SRNL-STI-2012-00504, REVISION 0

Key Words:
Deactivation and
Decommissioning

Retention:
Permanent

BUILDING 235-F GOLDSIM FATE AND TRANSPORT MODEL

G. A. Taylor
M. A. Phifer

SEPTEMBER 14, 2012

Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, SC 29808

Prepared for the U.S. Department of Energy Under
Contract Number DE-AC09-08SR22470

DISCLAIMER

This work was prepared under an agreement with and funded by the U.S. Government. Neither the U. S. Government or its employees, nor any of its contractors, subcontractors or their employees, makes any express or implied:
1. warranty or assumes any legal liability for the accuracy, completeness, or for the use or results of such use of any information, product, or process disclosed; or
2. representation that such use or results of such use would not infringe privately owned rights; or
3. endorsement or recommendation of any specifically identified commercial product, process, or service.
Any views and opinions of authors expressed in this work do not necessarily state or reflect those of the United States Government, or its contractors, or subcontractors.

Printed in the United States of America

Prepared for
U.S. Department of Energy

SRNL-STI-2012-00504, REVISION 0

Key Words:
Deactivation and
Decommissioning

Retention:
Permanent

BUILDING 235-F GOLDSIM FATE AND TRANSPORT MODEL

G. A. Taylor
M. A. Phifer

SEPTEMBER 14, 2012

Savannah River National Laboratory
Savannah River Nuclear Solutions
Savannah River Site
Aiken, SC 29808

Prepared for the U.S. Department of Energy Under Contract Number DE-AC09-08SR22470

REVIEWS AND APPROVALS

G. A. Taylor, Radiological Performance Assessment	Date
M. A. Phifer, Radiological Performance Assessment	Date
F. G. Smith, III, Peer Reviewer, Computational Engineering & Sciences	Date
D. A. Crowley, Manager, Radiological Performance Assessment	Date
R. S. Aylward, Manager, Environmental Restoration Technology	Date
W. E. Austin, Jr., Area Completion Engineering	Date
T. F. Gaughan, Manager, Area Completion Engineering	Date

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ABL	Actinide Billet Line
Bq	Becquerel (1 Bq = 2.7 e-11 Ci)
CA	Composite Analysis
CDP	Cellulose Degradation Products
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CIG	Component-in-Grout
CL	Low plasticity clay
CLSM	Controlled Low Strength Material
D&D	Deactivation and Decommissioning
DOE	Department of Energy
EPA	Environmental Protection Agency
GSA	General Separations Area
HELP	Hydrologic Evaluation of Landfill Performance
ICRP	International Commission on Radiological Protection
ISD	In-Situ Disposal
K_d	Distribution Coefficient
LAW	Low-Activity Waste Vault
MCL	Maximum Contaminant Level
msl	mean sea level
NCRP	National Council on Radiation Protection and Measurements
NDA	Non Destructive Assay
NRC	Nuclear Regulatory Commission
PA	Performance Assessment
PCBs	Polychlorinated Biphenyls
PEF	Plutonium Experimental Facility
PRGs	Preliminary Remediation Goals
PuFF	Plutonium Fuel Form Facility
SC	Clayey sand
SD	Standard Deviation
SM	Silty sand
SP	Poorly graded sand
S/RID	Standards / Requirements Identification Document
SRNS	Savannah River Nuclear Solutions
SRS	Savannah River Site
Sv	Sievert (1 Sv = 100 rem)
UTR	Upper Three Runs

VOC	Volatile organic carbon
VZ	Vadose Zone
WSRC	Westinghouse or Washington Savannah River Company
SZ	Saturated Zone

ACKNOWLEDGEMENTS

The contribution of the following ACP personnel to the development of the conceptual model and input data for the Building 235-F GoldSim Fate and Transport Model is greatly appreciated:

Greg Rucker
Jack Musall

The contribution of the following SRNL personnel to the development of the Building 235-F GoldSim Fate and Transport Model is greatly appreciated:

Larry Hamm
Frank Smith
Bill Jones

1.0 EXECUTIVE SUMMARY

Savannah River National Laboratory (SRNL) personnel, at the request of Area Completion Projects (ACP), evaluated In-Situ Disposal (ISD) alternatives that are under consideration for deactivation and decommissioning (D&D) of Building 235-F and the Building 294-2F Sand Filter. SRNL personnel developed and used a GoldSim fate and transport model, which is consistent with Musall 2012, to evaluate relative to groundwater protection, ISD alternatives that involve either source removal and/or the grouting of portions or all of 235-F. The following ISD alternatives have been evaluated:

- No action,
- Grout Plutonium Fuel Form (PuFF) Facility Cells 1-5 (grout only cells 1-5 with no inventory removal),
- Grout PuFF Facility Cells 6-9 (grout only cells 6-9 with no inventory removal),
- Grout the entire first floor of 235-F (with no inventory removal),
- Grout the entire 235-F (with no inventory removal),
- Remove 60% of the inventory from PuFF Facility Cells 1-5 (with no grouting)
- Remove 75% of the inventory from PuFF Facility Cells 1-5 (with no grouting)
- Remove 95% of the inventory from PuFF Facility Cells 1-5 (with no grouting)

The protectiveness of each of the above ISD alternatives was evaluated against the following groundwater standards:

- Beta-gamma maximum contaminant limit (MCL) of 4 mrem/yr;
- Combined Radium (Ra-226 and Ra-228) MCL of 5 ρCi/L;
- Adjusted combined gross alpha MCL of 15 ρCi/L;
- Uranium MCL of 30 μg/L, which results in individual isotope limits of 10, 0.47, and 10 ρCi/L for U-234, U-235, and U-238, respectively;
- Elemental lead MCL of 15 μg/L;
- Polychlorinated biphenyl (PCB) MCL of 0.5 μg/L;
- Preliminary Remediation Goals (PRGs) for Ac-227, Ac-228, Bi-210, Bi-212, Bi-213, Bi-214, Fr-223, Pb-209, Pb-210, Pb-211, Pb-212, Pb-214, Pu-241, Ra-225, Th-231, and Th-234; and
- The DOE Order 435.1 all-pathways dose limit of 25 mrem/yr.

This evaluation was conducted through the development and use of a Building 235-F GoldSim fate and transport model. The model simulates contaminant release from four 235-F process areas (Plutonium Fuel Form (PuFF) Facility cells 1-5, PuFF cells 6-9, Actinide Billet Line (ABL), and the rest of the building) and the 294-2F Sand Filter. In addition, it simulates the fate and transport through the vadose zone, the Upper Three Runs (UTR) aquifer, and the Upper Three Runs (UTR) creek. The model is designed as a stochastic model, and as such it can provide both deterministic and stochastic (probabilistic) results. The model results are based on 1,000 realizations, and the aquifer flow path cross-section emanating from the entire 235-F footprint, unless otherwise notated.

The results show that the median radium activity concentrations exceed the 5 ρCi/L radium MCL at the edge of the building (Assessment Point 1) for all ISD alternatives after 10,000 years, except those with a sufficient amount of inventory removed. Figure 1-1 provides the mean radium results for each of the ISD alternatives considered. The blue line is the 5 ρCi/L radium MCL, the upper green line is the mean result from the entire building inventory, and the upper red line is the mean result from PuFF Cells 1-5 inventory. The plots show the maximum mean values recorded up to the time and therefore the leveling off shown in the plots implies that the value of the radium activity concentration has decreased below the maximum value. As seen PuFF Cells 1-5 are the greatest contributor to the radium activity concentration for all ISD alternatives, except when 95% of the inventory is removed from PuFF Facility Cells 1-5. A very interesting result was that grouting was shown to basically have minimal effect on the radium activity concentration. During the first 1,000 years grouting may have some small positive benefit relative to radium, however after that it may have a slightly deleterious effect. At least 60% of the PuFF Facility Cells 1-5 inventory must be removed to get the mean radium activity concentration below the 5 ρCi/L radium MCL.

The Pb-210 results, relative to its 0.06 ρCi/L PRG, are essentially identical to the radium results, but the Pb-210 results exhibit a lesser degree of exceedance. None of the other median values associated with the other groundwater standards exceed their respectively standards at the edge of the building (Assessment Point 1) for any of the ISD alternatives. However a small fraction of the 1,000 probabilistic realizations for gross alpha exceeds the 15 ρCi/L gross alpha MCL. For gross alpha approximately 20% of the realizations exceed the MCL without some inventory removal (Figure 1-2 shows the gross alpha distribution of results for the No Action ISD alternative). No limits were exceeded at UTR creek (Assessment Point 2). The DOE Order 435.1 all-pathways dose limit (25 mrem/yr) was not exceeded at the specified assessment point 100 m from the edge of the building (Assessment Point 3). The only contaminant which did not peak within 100,000 years was elemental lead. The imputed peak mean of the elemental lead concentration approached 40% of its MCL at 186,000 years at the edge of the building (Assessment Point 1).

In summary, some level of inventory removal will be required to ensure that groundwater standards are met. The following provides a comparison of the maximum mean radium activity concentration at the edge of the building (Assessment Point 1) over 100,000 years for various levels of inventory removal from PuFF Facility Cells 1-5:

Inventory Removal [1] (%)	Radium Concentration [2,3] (ρCi/L)
0	~10.4
60	~4.7
75	~3.4
95	~1.5

[1] Level of inventory removal from PuFF Facility Cells 1-5
[2] Maximum mean radium activity concentration at Assessment Point 1 over 100,000 years
[3] Radium MCL = 5 ρCi/L

Figure 1-1 shows maximum values, i.e. when the line levels off no higher value is recorded.

