1.08E-02 | 2.15E-05 | 1.13E-13 | 5.06E-22 | 2.18E-30 |
| I135Part | 0.00E+01 | 2.10E+02 | 5.06E+02 | 8.49E+02 | 9.66E+02 | 6.72E+02 | 3.62E+02 | 3.76E+01 | 3.31E-00 | 2.81E-01 |
| Rb86 | 0.00E+01 | 3.22E-01 | 5.84E-01 | 6.75E-01 | 5.32E-01 | 3.25E-01 | 1.99E-01 | 4.54E-02 | 1.04E-02 | 2.37E-03 |
| Cs134 | 0.00E+01 | 3.82E+01 | 6.95E+01 | 8.05E+01 | 6.39E+01 | 3.95E+01 | 2.45E+01 | 5.79E-00 | 1.37E-00 | 3.25E-01 |
| Cs136 | 0.00E+01 | 1.03E+01 | 1.87E+01 | 2.16E+01 | 1.70E+01 | 1.03E+01 | 6.27E-00 | 1.41E-00 | 3.17E-01 | 7.11E-02 |
| Cs137 | 0.00E+01 | 1.77E+01 | 3.22E+01 | 3.73E+01 | 2.96E+01 | 1.83E+01 | 1.14E+01 | 2.69E-00 | 6.37E-01 | 1.51E-01 |
| Sb127 | 0.00E+01 | 1.04E-00 | 3.30E-00 | 4.18E-00 | 3.23E-00 | 1.89E-00 | 1.10E-00 | 2.18E-01 | 4.31E-02 | 8.55E-03 |
| Sb129 | 0.00E+01 | 2.50E-00 | 6.84E-00 | 6.39E-00 | 2.69E-00 | 4.67E-01 | 8.09E-02 | 4.21E-04 | 2.19E-06 | 1.14E-08 |
| Te127m | 0.00E+01 | 1.41E-01 | 4.53E-01 | 5.82E-01 | 4.63E-01 | 2.86E-01 | 1.76E-01 | 4.15E-02 | 9.77E-03 | 2.30E-03 |
| Te127 | 0.00E+01 | 9.84E-01 | 3.05E-00 | 3.90E-00 | 3.15E-00 | 1.94E-00 | 1.17E-00 | 2.40E-01 | 4.79E-02 | 9.50E-03 |
| Te129m | 0.00E+01 | 4.91E-01 | 1.57E-00 | 2.02E-00 | 1.60E-00 | 9.84E-01 | 6.05E-01 | 1.40E-01 | 3.26E-02 | 7.57E-03 |
| Te129 | 0.00E+01 | 1.97E-00 | 5.36E-00 | 6.87E-00 | 3.58E-00 | 6.49E-01 | 1.13E-01 | 5.85E-04 | 3.04E-06 | 1.58E-08 |
| Te131m | 0.00E+01 | 1.53E-00 | 4.79E-00 | 5.88E-00 | 4.27E-00 | 2.19E-00 | 1.13E-00 | 1.54E-01 | 2.09E-02 | 2.84E-03 |
| Te132 | 0.00E+01 | 1.20E+01 | 3.81E+01 | 4.81E+01 | 3.69E+01 | 2.13E+01 | 1.22E+01 | 2.33E-00 | 4.45E-01 | 8.49E-02 |
| Ba137m | 0.00E+01 | 1.71E+01 | 3.16E+01 | 3.73E+01 | 2.96E+01 | 1.83E+01 | 1.14E+01 | 2.69E-00 | 6.37E-01 | 1.51E-01 |
| Ba139 | 0.00E+01 | 3.70E-00 | 7.20E-00 | 3.40E-00 | 3.66E-01 | 4.14E-03 | 4.67E-05 | 6.74E-11 | 9.71E-17 | 1.40E-22 |
| Ba140 | 0.00E+01 | 5.98E-00 | 1.91E+01 | 2.45E+01 | 1.93E+01 | 1.18E+01 | 7.14E-00 | 1.60E-00 | 3.60E-01 | 8.07E-02 |
| Mo99 | 0.00E+01 | 7.83E-01 | 2.49E-00 | 3.13E-00 | 2.39E-00 | 1.36E-00 | 7.76E-01 | 1.44E-01 | 2.65E-02 | 4.91E-03 |
| Tc99m | 0.00E+01 | 6.40E-01 | 1.97E-00 | 2.60E-00 | 2.20E-00 | 1.39E-00 | 8.27E-01 | 1.57E-01 | 2.92E-02 | 5.39E-03 |
| Ru103 | 0.00E+01 | 7.36E-01 | 2.36E-00 | 3.03E-00 | 2.40E-00 | 1.48E-00 | 9.09E-01 | 2.12E-01 | 4.93E-02 | 1.15E-02 |
| Ru105 | 0.00E+01 | 4.84E-01 | 1.33E-00 | 1.26E-00 | 5.48E-01 | 1.01E-01 | 1.85E-02 | 1.14E-04 | 7.06E-07 | 4.36E-09 |
| Ru106 | 0.00E+01 | 3.82E-01 | 1.22E-00 | 1.57E-00 | 1.25E-00 | 7.75E-01 | 4.79E-01 | 1.13E-01 | 2.68E-02 | 6.34E-03 |
| Rh105 | 0.00E+01 | 5.15E-01 | 1.63E-00 | 2.07E-00 | 1.58E-00 | 8.65E-01 | 4.63E-01 | 6.92E-02 | 1.03E-02 | 1.53E-03 |
| Y90 | 0.00E+01 | 5.84E-03 | 2.63E-02 | 6.89E-02 | 1.16E-01 | 1.43E-01 | 1.29E-01 | 5.47E-02 | 1.74E-02 | 4.93E-03 |
| Y91 | 0.00E+01 | 4.69E-02 | 1.54E-01 | 2.10E-01 | 1.87E-01 | 1.31E-01 | 8.60E-02 | 2.15E-02 | 5.09E-03 | 1.19E-03 |
| Y92 | 0.00E+01 | 2.19E-01 | 1.46E-00 | 3.80E-00 | 3.13E-00 | 7.20E-01 | 1.19E-01 | 3.35E-04 | 8.05E-07 | 1.89E-09 |
| Y93 | 0.00E+01 | 4.99E-02 | 1.50E-01 | 1.67E-01 | 1.01E-01 | 3.62E-02 | 1.29E-02 | 5.87E-04 | 2.67E-05 | 1.22E-06 |
| Zr95 | 0.00E+01 | 5.82E-02 | 1.87E-01 | 2.40E-01 | 1.91E-01 | 1.17E-01 | 7.24E-02 | 1.70E-02 | 3.98E-03 | 9.32E-04 |
| Zr97 | 0.00E+01 | 5.67E-02 | 1.75E-01 | 2.07E-01 | 1.40E-01 | 6.26E-02 | 2.80E-02 | 2.50E-03 | 2.23E-04 | 1.99E-05 |
| Nb95 | 0.00E+01 | 5.85E-02 | 1.87E-01 | 2.41E-01 | 1.92E-01 | 1.19E-01 | 7.34E-02 | 1.74E-02 | 4.12E-03 | 9.75E-04 |
| La140 | 0.00E+01 | 8.68E-02 | 4.35E-01 | 1.28E-00 | 2.24E-00 | 2.73E-00 | 2.40E-00 | 9.31E-01 | 2.71E-01 | 7.04E-02 |
| La141 | 0.00E+01 | 4.59E-02 | 1.23E-01 | 1.11E-01 | 4.34E-02 | 6.47E-03 | 9.65E-04 | 3.20E-06 | 1.06E-08 | 3.53E-11 |