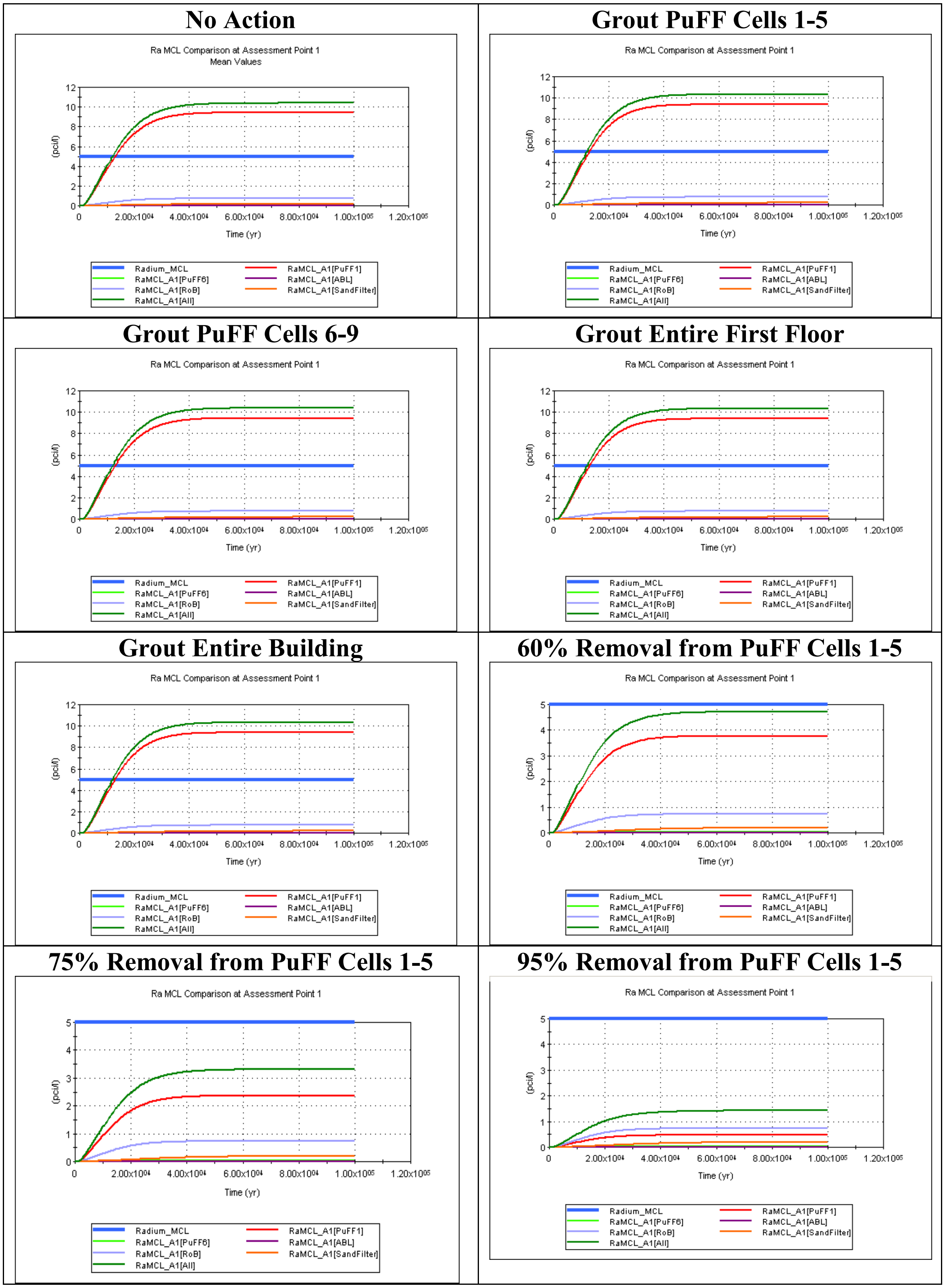


Figure 1-1 ISD Alternatives Mean Radium Results

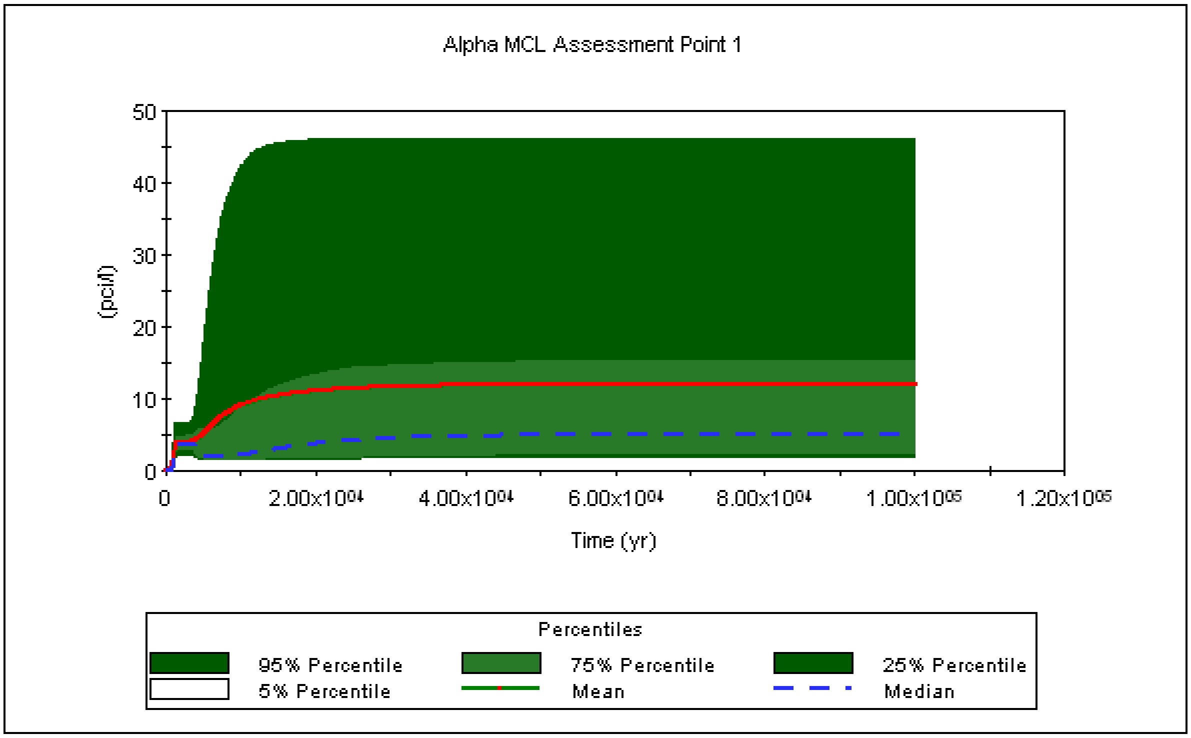


Figure 1-2 Gross Alpha Distribution for No Action ISD Alternative at Edge of Building

2.0 INTRODUCTION

Building 235-F was constructed in the 1950s as part of the original SRS project. 235-F is a blast-resistant, windowless, two-story, reinforced-concrete structure approximately 222 feet long, 109 feet wide and 28 feet high. The two-story structure has 14-inch-thick exterior walls supported by a five-foot-wide perimeter grade beam. The first floor consists of an 8-inch reinforced-concrete slab on grade. Pier footings and columns support the 8-inch second floor and the 6- to 9-inch roof slabs which are directly supported by a reinforced concrete beam and girder system. The roof includes a 9-inch high perimeter curb or parapet. Drainage off the roof is directed through roof drains. Some interior walls are reinforced concrete load-bearing walls. Within 235-F, exhaust air from various process areas/enclosures (containing residual Pu-238 and Np-237) is passed through double HEPA filtration before discharge to the Building 294-2F Sand Filter through an underground tunnel, which is considered part of Building 294-2F. The sand filter provides final filtration for the air exhausted from radiologically-contaminated process areas/enclosures within Building 235-F. Exhaust air is drawn through the sand filter by fans located within the Building 292-2F Fan House. The Sand Filter including the tunnel and the Fan House are also reinforced concrete structures. (WSRC 2003a; Rose 2008; and Musall 2012)

The original mission slated for Building 235-F was cancelled before any equipment was installed. Following the cancellation, the building was reconfigured. The first mission for the reconfigured Building 235-F was the Actinide Billet Line (ABL). This line produced special billets (e.g. containing Np-237) for irradiation in SRS reactors. The next mission was the fabrication of heat sources from Pu-238 oxide powder for space program applications within the Plutonium Experimental Facility (PEF), the Plutonium Fuel Form (PuFF) Facility, and the Old Metallography Lab (OML). Fabrication processes were developed in PEF, large scale fabrication was carried out in the PuFF Facility, and metallographic examinations of the finished product were conducted in the OML. All metallurgical processes within Building 235-F (including PEF, PuFF, OML and ABL) were shut-down by 1990. The building's most recent mission provided for the receipt, storage (within vaults), and disbursement of plutonium bearing materials in support of SRS and the DOE complex. Around October 2006, the vaults were de-inventoried and the facility was transitioned to a reduced surveillance and maintenance (S&M) state. (WSRC 2003a; Rose 2008; and Musall 2012)

Extensive assays of 235-F have been performed that indicate significant radiological material (oxides of Pu-238 and Np-237) called "holdup" remain within 235-F. The majority of the holdup is located within PuFF and ABL. Due to this holdup 235-F is a Category 2 nuclear facility. (WSRC 2003a; Rose 2008; and Musall 2012)

In-Situ Disposal (ISD) alternatives are under consideration for deactivation and decommissioning (D&D) of Building 235-F and the Building 294-2F Sand Filter. Various D&D alternatives are currently under evaluation in regard to groundwater protection, public/industrial worker protection, and cost. Musall 2012 provided a controlled listing of D&D alternatives and basic data for the subsequent studies (i.e. groundwater protection, public/industrial worker protection, and cost), which will support a future recommendation/decision as to which ISD alternative is most appropriate for Buildings 235-F and 294-2F (Musall 2012). The ISD alternatives under consideration primarily involve either source removal and/or grouting portions or all of the building. This report provides an evaluation of a subset of the D&D alternatives listed by Musall 2012 in regard to groundwater protection.

The evaluation of D&D alternative relative to groundwater protection has been conducted through development and use of a Building 235-F GoldSim fate and transport model as described herein. This report includes the following major sections which address this Building 235-F GoldSim fate and transport model:

- Section 3.0, Conceptual Model and Input Data,
- Section 4.0, 235-F GoldSim Fate and Transport Model, and
- Section 5.0, Results

3.0 CONCEPTUAL MODEL AND INPUT DATA

Section 3.1 provides an overview of the Building 235-F GoldSim fate and transport conceptual model and Sections 3.2 through 3.10 provide detailed information on the various parts of the conceptual model along with the associated input data.

3.1 CONCEPTUAL MODEL

Figure 3-1 provides a diagram of the Building 235-F GoldSim fate and transport conceptual model with model output locations (or assessment points) #1 through #5 shown, and Table 3-1 provides the model output required for each model output location. Figure 3-1 also provides a listing of the subsequent sections which provide detailed information on the various parts of the conceptual model.

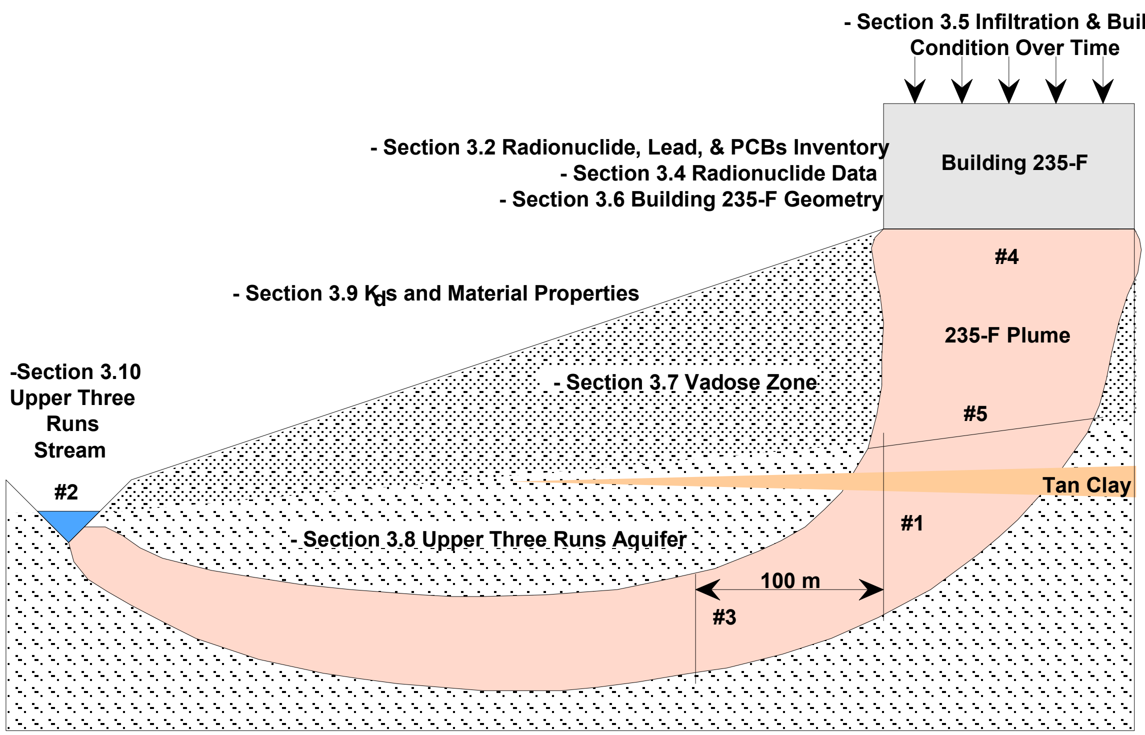


Figure 3-1 Building 235-F GoldSim Fate and Transport Conceptual Model

Table 3-1 Required Model Output

Location	Description	Required Model Output
#1	Upper Three Runs Aquifer at the downgradient edge of Building 235-F	Comparison to CERCLA standards (see Tables 9 and 10) Cumulative mass release
#2	Upper Three Runs (stream)	Comparison to CERCLA standards (see Tables 9 and 10)
#3	Upper Three Runs Aquifer 100 m downgradient from edge of Building 235-F	Comparison to 25 mrem/yr all-pathways dose standard (DOE Order 435.1)
#4	Bottom of Building 235-F floor slab	Cumulative mass release
#5	Plane of Building 235-F across the water table surface	Cumulative mass release