| Ci in RB<br>Hours: | 120 | 144 | 168 | 192 | 216 | 240 | 264 | 288 | 312 | 336 | 360 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kr83m | 6.01E-16 | 7.77E-20 | 9.40E-24 | 1.16E-27 | 1.44E-31 | 1.79E-35 | 2.23E-39 | 2.78E-43 | 3.46E-47 | 4.31E-51 | 5.35E-55 |
| Kr85m | 2.50E-04 | 5.59E-06 | 1.25E-07 | 2.80E-09 | 6.27E-11 | 1.40E-12 | 3.14E-14 | 7.03E-16 | 1.58E-17 | 3.56E-19 | 7.94E-21 |
| Kr85 | 2.45E+03 | 2.43E+03 | 2.41E+03 | 2.40E+03 | 2.38E+03 | 2.37E+03 | 2.35E+03 | 2.34E+03 | 2.32E+03 | 2.31E+03 | 2.29E+03 |
| Kr87 | 2.58E-24 | 5.07E-30 | 9.96E-36 | 1.96E-41 | 3.85E-47 | 7.58E-53 | 1.50E-58 | 2.93E-64 | 5.76E-70 | 1.14E-75 | 2.24E-81 |
| Kr88 | 1.47E-08 | 3.83E-11 | 9.97E-14 | 2.60E-16 | 7.27E-19 | 1.80E-21 | 4.64E-24 | 1.20E-26 | 3.14E-29 | 8.16E-32 | 2.12E-34 |
| Kr89 | | | | | | | | | | | |
| Xe131m | 1.39E+03 | 1.30E+03 | 1.22E+03 | 1.15E+03 | 1.08E+03 | 1.01E+03 | 9.46E+02 | 8.88E+02 | 8.33E+02 | 7.81E+02 | 7.32E+02 |
| Xe133m | 2.01E+03 | 1.48E+03 | 1.08E+03 | 7.97E+02 | 5.86E+02 | 4.31E+02 | 3.16E+02 | 2.33E+02 | 1.71E+02 | 1.26E+02 | 9.24E+01 |
| Xe133 | 1.63E+05 | 1.42E+05 | 1.24E+05 | 1.08E+05 | 9.43E+04 | 8.22E+04 | 7.16E+04 | 6.24E+04 | 5.44E+04 | 4.74E+04 | 4.13E+04 |
| Xe135m | | | | | | | | | | | |
| Xe135 | 5.37E+01 | 9.01E-00 | 1.49E-00 | 2.46E-01 | 4.03E-02 | 6.60E-03 | 1.08E-03 | 1.77E-04 | 2.89E-05 | 4.72E-06 | 7.72E-07 |
| Xe137 | | | | | | | | | | | |
| Xe138 | | | | | | | | | | | |
| I131Org | 4.59E+01 | 4.19E+01 | 3.82E+01 | 3.48E+01 | 3.17E+01 | 2.89E+01 | 2.64E+01 | 2.41E+01 | 2.20E+01 | 2.00E+01 | 1.83E+01 |
| I132Org | 3.07E-14 | 2.41E-17 | 1.94E-20 | 1.49E-23 | 1.17E-26 | 9.13E-30 | 7.15E-33 | 5.59E-36 | 4.39E-39 | 3.44E-42 | 2.69E-45 |
| I133Org | 2.61E-00 | 1.17E-00 | 5.23E-01 | 2.34E-01 | 1.05E-01 | 4.71E-02 | 2.11E-02 | 9.45E-03 | 4.24E-03 | 1.90E-03 | 8.51E-04 |
| I134Org | 2.27E-40 | 9.67E-49 | 4.13E-57 | 1.75E-65 | 7.48E-74 | 3.19E-82 | 1.36E-90 | 5.80E-99 | | | |
| I135Org | 5.73E-04 | 4.80E-05 | 4.03E-06 | 3.39E-07 | 2.84E-08 | 2.39E-09 | 2.01E-10 | 1.69E-11 | 1.42E-12 | 1.19E-13 | 9.98E-15 |
| I131Elem | 9.74E+01 | 8.91E+01 | 8.16E+01 | 7.46E+01 | 6.83E+01 | 6.25E+01 | 5.72E+01 | 5.23E+01 | 4.79E+01 | 4.38E+01 | 4.01E+01 |
| I132Elem | 1.67E-02 | 3.19E-03 | 6.08E-04 | 1.16E-04 | 2.21E-05 | 4.22E-06 | 8.04E-07 | 1.53E-07 | 2.93E-08 | 5.58E-09 | 1.06E-09 |
| I133Elem | 5.53E-00 | 2.49E-00 | 1.12E-00 | 5.03E-01 | 2.26E-01 | 1.02E-01 | 4.57E-02 | 2.05E-02 | 9.24E-03 | 4.15E-03 | 1.87E-03 |
| I134Elem | 4.78E-40 | 2.05E-48 | 8.76E-57 | 3.75E-65 | 1.60E-73 | 6.85E-82 | 2.93E-90 | 1.25E-98 | | | |
| I135Elem | 1.21E-03 | 1.02E-04 | 8.62E-06 | 7.27E-07 | 6.12E-08 | 5.16E-09 | 4.35E-10 | 3.66E-11 | 3.09E-12 | 2.60E-13 | 2.19E-14 |
| I131Part | 1.91E+03 | 1.75E+03 | 1.60E+03 | 1.46E+03 | 1.34E+03 | 1.22E+03 | 1.12E+03 | 1.02E+03 | 9.38E+02 | 8.58E+02 | 7.85E+02 |
| I132Part | 1.27E-12 | 1.00E-15 | 7.88E-19 | 6.19E-22 | 4.87E-25 | 3.83E-28 | 3.01E-31 | 2.37E-34 | 1.86E-37 | 1.46E-40 | 1.15E-43 |
| I133Part | 1.08E+02 | 4.87E+01 | 2.19E+01 | 9.85E-00 | 4.43E-00 | 1.99E-00 | 8.95E-01 | 4.02E-01 | 1.81E-01 | 8.14E-02 | 3.66E-02 |
| I134Part | 9.37E-39 | 4.01E-47 | 1.71E-55 | 7.34E-64 | 3.14E-72 | 1.34E-80 | 5.74E-89 | 2.46E-97 | | | |
| I135Part | 2.38E-02 | 2.00E-03 | 1.69E-04 | 1.42E-05 | 1.20E-06 | 1.01E-07 | 8.52E-09 | 7.18E-10 | 6.05E-11 | 5.09E-12 | 4.29E-13 |
| Rb86 | 5.40E-04 | 1.23E-04 | 2.82E-05 | 6.43E-06 | 1.47E-06 | 3.35E-07 | 7.65E-08 | 1.75E-08 | 3.99E-09 | 9.11E-10 | 2.08E-10 |
| Cs134 | 7.68E-02 | 1.82E-02 | 4.31E-03 | 1.02E-03 | 2.41E-04 | 5.71E-05 | 1.35E-05 | 3.20E-06 | 7.58E-07 | 1.79E-07 | 4.25E-08 |
| Cs136 | 1.60E-02 | 3.59E-03 | 8.06E-04 | 1.81E-04 | 4.07E-05 | 9.14E-06 | 2.05E-06 | 4.61E-07 | 1.04E-07 | 2.33E-08 | 5.23E-09 |
| Cs137 | 3.58E-02 | 8.47E-03 | 2.01E-03 | 4.75E-04 | 1.13E-04 | 2.67E-05 | 6.32E-06 | 1.50E-06 | 3.55E-07 | 8.41E-08 | 1.99E-08 |
| Sb127 | 1.69E-03 | 3.36E-04 | 6.65E-05 | 1.32E-05 | 2.61E-06 | 5.17E-07 | 1.02E-07 | 2.03E-08 | 4.02E-09 | 7.97E-10 | 1.58E-10 |
| Sb129 | 5.92E-11 | 3.08E-13 | 1.60E-15 | 8.33E-18 | 4.33E-20 | 2.25E-22 | 1.17E-24 | 6.09E-27 | 3.17E-29 | 1.65E-31 | 8.57E-34 |
| Te127m | 5.41E-04 | 1.27E-04 | 3.00E-05 | 7.06E-06 | 1.66E-06 | 3.91E-07 | 9.20E-08 | 2.17E-08 | 5.10E-09 | 1.20E-09 | 2.82E-10 |
| Te127 | 1.88E-03 | 3.73E-04 | 7.39E-05 | 1.46E-05 | 2.90E-06 | 5.75E-07 | 1.14E-07 | 2.26E-08 | 4.47E-09 | 8.86E-10 | 1.75E-10 |
| Te129m | 1.76E-03 | 4.08E-04 | 9.47E-05 | 2.20E-05 | 5.10E-06 | 1.18E-06 | 2.75E-07 | 6.38E-08 | 1.48E-08 | 3.44E-09 | 7.98E-10 |
| Te129 | 8.24E-11 | 4.28E-13 | 2.23E-15 | 1.16E-17 | 6.03E-20 | 3.14E-22 | 1.63E-24 | 8.48E-27 | 4.41E-29 | 2.29E-31 | 1.19E-33 |
| Te131m | 3.87E-04 | 5.26E-05 | 7.16E-06 | 9.74E-07 | 1.33E-07 | 1.80E-08 | 2.45E-09 | 3.34E-10 | 4.54E-11 | 6.18E-12 | 8.41E-13 |
| Te132 | 1.62E-02 | 3.09E-03 | 5.89E-04 | 1.12E-04 | 2.14E-05 | 4.09E-06 | 7.80E-07 | 1.49E-07 | 2.84E-08 | 5.41E-09 | 1.03E-09 |
| Ba137m | 3.58E-02 | 8.47E-03 | 2.01E-03 | 4.75E-04 | 1.13E-04 | 2.67E-05 | 6.32E-06 | 1.50E-06 | 3.55E-07 | 8.41E-08 | 1.99E-08 |
| Ba139 | 2.02E-28 | 2.91E-34 | 4.20E-40 | 6.05E-46 | 8.73E-52 | 1.26E-57 | 1.81E-63 | 2.62E-69 | 3.77E-75 | 5.44E-81 | 7.84E-87 |
| Ba140 | 1.81E-02 | 4.07E-03 | 9.13E-04 | 2.05E-04 | 4.60E-05 | 1.03E-05 | 2.32E-06 | 5.20E-07 | 1.17E-07 | 2.62E-08 | 5.88E-09 |
| Mo99 | 9.07E-04 | 1.68E-04 | 3.10E-05 | 5.74E-06 | 1.06E-06 | 1.96E-07 | 3.63E-08 | 6.70E-09 | 1.24E-09 | 2.29E-10 | 4.24E-11 |
| Tc99m | 9.97E-04 | 1.84E-04 | 3.41E-05 | 6.30E-06 | 1.17E-06 | 2.16E-07 | 3.98E-08 | 7.37E-09 | 1.36E-09 | 2.52E-10 | 4.66E-11 |
| Ru103 | 2.67E-03 | 6.22E-04 | 1.45E-04 | 3.37E-05 | 7.85E-06 | 1.83E-06 | 4.25E-07 | 9.90E-08 | 2.31E-08 | 5.37E-09 | 1.25E-09 |
| Ru105 | 2.70E-11 | 1.67E-13 | 1.03E-15 | 6.37E-18 | 3.94E-20 | 2.44E-22 | 1.51E-24 | 9.31E-27 | 5.76E-29 | 3.56E-31 | 2.20E-33 |
| Ru106 | 1.50E-03 | 3.54E-04 | 8.38E-05 | 1.98E-05 | 4.69E-06 | 1.11E-06 | 2.62E-07 | 6.20E-08 | 1.47E-08 | 3.47E-09 | 8.20E-10 |
| Rh105 | 2.27E-04 | 3.37E-05 | 5.01E-06 | 7.45E-07 | 1.11E-07 | 1.65E-08 | 2.44E-09 | 3.63E-10 | 5.40E-11 | 8.02E-12 | 1.19E-12 |
| Y90 | 1.32E-03 | 3.39E-04 | 8.53E-05 | 2.11E-05 | 5.17E-06 | 1.25E-06 | 3.03E-07 | 7.27E-08 | 1.74E-08 | 4.16E-09 | 9.92E-10 |
| Y91 | 2.79E-04 | 6.54E-05 | 1.53E-05 | 3.59E-06 | 8.40E-07 | 1.97E-07 | 4.60E-08 | 1.08E-08 | 2.52E-09 | 5.91E-10 | 1.38E-10 |
| Y92 | 4.40E-12 | 1.02E-14 | 2.39E-17 | 5.55E-20 | 1.29E-22 | 3.01E-25 | 7.02E-28 | 1.63E-30 | 3.80E-33 | 8.86E-36 | 2.06E-38 |
| Y93 | 5.53E-08 | 2.52E-09 | 1.14E-10 | 5.20E-12 | 2.37E-13 | 1.08E-14 | 4.90E-16 | 2.23E-17 | 1.01E-18 | 4.61E-20 | 2.10E-21 |
| Zr95 | 2.18E-04 | 5.12E-05 | 1.20E-05 | 2.81E-06 | 6.59E-07 | 1.54E-07 | 3.62E-08 | 8.48E-09 | 1.99E-09 | 4.66E-10 | 1.09E-10 |
| Zr97 | 1.78E-06 | 1.58E-07 | 1.41E-08 | 1.26E-09 | 1.13E-10 | 1.01E-11 | 8.97E-13 | 8.01E-14 | 7.15E-15 | 6.38E-16 | 5.69E-17 |
| Nb95 | 2.31E-04 | 5.46E-05 | 1.29E-05 | 3.06E-06 | 7.23E-07 | 1.71E-07 | 4.04E-08 | 9.56E-09 | 2.26E-09 | 5.34E-10 | 1.26E-10 |
| La140 | 1.73E-02 | 4.13E-03 | 9.64E-04 | 2.22E-04 | 5.08E-05 | 1.15E-05 | 2.61E-06 | 5.90E-07 | 1.33E-07 | 2.99E-08 | 6.73E-09 |
| La141 | 1.17E-13 | 3.89E-16 | 1.29E-18 | 4.28E-21 | 1.42E-23 | 4.71E-26 | 1.56E-28 | 5.19E-31 | 1.72E-33 | 5.72E-36 | 1.90E-38 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| La142 | 0.00E+01 | 3.39E-02 | 6.91E-02 | 3.58E-02 | 4.65E-03 | 7.64E-05 | 1.26E-06 | 5.56E-12 | 2.47E-17 | 1.09E-22 | 4.85E-28 | 2.15E-33 | 9.53E-39 | 4.22E-44 | 1.87E-49 | 8.30E-55 | 3.68E-60 | 1.63E-65 | 7.23E-71 | 3.21E-76 | 1.42E-81 |
| Pr143 | 0.00E+01 | 5.19E-02 | 1.67E-01 | 2.15E-01 | 1.73E-01 | 1.09E-01 | 6.79E-02 | 1.62E-02 | 3.78E-03 | 8.68E-04 | 1.98E-04 | 4.50E-05 | 1.02E-05 | 2.30E-06 | 5.19E-07 | 1.17E-07 | 2.64E-08 | 5.94E-09 | 1.34E-09 | 3.02E-10 | 6.80E-11 |
| Nd147 | 0.00E+01 | 2.16E-02 | 6.90E-02 | 8.82E-02 | 6.95E-02 | 4.21E-02 | 2.55E-02 | 5.69E-03 | 1.27E-03 | 2.83E-04 | 6.30E-05 | 1.40E-05 | 3.13E-06 | 6.97E-07 | 1.55E-07 | 3.46E-08 | 7.71E-09 | 1.72E-09 | 3.83E-10 | 8.53E-11 | 1.90E-11 |
| Am241 | 0.00E+01 | 1.21E-05 | 3.87E-05 | 4.97E-05 | 3.96E-05 | 2.45E-05 | 1.52E-05 | 3.59E-06 | 8.51E-07 | 2.02E-07 | 4.78E-08 | 1.13E-08 | 2.68E-09 | 6.35E-10 | 1.51E-10 | 3.57E-11 | 8.45E-12 | 2.00E-12 | 4.74E-13 | 1.12E-13 | 2.66E-14 |
| Cm242 | 0.00E+01 | 3.92E-03 | 1.26E-02 | 1.61E-02 | 1.28E-02 | 7.93E-03 | 4.90E-03 | 1.16E-03 | 2.73E-04 | 6.44E-05 | 1.52E-05 | 3.58E-06 | 8.45E-07 | 1.99E-07 | 4.70E-08 | 1.11E-08 | 2.62E-09 | 6.18E-10 | 1.46E-10 | 3.44E-11 | 8.11E-12 |
| Cm244 | 0.00E+01 | 7.18E-04 | 2.30E-03 | 2.96E-03 | 2.36E-03 | 1.46E-03 | 9.02E-04 | 2.14E-04 | 5.06E-05 | 1.20E-05 | 2.84E-06 | 6.73E-07 | 1.59E-07 | 3.78E-08 | 8.95E-09 | 2.12E-09 | 5.02E-10 | 1.19E-10 | 2.82E-11 | 6.68E-12 | 1.58E-12 |
| Ce141 | 0.00E+01 | 1.40E-01 | 4.49E-01 | 5.77E-01 | 4.58E-01 | 2.81E-01 | 1.73E-01 | 4.01E-02 | 9.29E-03 | 2.15E-03 | 4.99E-04 | 1.16E-04 | 2.68E-05 | 6.22E-06 | 1.44E-06 | 3.35E-07 | 7.76E-08 | 1.80E-08 | 4.17E-09 | 9.67E-10 | 2.24E-10 |
| Ce143 | 0.00E+01 | 1.29E-01 | 4.06E-01 | 4.99E-01 | 3.65E-01 | 1.90E-01 | 9.87E-02 | 1.39E-02 | 1.95E-03 | 2.75E-04 | 3.87E-05 | 5.44E-06 | 7.66E-07 | 1.08E-07 | 1.52E-08 | 2.13E-09 | 3.00E-10 | 4.23E-11 | 5.95E-12 | 8.37E-13 | 1.18E-13 |
| Ce144 | 0.00E+01 | 1.15E-01 | 3.70E-01 | 4.76E-01 | 3.79E-01 | 2.34E-01 | 1.45E-01 | 3.42E-02 | 8.09E-03 | 1.91E-03 | 4.52E-04 | 1.07E-04 | 2.52E-05 | 5.97E-06 | 1.41E-06 | 3.33E-07 | 7.88E-08 | 1.86E-08 | 4.40E-09 | 1.04E-09 | 2.46E-10 |
| Np239 | 0.00E+01 | 2.10E-00 | 6.65E-00 | 8.33E-00 | 6.32E-00 | 3.54E-00 | 1.98E-00 | 3.49E-01 | 6.15E-02 | 1.08E-02 | 1.90E-03 | 3.35E-04 | 5.90E-05 | 1.04E-05 | 1.83E-06 | 3.22E-07 | 5.66E-08 | 9.96E-09 | 1.75E-09 | 3.09E-10 | 5.43E-11 |
| Pu238 | 0.00E+01 | 9.09E-04 | 2.92E-03 | 3.75E-03 | 2.98E-03 | 1.85E-03 | 1.14E-03 | 2.71E-04 | 6.42E-05 | 1.52E-05 | 3.60E-06 | 8.53E-07 | 2.02E-07 | 4.79E-08 | 1.13E-08 | 2.69E-09 | 6.37E-10 | 1.51E-10 | 3.58E-11 | 8.47E-12 | 2.01E-12 |
| Pu239 | 0.00E+01 | 5.73E-05 | 1.84E-04 | 2.36E-04 | 1.88E-04 | 1.16E-04 | 7.20E-05 | 1.71E-05 | 4.04E-06 | 9.58E-07 | 2.27E-07 | 5.38E-08 | 1.27E-08 | 3.02E-09 | 7.15E-10 | 1.69E-10 | 4.01E-11 | 9.51E-12 | 2.25E-12 | 5.34E-13 | 1.26E-13 |
| Pu240 | 0.00E+01 | 9.43E-05 | 3.02E-04 | 3.89E-04 | 3.09E-04 | 1.91E-04 | 1.18E-04 | 2.81E-05 | 6.65E-06 | 1.58E-06 | 3.73E-07 | 8.85E-08 | 2.10E-08 | 4.97E-09 | 1.18E-09 | 2.79E-10 | 6.60E-11 | 1.56E-11 | 3.71E-12 | 8.78E-13 | 2.08E-13 |
| Pu241 | 0.00E+01 | 2.68E-02 | 8.60E-02 | 1.11E-01 | 8.80E-02 | 5.45E-02 | 3.37E-02 | 7.99E-03 | 1.89E-03 | 4.48E-04 | 1.06E-04 | 2.52E-05 | 5.96E-06 | 1.41E-06 | 3.34E-07 | 7.92E-08 | 1.88E-08 | 4.45E-09 | 1.05E-09 | 2.49E-10 | 5.91E-11 |
| Sr89 | 0.00E+01 | 3.77E-00 | 1.21E+01 | 1.55E+01 | 1.23E+01 | 7.60E-00 | 4.68E-00 | 1.09E-00 | 2.56E-01 | 5.97E-02 | 1.40E-02 | 3.26E-03 | 7.62E-04 | 1.78E-04 | 4.16E-05 | 9.73E-06 | 2.27E-06 | 5.31E-07 | 1.24E-07 | 2.90E-08 | 6.78E-09 |
| Sr90 | 0.00E+01 | 4.59E-01 | 1.47E-00 | 1.89E-00 | 1.51E-00 | 9.33E-01 | 5.77E-01 | 1.37E-01 | 3.24E-02 | 7.68E-03 | 1.82E-03 | 4.31E-04 | 1.02E-04 | 2.42E-05 | 5.73E-06 | 1.36E-06 | 3.22E-07 | 7.62E-08 | 1.80E-08 | 4.28E-09 | 1.01E-09 |
| Sr91 | 0.00E+01 | 4.26E-00 | 1.27E+01 | 1.41E+01 | 8.43E-00 | 2.92E-00 | 1.01E-00 | 4.23E-02 | 1.77E-03 | 7.37E-05 | 3.07E-06 | 1.28E-07 | 5.35E-09 | 2.23E-10 | 9.32E-12 | 3.89E-13 | 1.62E-14 | 6.77E-16 | 2.82E-17 | 1.18E-18 | 4.92E-20 |
| Sr92 | 0.00E+01 | 3.73E-00 | 9.20E-00 | 7.00E-00 | 1.95E-00 | 1.48E-01 | 1.12E-02 | 4.88E-06 | 2.13E-09 | 9.27E-13 | 4.04E-16 | 1.76E-19 | 7.67E-23 | 3.34E-26 | 1.46E-29 | 6.34E-33 | 2.76E-36 | 1.20E-39 | 5.25E-43 | 2.29E-46 | 9.96E-50 |
| Total | | 9.10E+03 | 5.28E+04 | 1.53E+05 | 2.80E+05 | 4.14E+05 | 4.70E+05 | 2.87E+05 | 2.29E+05 | 1.97E+05 | 1.71E+05 | 1.49E+05 | 1.31E+05 | 1.14E+05 | 1.00E+05 | 8.76E+04 | 7.67E+04 | 6.72E+04 | 5.90E+04 | 5.19E+04 | 4.56E+04 |