Note to Table 3-1:

- CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act

3.2 INVENTORY

The following inventories utilized within the 235-F GoldSim fate and transport model have been developed as outlined within the following sections:

- Building 235-F Radionuclide Inventory (Section 3.2.1)
- Building 235-F Lead Inventory (Section 3.2.2)
- Building 235-F Polychlorinated Biphenyls (PCBs) Inventory (Section 3.2.3)
- Building 294-2F Sand Filter Radionuclide Inventory (Section 3.2.4)

3.2.1 Building 235-F Radionuclide Inventory

The 235-F radionuclide inventory has been primarily developed from Radder 2007, Bracken et al. 2009, and WSRC 2003a. Radder 2007 provides the results of inventory calculations based upon 235-F radionuclide holdup measurements. Bracken et al. 2009 provides a re-examination of the Plutonium Fuel Form (PuFF) Facility Cell 1. WSRC 2003a is the 235-F Safety Analysis Report which provides information on the impurities associated with the Pu-238 and Np-237 that was processed within 235-F and on the potential U-235 inventory. The 235-F inventory was developed as outlined below:

- The 2006 Pu-238 and Np-237 inventory for 235-F (see Table 3-2) was obtained from Bracken et al. 2009 for the Pu-238 inventory for Cell 1, and Radder 2007 Attachment 8.3, Spreadsheet for New 235-F D&D NDA Measured Value Summary (also see SRNS 2010) for the Pu-238 and Np-237 inventory for the rest of 235-F.
- The U-235 inventory was taken from WSRC 2003a Section 9.1.1.5.1.2, which indicated that there was 32.1 grams of U-235 within the process exhaust ducts with an assumed error of 100%.

- The inventory of the radionuclide impurities associated with the PuO_2 and NpO_2 Feed Powders received in 235-F were obtained as follows:
  - The preponderance of information (WSRC 2007; Reed et al. 2002; WSRC 2006) indicates that operations associated with the PuO_2 and NpO_2 Feed Powders were primarily conducted between 1979 and 1983. Therefore the year 1981 has been taken as the representative year that the PuO_2 (Pu-238) and NpO_2 (Np-237) Feed Powders entered 235-F along with the impurities that they contain.
  - The 2006 inventory of Pu-238 and Np-237 from Table 3-2 was decay corrected to the year 1981 (i.e. representative year that the PuO_2 (Pu-238) and NpO_2 (Np-237) Feed Powders entered 235-F) based upon 26 years of decay using the following equation $A=A_o e^{((-0.693t)/\text{half-life})}$.
  - The 1981 inventory of the impurities within the Pu-238 and Np-237 were determined based upon the Table 3-3 typical isotopic fractions of PuO_2 and NpO_2 Feed Powders as received in 235-F (WSRC 2003a Tables 5.3-1, 5.3-4, and 9.1-3).
- The 1981 Pu-238 inventory is the combination of the 2006 Pu-238 inventory decay corrected to 1981 and the Pu-238 which is an impurity within the NpO_2 (Np-237) Feed Powder (the Actinide Billet Line (ABL), Rest of Building 235-F, and Entire Building 235-F contains Pu-238, which is an impurity within the NpO_2 (Np-237) Feed Powder).
- The 1981 Np-237 inventory is the combination of the 2006 Np-237 inventory decay corrected to 1981 and the Np-237 which is an impurity within the PuO_2 (Pu-238) Feed Powder (PuFF Process Cells 1-5, PuFF Process Cells 6-9, Rest of Building 235-F, and Entire Building 235-F contains Np-237 which is an impurity within the PuO_2 (Pu-238) Feed Powder).
- Table 3-4 provides the resulting 1981 235-F radionuclide inventory and effective uncertainty. The effective uncertainties provided in Table 3-4 are weighted average effective uncertainties derived from the associated uncertainties of the respective components.
- Table 3-5 provides the 2013 235-F inventory, which has been decay corrected from the Table 3-4 data. Only those daughters with a half-life of 3 years or greater that will be explicitly modeled are shown. Daughters with a half-life less than three years will be modeled implicitly by assuming that they are in secular equilibrium with the closest parent that is explicitly modeled.
- The model will be based off of the Table 3-4 inventory, which will be decay corrected to whatever date the simulation will be assumed to start. Table 3-5 is for informational purposes only.

Table 3-2 2006 235-F Pu-238 and Np-237 Inventory

Inventory Division	Location	Pu-238 (g)	Effective Uncertainty (%)	Np-237 (g)	Effective Uncertainty (%)
PUFF Process Cells 1-5	Cell 1	524	42		
	Cold Press GB (Cell 1)	12.35	43.4		
	Maintenance GB (Cell 1)	6.31	64		
	Cell 2	59.7	73		
	Cell 3	2.17	67		
	Particle Coating GB (Cell 3)	0.06	0		
	Diffusion Pump (Cell 3)	0.181	0		
	Cell 4	9.82	74		
	Hot Press Entry GB (Cell 4)	7.32	73		
	Yellow Elephant Vacuum Line (Cell 4)	0.032	50		
	Cell 5	4.58	71		
	Lathe Maintenance GB (Cell 5)	0.026	0		
	Subtotal	**626.5**	**46.3**		
PUFF Process Cells 6-9	Cell 6	1.78	68		
	Cell 7	0.055	82		
	Cell 8	7.8E-03	0		
	Cell 9	9.1E-03	0		
	Subtotal	**1.9**	**67.8**		
Actinide Billet Line (ABL)	Gloveboxes (ABL)			34.84	58.4
	ABL GB HEPA (ABL)			24	25
	ABL Room 107 (ABL)			41.4	35
	ABL Exhaust 2nd (ABL)			15	35
	235-F HEPA (ABL)			0.73	50.7
	Subtotal			**116.0**	**40.1**
Rest of 235-F	PuFF Transfer	0.16	61.4		
	PuFF Exhaust System	6.35	50.5		
	PuFF Ar/He	3.69	30.1		
	GB Floor Area (PEF)	2.95	35.3		
	GB HEPA Filter (PEF)	3.06	34		
	Exhaust Piping (PEF)	0.2	30		
	Miscellaneous Equipment (PEF)	0.11	30.3		
	235-F HEPA Filters (PEF)	0.21	42		
	Old Met Lab	13.47	34.2	0.11	38.5
	Subtotal	**30.2**	**37.4**	**0.11**	**38.5**
Entire 235-F	**Total**	**658.6**	**46.0**	**116.1**	**40.1**

Note to Table 3-2:

- Yellow highlight indicates inventory divisions to be tracked in the model

Table 3-3 Typical Isotopic Fractions of PuO_2 and NpO_2 Feed Powders

Pu-238 Feed [1]		Np-237 Feed [2]	
Isotope	**Typical Isotopic Fraction (g/g metal)**	**Isotope**	**Typical Isotopic Fraction (g/g metal)**
Pu-238	0.835	Np-237	0.99
Pu-239	0.138	Pu-238	0.01
Pu-240	0.02	Pa-233	3.24E-08
Pu-241	4.1E-03	U-233	1.0E-10
Pu-242	1.6E-03	Th-229	4.0E-17
Np-237	5.0E-04		
Th-232	5.0E-04		
Am-241	3.0E-04		

Notes to Table 3-3:

[1] Taken from WSRC 2003a Table 5.3-1

[2] Taken from WSRC 2003a Tables 5.3-4 and 9.1-3 (Pa-233 from Table 9.1-3 and others from Table 5.3-4)

Table 3-4 1981 235-F Radionuclide Inventory [1]

Inventory Division	Pu-238 [2]		Np-237 [3]		U-235 [4]	
	Total Pu-238 (g)	Combined Effective Uncertainty (%)	Total Np-237 (g)	Combined Effective Uncertainty (%)	U-235 (g)	Effective Uncertainty (%)
PuFF Process Cells 1-5	769.45	46.35	0.46	46.35		
PuFF Process Cells 6-9	2.27	67.79	1.36E-03	67.79		
Actinide Billet Line	1.17	40.06	115.97	40.06		
Rest of Building 235-F	37.09	37.37	0.13	38.31	32.1	100
Entire Building 235-F	809.99	45.99	116.57	40.08	32.1	100

Inventory Division	Pu-238 impurities [5]						
	Pu-239 (g)	Pu-240 (g)	Pu-241 (g)	Pu-242 (g)	Th-232 (g)	Am-241 (g)	Effective Uncertainty (%)
PuFF Process Cells 1-5	127.17	18.43	3.78	1.47	0.46	0.28	46.3
PuFF Process Cells 6-9	0.38	5.45E-02	1.12E-02	4.36E-03	1.36E-03	8.17E-04	67.79
Actinide Billet Line							
Rest of Building 235-F	6.13	0.89	0.18	7.11E-02	2.22E-02	1.33E-02	37.4
Entire Building 235-F	133.67	19.37	3.97	1.55	0.48	0.29	46.0

Inventory Division	Np-237 impurities [6]			
	Pa-233 (g)	U-233 (g)	Th-229 (g)	Effective Uncertainty (%)
PuFF Process Cells 1-5				
PuFF Process Cells 6-9				
Actinide Billet Line	3.80E-06	1.17E-08	4.69E-15	40.06
Rest of Building 235-F	3.60E-09	1.11E-11	4.44E-18	38.50
Entire Building 235-F	3.80E-06	1.17E-08	4.69E-15	40.06

Notes to Table 3-4:

1. The preponderance of information indicate that operations were primarily conducted between 1979 and 1983; therefore the year 1981 has been taken as the year that the Pu-238 and Np-237 entered 235-F along with the impurities that they contain (WSRC 2007; Reed et al. 2002; WSRC 2006).
2. Pu-238 inventory for Cell 1 taken from Bracken et al. 2009; Pu-238 inventory for the other 235-F inventory divisions taken from Radder 2007; Pu-238 inventory for the Actinide Billet Line, Rest of Building 235-F, and Entire Building 235-F includes Pu-238 which is an impurity within the Np-237 (WSRC 2003a Table 5.3-4). The 1981

Pu-238 inventory was calculated based upon decay to 2006 (i.e. 26 years of decay; $A=A_oe^{((-0.693t)/\text{half-life})}$

3 Np-237 inventory for all 235-F inventory divisions taken from Radder 2007; Np-237 inventory for the PuFF Process Cells 1-5, PuFF Process Cells 6-9, Rest of Building 235-F, and Entire Building 235-F includes Np-237 which is an impurity within the Pu-238 (WSRC 2003a Table 5.3-1). The 1981 Np-237 inventory was calculated based upon decay to 2006 (i.e. 26 years of decay; $A=A_oe^{((-0.693t)/\text{half-life})}$

4 WSRC 2003a Section 9.1.1.5.1.2 indicated that there was 32.1 grams of U-235 within the process exhaust ducts with an assumed error of 100%.

5 The inventory for other Pu-238 impurities (i.e. Pu-239, Pu-240, Pu-241, Pu-242, Th-232, and Am-241) was calculated based upon their typical isotopic fraction provided within WSRC 2003a Table 5.3-1.

6 The inventory for other Np-237 impurities (i.e. Pa-233, U-233, and Th-229) was calculated based upon their typical isotopic fraction provided within WSRC 2003a Tables 5.3-4 and 9.1-3.

Table 3-5 2013 235-F Radionuclide Inventory

Inventory Division	Pu-238 (g)	Np-237 (g)	U-235 (g)	Np-237 Impurities & Daughters	
				U-233 (g)	Th-229 (g)
PuFF Process Cells 1-5	5.98E+02	5.66E-01	1.10E-01	5.11E-06	3.39E-10
PuFF Process Cells 6-9	1.76E+00	1.67E-03	3.44E-04	1.51E-08	1.00E-12
Actinide Billet Line	9.09E-01	1.16E+02	0	1.16E+02	8.12E-08
Rest of Building 235-F	2.88E+01	1.35E-01	3.21E+01	1.34E-06	9.19E-11
Entire Building 235-F	6.29E+02	1.17E+02	3.22E+01	1.16E+02	8.17E-08

Inventory Division	Pu-238 Impurities					
	Pu-239 (g)	Pu-240 (g)	Pu-241 (g)	Pu-242 (g)	Th-232 (g)	Am-241 (g)
PuFF Process Cells 1-5	1.21E+02	1.84E+01	8.05E-01	1.47E+00	4.60E-01	3.00E-13
PuFF Process Cells 6-9	3.80E-01	5.43E-02	2.39E-03	4.36E-03	1.36E-03	9.31E-03
Actinide Billet Line	0	0	0	0	0	0.00E+00
Rest of Building 235-F	6.12E+00	8.87E-01	3.83E-02	7.11E-02	2.22E-02	1.50E-01
Entire Building 235-F	1.28E+02	1.93E+01	8.46E-01	1.55E+00	4.84E-01	1.59E-01

Inventory Division	Pu-238 Daughters			
	U-234 (g)	Th-230 (g)	Ra-226 (g)	Pb-210 (g)
PuFF Process Cells 1-5	1.69E+02	7.83E-03	7.73E-07	9.21E-10
PuFF Process Cells 6-9	4.99E-01	2.31E-05	2.28E-09	6.22E-12
Actinide Billet Line	2.57E-01	1.19E-05	1.18E-09	3.21E-12
Rest of Building 235-F	8.15E+00	3.77E-04	3.73E-08	1.02E-10
Entire Building 235-F	1.78E+02	8.24E-03	8.14E-07	1.03E-09

Inventory Division	Pu-239 Daughters		Pu-240 Daughters		Pu-242 Daughter
	Pa-231 (g)	Ac-227 (g)	U-236 (g)	Ra-228 (g)	U-238 (g)
PuFF Process Cells 1-5	1.70E-09	3.00E-13	6.12E-02	1.80E-10	8.55E-05
PuFF Process Cells 6-9	5.34E-12	9.40E-16	1.81E-04	5.33E-13	2.54E-07
Actinide Billet Line	0	0	0	0	0
Rest of Building 235-F	9.94E-07	2.42E-10	2.95E-03	8.70E-12	4.14E-06
Entire Building 235-F	9.96E-07	2.43E-10	6.43E-02	1.90E-10	8.99E-05

Notes to Table 3-5:

- U-235 is also a daughter of Pu-239
- Th-232 is also a daughter of Pu-240
- Am-241, Np-237, U-233, Th-229 are also daughters of Pu-241
- U-238, U-234, Th-230, Ra-226, and Pb-210 are also daughters of Pu-242
- Ra-228 is also a daughter of Th-232
- Np-237, U-233, Th-229 are also daughters of Am-241

- Pa-231 and Ac-227 are also daughters of U-235
- Pa-233, which is an impurity and daughter of Np-237, is assumed to be in secular equilibrium with Np-237

3.2.2 Building 235-F Lead Inventory

Lead shielding was utilized throughout 235-F on cells, gloveboxes and cabinets. Roe 2006 provided a quantification of lead shielding used throughout 235-F. In general the lead shielding consisted of ½- inch plate with 1-inch plate used in the ABL. The 235-F lead inventory as extracted from Roe 2006 Table 3-3 is provided in Table 3-6.

Table 3-6 235-F Lead Inventory

Inventory Division	Thickness (in)	Surface Area [1] (sq ft)	Volume (cu ft)
PuFF 1-5	0.5	1978.1	41.21
PuFF 6-9	0.5	579.1	12.06
ABL [2]	1	384.5	16.02
Rest of Building	0.5	607.9	12.66
	Density (lb/cu ft)	**Specific Gravity (g/cc)**	
Lead Properties	710	11.37	

Notes to Table 3-6

1. The surface area provided represents the surface area of both sides of the lead plate to account for corrosion release from both sides of the lead plate.
2. The total area and volume of lead plate provided in Roe 2006 Table 3 for ABL of 73.29 sq ft and 6.11 cu ft, respectively, is incorrect. Within Roe 2006 Table 3 the ABL lead area and volume shown was the sum of column H rather than column I as it should have been. The correct total area and volume of lead plate for ABL is 192.24 sq ft and 16.02 cu ft, respectively

3.2.3 Building 235-F PCBs Inventory

Amercoat 33, a coating/paint containing Polychlorinated Biphenyls (PCBs), was utilized within 235-F. Roe 2006 provided the following information concerning PCBs in the interior coating/paint within 235-F:

- The worse-case coating sample from 235-F contained 3,900 mg of PCBs per kg of coating.
- It has been estimated that 48,500 ft^2 of 235-F surface area is coated with Amercoat 33.

Roe 2006 referenced Santos 2006 in regards to 235-F PCBs. Santos 2006 reported that paint samples were obtained from two locations within 235-F as shown in Table 3-7.

Table 3-7 Building 235-F Coating PCBs Content

Sample Location	Result (mg/kg)
Room 105 floor	3,900
Room 109 floor	25

While Roe 2006 and Santos 2006 provide information on the mass concentration of PCBs within 235-F coating and the surface area of 235-F coated, it does not provide information on the mass of the coating per surface area in order to convert the concentration results to a mass inventory. Therefore additional information regarding Amercoat 33 was required in order to arrive at a PCBs inventory.

Brookhaven National Laboratory conducted a corrosion evaluation of carbon steel tanks coated with Amercoat 33 (Soo and Roberts 1995). Soo and Roberts 1995 stated the following concerning Amercoat 33 that was utilized in the 1950s at Brookhaven National Laboratory:

- Amercoat 33 is a chlorinated rubber coating.
- Two coats of Amercoat 33 were used.

Amercoat 33 is apparently no longer on the market. Therefore information on current chlorinated rubber coatings was evaluated for use in determining an appropriate mass of coating per surface area. The following is pertinent information on four different chlorinated rubber coatings that were evaluated:

- Berger Protecton Protective Coatings Linosol Chlorinated Rubber Paint has the following characteristics:
  - Theoretical coverage per coat = 12 m^2/liter (i.e. 489 ft^2/gal)
  - Two coats should be used on concrete surfaces.
- Sealocrete chlorinated rubber paint has a typical coverage per coat of 50 to 60 m^2/ 5 liters (i.e. 407 to 489 ft^2/gal).
- Teamac Chlorvar chlorinated rubber paint has the following characteristics:
  - Wet specific gravity = 1.09 to 1.23 (i.e. 9.1 to 10.3 lbs/gal) @ 20^{o}C
  - Expected Spreading Rate per coat = 14 m^2/liter (i.e. 570 ft^2/gal)
  - Volatile organic carbon (VOC) content of 625 g/liter (i.e. 5.2 lbs/gal)
  - The wet specific gravity and VOC content result in a dry coating weight of 3.9 to 5.1 lbs/gal (i.e. 9.1 - 5.2 = 3.9; 10.3 – 5.2 = 5.1)
- TriCom Coatings, Inc. chlorinated rubber coating has the following characteristics:
  - Wet weight = 10.5 lbs/gal
  - Theoretical coverage per coat = 451 ft^2/gal

- Weight of solids = 52%
- The wet weight and weight of solids result in a dry coating weight of 5.5 lbs/gal (i.e. 10.5 × 0.52 = 5.5)

Based upon the four chlorinated rubber coatings described above, the following coating parameters were used to calculate the 235-F PCB content:

- Coverage per coat = 400 ft^2/gal (the anticipated coverage ranged from 407 to 570 ft^2/gal; a low coverage rate was taken as conservatively resulting in a greater PCB inventory)
- Dry coating weight of 5.5 lbs/gal (the anticipated dry coating weight ranged from 3.9 to 5.5 lbs/gal; a high weight was taken as conservatively resulting in a greater PCB inventory)
- Two coats of Amercoat 33

Based upon this information, the following are the 235-F PCB inventory calculations:

- Gallons of Amercoat 33 used for one coat = $\frac{48{,}500\ ft^2}{400\frac{ft^2}{gal}} \cong 122\ gallons$
- Gallons of Amercoat 33 used for two coats = 122 gal × 2 = 244 gal
- Pounds of dried Amercoat 33 in 235-F = 244 gal × 5.5 lbs/gal = 1,342 lbs
- Kilogram of dried Amercoat 33 in 235-F = 1,342 lbs × 0.45359 kg/lbs ≈ 609 kg
- Assuming that the 235-F room 109 floor coating content of 25 mg PCBs per kg of coating represents a low end inventory of PCBs in 235-F the following would be the 235-F inventory:

Low end PCBs Inventory = 25 mg/kg × 609 kg = 15,225 mg = 15.2 g

- Assuming that the 235-F room 105 floor coating content of 3,900 mg PCBs per kg of coating represents a high end inventory of PCBs in 235-F the following would be the 235-F inventory:

High end PCBs Inventory = 3,900 mg/kg × 609 kg = 2,375,100 mg = 2,375 g

Based upon the available information the PCBs inventory for the 235-F GoldSim Fate and Transport Modeling will be assumed to range from 15.2 g to 2,375 g with a uniform distribution and to be distributed throughout the entire building.

3.2.4 Building 294-2F Sand Filter Radionuclide Inventory

SRNS 2010 Section 7.1 states the following regarding the Building 294-2F Sand Filter inventory:

> "At the time this report was prepared, no assay results were available for the 292-2F Fan House, the 291-2F Exhaust Stack, or the 294-2F Sand Filter (including the underground tunnel). Until assay results are available, these facilities are also assumed to be Hazard

Category 2 nonreactor nuclear facilities based on the potential for each to contain greater than 3.6 g plutonium-238 holdup. These facilities are expected to ultimately become Hazard Category 3 nonreactor nuclear facilities and then possibly Radiological Facilities as holdup is removed; however, holdup may be sufficient to preclude a Radiological Facility hazard categorization until substantial portions of the facilities are dismantled."

WSRC 2006 Section 4.0 provides the following regarding the Building 294-2F Sand Filter inventory:

"The sandfilter contains <1 gm Pu 238 based on facility process history and building assays. Note that the sandfilter and associated underground ventilation tunnel will be characterized prior to D&D activities"

WSRC 2003b Appendix A-1 lists the Building 292-2F Sand Filter Fan House as a Radiological facility whose end state is to demolish and the Building 294-2F Sand Filter for 235-F as a Nuclear Category 2 facility whose end state is to demolish. The Building 291-2F Exhaust Stack is not listed separately within WSRC 2003b Appendix A-1, and it is assumed that it is included with the Building 292-2F Sand Filter Fan House, because the stack is on the fan house.

SRS Standards / Requirements Identification Document (S/RID) lists the Building 292-2F Sand Filter Fan House as a Nuclear Category 2 facility and the Building 294-2F Sand Filter for 235-F as a Nuclear Category 2 facility.

WSRC 2007 Section 5.2 lists the following two likely end states for the Building 294-2F Sand Filter for 235-F: In-Situ Disposal (ISD) or demolish.

DOE 1997 defines the Hazard Categories for Pu-238 holdup as shown in Table 3-8.