Memo to files | Attachment 3 | 07/30/03
From: J. Metcalf
Subject: Impact of Skyshine on the Vermont Yankee TSC Integrated Dose Calculation

## Purpose

The purpose of this memorandum is to document the decision in the preliminary assessment of TSC external shine not to include a contribution from skyshine in the model.

## Approach

The MicroSkyshine computer (Reference 1) has been used to evaluate the potential for skyshine influencing the results of the TSC shine calculation. A second methodology (Reference 2) has also been employed to confirm the estimate.

## References


1. "MicroSkyshine User's Manual", Grove Engineering, 1987

2. Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities, National Council on Radiation Protection and Measurements Document NCRP No. 51, Eds. E. Murrill, J. Beyster, G. Brownell, A. Chilton, J. Haimson, C. Karymark, W. Kreger, J. Wyckoff and D. Grace, Washington, DC (1977)

3. Memo to file, B. Nowack "MicroShield 5 Verification Using QADMOD-GP", 7/29/03

4. Memo to File, R. Sher, "Vermont Yankee TSC Integrated Dose Calculation", 5/9/03


## Analysis

The MicroSkyshine input for this case is as follows:

```
"record ver 3"
Polestar_Applied_Technology
1.18 - 1.18-00110
VYRBTest
Input only
Case never run
 3 ,GEOMETRY
 48.2 ,X
 .1 ,        Y
 0 ,         Z
 24.1 ,       H
 22 ,R1
 0 ,R2
 0 ,T1
 0 ,T2
 24 ,L
```

21.9 ,W
0 ,D
5 ,M
0 ,N
0 ,C
.0012 ,RHO
"sensitivity variable index (or 0):"
0 ,SENSEVAR
1 ,# saved results or 1
"# sensitivity cycles or 1 if none:"
1 ,NCYCLES
"20 densities:"
0
0
0
0
0
0
0
0
0
0
0
0
0
0
.0012
0
0
0
0
0
0
1 ,BUILDUP INDEX
8 ,QUADRATURE ORDER
"20 energies:"
2.5
1.75
1.25
.75
.4
.15
0
0

0
0
0
0
0
0
0
0
0
0
0
0
"20 activities:"
3.09e+14
7.81e+13
8.13e+13
2.27e+14
1.34e+14
3.13e+15
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0 ,1=RESULTS EXIST 0=NO
"no results exist."
3 ,SOURCE MODE
"isotope bit flags:"

0 ,NUMBER OF ISOTOPES
"end of source inputs. 5 decay times:"
0
0
0
0

0

The model consists of the photons per second at t = 4 hours that correspond to the energies (by energy group) that were used in the QADMOD-GP assessment, Reference 3. The distance from the centerline of the "silo" model is 48.2 m (158'), and the distance from the top of the "silo" to the dose point is 24.1 m (79'). The resulting dose rate (the peak dose rate from the QADMOD-GP study and unshielded at the TSC) is 613 mr/hr.

Application of the second method requires the peak dose rate at the surface of the RB (about 0.008 R/s) to be converted to cGy/s at a distance one meter from an imaginary point source. Knowing this, the associated skyshine can be estimated from the Reference 2 expression:

$$\text{Dose rate in nSv/s} = 2.49E5 B_{XS} D_{i0} \Omega^{1.3}/(d_i d_s)^2$$

Where: $B_{XS}$ is the ceiling transmission factor,
$D_{i0}$ is the dose rate in cGy/s one meter from the source,
$\Omega$ is the solid angle of the beam,
$d_i$ is the distance from the point source to a point two meters above the ceiling, and
$d_s$ is the distance from the centerline of the beam to a the dose point.

This can be solved as follows for an assumed transmission factor of unity (unshielded) and an assumed beam angle of $2\pi$ steradians (a hemisphere):

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Vol = | 42 | ft x | 72 | ft x | 72 | ft x | 3.14159 | |
| or | 684012.1 | ft3 = | 19383.95 | m3 | | | | |
| R sph = | 16.61739 | m | | | | | | |
| R cyl = | 21.95122 | m | | | | | | |
| Surface dose rate of cylinder = | | | 8.00E-03 | R/s | | | | |
| Dose rate one meter from sphere center = | | | | 2.209102 | R/s or cGy/s | | | |
| Source point relative to (below) shield = | | | | 0 | M | | | |
| Solid angle of opening = | | | 6.28318 | Radians (hemisphere) | | | | |
| Horizontal distance to target = | | | 48.2 | M | | | | |
| Dose rate due to skyshine = | | | 645.4972 | nSv/sec = | 0.002324 | Sv/hr = | 0.232379 | rem/hr |

This estimated peak dose rate is a factor of 2.6 smaller than the MicroShield calculation, but even if the higher value is used, an 8" concrete shield for the low-energy scattered photons will decrease the dose rate by a significant factor (a hundred times or more). This will make the skyshine dose rate in the single-digit mr/hr range compared to the direct shine peak dose rates which are about two orders of magnitude larger.

## Conclusion

Skyshine dose rates are low enough with an 8" concrete shield to be neglected, and the preliminary evaluation done with MicroShield (Reference 4) is acceptable.

**MicroShield Dose Calculation for the Vermont Yankee Technical Support Center**

A calculation of the integrated dose in the Technical Support Center (TSC) following a LOCA release to the Reactor Building (RB) was performed using MicroShield MS5 and is described in Reference 1. The RB was modeled as a cylinder equivalent in volume to the actual building. The source was assumed to be uniformly distributed throughout the free area of the building; however the areas below the refuel floor are heavily shielded with at least 24 inches (61 cm) of concrete. The source volume that was considered in the calculation was the free volume above the refuel floor. This portion of the RB is primarily steel sheet and beam construction and no shielding credit was taken in the calculation. Two source correction factors were developed to: 1) account for the fraction of free volume represented by the volume above the refuel floor and 2) account for the fractional difference between the total building volume and the free volume. The calculation takes credit for an 8-inch horizontal concrete shield representing the floor above the TSC. However, it was modeled as a vertical shield due to the limitations of the MicroShield code. The TSC receptor location was modeled at a horizontal distance of 127.7 feet from the centerline of the source volume and a vertical distance of 100 feet below the centerline of the source volume. As stated above, the portion of the RB below the refuel floor has an annular concrete shield. This shield "shadows" the TSC receptor from a portion of the source volume, reducing the dose rate. Since it is not possible for MicroShield to model the shadow effect of the annular shield, a correction factor was calculated and applied to the results. The MicroShield dose rate results are presented in Table 1.

**Table 1. MicroShield Dose Rate Calculation Results**

| Time (hrs) | MicroShield Dose Rate (mrad/hr) | | Time (hrs) | MicroShield Dose Rate (mrad/hr) |
|---|---|---|---|---|
| 1 | 44.0 | | 144 | 3.9 |
| 2 | 185.3 | | 168 | 3.5 |
| 4 | 350.1 | | 192 | 3.1 |
| 8 | 291.1 | | 216 | 2.8 |
| 16 | 111.3 | | 240 | 2.6 |
| 24 | 53.8 | | 264 | 2.3 |
| 48 | 14.6 | | 288 | 2.1 |
| 72 | 7.8 | | 312 | 2.0 |
| 96 | 5.6 | | 336 | 1.8 |
| 120 | 4.5 | | 360 | 1.6 |

**Independent Review of TSC Dose Calculation Results Using QADMOD-GP**

An independent review of the calculation was performed using QADMOD-GP (Reference 2). QADMOD-GP is a PC version of the mainframe code CCC-396/ QADMOD-G, a point-kernel integration code for calculating gamma ray fluxes and dose rates at specific locations. QADMOD-GP allows the user to set up a three-dimensional source volume and three-dimensional shielding geometry configurations. Source geometry configuration is represented by arraying isotropic point sources uniformly in a specified volume geometry. QADMOD-GP allows the use of plane, conical, cylindrical and spherical surface combinations to model shielding configuration geometry. QADMOD-GP computes the distances through all regions traversed by the line-of-sight ray from the source point to the designated receptor point. It takes into account the geometry and the characteristics of the materials which the rays pass through. Energy dependent attenuation and build-up factors are applied to calculate the direct gamma ray dose and gamma ray dose with build-up. For the review three models were simulated using QADMOD-GP.

**QADMOD-GP Cylindrical Model with no Annular Shield**

This model was setup in order to directly compare MicroShield and QADMOD-GP results. Identical source strength and photon energy groups were used. Figure 1 is a plan view of the true building dimensions (solid lines) and the equivalent cylindrical model (dashed lines). A cylindrical geometry model was setup source volume identical to the MicroShield model. Distance to the receptor (a radial distance 127.7 feet from the source centerline, a vertical distance of 100 feet below the source centerline) was identical to the MicroShield model. (Note that while the actual radial distance to the receptor is 157.7-feet, 127.7-feet was used in cylindrical model to approximate the air gap between the outer wall of the RB and the receptor.)