Table 3-8 Hazard Categories based upon Pu-238

Hazard Category	Pu-238 Holdup
Nuclear Category 2	≥ 3.6 g
Nuclear Category 3	≥ 0.036 g and < 3.6 g
Radiological	≥ 0.01 Ci (0.00058 g) and < 0.036 g

Based upon the above information, the following assumptions, which appear reasonable and conservative, have been made relative to the inventory associated with 292-2F, 291-2F, and 294-2F:

- That the Building 292-2F Sand Filter Fan House and associated Building 291-2F Exhaust Stack will be demolished and all radiological inventories will be removed. Therefore these buildings will not be considered in the 235-F GoldSim fate and transport modeling.
- That the end state for Building 294-2F Sand Filter for 235-F will be ISD and that the inventory consists of 3.6 g of Pu-238 holdup (i.e. 3.6 g of Pu-238 and its impurities

(Pu239, Pu240, Pu241, Pu242, Np237, Th232, and Am241)). The 3.6 g of Pu-238 holdup has been divided into the respective radionuclides based upon its ratio with the Pu-238 holdup within 235-F (see Table 3-4). Table 3-9 provides the resulting 294-2F inventory.

Table 3-9 Building 294-2F Sand Filter 1981 Inventory

Pu238 and its impurities								
Pu-238 (g)	**Pu-239 (g)**	**Pu-240 (g)**	**Pu-241 (g)**	**Pu-242 (g)**	**Np-237 (g)**	**Th-232 (g)**	**Am-241 (g)**	**Effective Uncertainty (%)**
3.01	0.50	7.20E-02	1.48E-02	5.76E-03	1.80E-03	1.80E-03	1.08E-03	46.0

3.3 BUILDING 235-F STANDARDS

Table 3-10 provides the radionuclide standards to which the results of the 235-F GoldSim fate and transport modeling results will be compared. In addition to the Table 3-10 comparison, the results will also be compared to the DOE Order 435.1, Radioactive Waste Management, 25 mrem/yr all-pathways dose performance objective using the existing SRS Performance Assessment (PA) GoldSim Dose Model. Table 3-11 provides the standards for lead and PCBs to which the results of the 235-F GoldSim fate and transport modeling results will be compared. See Section 3.1 for the locations (i.e. assessment points) where the various standards are applicable.

Table 3-10 Building 235-F Radionuclide Standards

Nuclide	Decay Mode	Beta-Gamma 4 mrem/yr dose Equivalence [1] (pCi/L)	Combined Radium (Ra-226 & Ra-228) [2] (pCi/L)	Adjusted Combined Gross Alpha [3] (pCi/L)	Calculated Activity Concentration from 30 ug/L Uranium MCL [4] (pCi/L)	August 2010 Radionuclide Tap Water PRGs 1E-6 Cancer Risk Equivalence [5] (pCi/L)	Source
Tl-207	β–						1
Tl-208	β–						1
Tl-209	β–						1
Pb-209	β–					2.20E+02	2
Pb-210	β–					6.01E-02	2
Pb-211	β–					1.29E+02	2
Pb-212	β–					2.12E+00	2
Pb-214	β–					1.54E+02	2
Bi-210	β–					5.93E+00	2
Bi-211	α			15			3
Bi-212	β–					7.45E+01	2
Bi-213	β–					1.04E+02	2
Bi-214	β–					2.76E+02	2
Po-210	α			15			3
Po-212	α			15			3
Po-213	α			15			3
Po-214	α			15			3
Po-215	α			15			3
Po-216	α			15			3
Po-218	α			15			3
At-217	α			15			3
Rn-219	α						1
Rn-220	α						1
Rn-222	α						1
Fr-221	α			15			3
Fr-223	β–					7.26E+00	2
Ra-223	α			15			3
Ra-224	α			15			3
Ra-225	β–					4.64E-01	2
Ra-226	α		5				3
Ra-228	β–		5				3
Ac-225	α			15			3
Ac-227	β–					2.63E-01	2
Ac-228	β–					2.66E+01	2

Table 3-10 Building 235-F Radionuclide Standards (continued)

Nuclide	Decay Mode	Beta-Gamma 4 mrem/yr dose Equivalence [1] (pCi/L)	Combined Radium (Ra-226 & Ra-228) [2] (pCi/L)	Adjusted Combined Gross Alpha [3] (pCi/L)	Calculated Activity Concentration from 30 ug/L Uranium MCL [4] (pCi/L)	August 2010 Radionuclide Tap Water PRGs 1E-6 Cancer Risk Equivalence [5] (pCi/L)	Source
Th-227	α			15			3
Th-228	α			15			3
Th-229	α			15			3
Th-230	α			15			3
Th-231	β–					2.39E+01	2
Th-232	α			15			3
Th-234	β–					2.29E+00	2
Pa-231	α			15			3
Pa-233	β–	3.00E+02					4
Pa-234m	β–						1
U-233	α			15			3
U-234	α				10		5
U-235	α				0.47		5
U-235m	IT						1
U-236	α			15			3
U-238	α				10		5
Np-237	α			15			3
Pu-238	α			15			3
Pu-239	α			15			3
Pu-240	α			15			3
Pu-241	β–					3.01E+01	2
Pu-242	α			15			3
Am-241	α			15			3

Notes to Table 3-10:

[1] Activity concentration of radionuclide equivalent to a 4 mrem/yr drinking water dose; the sum-of-fractions must be less than 1 or the total combined dose of all radionuclide that decay by beta-gamma must be less than 4 mrem/yr. Within the 235-F GoldSim fate and transport model this standard will be evaluated as a combined dose.

[2] The MCL is 5 pCi/L combined Ra-226 and Ra-228.

[3] The MCL is 15pCi/L combined total alpha excluding radon, radium-226, and uranium (i.e. U-234, U-235, and U-238).

[4] Activity concentration applicable to each individual uranium isotope (U-234, U-235, & U-238) based upon the 30 ug/L uranium MCL.

[5] Activity concentration of radionuclide equivalent to a 1E-6 cancer risk; the sum-of-fractions must be less than 1 or the total combined risk of all radionuclides with only PRGs must be less than a cancer risk of 1E-6. Within the 235-F GoldSim fate and transport model this standard will be evaluated as a combined cancer risk.

Source:

1) No applicable standard
2) August 2010 Radionuclide Preliminary Remediation Goals (PRGs)
3) EPA 2009 Maximum Contaminant Level (MCL)
4) EPA calculated concentration yielding a 4 mrem/yr dose from EPA 1981 (Rucker 2001b)
5) Activity concentration derived from the 30 µg/L uranium MCL based upon the mass isotopic distribution of natural uranium (0.0055% U-234, 0.72% U-235, and 99.2745% U-238) (Rucker 2001a)

Table 3-11 Building 235-F Lead and PCBs Standards

Contaminant	MCL (EPA 2009) (µg/L)
Lead	15
PCBs	0.5

3.4 RADIONUCLIDE DATA

As outlined in Section 3.2, the 235-F parent radionuclides consist of Pu-238, Np-237, U-235, and associated impurities as received at 235-F (i.e. Th-229, Th-232, Pa-233, U-233, Pu-239, Pu-240, Pu-241, Pu-242, and Am-241). Radionuclide decay chains associated with these parent radionuclides have been extracted from ICRP 2008. Figure 3-2 through Figure 3-5, respectively, provide the decay chains associated with these parents (i.e. Neptunium Series, Uranium Series, Actinium Series, and Thorium Series). Only decay modes with branching fractions greater than 1% are shown in Figure 3-2 through Figure 3-5 and only these will be included in the calculations. Parents and radionuclide daughters with half-lives greater than three years (shown in black and blue, respectively, in the figures) will be explicitly modeled within the 235-F GoldSim fate and transport model. Daughters with half-lives less than three years (shown in green in the figures) will be implicitly modeled within the fate and transport model by assuming secular equilibrium with the closest preceding member in their decay chain for which an activity concentration is calculated at a point of interest ($N_D = (t_{½D} / t_{½P}) \times N_P$). Pa-233, which is an impurity and daughter of Np-237, will not be modeled explicitly, but it will be assumed to be in secular equilibrium with Np-237, due to its short half-life.

Table 3-12 provides the atomic weight, half-life, decay mode, and branching fractions extracted from ICRP 2008 for each radionuclide included in the Figure 3-2 through Figure 3-5 decay chains (the Table 3-12 nuclides are color coded consistent with Figure 3-2 through Figure 3-5). Although they are not included in the calculations, decay modes with branching fractions less than 1% are also shown in Table 3-12 for informational purposes and to demonstrate their insignificance.

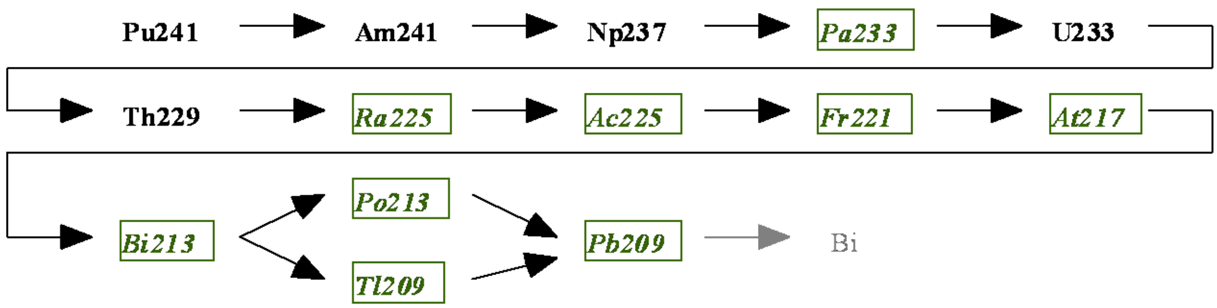


Figure 3-2 Neptunium Series

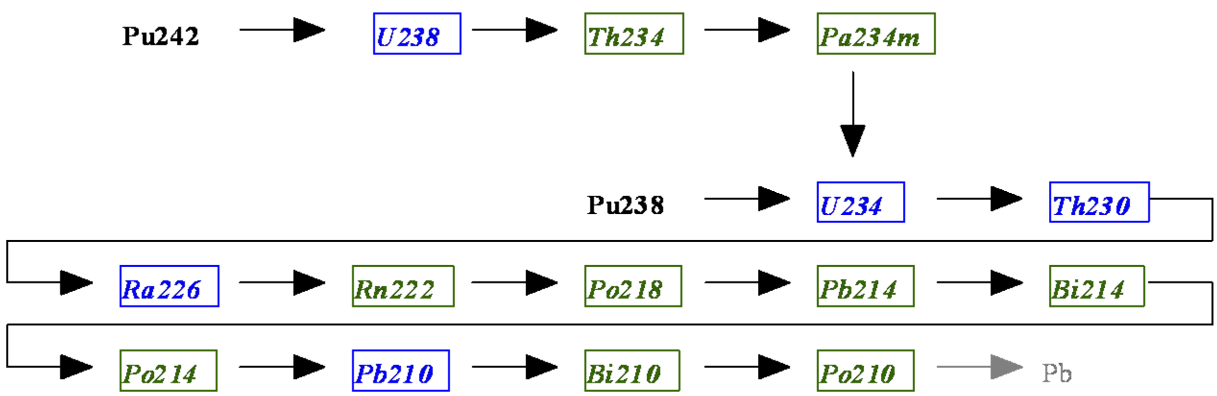


Figure 3-3 Uranium Series

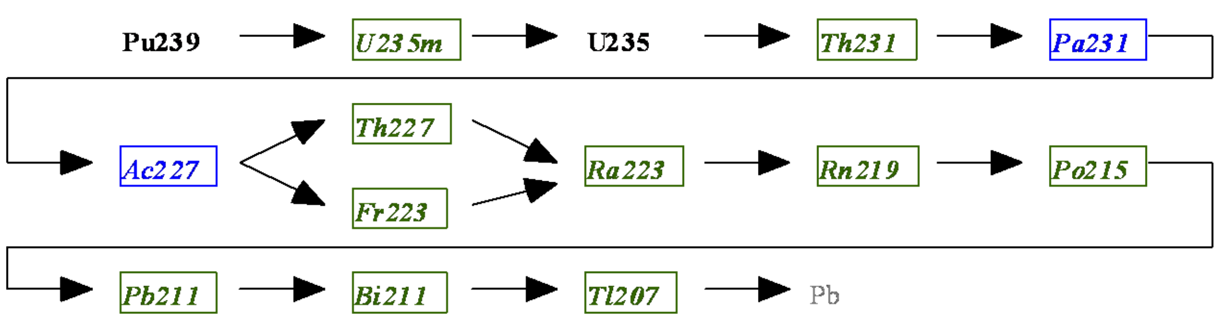


Figure 3-4 Actinium Series

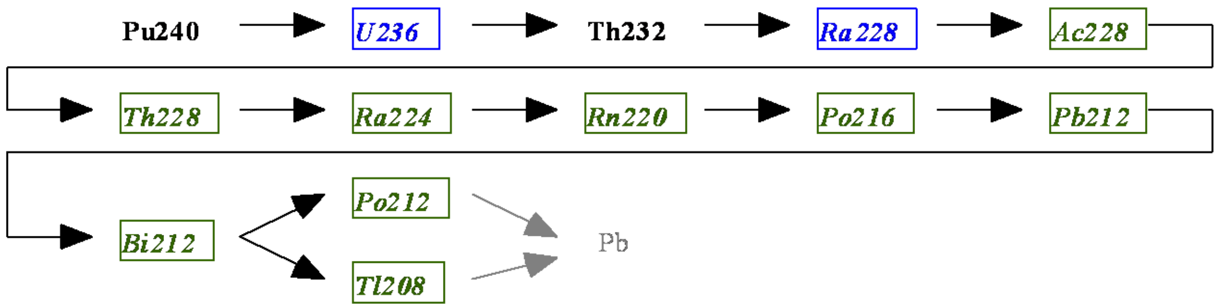


Figure 3-5 Thorium Series

LEGEND for Figure 3-2 through Figure 3-5	
Bold Black Lettering	235-F Parent Radionuclides (Pu-238, Np-237, U-235, and associated impurities as received at 235-F)
Bold Blue Italic Lettering in Box	Radionuclide daughters (progeny) with half-lives > 3 years (transport to be explicitly modeled)
Bold Green Italic Lettering in Box	Radionuclide daughters (progeny) with half-lives < 3 years (implicitly modeled assuming secular equilibrium with closest preceding member in their decay chain for which an activity concentration is calculated)
Grey Lettering	Stable daughters (progeny)
Note: Only decay modes with branching fractions greater than 1% are shown in Figure 3-2 through Figure 3-5 and included in the calculations	

Table 3-12 Building 235-F Radionuclide Data

Nuclide	GoldSim Nuclide	Atomic Weight	Half-life	Units [1]	Decay Mode 1 [2]	Daughter 1 [3]	Branching Fraction 1	Decay Mode 2 [2]	Daughter 2 [1]	Branching Fraction 2 [4]
Tl-207	*Tl207*	207	4.77	m	β-	Pb-207	1	na	na	na
Tl-208	*Tl208*	208	3.053	m	β-	Pb-208	1	na	na	na
Tl-209	*Tl209*	209	2.161	m	β-	*Pb-209*	1	na	na	na
Pb-209	*Pb209*	209	3.253	h	β-	Bi-209	1	na	na	na
Pb-210	*Pb210*	210	22.20	y	β-	*Bi-210*	1	α	Hg-206	1.9E-08
Pb-211	*Pb211*	211	36.1	m	β-	*Bi-211*	1	na	na	na
Pb-212	*Pb212*	212	10.64	h	β-	*Bi-212*	1	na	na	na
Pb-214	*Pb214*	214	26.8	m	β-	*Bi-214*	1	na	na	na
Bi-210	*Bi210*	210	5.013	d	β-	*Po-210*	1	α	Tl-206	1.32E-06
Bi-211	*Bi211*	211	2.14	m	α	*Tl-207*	0.99724	β-	Po-211	2.76E-03
Bi-212	*Bi212*	212	60.55	m	β-	*Po-212*	0.6406	α	***Tl-208***	***0.3594***
Bi-213	*Bi213*	213	45.59	m	β-	*Po-213*	0.9791	α	***Tl-209***	***0.0209***
Bi-214	*Bi214*	214	19.9	m	β-	*Po-214*	0.99979	α	Tl-210	2.10E-04
Po-210	*Po210*	210	138.376	d	α	Pb-206	1	na	na	na
Po-212	*Po212*	212	2.99E-07	s	α	Pb-208	1	na	na	na
Po-213	*Po213*	213	4.2E-06	s	α	*Pb-209*	1	na	na	na
Po-214	*Po214*	214	1.643E-04	s	α	*Pb-210*	1	na	na	na
Po-215	*Po215*	215	1.781E-03	s	α	*Pb-211*	1	na	na	na
Po-216	*Po216*	216	0.145	s	α	*Pb-212*	1	na	na	na
Po-218	*Po218*	218	3.10	m	α	*Pb-214*	0.9998	β-	At-218	2.00E-04
At-217	*At217*	217	3.23E-02	s	α	*Bi-213*	1	na	na	na
Rn-219	*Rn219*	219	3.96	s	α	*Po-215*	1	na	na	na
Rn-220	*Rn220*	220	55.6	s	α	*Po-216*	1	na	na	na
Rn-222	*Rn222*	222	3.8235	d	α	*Po-218*	1	na	na	na

Table 3-12 Building 235-F Radionuclide Data(continued)

Nuclide	GoldSim Nuclide	Atomic Weight	Half-life	Units [1]	Decay Mode 1 [2]	Daughter 1 [3]	Branching Fraction 1	Decay Mode 2 [2]	Daughter 2 [1]	Branching Fraction 2 [4]
Fr-221	***Fr221***	221	4.9	m	α	*At-217*	1	na	na	na
Fr-223	***Fr223***	223	22.0	m	β-	*Ra-223*	1	α	*At-219*	6.00E-05
Ra-223	***Ra223***	223	11.43	d	α	*Rn-219*	1	na	na	na
Ra-224	***Ra224***	224	3.66	d	α	*Rn-220*	1	na	na	na
Ra-225	***Ra225***	225	14.9	d	β-	*Ac-225*	1	na	na	na
Ra-226	***Ra226***	226	1600	y	α	*Rn-222*	1	na	na	na
Ra-228	***Ra228***	228	5.75	y	β-	*Ac-228*	1	na	na	na
Ac-225	***Ac225***	225	10.0	d	α	*Fr-221*	1	na	na	na
Ac-227	***Ac227***	227	21.772	y	β-	*Th-227*	0.9862	**α**	***Fr-223***	***0.0138***
Ac-228	***Ac228***	228	6.15	h	β-	*Th-228*	1	na	na	na
Th-227	***Th227***	227	18.68	d	α	*Ra-223*	1	na	na	na
Th-228	***Th228***	228	1.9116	y	α	*Ra-224*	1	na	na	na
Th-229	**Th229**	229	7.34E+03	y	α	*Ra-225*	1	na	na	na
Th-230	***Th230***	230	7.538E+04	y	α	*Ra-226*	1	na	na	na
Th-231	***Th231***	231	25.52	h	β-	*Pa-231*	1	na	na	na
Th-232	**Th232**	232	1.405E+10	y	α	*Ra-228*	1	na	na	na
Th-234	***Th234***	234	24.10	d	β-	*Pa-234m*	1	na	na	na
Pa-231	***Pa231***	231	3.276E+04	y	α	*Ac-227*	1	na	na	na
Pa-233	***Pa233***	233	26.967	d	β-	*U-233*	1	na	na	na
Pa-234m	***Pa234m***	234	1.17	m	β-	*U-234*	0.9984	IT	*Pa-234*	1.60E-03
U-233	**U233**	233	1.592E+05	y	α	*Th-229*	1	na	na	na
U-234	***U234***	234	2.455E+05	y	α	*Th-230*	1	na	na	na
U-235	**U235**	235	7.04E+08	y	α	*Th-231*	1	na	na	na
U-235m	***U235m***	235	26	m	IT	*U-235*	1	na	na	na
U-236	***U236***	236	2.342E+07	y	α	*Th-232*	1	na	na	na
U-238	***U238***	238	4.468E+09	y	α	*Th-234*	1	SF	--	5.45E-07

Table 3-12 Building 235-F Radionuclide Data(continued)

Nuclide	GoldSim Nuclide	Atomic Weight	Half-life	Units [1]	Decay Mode 1 [2]	Daughter 1 [3]	Branching Fraction 1	Decay Mode 2 [2]	Daughter 2 [3]	Branching Fraction 2 [4]
Np-237	**Np237**	237	2.144E+06	y	α	*Pa-233*	1	na	na	na
Pu-238	**Pu238**	238	87.7	y	α	*U-234*	1	SF	--	1.85E-09
Pu-239	**Pu239**	239	2.411E+04	y	α	*U-235m*	0.9994	α	*U-235*	6.00E-04
Pu-240	**Pu240**	240	6564	y	α	*U-236*	1	SF	--	5.75E-08
Pu-241	**Pu241**	241	14.35	y	β-	*Am-241*	0.99998	α	*U-237*	2.45E-05
Pu-242	**Pu242**	242	3.75E+05	y	α	*U-238*	1	SF	--	5.54E-06
Am-241	**Am241**	241	432.2	y	α	*Np-237*	1	na	na	na

Notes to Table 3-12:

- Nuclides in **Bold Black Lettering** are 235-F Parent Radionuclides (Pu-238, Np-237, U-235, and associated impurities as received at 235-F (i.e. Th-229, Th-232, Pa-233, U-233, Pu-239, Pu-240, Pu-241, Pu-242, and Am-241)).
- Nuclides in ***Bold Blue Italic Lettering*** are radionuclide daughters (progeny) with half-lives > 3 years (transport to be explicitly modeled within the 235-F GoldSim fate and transport model).
- Nuclides in ***Bold Green Italic Lettering*** are radionuclide daughters (progeny) with half-lives < 3 years (implicitly modeled within the fate and transport model by assuming secular equilibrium with the closest preceding member in their decay chain for which an activity concentration is calculated at a point of interest).
- Half-life, decay mode, and branching fraction data taken from ICRP Publication 107 Table A-1.

[1] Units for half-lives are: y = years; d= days; h = hours; m= minutes; and s= seconds.

[2] Decay modes: α = alpha; β- = beta (electron); IT = internal transition; and SF = spontaneous fission.

[3] Daughters in *Italic Lettering* are radioactive isotopes; daughters in **Bold Grey Lettering** are stable isotopes; and "na" indicates that an item is not applicable.

[4] Only those decay modes with branching fractions greater than 1%, shown by ***Bold Black Italic Lettering***, have been included in the calculations. The other decay modes with branching fraction less than 1% are shown for informational purposes and to demonstrate their insignificance.

3.5 INFILTRATION AND BUILDING 235-F CONDITION OVER TIME

Infiltration through 235-F is driven by the condition of the building (intact versus collapsed) and has a significant impact upon contaminant migration out of 235-F. Infiltration through 235-F has been developed for the following conditions:

- Generic Background Infiltration,
- Intact Building 235-F Infiltration,
- Partially Collapsed Building 235-F Infiltration,
- Completely Collapsed Building 235-F Infiltration, and
- Infiltration Equated to Precipitation.

The likely condition of Building 235-F over time has been evaluated based upon the following existing information:

- Current Building 235-F Structure and Condition,
- Long-Term Structural Degradation Predictions associated with other Facilities at the Savannah River Site (SRS), and
- Typical Institutional Control Considerations.

3.5.1 Infiltration

3.5.1.1 Generic Background Infiltration

Generic background infiltration represents the typical Savannah River Site (SRS) background infiltration within undeveloped areas of SRS (i.e. no pavement, sidewalks, buildings, etc.). This infiltration rate will be utilized to model a "generic" alternative where the entire inventory is assumed to be on the ground surface with no consideration of 235-F barriers. The results of the "generic" alternative will be used for comparative purposes with other 235-F D&D alternatives. Shine 2008 determined the distribution of the 1,000-year mean background infiltration in SRS soils (i.e. background infiltration through undeveloped areas of SRS). Shine 2008 recommended using a normal distribution with a mean infiltration of 15 inches/year and a standard deviation of 0.17 inches/year for the background infiltration.