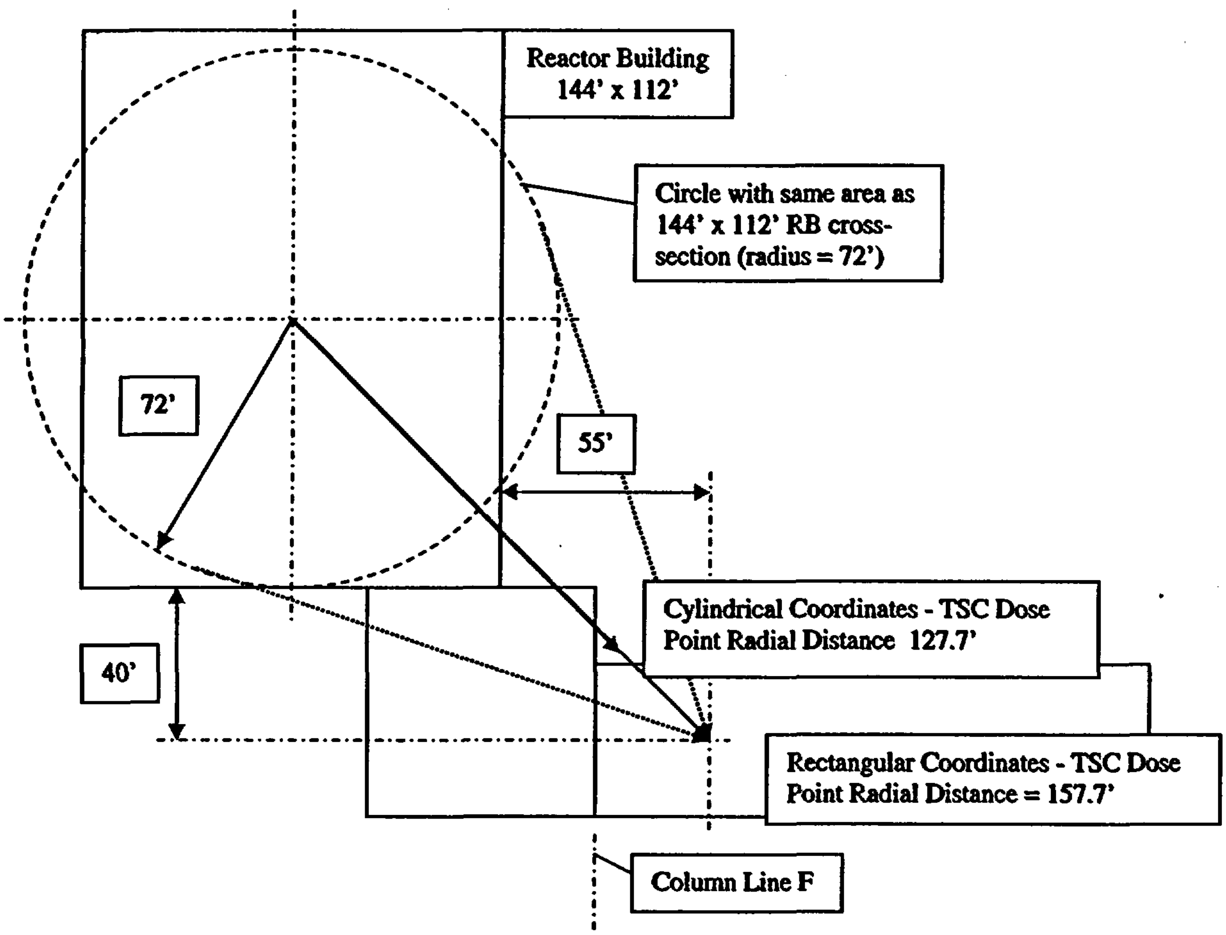



Figure 1. Equivalent Cylinder.

One difference between the MicroShield model and the QADMOD-GP model was that the 8-inch horizontal concrete shield representing the floor above the TSC was modeled as a horizontal shield (the as-built configuration). A dose rate comparison of the MicroShield model and the first QADMOD-GP model was made for nine time points, 1-hour, 2-hours, 4-hours, 8-hours, 24-hours, 48-hours, 144-hours, 240-hours and 336-hours. (The QADMOD-GP input data sheets are presented in Attachment 1.) During this review it was noted that the MicroShield code partitions gamma decay energies into 25 groups whereas QADMOD-GP uses 6 energy partitions. The use of 6 partitions causes the calculated dose rates to be overestimated, especially for low energy photons. As such, it was necessary to set up the MicroShield model using 6 energy partitions to validate the comparison to QADMOD-GP. The results of the comparison are shown in Table 2 below:

**Table 2. MicroShield and QADMOD-GP Dose Rate Comparison**

| Time (hrs) | MicroShield Dose Rate (mrad/hr) 25 Partitions | | MicroShield Dose Rate (mrad/hr) 6 Partitions | QADMOD Dose Rate (mrem/hr) 6 Partitions | Percent Dose Rate Difference (MS/QM-1)x100% |
|---|---|---|---|---|---|
| 1 | 44.0 | | 48.4 | 47.6 | -2% |
| 2 | 185.3 | | 209.7 | 199.4 | -5% |
| 4 | 350.1 | | 403.4 | 383.5 | -5% |
| 8 | 291.1 | | 345.5 | 328.3 | -5% |
| 24 | 53.8 | | 71.6 | 83.3 | 16% |
| 48 | 14.6 | | 28.3 | 32.8 | 16% |
| 144 | 3.9 | | 11.0 | 13.2 | 20% |
| 240 | 2.6 | | 6.6 | 7.3 | 10% |
| 336 | 1.8 | | 4.1 | 4.9 | 19% |

It is worth noting that the fractional distribution of photon energy groups are dominated by high energy photon during the first 12 hours (e.g., 41% of all photons have an average energy of 2.5 MeV at time = 1-hour) and that thereafter the fractional distribution rapidly shifts to low energy photons (e.g., 86% of all photons have an average energy of 0.15 MeV at time = 24-hours). The differences in the calculated dose rates clearly correspond to the shift in the energy spectrum to lower energy photons. This is a minor difference in comparing calculated dose rates using two difference codes. It appears that the MicroShield and QADMOD-GP results for the Cylindrical Model with no Annular Shield provide consistent results and that the model used in the MicroShield model is valid.

**QADMOD-GP Cylindrical Model including the Annular Shield**

To develop the second model, the first QADMOD-GP cylindrical model was modified to include a 24-inch thick concrete annular shield in the RB from grade level up to the refueling floor level. Dose rates for several distances were calculated to obtain a representation of how rates varied.

A comparison of dose rates for time points at 1-hour, 2-hours, 4-hours and 8-hours were calculated for various distances at the height of the TSC receptor. (The QADMOD-GP input data sheets are presented in Attachment 2.) For the TSC receptor, the shielding value of the annular shield decreases as the radial distance from the source increases. This is a result of the shadow effect. Conversely, the photon flux decreases with distance as a result of the $1/r^2$ geometric effect plus attenuation. A plot of TSC dose rates as a function of distance is presented in Figure 2.

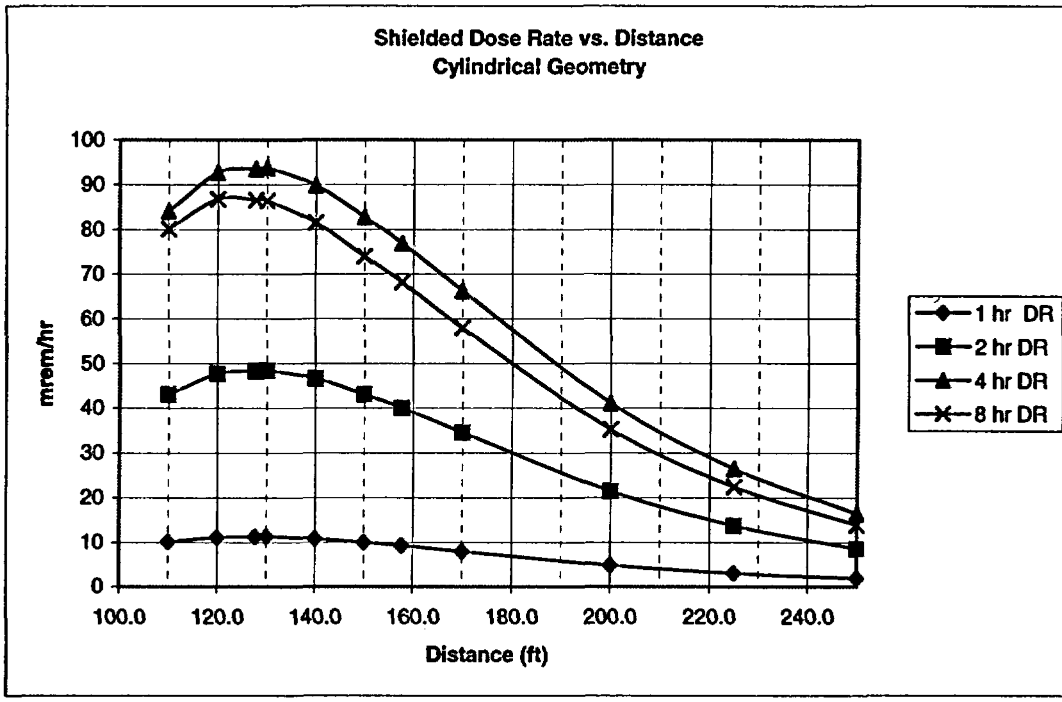



**Figure 2. Shielded Dose Rates**

In the first QADMOD-GP model (cylindrical model with no annular shield) dose rate is calculated as a function of the $1/r^2$ geometric effect, attenuation and the 8-inch horizontal shield. The second model adds the annular shield and presents a more realistic representation actual configuration in the calculation of the dose rate as a function of distance. The combination of these effects results in peak dose rate at approximately the radial distance range of 125 to 130-feet from the source centerline. Figure 2 also indicates that use of the radial distance of 127.7 was an optimum choice for the calculation since it results in the worst-case dose rates.

As previously stated, a correction factor was calculated and applied to the MicroShield results to account for the shadow effect of the annular shield. The QADMOD-GP shielded and non-shielded dose rate calculations were compared to determine the "shielding factor" and compare it to the correction factor used in the MicroShield calculation. A plot of the ratio of the QADMOD-GP non-shielded dose rate / shielded dose rate ratio as a function of distance is presented in Figure 3.

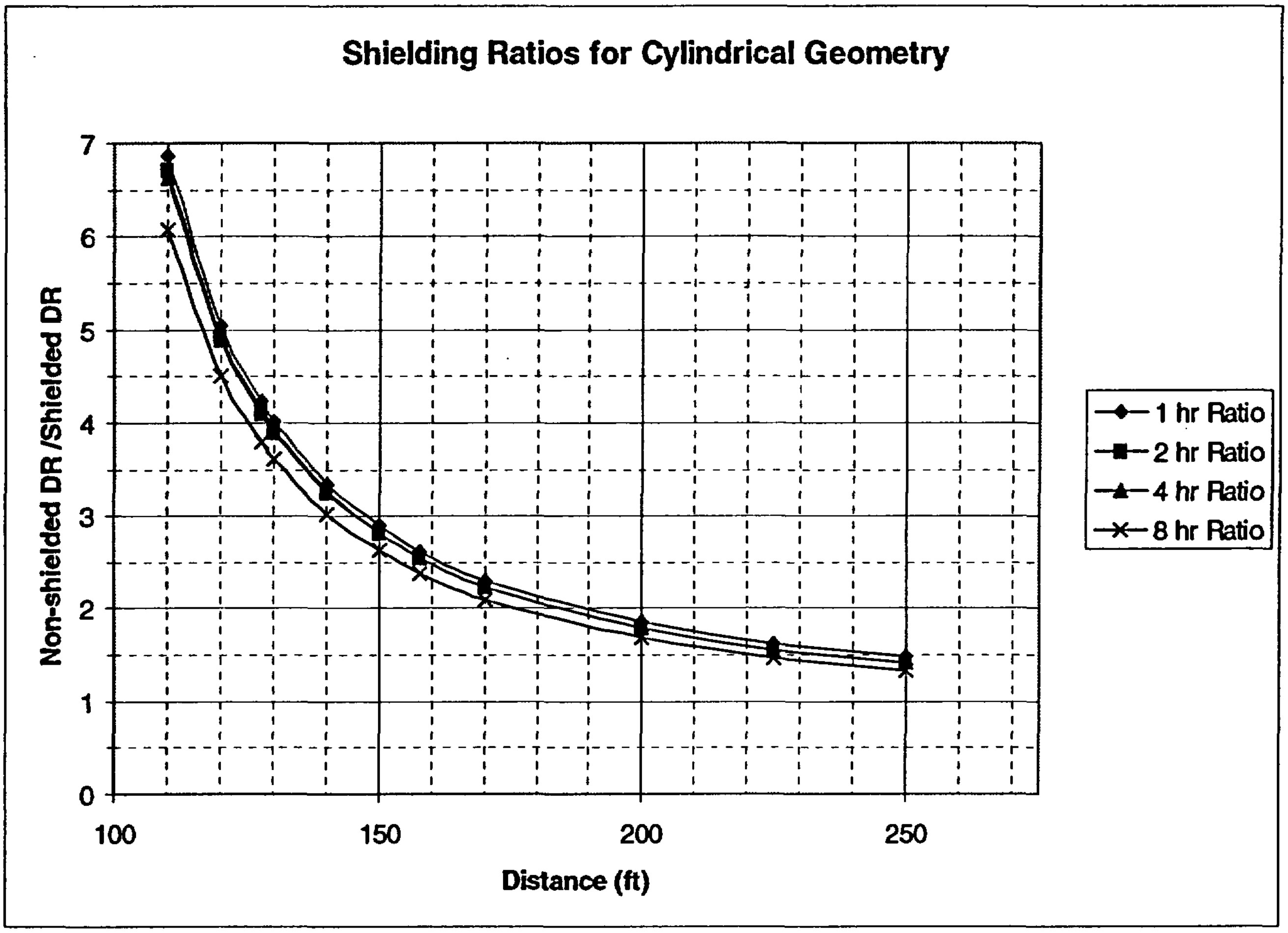



**Figure 3. Shielding Ratios**

As expected the shielding factor (shadow effect) of the annular shield diminishes with distance, as the angle to the receptor becomes shallower, approaching unity. For the receptor in the TSC, a shielding ratio of 2.0 appears to be a conservative assumption.

## QADMOD-GP Rectangular Model including the Annular Shield

A third model using QADMOD-GP was setup using rectangular geometry. Results from the rectangular geometry and cylindrical geometry (with annular shield) were compared as a means to validate the use of the cylindrical model used in the MicroShield calculation. For the rectangular model, dose rates for time points at 4-hours and 8-hours were calculated for various distances at the height of the TSC. (The QADMOD-GP input data sheets are presented in Attachment 3.) A plot of the cylindrical and rectangular 4-hour dose rates as a function of distance is presented in Figure 4. Though it is not shown, the 8-hour data resulted in a similar plot.

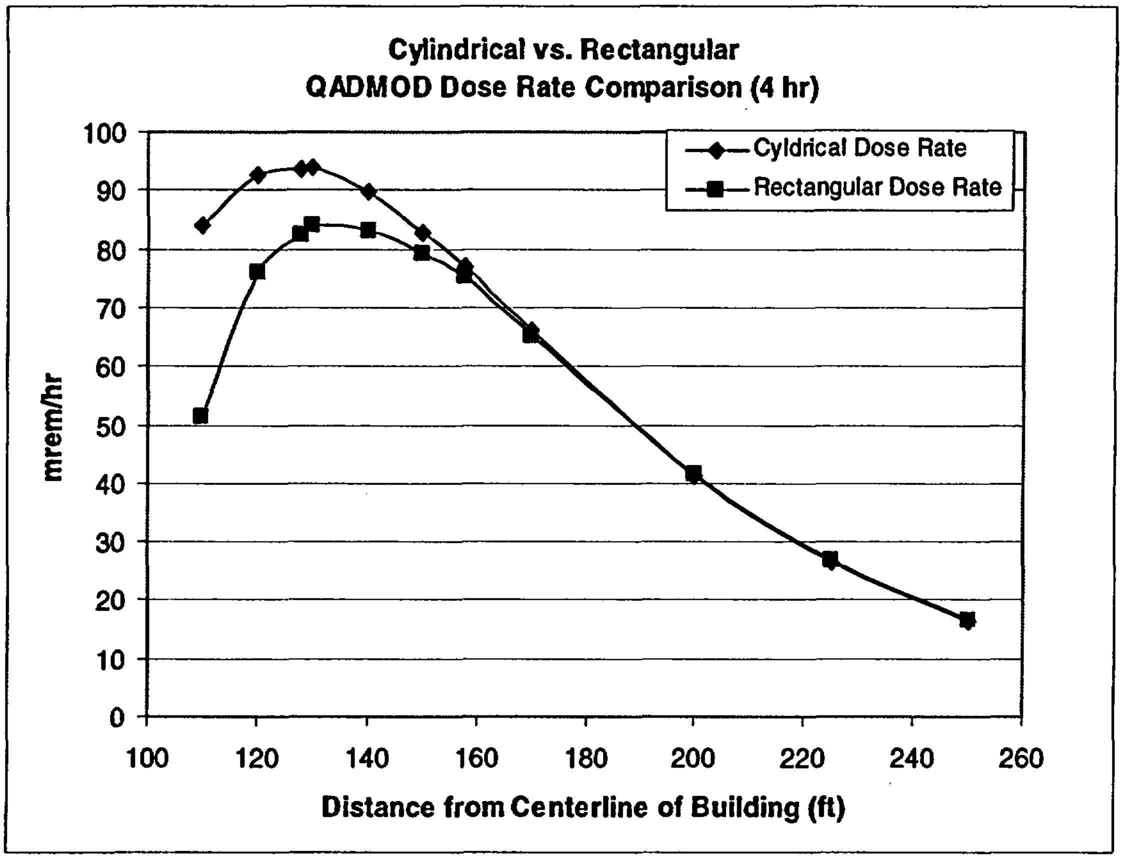



**Figure 4. Cylindrical vs. Rectangular Dose Rate Comparison**

Figure 4 clearly shows that the use of a cylindrical model yields higher dose rates in the range of distances corresponding to the TSC receptor and is a more conservative model. It is noted that the dose rates merge as distance from the source and the annular shield increases. This is expected since the source starts to look like a point source and comes out of the shadow of annular shield. It should also be emphasized that both the MicroShield and QADMOD-GP cylindrical calculations use a radial distance of 127.7-feet for the TSC receptor (as an approximation associated with use of cylindrical geometry). This produces a conservative estimate of the dose rate since the actual RB structure is cubic (see Figure 1) and the actual TSC receptor is expected to be at a further radial distance of 157.7-feet.

## Conclusions

It is concluded that the MicroShield cylindrical model is valid and that provides conservative estimates of dose rates. The following conservatisms are included in the MicroShield model:

- Radial Distance – The cylindrical calculations use a radial distance of 127.7-feet whereas the actual TSC receptor is expected to be at a further radial distance of 157.7-feet.
- Shielding Factor – Choosing a shielding factor of 2 is conservative since the calculation indicates a range from about 2.5 to 4 for various distances within the TSC.
- Cylindrical Model – The use of a cylindrical model is conservative since the comparison of cylindrical and rectangular models shows that cylindrical model yields higher dose rates in the range of distances corresponding to the TSC receptor.

## References

1. Memo to File, R. Sher, "Vermont Yankee TSC Integrated Dose Calculation", 5/9/03

2. RSIC Code Package CCC-565, "QADMOD-GP Point Kernel Gamma Ray Shielding Code with Geometric Progression Buildup Factors" November 1990

| | |
|---|---|
| Attachment 1 | MicroShield to QADMOD Comparison<br>(Cylindrical Geometry – Unshielded Annulus)<br>QADMOD Input Data (9 runs) |
| Attachment 2 | QADMOD Concrete Annulus<br>Cylindrical Geometry<br>QADMOD Input Data (4 runs) |
| Attachment 3 | QADMOD Concrete Annulus<br>Rectangular Geometry<br>QADMOD Input Data (2 runs) |

Attachment 1 to "MicroShield 5 Verification Using QADMOD-GP"
MicroShield to QADMOD Comparison (Cylindrical Geometry – Unshielded Annulus)
QADMOD Input Data (9 runs)

```
1 hr - Air Annulus - Cylindrical Geometry
   6    2    3    2    8   11    1   -2    0   22   13   16    0    0
   0    0    0    0    0    3    5    0
8.61+13
     0.0     100.0     200.0     300.0     400.0     500.0     600.0     700.0
   800.0     900.0    1000.0    1100.0    1200.0    1300.0    1400.0    1500.0
  1600.0    1700.0    1800.0    1900.0    2000.0    2100.0    2195.0
  2720.0    2820.0    2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
  3520.0    3620.0    3720.0    3820.0    3920.0    4000.0
     0.0    0.3927    0.7854    1.1781    1.5708    1.9635    2.3562    2.7489
  3.1416    3.5343    3.9270    4.3197    4.7124    5.1051    5.4978    5.8905
  6.2832
 1  0 12       0.0    2195.0       0.0    2195.0
 2  0 12       0.0      7000       0.0      7000
 3     3       0.0
 4     3     313.0
 5     3     333.0
 6     3    2720.0
 7     3    4000.0
 8  0 12       0.0    2134.0       0.0    2134.0
 1     2  8  3  4                                      0         0       100
 2     2  1  2  3  4                                3000         0       100
 3     2  8  4  5                                      0         0       320
 4     1  1  2  4  5                                3000         0       320
 5     2  8  5  6                                      0         0      2000
 6     2  1  2  5  6                                3000         0      2000
 7     2  1  6  7                                      0         0      3000
 8     2  1  2  6  7                                3000         0      3000
 9     2  1  8  3  4                                2160         0       100
10     2  1  8  4  5                                2160         0       320
11     2  1  8  5  6                                2160         0      2000
    2.33
         1.22-03
  25   23
    2.5       1.75      1.25      0.75       0.4      0.15
  0.409      0.104     0.100     0.205     0.051     0.130
AIR  EXP
                             MREM                                PER HOUR
  2256.0       0.0  3420.0     0                                 Ht 112ft
  2300.0       0.0   312.0     0                                  75.5 ft
  3352.8       0.0   312.0     0                                 110.0 ft
  3657.6       0.0   312.0     0                                 120.0 ft
  3892.3       0.0   312.0     0                                 127.7 ft
  3962.4       0.0   312.0     0                                 130.0 ft
  4267.2       0.0   312.0     0                                 140.0 ft
  4572.0       0.0   312.0     0                                 150.0 ft
  4806.7       0.0   312.0     0                                 157.7 ft
  5181.6       0.0   312.0     0                                 170.0 ft
  6096.0       0.0   312.0     0                                 200.0 ft
  6858.0       0.0   312.0     0                                 225.0 ft
  7620.0       0.0   312.0     0                                 250.0 ft
                              -1
```

Attachment 1 to "MicroShield 5 Verification Using QADMOD-GP"
MicroShield to QADMOD Comparison (Cylindrical Geometry – Unshielded Annulus)
QADMOD Input Data (9 runs)

```
2hr - Air Annulus - Cylindrical Geometry
   6    2    3    2    8   11    1   -2    0   22   13   16    0    0
   0    0    0    0    0    3    5    0
3.73+14
     0.0     100.0     200.0     300.0     400.0     500.0     600.0     700.0
   800.0     900.0    1000.0    1100.0    1200.0    1300.0    1400.0    1500.0
  1600.0    1700.0    1800.0    1900.0    2000.0    2100.0    2195.0
  2720.0    2820.0    2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
  3520.0    3620.0    3720.0    3820.0    3920.0    4000.0
     0.0    0.3927    0.7854    1.1781    1.5708    1.9635    2.3562    2.7489
  3.1416    3.5343    3.9270    4.3197    4.7124    5.1051    5.4978    5.8905
  6.2832
 1  0 12       0.0    2195.0       0.0    2195.0
 2  0 12       0.0      7000       0.0      7000
 3     3       0.0
 4     3     313.0
 5     3     333.3
 6     3    2720.0
 7     3    4000.0
 8  0 12       0.0    2134.0       0.0    2134.0
 1     2  8  3  4                                  0          0       100
 2     2  1  2  3  4                            3000          0       100
 3     2  8  4  5                                  0          0       320
 4     1  1  2  4  5                            3000          0       320
 5     2  8  5  6                                  0          0      2000
 6     2  1  2  5  6                            3000          0      2000
 7     2  1  6  7                                  0          0      3000
 8     2  1  2  6  7                            3000          0      3000
 9     2  1  8  3  4                            2160          0       100
10     2  1  8  4  5                            2160          0       320
11     2  1  8  5  6                            2160          0      2000
     2.33
          1.22-03
  25   23
     2.5      1.75      1.25      0.75       0.4      0.15
    0.48      0.09     0.071     0.127     0.042      0.19
AIR  EXP
                                MREM                                PER HOUR
  2256.0       0.0    3420.0    0                                   Ht 112ft
  2300.0       0.0     312.0    0                                    75.5 ft
  3352.8       0.0     312.0    0                                   110.0 ft
  3657.6       0.0     312.0    0                                   120.0 ft
  3892.3       0.0     312.0    0                                   127.7 ft
  3962.4       0.0     312.0    0                                   130.0 ft
  4267.2       0.0     312.0    0                                   140.0 ft
  4572.0       0.0     312.0    0                                   150.0 ft
  4806.7       0.0     312.0    0                                   157.7 ft
  5181.6       0.0     312.0    0                                   170.0 ft
  6096.0       0.0     312.0    0                                   200.0 ft
  6858.0       0.0     312.0    0                                   225.0 ft
  7620.0       0.0     312.0    0                                   250.0 ft
                               -1
```