3.5.1.2 Intact Building 235-F Infiltration

Intact 235-F infiltration represents infiltration through the intact 235-F concrete roof slab prior to building collapse. Council 2008 and Council 2009 utilized a default roof infiltration of 0.49 inches/year (i.e. one hundredth of normal precipitation) for the intact concrete roof for the P-Area and R-Area Reactor Buildings. This appears to be a very conservative infiltration for an intact concrete roof of a massive concrete structure. Jones and Phifer 2007 performed modeling of the E-Area Low Activity Waste (LAW) Vault during institutional control when it is assumed that the vault would be exposed to the atmosphere. Jones and Phifer 2007 estimated an infiltration through the LAW Vault roof of 0.0005 inches/year. Because the default roof infiltration of 0.49 inches/year appears to be conservative, it will be utilized as the infiltration through the intact 235-F concrete roof. Assuming that the 1000-year mean intact 235-F standard deviation is proportional to that of the 1000-year mean background infiltration results in a 1000-year mean intact 235-F standard deviation of 0.0056 inches/year ((0.49/15) × 0.17 = 0.0056). For intact 235-F infiltration this results in a normal distribution with a mean infiltration of 0.49 inches/year and a standard deviation of 0.0056 inches/year.

3.5.1.3 Partially Collapsed Building 235-F Infiltration

Partially collapsed 235-F infiltration represents infiltration through 235-F after the roof has collapsed but the second floor slab remains intact over a grouted first floor. Such infiltration has been estimated by performing Hydrologic Evaluation of Landfill Performance (HELP) modeling (Schroeder 1994a; Schroeder 1994b). Under partially collapsed conditions, the 235-F has been assumed to be adequately represented by:

- The collapsed roof represented by 10 inches of a relatively clean fine sand (<15% fines),
- The intact second floor slab represented by 8 inches of a low quality concrete,
- The grout underlying the second floor represented by 12 feet Controlled Low Strength Material (CLSM), and
- Evaporation considered only within the top 10 inches, no runoff allowed, and no plant transpiration.

This is considered a reasonable representation, because with low precipitation rates the concrete rubble of the roof would absorb the moisture which would be later released as evaporation with very little infiltration, while with high precipitation rates, some storage in the concrete rubble would occur for later evaporation but some infiltration through the intact second floor slab would also occur. A relatively clean fine sand behaves in a similar manner to concrete rubble. Table 3-13 provides the HELP model input. The sand properties were derived from Table 5-18 and Table 5-22 of Phifer et al. 2006 based upon the Intermediate Level (IL) Vault permeable backfill. The second floor concrete properties were derived from Table 6-47 and Table 6-48 of Phifer et al. 2006 based upon low quality concrete (E-Area Component-in-Grout (CIG) concrete mats). The properties of the grout underlying the second floor were derived from Table 6-47 and Table 6-48 of Phifer et al. 2006 based upon E-Area CLSM. The HELP modeling was first run with the intact second floor slab designated as a HELP Layer Type 3, Barrier Soil Layer, which resulted in an estimated infiltration of 0.28 inches/years. This estimated infiltration is less than that assumed under intact roof conditions (i.e. 0.49 inches/year) and is therefore considered too low. The HELP modeling was then run with the intact second floor slab designated as a HELP Layer Type 1, Vertical Percolation Layer, which resulted in an estimated infiltration of 24.5 inches/years. This second estimate is essentially the same as that under completely collapsed 235-F conditions (i.e. 24.6 inches/year; see Section 3.5.1.4) and is therefore considered too high. Therefore the infiltration under partially collapsed Building 235-F conditions (i.e. after the roof has collapsed but the second floor slab remains intact over a grouted first floor) will be assumed to be 12.4 inches/year, which is the average of the previous estimates. Assuming that the 1000-year mean partially collapsed 235-F standard deviation is proportional to that of the 1000-year mean background infiltration results in a 1000-year mean collapsed 235-F standard deviation of 0.14 inches/year ((12.4/15) × 0.17 = 0.14). For partially collapsed 235-F infiltration, this results in a normal distribution with a mean infiltration of 12.4 inches/year and a standard deviation of 0.14 inches/year.

Table 3-13 Partially Collapsed Building 235-F Infiltration HELP Model Soil and Design Data Input (Input files: 235FFPC1.D10 and 235FPC2.D10)

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	1 acres
Percent of area where runoff is possible =	0%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
User-Specified Curve Number = 0	

Layer	Layer Number	Layer Type
Clean Sand	1	1 (vertical percolation layer)
Low Quality Concrete	2	3 (barrier soil liner) or 1 (vertical percolation layer)
CLSM	3	1 (vertical percolation layer)

	Layer Type	Layer Thickness (in)	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)	Saturated Hydraulic Conductivity (cm/sec)
1	1	10	0.41	0.19	0.16	0.19	7.6E-04
2	3 or 1	8	0.211	0.2	0.19	0.211	1.0E-08
3	1	144	0.328	0.292	0.083	0.292	2.2E-06

Notes to Table 3-13:

- Precipitation data file: FPREC.D4 (data set generated from 200-F Weather Station precipitation data from 1961 to 2006 with an average precipitation rate of 49.14 inches/year (Phifer et al. 2007))
- Temperature data file: FTEMP.D7 (data set generated from SRNL and SRS Central Climatology weather stations between 1968 and 2006 (Phifer et al. 2007))
- Solar radiation data file: FSOLAR.D13 (data set generated from HELP model default data for Augusta, GA (Phifer et al. 2007))
- Evapotranspiration data file: 235EVAP.D11 (data set generated from HELP model default data for Augusta, GA with the maximum leaf area index set to 0 to simulate no plant transpiration and evaporative zone depth set to 10 inches, which is the lowest value recommended for the Augusta, GA area)
- Output Files: 235FPC1O.OUT and 235FPC2O.OUT

3.5.1.4 Completely Collapsed Building 235-F Infiltration

Completely collapsed 235-F infiltration represents infiltration through 235-F after it has collapsed. Such infiltration has been estimated by performing Hydrologic Evaluation of Landfill Performance (HELP) modeling (Schroeder 1994a; Schroeder 1994b). Under collapsed conditions 235-F has been assumed to be adequately represented by a relatively clean fine sand (<15% fines) with evaporation considered within the top 10 inches but with no runoff and no plant transpiration. This is considered a reasonable representation, because with low precipitation rates the concrete rubble would absorb the moisture which would be later released as evaporation with very little infiltration, while with high precipitation rates, some storage in the concrete would occur for later evaporation but significant infiltration would occur. A relatively clean fine sand behaves in a similar manner. Table 3-14 provides the HELP model input. The sand properties were derived from Table 5-18 and Table 5-22 of Phifer et al. 2006 based upon the IL Vault permeable backfill. The HELP modeling results in an estimated 24.6 inches/year of infiltration through the collapsed 235-F. Assuming that the 1000-year mean collapsed 235-F standard deviation is proportional to that of the 1000-year mean background infiltration results in a 1000-year mean collapsed 235-F standard deviation of 0.28 inches/year ((24.6/15) × 0.17 = 0.28). For collapsed 235-F infiltration this results in a normal distribution with a mean infiltration of 24.6 inches/year and a standard deviation of 0.28 inches/year.

Table 3-14 Completely Collapsed Building 235-F Infiltration HELP Model Soil and Design Data Input (Input file: 235FSOIL.D10)

<table>
<tr><td colspan="5">Input Parameter (HELP Model Query)</td><td colspan="3">Generic Input Parameter Value</td></tr>
<tr><td colspan="5">Landfill area =</td><td colspan="3">1 acres</td></tr>
<tr><td colspan="5">Percent of area where runoff is possible =</td><td colspan="3">0%</td></tr>
<tr><td colspan="5">Do you want to specify initial moisture storage? (Y/N)</td><td colspan="3">Y</td></tr>
<tr><td colspan="5">Amount of water or snow on surface =</td><td colspan="3">0 inches</td></tr>
<tr><td colspan="5">CN Input Parameter (HELP Model Query)</td><td colspan="3">CN Input Parameter Value</td></tr>
<tr><td colspan="8">User-Specified Curve Number = 0</td></tr>
<tr><td colspan="3">Layer</td><td colspan="3">Layer Number</td><td colspan="2">Layer Type</td></tr>
<tr><td colspan="3">Clean Sand</td><td colspan="3">1</td><td colspan="2">1 (vertical percolation layer)</td></tr>
<tr><td></td><td>Layer Type</td><td>Layer Thickness (in)</td><td>Total Porosity (Vol/Vol)</td><td>Field Capacity (Vol/Vol)</td><td>Wilting Point (Vol/Vol)</td><td>Initial Moisture (Vol/Vol)</td><td>Saturated Hydraulic Conductivity (cm/sec)</td></tr>
<tr><td>1</td><td>1</td><td>36</td><td>0.41</td><td>0.19</td><td>0.16</td><td>0.19</td><td>7.6E-04</td></tr>
</table>

Notes to Table 3-14:

- Precipitation data file: FPREC.D4 (data set generated from 200-F Weather Station precipitation data from 1961 to 2006 with an average precipitation rate of 49.14 inches/year (Phifer et al. 2007))
- Temperature data file: FTEMP.D7 (data set generated from SRNL and SRS Central Climatology weather stations between 1968 and 2006 (Phifer et al. 2007))
- Solar radiation data file: FSOLAR.D13 (data set generated from HELP model default data for Augusta, GA (Phifer et al. 2007))
- Evapotranspiration data file: 235EVAP.D11 (data set generated from HELP model default data for Augusta, GA with the maximum leaf area index set to 0 to simulate no plant transpiration and evaporative zone depth set to 10 inches, which is the lowest value recommended for the Augusta, GA area)
- Output File: 235FOUT1.OUT

3.5.1.5 Infiltration Equated to Precipitation

Infiltration equated to precipitation represents an extremely conservative infiltration because evapotranspiration typically accounts for two thirds of the water balance and the removal of water through evapotranspiration is not taken into consideration if infiltration is equated with precipitation. Council 2008 and Council 2009 utilized a default infiltration of 49 inches/year (i.e. equivalent to normal precipitation) for the collapsed P-Area and R-Area Reactor Buildings. Based upon this usage for P and R-Area Reactor Buildings, equating infiltration to precipitation will be considered an extreme case for 235-F. Phifer et al. 2007 developed a daily precipitation data set based primarily upon data from the 200-F Weather Station from 1961 to 2006. This F-Area precipitation data set had an average precipitation of 49.14 inches/year. Assuming that the 1000-year mean precipitation standard deviation is proportional to that of the 1000-year mean background infiltration results in a 1000-year mean precipitation standard deviation of 0.56 inches/year ((49.14/15) × 0.17 = 0.56). This results in a normal distribution with a mean precipitation of 49.14 inches/year and a standard deviation of 0.56 inches/year, which represents an absolute extreme infiltration.

3.5.1.6 Infiltration Summary

Table 3-15 provides a summary of the infiltration to be utilized in association with the 235-F GoldSim fate and transport modeling effort.