Attachment 1 to "MicroShield 5 Verification Using QADMOD-GP"
MicroShield to QADMOD Comparison (Cylindrical Geometry – Unshielded Annulus)
QADMOD Input Data (9 runs)

```
4hr - Air Annulus - Cylindrical Geometry
   6     2     3     2     8    11     1    -2     0    22    13    16     0     0
   0     0     0     0     0     3     5     0
7.77+14
     0.0     100.0      200.0     300.0     400.0     500.0     600.0     700.0
   800.0     900.0     1000.0    1100.0    1200.0    1300.0    1400.0    1500.0
  1600.0    1700.0     1800.0    1900.0    2000.0    2100.0    2195.0
  2720.0    2820.0     2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
  3520.0    3620.0     3720.0    3820.0    3920.0    4000.0
     0.0    0.3927     0.7854    1.1781    1.5708    1.9635    2.3562    2.7489
  3.1416    3.5343     3.9270    4.3197    4.7124    5.1051    5.4978    5.8905
  6.2832
 1  0 12       0.0     2195.0       0.0    2195.0
 2  0 12       0.0       7000       0.0      7000
 3     3       0.0
 4     3     313.0
 5     3     333.3
 6     3    2720.0
 7     3    4000.0
 8  0 12       0.0     2134.0       0.0    2134.0
 1     2  8  3  4                                    0         0       100
 2     2  1  2  3  4                              3000         0       100
 3     2  8  4  5                                    0         0       320
 4     1  1  2  4  5                              3000         0       320
 5     2  8  5  6                                    0         0      2000
 6     2  1  2  5  6                              3000         0      2000
 7     2  1  6  7                                    0         0      3000
 8     2  1  2  6  7                              3000         0      3000
 9     2  1  8  3  4                              2160         0       100
 10    2  1  8  4  5                              2160         0       320
 11    2  1  8  5  6                              2160         0      2000
     2.33
         1.22-03
  25    23
    2.5       1.75      1.25      0.75      0.4       0.15
    0.45      0.08      0.06      0.1       0.03      0.28
AIR  EXP
                                  MREM                                 PER HOUR
  2256.0       0.0  3420.0         0                                   Ht 112ft
  2300.0       0.0   312.0         0                                    75.5 ft
  3352.8       0.0   312.0         0                                   110.0 ft
  3657.6       0.0   312.0         0                                   120.0 ft
  3892.3       0.0   312.0         0                                   127.7 ft
  3962.4       0.0   312.0         0                                   130.0 ft
  4267.2       0.0   312.0         0                                   140.0 ft
  4572.0       0.0   312.0         0                                   150.0 ft
  4806.7       0.0   312.0         0                                   157.7 ft
  5181.6       0.0   312.0         0                                   170.0 ft
  6096.0       0.0   312.0         0                                   200.0 ft
  6858.0       0.0   312.0         0                                   225.0 ft
  7620.0       0.0   312.0         0                                   250.0 ft
                                  -1
```

Attachment 1 to "MicroShield 5 Verification Using QADMOD-GP"
MicroShield to QADMOD Comparison (Cylindrical Geometry – Unshielded Annulus)
QADMOD Input Data (9 runs)

```
8hr - Air Annulus - Cylindrical Geometry
   6    2     3     2     8    11     1    -2     0    22    13    16     0     0
   0    0     0     0     0     3     5     0
8.50+14
     0.0     100.0     200.0     300.0     400.0     500.0     600.0     700.0
   800.0     900.0    1000.0    1100.0    1200.0    1300.0    1400.0    1500.0
  1600.0    1700.0    1800.0    1900.0    2000.0    2100.0    2195.0
  2720.0    2820.0    2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
  3520.0    3620.0    3720.0    3820.0    3920.0    4000.0
     0.0    0.3927    0.7854    1.1781    1.5708    1.9635    2.3562    2.7489
  3.1416    3.5343    3.9270    4.3197    4.7124    5.1051    5.4978    5.8905
  6.2832
 1  0 12       0.0    2195.0       0.0    2195.0
 2  0 12       0.0      7000       0.0      7000
 3     3       0.0
 4     3     313.0
 5     3     333.3
 6     3    2720.0
 7     3    4000.0
 8  0 12       0.0    2134.0       0.0    2134.0
 1     2  8  3  4                                          0         0       100
 2     2  1  2  3  4                                    3000         0       100
 3     2  8  4  5                                          0         0       320
 4     1  1  2  4  5                                    3000         0       320
 5     2  8  5  6                                          0         0      2000
 6     2  1  2  5  6                                    3000         0      2000
 7     2  1  6  7                                          0         0      3000
 8     2  1  2  6  7                                    3000         0      3000
 9     2  1  8  3  4                                    2160         0       100
10     2  1  8  4  5                                    2160         0       320
11     2  1  8  5  6                                    2160         0      2000
    2.33
         1.22-03
  25    23
    2.5       1.75      1.25      0.75       0.4      0.15
   0.323     0.060     0.049     0.089     0.024     0.455
AIR  EXP
                                MREM                                PER HOUR
  2256.0       0.0  3420.0       0                                  Ht 112ft
  2300.0       0.0   312.0       0                                   75.5 ft
  3352.8       0.0   312.0       0                                  110.0 ft
  3657.6       0.0   312.0       0                                  120.0 ft
  3892.3       0.0   312.0       0                                  127.7 ft
  3962.4       0.0   312.0       0                                  130.0 ft
  4267.2       0.0   312.0       0                                  140.0 ft
  4572.0       0.0   312.0       0                                  150.0 ft
  4806.7       0.0   312.0       0                                  157.7 ft
  5181.6       0.0   312.0       0                                  170.0 ft
  6096.0       0.0   312.0       0                                  200.0 ft
  6858.0       0.0   312.0       0                                  225.0 ft
  7620.0       0.0   312.0       0                                  250.0 ft
                                -1
```

Attachment 1 to "MicroShield 5 Verification Using QADMOD-GP"
MicroShield to QADMOD Comparison (Cylindrical Geometry – Unshielded Annulus)
QADMOD Input Data (9 runs)

```
24 hr - Air Annulus - Cylindrical Geometry
   6    2    3    2    8   11    1   -2    0   22   13   16    0    0
   0    0    0    0    0    3    5    0
5.94+14
     0.0     100.0     200.0     300.0     400.0     500.0     600.0     700.0
   800.0     900.0    1000.0    1100.0    1200.0    1300.0    1400.0    1500.0
  1600.0    1700.0    1800.0    1900.0    2000.0    2100.0    2195.0
  2720.0    2820.0    2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
  3520.0    3620.0    3720.0    3820.0    3920.0    4000.0
     0.0    0.3927    0.7854    1.1781    1.5708    1.9635    2.3562    2.7489
  3.1416    3.5343    3.9270    4.3197    4.7124    5.1051    5.4978    5.8905
  6.2832
 1  0 12       0.0    2195.0       0.0    2195.0
 2  0 12       0.0      7000       0.0      7000
 3     3       0.0
 4     3     313.0
 5     3     333.0
 6     3    2720.0
 7     3    4000.0
 8  0 12       0.0    2134.0       0.0    2134.0
 1     2  8  3  4                                    0         0       100
 2     2  1  2  3  4                              3000         0       100
 3     2  8  4  5                                    0         0       320
 4     1  1  2  4  5                              3000         0       320
 5     2  8  5  6                                    0         0      2000
 6     2  1  2  5  6                              3000         0      2000
 7     2  1  6  7                                    0         0      3000
 8     2  1  2  6  7                              3000         0      3000
 9     2  1  8  3  4                              2160         0       100
10     2  1  8  4  5                              2160         0       320
11     2  1  8  5  6                              2160         0      2000
    2.33
         1.22-03
  25    23
    2.5       1.75      1.25      0.75       0.4      0.15
  0.020      0.008     0.016     0.072     0.025     0.859
AIR  EXP
                                MREM                                PER HOUR
  2256.0      0.0  3420.0      0                                    Ht 112ft
  2300.0      0.0   312.0      0                                     75.5 ft
  3352.8      0.0   312.0      0                                    110.0 ft
  3657.6      0.0   312.0      0                                    120.0 ft
  3892.3      0.0   312.0      0                                    127.7 ft
  3962.4      0.0   312.0      0                                    130.0 ft
  4267.2      0.0   312.0      0                                    140.0 ft
  4572.0      0.0   312.0      0                                    150.0 ft
  4806.7      0.0   312.0      0                                    157.7 ft
  5181.6      0.0   312.0      0                                    170.0 ft
  6096.0      0.0   312.0      0                                    200.0 ft
  6858.0      0.0   312.0      0                                    225.0 ft
  7620.0      0.0   312.0      0                                    250.0 ft
                              -1
```

Attachment 1 to "MicroShield 5 Verification Using QADMOD-GP"
MicroShield to QADMOD Comparison (Cylindrical Geometry – Unshielded Annulus)
QADMOD Input Data (9 runs)

```
48 hr - Air Annulus - Cylindrical Geometry
   6    2    3    2    8   11    1   -2    0   22   13   16    0    0
   0    0    0    0    0    3    5    0
2.75+14
     0.0     100.0     200.0     300.0     400.0     500.0     600.0     700.0
   800.0     900.0    1000.0    1100.0    1200.0    1300.0    1400.0    1500.0
  1600.0    1700.0    1800.0    1900.0    2000.0    2100.0    2195.0
  2720.0    2820.0    2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
  3520.0    3620.0    3720.0    3820.0    3920.0    4000.0
     0.0    0.3927    0.7854    1.1781    1.5708    1.9635    2.3562    2.7489
  3.1416    3.5343    3.9270    4.3197    4.7124    5.1051    5.4978    5.8905
  6.2832
 1  0 12       0.0    2195.0       0.0    2195.0
 2  0 12       0.0      7000       0.0      7000
 3     3       0.0
 4     3     313.0
 5     3     333.0
 6     3    2720.0
 7     3    4000.0
 8  0 12       0.0    2134.0       0.0    2134.0
 1     2  8  3  4                                       0         0       100
 2     2  1  2  3  4                                 3000         0       100
 3     2  8  4  5                                       0         0       320
 4     1  1  2  4  5                                 3000         0       320
 5     2  8  5  6                                       0         0      2000
 6     2  1  2  5  6                                 3000         0      2000
 7     2  1  6  7                                       0         0      3000
 8     2  1  2  6  7                                 3000         0      3000
 9     2  1  8  3  4                                 2160         0       100
10     2  1  8  4  5                                 2160         0       320
11     2  1  8  5  6                                 2160         0      2000
     2.33
          1.22-03
  25    23
     2.5       1.75      1.25      0.75       0.4      0.15
   0.000      0.001     0.007     0.063     0.048     0.881
AIR  EXP
                                MREM                                PER HOUR
  2256.0        0.0  3420.0      0                                  Ht 112ft
  2300.0        0.0   312.0      0                                   75.5 ft
  3352.8        0.0   312.0      0                                  110.0 ft
  3657.6        0.0   312.0      0                                  120.0 ft
  3892.3        0.0   312.0      0                                  127.7 ft
  3962.4        0.0   312.0      0                                  130.0 ft
  4267.2        0.0   312.0      0                                  140.0 ft
  4572.0        0.0   312.0      0                                  150.0 ft
  4806.7        0.0   312.0      0                                  157.7 ft
  5181.6        0.0   312.0      0                                  170.0 ft
  6096.0        0.0   312.0      0                                  200.0 ft
  6858.0        0.0   312.0      0                                  225.0 ft
  7620.0        0.0   312.0      0                                  250.0 ft
                                -1
```

MicroShield to QADMOD Comparison (Cylindrical Geometry – Unshielded Annulus)

QADMOD Input Data (9 runs)

```
144 hr - Air Annulus - Cylindrical Geometry
   6     2     3     2     8    11     1    -2     0    22    13    16     0     0
   0     0     0     0     0     3     5     0
1.23+14
     0.0     100.0     200.0     300.0     400.0     500.0     600.0     700.0
   800.0     900.0    1000.0    1100.0    1200.0    1300.0    1400.0    1500.0
  1600.0    1700.0    1800.0    1900.0    2000.0    2100.0    2195.0
  2720.0    2820.0    2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
  3520.0    3620.0    3720.0    3820.0    3920.0    4000.0
     0.0    0.3927    0.7854    1.1781    1.5708    1.9635    2.3562    2.7489
  3.1416    3.5343    3.9270    4.3197    4.7124    5.1051    5.4978    5.8905
  6.2832
 1   0 12       0.0    2195.0       0.0    2195.0
 2   0 12       0.0      7000       0.0      7000
 3      3       0.0
 4      3     313.0
 5      3     333.0
 6      3    2720.0
 7      3    4000.0
 8   0 12       0.0    2134.0       0.0    2134.0
 1      2  8  3  4                                        0         0       100
 2      2  1  2  3  4                                  3000         0       100
 3      2  8  4  5                                        0         0       320
 4      1  1  2  4  5                                  3000         0       320
 5      2  8  5  6                                        0         0      2000
 6      2  1  2  5  6                                  3000         0      2000
 7      2  1  6  7                                        0         0      3000
 8      2  1  2  6  7                                  3000         0      3000
 9      2  1  8  3  4                                  2160         0       100
 10     2  1  8  4  5                                  2160         0       320
 11     2  1  8  5  6                                  2160         0      2000
     2.33
          1.22-03
  25    23
     2.5      1.75      1.25      0.75       0.4      0.15
   0.000     0.000     0.000     0.021     0.077     0.902
AIR   EXP
                              MREM                                PER HOUR
  2256.0       0.0  3420.0     0                                  Ht 112ft
  2300.0       0.0   312.0     0                                   75.5 ft
  3352.8       0.0   312.0     0                                  110.0 ft
  3657.6       0.0   312.0     0                                  120.0 ft
  3892.3       0.0   312.0     0                                  127.7 ft
  3962.4       0.0   312.0     0                                  130.0 ft
  4267.2       0.0   312.0     0                                  140.0 ft
  4572.0       0.0   312.0     0                                  150.0 ft
  4806.7       0.0   312.0     0                                  157.7 ft
  5181.6       0.0   312.0     0                                  170.0 ft
  6096.0       0.0   312.0     0                                  200.0 ft
  6858.0       0.0   312.0     0                                  225.0 ft
  7620.0       0.0   312.0     0                                  250.0 ft
                              -1
```

# Attachment 1 to "MicroShield 5 Verification Using QADMOD-GP"
## MicroShield to QADMOD Comparison (Cylindrical Geometry – Unshielded Annulus)
## QADMOD Input Data (9 runs)

```
240hr - Air Annulus - Cylindrical Geometry
   6    2    3    2    8   11    1   -2    0   22   13   16    0    0
   0    0    0    0    0    3    5    0
7.20+13
     0.0    100.0    200.0    300.0    400.0    500.0    600.0    700.0
   800.0    900.0   1000.0   1100.0   1200.0   1300.0   1400.0   1500.0
  1600.0   1700.0   1800.0   1900.0   2000.0   2100.0   2195.0
  2720.0   2820.0   2920.0   3020.0   3120.0   3220.0   3320.0   3420.0
  3520.0   3620.0   3720.0   3820.0   3920.0   4000.0
     0.0   0.3927   0.7854   1.1781   1.5708   1.9635   2.3562   2.7489
  3.1416   3.5343   3.9270   4.3197   4.7124   5.1051   5.4978   5.8905
  6.2832
 1   0 12      0.0   2195.0      0.0   2195.0
 2   0 12      0.0     7000      0.0     7000
 3     3       0.0
 4     3     313.0
 5     3     333.3
 6     3    2720.0
 7     3    4000.0
 8   0 12      0.0   2134.0      0.0   2134.0
 1     2  8  3  4                                  0        0      100
 2     2  1  2  3  4                            3000        0      100
 3     2  8  4  5                                  0        0      320
 4     1  1  2  4  5                            3000        0      320
 5     2  8  5  6                                  0        0     2000
 6     2  1  2  5  6                            3000        0     2000
 7     2  1  6  7                                  0        0     3000
 8     2  1  2  6  7                            3000        0     3000
 9     2  1  8  3  4                            2160        0      100
 10    2  1  8  4  5                            2160        0      320
 11    2  1  8  5  6                            2160        0     2000
    2.33
         1.22-03
  25    23
    2.5     1.75     1.25     0.75      0.4     0.15
   0.00     0.00    0.000    0.021    0.091    0.888
AIR  EXP
                               MREM                               PER HOUR
  2256.0       0.0  3420.0      0                                  Ht 112ft
  2300.0       0.0   312.0      0                                   75.5 ft
  3352.8       0.0   312.0      0                                  110.0 ft
  3657.6       0.0   312.0      0                                  120.0 ft
  3892.3       0.0   312.0      0                                  127.7 ft
  3962.4       0.0   312.0      0                                  130.0 ft
  4267.2       0.0   312.0      0                                  140.0 ft
  4572.0       0.0   312.0      0                                  150.0 ft
  4806.7       0.0   312.0      0                                  157.7 ft
  5181.6       0.0   312.0      0                                  170.0 ft
  6096.0       0.0   312.0      0                                  200.0 ft
  6858.0       0.0   312.0      0                                  225.0 ft
  7620.0       0.0   312.0      0                                  250.0 ft
                               -1
```

Attachment 1 to "MicroShield 5 Verification Using QADMOD-GP"
MicroShield to QADMOD Comparison (Cylindrical Geometry – Unshielded Annulus)
QADMOD Input Data (9 runs)

```
336 hr - Air Annulus - Cylindrical Geometry
   6     2     3     2     8    11     1    -2     0    22    13    16     0     0
   0     0     0     0     0     3     5     0
4.26+13
      0.0     100.0     200.0     300.0     400.0     500.0     600.0     700.0
    800.0     900.0    1000.0    1100.0    1200.0    1300.0    1400.0    1500.0
   1600.0    1700.0    1800.0    1900.0    2000.0    2100.0    2195.0
   2720.0    2820.0    2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
   3520.0    3620.0    3720.0    3820.0    3920.0    4000.0
      0.0    0.3927    0.7854    1.1781    1.5708    1.9635    2.3562    2.7489
   3.1416    3.5343    3.9270    4.3197    4.7124    5.1051    5.4978    5.8905
   6.2832
 1   0 12       0.0    2195.0       0.0    2195.0
 2   0 12       0.0      7000       0.0      7000
 3      3       0.0
 4      3     313.0
 5      3     333.0
 6      3    2720.0
 7      3    4000.0
 8   0 12       0.0    2134.0       0.0    2134.0
 1      2  8  3  4                                    0         0       100
 2      2  1  2  3  4                              3000         0       100
 3      2  8  4  5                                    0         0       320
 4      1  1  2  4  5                              3000         0       320
 5      2  8  5  6                                    0         0      2000
 6      2  1  2  5  6                              3000         0      2000
 7      2  1  6  7                                    0         0      3000
 8      2  1  2  6  7                              3000         0      3000
 9      2  1  8  3  4                              2160         0       100
10      2  1  8  4  5                              2160         0       320
11      2  1  8  5  6                              2160         0      2000
     2.33
          1.22-03
  25    23
     2.5       1.75      1.25      0.75      0.4       0.15
   0.000      0.000     0.000     0.025     0.109     0.867
AIR  EXP
                                 MREM                                   PER HOUR
   2256.0       0.0   3420.0      0                                     Ht 112ft
   2300.0       0.0    312.0      0                                      75.5 ft
   3352.8       0.0    312.0      0                                     110.0 ft
   3657.6       0.0    312.0      0                                     120.0 ft
   3892.3       0.0    312.0      0                                     127.7 ft
   3962.4       0.0    312.0      0                                     130.0 ft
   4267.2       0.0    312.0      0                                     140.0 ft
   4572.0       0.0    312.0      0                                     150.0 ft
   4806.7       0.0    312.0      0                                     157.7 ft
   5181.6       0.0    312.0      0                                     170.0 ft
   6096.0       0.0    312.0      0                                     200.0 ft
   6858.0       0.0    312.0      0                                     225.0 ft
   7620.0       0.0    312.0      0                                     250.0 ft
                             -1
```

Attachment 2 to "MicroShield 5 Verification Using QADMOD-GP"
QADMOD Concrete Annulus Cylindrical Geometry
QADMOD Input Data (4 runs)

```
1 hr - Concrete Annulus - Cylindrical Geometry
   6     2     3     2     8    11     1    -2     0    22    13    16     0     0
   0     0     0     0     0     3     5     0
8.61+13
      0.0     100.0     200.0     300.0     400.0     500.0     600.0     700.0
    800.0     900.0    1000.0    1100.0    1200.0    1300.0    1400.0    1500.0
   1600.0    1700.0    1800.0    1900.0    2000.0    2100.0    2195.0
   2720.0    2820.0    2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
   3520.0    3620.0    3720.0    3820.0    3920.0    4000.0
      0.0    0.3927    0.7854    1.1781    1.5708    1.9635    2.3562    2.7489
   3.1416    3.5343    3.9270    4.3197    4.7124    5.1051    5.4978    5.8905
   6.2832
 1  0 12       0.0    2195.0       0.0    2195.0
 2  0 12       0.0      7000       0.0      7000
 3     3       0.0
 4     3     313.0
 5     3     333.3
 6     3    2720.0
 7     3    4000.0
 8  0 12       0.0    2134.0       0.0    2134.0
 1     2  8  3  4                                      0         0       100
 2     2  1  2  3  4                                3000         0       100
 3     2  8  4  5                                      0         0       320
 4     1  1  2  4  5                                3000         0       320
 5     2  8  5  6                                      0         0      2000
 6     2  1  2  5  6                                3000         0      2000
 7     2  1  6  7                                      0         0      3000
 8     2  1  2  6  7                                3000         0      3000
 9     1  1  8  3  4                                2160         0       100
10     1  1  8  4  5                                2160         0       320
11     1  1  8  5  6                                2160         0      2000
    2.33
         1.22-03
 25    23
    2.5       1.75      1.25      0.75       0.4      0.15
  0.409      0.104     0.100     0.205     0.051     0.130
AIR   EXP
                          MREM                                    PER HOUR
  2256.0       0.0  3420.0   0                                    Ht 112ft
  2300.0       0.0   312.0   0                                     75.5 ft
  3352.8       0.0   312.0   0                                    110.0 ft
  3657.6       0.0   312.0   0                                    120.0 ft
  3892.3       0.0   312.0   0                                    127.7 ft
  3962.4       0.0   312.0   0                                    130.0 ft
  4267.2       0.0   312.0   0                                    140.0 ft
  4572.0       0.0   312.0   0                                    150.0 ft
  4806.7       0.0   312.0   0                                    157.7 ft
  5181.6       0.0   312.0   0                                    170.0 ft
  6096.0       0.0   312.0   0                                    200.0 ft
  6858.0       0.0   312.0   0                                    225.0 ft
  7620.0       0.0   312.0   0                                    250.0 ft
                            -1
```

Attachment 2 to "MicroShield 5 Verification Using QADMOD-GP"
QADMOD Concrete Annulus Cylindrical Geometry
QADMOD Input Data (4 runs)

```
2hr - Concrete Annulus - Cylindrical Geometry
   6    2    3    2    8   11    1   -2    0   22   13   16    0    0
   0    0    0    0    0    3    5    0
3.73+14
     0.0     100.0     200.0     300.0     400.0     500.0     600.0     700.0
   800.0     900.0    1000.0    1100.0    1200.0    1300.0    1400.0    1500.0
  1600.0    1700.0    1800.0    1900.0    2000.0    2100.0    2195.0
  2720.0    2820.0    2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
  3520.0    3620.0    3720.0    3820.0    3920.0    4000.0
     0.0    0.3927    0.7854    1.1781    1.5708    1.9635    2.3562    2.7489
  3.1416    3.5343    3.9270    4.3197    4.7124    5.1051    5.4978    5.8905
  6.2832
 1  0 12       0.0    2195.0       0.0    2195.0
 2  0 12       0.0      7000       0.0      7000
 3     3       0.0
 4     3     313.0
 5     3     333.3
 6     3    2720.0
 7     3    4000.0
 8  0 12       0.0    2134.0       0.0    2134.0
 1     2  8  3  4                                        0         0       100
 2     2  1  2  3  4                                  3000         0       100
 3     2  8  4  5                                        0         0       320
 4     1  1  2  4  5                                  3000         0       320
 5     2  8  5  6                                        0         0      2000
 6     2  1  2  5  6                                  3000         0      2000
 7     2  1  6  7                                        0         0      3000
 8     2  1  2  6  7                                  3000         0      3000
 9     1  1  8  3  4                                  2160         0       100
10     1  1  8  4  5                                  2160         0       320
11     1  1  8  5  6                                  2160         0      2000
   2.33
          1.22-03
  25    23
    2.5      1.75      1.25      0.75       0.4      0.15
   0.48      0.09     0.071     0.127     0.042      0.19
AIR  EXP
                             MREM                                PER HOUR
  2256.0       0.0  3420.0     0                                 Ht 112ft
  2300.0       0.0   312.0     0                                  75.5 ft
  3352.8       0.0   312.0     0                                 110.0 ft
  3657.6       0.0   312.0     0                                 120.0 ft
  3892.3       0.0   312.0     0                                 127.7 ft
  3962.4       0.0   312.0     0                                 130.0 ft
  4267.2       0.0   312.0     0                                 140.0 ft
  4572.0       0.0   312.0     0                                 150.0 ft
  4806.7       0.0   312.0     0                                 157.7 ft
  5181.6       0.0   312.0     0                                 170.0 ft
  6096.0       0.0   312.0     0                                 200.0 ft
  6858.0       0.0   312.0     0                                 225.0 ft
  7620.0       0.0   312.0     0                                 250.0 ft
                              -1
```

Attachment 2 to "MicroShield 5 Verification Using QADMOD-GP"
QADMOD Concrete Annulus Cylindrical Geometry
QADMOD Input Data (4 runs)

```
4hr - Concrete Annulus - Cylindrical Geometry
   6    2    3    2    8   11    1   -2    0   22    13    16    0    0
   0    0    0    0    0    3    5    0
7.77+14
     0.0     100.0     200.0     300.0     400.0     500.0     600.0     700.0
   800.0     900.0    1000.0    1100.0    1200.0    1300.0    1400.0    1500.0
  1600.0    1700.0    1800.0    1900.0    2000.0    2100.0    2195.0
  2720.0    2820.0    2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
  3520.0    3620.0    3720.0    3820.0    3920.0    4000.0
     0.0    0.3927    0.7854    1.1781    1.5708    1.9635    2.3562    2.7489
  3.1416    3.5343    3.9270    4.3197    4.7124    5.1051    5.4978    5.8905
  6.2832
 1   0 12        0.0    2195.0       0.0    2195.0
 2   0 12        0.0      7000       0.0      7000
 3     3         0.0
 4     3       313.0
 5     3       333.3
 6     3      2720.0
 7     3      4000.0
 8   0 12        0.0    2134.0       0.0    2134.0
 1     2  8  3  4                                       0        0       100
 2     2  1  2  3  4                                 3000        0       100
 3     2  8  4  5                                       0        0       320
 4     1  1  2  4  5                                 3000        0       320
 5     2  8  5  6                                       0        0      2000
 6     2  1  2  5  6                                 3000        0      2000
 7     2  1  6  7                                       0        0      3000
 8     2  1  2  6  7                                 3000        0      3000
 9     1  1  8  3  4                                 2160        0       100
 10    1  1  8  4  5                                 2160        0       320
 11    1  1  8  5  6                                 2160        0      2000
     2.33
         1.22-03
  25    23
    2.5       1.75      1.25      0.75      0.4       0.15
    0.45      0.08      0.06      0.1       0.03      0.28
AIR  EXP
                              MREM                                 PER HOUR
  2256.0       0.0  3420.0     0                                   Ht 112ft
  2300.0       0.0   312.0     0                                    75.5 ft
  3352.8       0.0   312.0     0                                   110.0 ft
  3657.6       0.0   312.0     0                                   120.0 ft
  3892.3       0.0   312.0     0                                   127.7 ft
  3962.4       0.0   312.0     0                                   130.0 ft
  4267.2       0.0   312.0     0                                   140.0 ft
  4572.0       0.0   312.0     0                                   150.0 ft
  4806.7       0.0   312.0     0                                   157.7 ft
  5181.6       0.0   312.0     0                                   170.0 ft
  6096.0       0.0   312.0     0                                   200.0 ft
  6858.0       0.0   312.0     0                                   225.0 ft
  7620.0       0.0   312.0     0                                   250.0 ft
                              -1
```

Attachment 2 to "MicroShield 5 Verification Using QADMOD-GP"
QADMOD Concrete Annulus Cylindrical Geometry
QADMOD Input Data (4 runs)

```
8hr - Concrete Annulus - Cylindrical Geometry
   6     2     3     2     8    11     1    -2     0    22    13    16     0     0
   0     0     0     0     0     3     5     0
8.50+14
     0.0     100.0     200.0     300.0     400.0     500.0     600.0     700.0
   800.0     900.0    1000.0    1100.0    1200.0    1300.0    1400.0    1500.0
  1600.0    1700.0    1800.0    1900.0    2000.0    2100.0    2195.0
  2720.0    2820.0    2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
  3520.0    3620.0    3720.0    3820.0    3920.0    4000.0
     0.0    0.3927    0.7854    1.1781    1.5708    1.9635    2.3562    2.7489
  3.1416    3.5343    3.9270    4.3197    4.7124    5.1051    5.4978    5.8905
  6.2832
 1  0 12       0.0    2195.0       0.0    2195.0
 2  0 12       0.0      7000       0.0      7000
 3     3       0.0
 4     3     313.0
 5     3     333.0
 6     3    2720.0
 7     3    4000.0
 8  0 12       0.0    2134.0       0.0    2134.0
 1     2  8  3  4                                        0         0       100
 2     2  1  2  3  4                                  3000         0       100
 3     2  8  4  5                                        0         0       320
 4     1  1  2  4  5                                  3000         0       320
 5     2  8  5  6                                        0         0      2000
 6     2  1  2  5  6                                  3000         0      2000
 7     2  1  6  7                                        0         0      3000
 8     2  1  2  6  7                                  3000         0      3000
 9     1  1  8  3  4                                  2160         0       100
10     1  1  8  4  5                                  2160         0       320
11     1  1  8  5  6                                  2160         0      2000
     2.33
         1.22-03
 25    23
     2.5      1.75      1.25      0.75       0.4      0.15
   0.323     0.060     0.049     0.089     0.024     0.455
AIR   EXP
                                   MREM                                        PER HOUR
   2256.0       0.0  3420.0         0                                          Ht 112ft
   2300.0       0.0   312.0         0                                           75.5 ft
   3352.8       0.0   312.0         0                                          110.0 ft
   3657.6       0.0   312.0         0                                          120.0 ft
   3892.3       0.0   312.0         0                                          127.7 ft
   3962.4       0.0   312.0         0                                          130.0 ft
   4267.2       0.0   312.0         0                                          140.0 ft
   4572.0       0.0   312.0         0                                          150.0 ft
   4806.7       0.0   312.0         0                                          157.7 ft
   5181.6       0.0   312.0         0                                          170.0 ft
   6096.0       0.0   312.0         0                                          200.0 ft
   6858.0       0.0   312.0         0                                          225.0 ft
   7620.0       0.0   312.0         0                                          250.0 ft
                                   -1
```

## Attachment 3 to "MicroShield 5 Verification Using QADMOD-GP"
## QADMOD Concrete Annulus Rectangular Geometry
## QADMOD Input Data (2 runs)

```
4hr - Concrete Annulus - Rectangular Geometry
    6    2    3    2   14   36    1   -2    1   22   13   17    0    0
    0    0    0    0    0    3    5    0
7.77+14
  -2194.5   -2000.0   -1800.0   -1600.0   -1400.0   -1200.0   -1000.0    -800.0
   -600.0    -400.0    -200.0       0.0     200.0     400.0     600.0     800.0
   1000.0    1200.0    1400.0    1600.0    1800.0    2000.0    2194.5
   2720.0    2820.0    2920.0    3020.0    3120.0    3220.0    3320.0    3420.0
   3520.0    3620.0    3720.0    3820.0    3920.0    4000.0
  -1706.8   -1500.0   -1300.0   -1100.0    -900.0    -700.0    -500.0    -300.0
   -100.0     100.0     300.0     500.0     700.0     900.0    1100.0    1300.0
   1500.0    1706.8
  1     1    2133.6
  2     2    1645.9
  3     1   -2133.6
  4     2   -1645.9
  5     3       0.0
  6     3     313.0
  7     3     333.3
  8     3    2720.0
  9     3    4000.0
 10     1    2194.6
 11     2    1706.9
 12     1   -2194.6
 13     2   -1706.9
 14   0 12       0.0   10000.0        0.0   10000.0
  1     2  1  2  3  4  5  6                       100        100        100
  2     2  1  2  3  4  6  7                       100        100        320
  3     2  1  2  3  4  7  8                       100        100       2000
  4     2 10 11 12 13  8  9                       100        100       3000
  5     1  1 10 13 11  5  6                      2160          0        100
  6     1  1 10 13 11  6  7                      2160          0        320
  7     1  1 10 13 11  7  8                      2160          0       2000
  8     1  1 12  2 11  5  6                         0       1700        100
  9     1  1 12  2 11  6  7                         0       1700        320
 10     1  1 12  2 11  7  8                         0       1700       2000
 11     1  2  3 12 13  5  6                     -2160          0        100
 12     1  2  3 12 13  6  7                     -2160          0        320
 13     1  2  3 12 13  7  8                     -2160          0       2000
 14     1  1  3  4 13  5  6                         0      -1700        100
 15     1  1  3  4 13  6  7                         0      -1700        320
 16     1  1  3  4 13  7  8                         0      -1700       2000
 17     2 14 10 11  5  6                         3000          0        100
 18     2 14 10 11  6  7                         3000          0        320
 19     2 14 10 11  7  8                         3000          0       2000
 20     2 14 10 11  8  9                         3000          0       3000
 21     2 14  1 11  5  6                         3000       3000        100
 22     1 14  1 11  6  7                         3000       3000        320
 23     2 14  1 11  7  8                         3000       3000       2000
 24     2 14  1 11  8  9                         3000       3000       3000
 25     2 14  1 11  5  6                        -3000       3000        100
 26     2 14  1 11  6  7                        -3000       3000        320
 27     2 14  1 11  7  8                        -3000       3000       2000
 28     2 14  1 11  8  9                        -3000       3000       3000
 29     2 14 12 11  5  6                        -3000          0        100
 30     2 14 12 11  6  7                        -3000          0        320
 31     2 14 12 11  7  8                        -3000          0       2000
 32     2 14 12 11  8  9                        -3000          0       3000
 33     2 14 10 13 12  5  6                         0      -3000        100
 34     2 14 10 13 12  6  7                         0      -3000        320
 35     2 14 10 13 12  7  8                         0      -3000       2000
 36     2 14 10 13 12  8  9                         0      -3000       3000
      2.33
           1.22-03
   25    23
```

Attachment 3 to "MicroShield 5 Verification Using QADMOD-GP"
QADMOD Concrete Annulus Rectangular Geometry
QADMOD Input Data (2 runs)

```
     2.5        1.75       1.25       0.75      0.4       0.15
     0.45       0.08       0.06       0.1       0.03      0.28
AIR  EXP
                                  MREM                                    PER HOUR
  3413.8        0.0  3420.0        0                                      Ht 112ft
  2300.0     0.7809   312.0        0                                       75.5 ft
  3352.8     0.7809   312.0        0                                      110.0 ft
  3657.6     0.7809   312.0        0                                      120.0 ft
  3892.3     0.7809   312.0        0                                      127.7 ft
  3962.4     0.7809   312.0        0                                      130.0 ft
  4267.2     0.7809   312.0        0                                      140.0 ft
  4572.0     0.7809   312.0        0                                      150.0 ft
  4806.7     0.7809   312.0        0                                      157.7 ft
  5181.6     0.7809   312.0        0                                      170.0 ft
  6096.0     0.7809   312.0        0                                      200.0 ft
  6858.0     0.7809   312.0        0                                      225.0 ft
  7620.0     0.7809   312.0        0                                      250.0 ft
                                  -1
```

Attachment 3 to "MicroShield 5 Verification Using QADMOD-GP"
QADMOD Concrete Annulus Rectangular Geometry
QADMOD Input Data (2 runs)

```
8hr - Concrete Annulus - Rectangular Geometry
   6    2    3    2   14   36    1   -2    1   22   13   17    0    0
   0    0    0    0    0    3    5    0
8.50+14
 -2194.5  -2000.0  -1800.0  -1600.0  -1400.0  -1200.0  -1000.0   -800.0
  -600.0   -400.0   -200.0      0.0    200.0    400.0    600.0    800.0
  1000.0   1200.0   1400.0   1600.0   1800.0   2000.0   2194.5
  2720.0   2820.0   2920.0   3020.0   3120.0   3220.0   3320.0   3420.0
  3520.0   3620.0   3720.0   3820.0   3920.0   4000.0
 -1706.8  -1500.0  -1300.0  -1100.0   -900.0   -700.0   -500.0   -300.0
  -100.0    100.0    300.0    500.0    700.0    900.0   1100.0   1300.0
  1500.0   1706.8
 1      1   2133.6
 2      2   1645.9
 3      1  -2133.6
 4      2  -1645.9
 5      3      0.0
 6      3    313.0
 7      3    333.3
 8      3   2720.0
 9      3   4000.0
10      1   2194.6
11      2   1706.9
12      1  -2194.6
13      2  -1706.9
14   0 12      0.0  10000.0       0.0  10000.0
 1      2  1  2  3  4  5  6                         100       100       100
 2      2  1  2  3  4  6  7                         100       100       320
 3      2  1  2  3  4  7  8                         100       100      2000
 4      2 10 11 12 13  8  9                         100       100      3000
 5      1  1 10 13 11  5  6                        2160         0       100
 6      1  1 10 13 11  6  7                        2160         0       320
 7      1  1 10 13 11  7  8                        2160         0      2000
 8      1  1 12  2 11  5  6                           0      1700       100
 9      1  1 12  2 11  6  7                           0      1700       320
10      1  1 12  2 11  7  8                           0      1700      2000
11      1  2  3 12 13  5  6                       -2160         0       100
12      1  2  3 12 13  6  7                       -2160         0       320
13      1  2  3 12 13  7  8                       -2160         0      2000
14      1  1  3  4 13  5  6                           0     -1700       100
15      1  1  3  4 13  6  7                           0     -1700       320
16      1  1  3  4 13  7  8                           0     -1700      2000
17      2 14 10 11  5  6                           3000         0       100
18      2 14 10 11  6  7                           3000         0       320
19      2 14 10 11  7  8                           3000         0      2000
20      2 14 10 11  8  9                           3000         0      3000
21      2 14  1 11  5  6                           3000      3000       100
22      1 14  1 11  6  7                           3000      3000       320
23      2 14  1 11  7  8                           3000      3000      2000
24      2 14  1 11  8  9                           3000      3000      3000
25      2 14  1 11  5  6                          -3000      3000       100
26      2 14  1 11  6  7                          -3000      3000       320
27      2 14  1 11  7  8                          -3000      3000      2000
28      2 14  1 11  8  9                          -3000      3000      3000
29      2 14 12 11  5  6                          -3000         0       100
30      2 14 12 11  6  7                          -3000         0       320
31      2 14 12 11  7  8                          -3000         0      2000
32      2 14 12 11  8  9                          -3000         0      3000
33      2 14 10 13 12  5  6                           0     -3000       100
34      2 14 10 13 12  6  7                           0     -3000       320
35      2 14 10 13 12  7  8                           0     -3000      2000
36      2 14 10 13 12  8  9                           0     -3000      3000      2.33
      2.33
           1.22-03
   25    23
```

Attachment 3 to "MicroShield 5 Verification Using QADMOD-GP"
QADMOD Concrete Annulus Rectangular Geometry
QADMOD Input Data (2 runs)

```
   2.5      1.75      1.25      0.75      0.4      0.15
 0.323     0.060     0.049     0.089     0.024     0.455
AIR  EXP
                              MREM                                PER HOUR
  3413.8      0.0  3420.0     0                                   Ht 112ft
  2300.0   0.7809   312.0     0                                    75.5 ft
  3352.8   0.7809   312.0     0                                   110.0 ft
  3657.6   0.7809   312.0     0                                   120.0 ft
  3892.3   0.7809   312.0     0                                   127.7 ft
  3962.4   0.7809   312.0     0                                   130.0 ft
  4267.2   0.7809   312.0     0                                   140.0 ft
  4572.0   0.7809   312.0     0                                   150.0 ft
  4806.7   0.7809   312.0     0                                   157.7 ft
  5181.6   0.7809   312.0     0                                   170.0 ft
  6096.0   0.7809   312.0     0                                   200.0 ft
  6858.0   0.7809   312.0     0                                   225.0 ft
  7620.0   0.7809   312.0     0                                   250.0 ft
                             -1
```