Table 3-15 235-F Infiltration Summary

Condition	Distribution Type	Mean (inches/year)	Standard Deviation (inches/year)
Generic background infiltration	normal	15	0.17
Intact Building 235-F	normal	0.49	0.0056
Partially collapsed Building 235-F	normal	12.4	0.14
Completely collapsed Building 235-F	normal	24.6	0.28
Infiltration Equated to Precipitation (absolute extreme infiltration)	normal	49.14	0.56

Notes to Table 3-15:

- The infiltration means and standard deviations represent 1000-year average values

3.5.2 Likely Condition of Building 235-F over Time

3.5.2.1 Current Building 235-F Structure and Condition

235-F is a windowless, cast-in-place, reinforced-concrete structure approximately 222 feet long, 109 feet wide, and 28 feet high, constructed in the early 1950s. 235-F was designed as a blast resistant structure, and as such, was designed to withstand a 1000 psf (roughly the equivalent of a 550 mph wind) overpressure acting simultaneously on the gross area of exterior walls and roof. The two-story structure has 14-inch-thick exterior walls supported by a five-foot-wide perimeter grade beam (bottom elevation 292 feet, 6 inches). The first floor consists of an 8-inch reinforced-concrete slab (top elevation 302 feet, 8 inches) on grade (top elevation 302 feet). Pier footings and columns support the 8-inch second floor (top elevation 316 feet, 2 inches) and the 6- to 9-inch roof slabs (elevation 330 feet, 2 inches) which are directly supported by a reinforced concrete beam and girder system. The roof includes a 9-inch high perimeter curb or parapet. Drainage off the roof is directed through roof drains. Some interior walls are reinforced concrete load-bearing walls. (WSRC 2003a; W146616; W147672)

Visual evaluations of the 235-F walls, floor slabs, elevated slabs, and select columns, beams, and girders were conducted during 1989-1990. These evaluations did not reveal any symptoms of overstressing and concluded that the building was structurally sound. An October 1989 inspection of the roof revealed that the roof slabs contained several deep grooves which had apparently been cut to help improve drainage. Also, small cracks in the roof slab appeared to be causing rain water leakage to the second floor. The lack of any roofing material covering the slab accentuated the water leakage problem. A subsequent inspection of the roof by SRS seismic/structural engineers, conducted to evaluate structural integrity with the roof cuts, found no immediate concern for the roof integrity under normal dead and live loadings. Restoration of the concrete roof slab to its original design capacity was completed in June 1990. Concrete was chipped from the damaged rebar areas. Those bars deemed critical for roof restoration were repaired by crimping a swage (sleeve) around the ends of the damaged bars and splicing in new sections. Grout was poured back in the trenches to complete the repair. During July through September 1990, a new Hypalon® roof system was installed over the repaired roof slab. (WSRC 2003a)

While evaluations have been conducted to determine that 235-F is currently structurally sound, no long-term structural degradation evaluation has been conducted. (Personal correspondence with Shawn Carey and Bill Peregoy)

3.5.2.2 Long-Term Structural Degradation Predictions

While a long-term structural degradation evaluation has not been conducted for 235-F, such evaluations have been conducted for other similar facilities.

The Low-Activity Waste (LAW) Vault is an above-grade, reinforced concrete structure that is approximately 643 feet long, 145 feet wide, and 27 feet high at the roof crest. The Low-Activity Waste (LAW) Vault has a 1-foot thick, cast-in-place, reinforced concrete floor slab, 2-foot thick, cast-in-place, reinforced, concrete walls, and bridge beams supporting 3-½ inch thick precast deck panels overlain by 12-½ inch thick cast-in-place, reinforced concrete slab for a total 16 inch thick concrete roof (Phifer et al. 2006). A long-term structural degradation evaluation was conducted for the Low-Activity Waste (LAW) Vault under the conditions of not being grouted up and with an overlying closure cap. The evaluation estimated that the roof slab would collapse due to the closure cap and seismic loading and rebar corrosion at a mean time of 2805 years with a standard deviation of 920 years. (Carey 2005)

The R- and P-Reactor buildings are massive reinforced concrete structures with cast-in-place, reinforced concrete roof slabs ranging from 1-foot to 10-foot thick. A long-term structural degradation evaluation was conducted for the R- and P-Reactor buildings which included two primary alternatives. Alternative A involved leaving all roofs as-is and allowing vegetative growth; whereas Alternative C involved sealing all roof penetrations and preventing all vegetative growth by such actions as removing the parapets and/or adding a sloping grout to all roofs. In neither alternative was the reactor buildings assumed to be grouted up beyond ground level. The evaluation estimated that the thinner non-process roofs would begin to collapse under Alternative A in 150 years and that under Alternative C they would begin to collapse in 1350 years. (Carey 2008; Carey 2009)

Closure of the F- and H-Tank Farms includes tank grouting. The worst case evaluation of grout hydraulic degradation associated with the F- and H-Tank Farms indicates that the grout begins to hydraulically degrade under fast flow conditions in year 500 and that full hydraulic degradation could occur at the earliest in year 501 (SRR 2010; SRR 2011).

3.5.2.3 Typical Institutional Control Considerations

Performance Assessments typically take into consideration a 100-year institutional control period after final closure or final deactivation and decommissioning (D&D) during which the facility is actively maintained and repairs are made as necessary (SRNS 2011; SRR 2010; SRR 2011).

3.5.2.4 Likely Building 235-F Condition over Time

Based upon the information provided above the likely condition of 235-F over time has been assigned for the following scenarios:

- No grouting of Building 235-F
- Grouting PuFF Facility within Building 235-F
- Grouting the first floor of Building 235-F
- Grouting all of Building 235-F

No Grouting of Building 235-F

For this scenario it was assumed that the building was maintained for the typical 100-year institutional control period so that the roof does not collapse prior to the end of institutional control. For the case where nothing is done to prevent vegetative growth and to slow roof degradation, it was assumed that the roof could collapse immediately after the 100-year institutional control period (i.e. at year 100). For the case where actions, such as removing the parapets and/or adding a sloping grout to the roof, are taken to prevent vegetative growth and to slow roof degradation, it was assumed that the roof could last as long as 600 years prior to collapse (i.e. essentially half the time estimated for the reactor buildings because the 235-F roof is half the thickness of the thinnest reactor building roof considered).

Grouting PuFF Facility within Building 235-F

For this scenario it was assumed that the building was also maintained for the typical 100-year institutional control period so that the roof does not collapse prior to the end of institutional control. For the case where nothing is done to prevent vegetative growth and to slow roof degradation, it was assumed that the roof could collapse immediately after the 100-

year institutional control period (i.e. at year 100). For the case where actions, such as removing the parapets and/or adding a sloping grout to the roof, are taken to prevent vegetative growth and to slow roof degradation, it was assumed that the roof could last as long as 600 years prior to collapse (i.e. essentially half the time estimated for the reactor buildings because the 235-F roof is half the thickness of the thinnest reactor building roof considered).

For this scenario it was also assumed that the PuFF facility is grouted up to the second floor slab and that collapse of the overlying roof does not result in collapse of the second floor slab over the grouted PuFF facility (i.e. collapse of the roof and underlying second floor slab over the PuFF facility are independent of one another). Based upon the work associated with grout degradation conducted for the tank farms, it was assumed that the grout provides structural support to the second floor slab for 500 years preventing the slab from collapsing until after the 500 year period. It was further assumed that the second floor could last as long as another 500 years (i.e. until year 1000) prior to collapse (i.e. same range in potential roof collapse).

Grouting the First Floor of Building 235-F

For this scenario it was again assumed that the building is maintained for the typical 100-year institutional control period so that the roof does not collapse prior to the end of institutional control. For the case where nothing is done to prevent vegetative growth and to slow roof degradation, it was assumed that the roof could collapse immediately after the 100-year institutional control period (i.e. at year 100). For the case where actions, such as removing the parapets and/or adding a sloping grout to the roof, are taken to prevent vegetative growth and to slow roof degradation, it was assumed that the roof could last as long as 600 years prior to collapse (i.e. essentially half the time estimated for the reactor buildings because the 235-F roof is half the thickness of the thinnest reactor building roof considered).

For this scenario it was also assumed that the entire 235-F first floor is grouted up to the second floor slab and that the second floor slab remains intact over the grouted first floor even after the roof collapses. Based upon the work associated with grout degradation conducted for the tank farms, it was assumed that the grout provides structural support to the second floor slab for 500 years preventing the slab from collapsing until after the 500 year period. It was further assumed that the second floor could last as long as another 500 years (i.e. until year 1000) prior to collapse (i.e. same range in potential roof collapse).

Grouting all of Building 235-F

For this scenario it was assumed that the entire 235-F first and second floors are grouted up to the roof slab and that the grout provides structural support to the roof slab. Based upon the work associated with grout degradation conducted for the tank farms, it was assumed that the grout provides structural support to the roof slab for 500 years preventing the slab from collapsing until after the 500 year period. It was further assumed that the roof slab could last as long as another 500 years (i.e. until year 1000) prior to collapse (i.e. same range in potential roof collapse for the other scenarios).

Likely Building 235-F Condition Summary

Table 3-16 provides a summary of likely 235-F conditions to be considered within the 235-F GoldSim fate and transport modeling.

Table 3-16 Likely Building 235-F Condition Summary

Scenario	Component	Distribution	Range
No grouting of Building 235-F	Roof collapse	Uniform	100 to 600 years
Grouting PuFF Facility within Building 235-F	Roof collapse	Uniform	100 to 600 years
	Second floor over PuFF collapse	Uniform	500 to 1000 years
Grouting the first floor of Building 235-F	Roof collapse	Uniform	100 to 600 years
	Second floor collapse	Uniform	500 to 1000 years
Grouting all of Building 235-F	Roof collapse	Uniform	500 to 1000 years

3.5.3 Infiltration versus Building 235-F Condition

Based upon the Table 3-15 infiltrations and Table 3-16 235-F condition timing, the following five infiltration/condition scenarios have been included in the 235-F GoldSim fate and transport model:

- Generic (assumed inventory simply dumped on the ground surface)
- No grouting of Building 235-F
- Grouting PuFF Facility within Building 235-F
- Grouting the first floor of Building 235-F
- Grouting all of Building 235-F

Table 3-17 provides the relationship of the 235-F condition to the associated infiltration for each infiltration/condition scenario. Figure 3-6 through Figure 3-10 provide pictorial representations of each of the scenarios. Additionally a one-off sensitivity to Scenario 2, no grouting of 235-F, will be run where the collapsed infiltration of 24.6 inches/year is replaced with 49.14 inches/year. Only Scenario 5, Grouting of the entire building will be considered for the Building 294-2F Sand Filter.

Table 3-17 Likely Building 235-F Condition Summary versus Infiltration

Scenario	Timing from Table 3-16	Infiltration Through	Infiltration Condition from Table 3-15
Generic	Not applicable (continuous)	Entire 235-F footprint	Generic background infiltration
No grouting of Building 235-F	Prior to roof collapse	Entire 235-F	Intact Building 235-F
	After roof collapse	Entire 235-F	Completely collapsed Building 235-F
Grouting PuFF Facility within Building 235-F	Prior to roof collapse	Entire 235-F	Intact Building 235-F
	After roof collapse but prior second floor over PuFF collapse	Over PuFF	Partially collapsed Building 235-F
		Rest of 235-F	Completely collapsed Building 235-F
	After roof collapse and second floor over PuFF collapse	Entire 235-F	Completely collapsed Building 235-F
Grouting the first floor of Building 235-F	Prior to roof collapse	Entire 235-F	Intact Building 235-F
	After roof collapse but prior second floor collapse	Entire 235-F	Partially collapsed Building 235-F
	After roof collapse and second floor collapse	Entire 235-F	Completely collapsed Building 235-F
Grouting all of Building 235-F	Prior to roof collapse	Entire 235-F	Intact Building 235-F
	After roof collapse	Entire 235-F	Completely collapsed Building 235-F

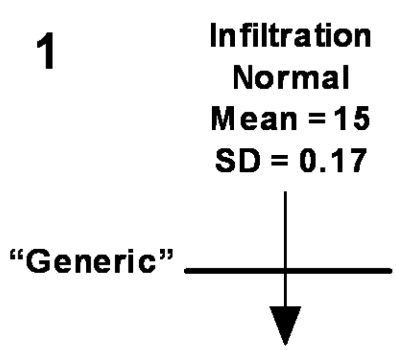


Figure 3-6 Scenario 1: Generic

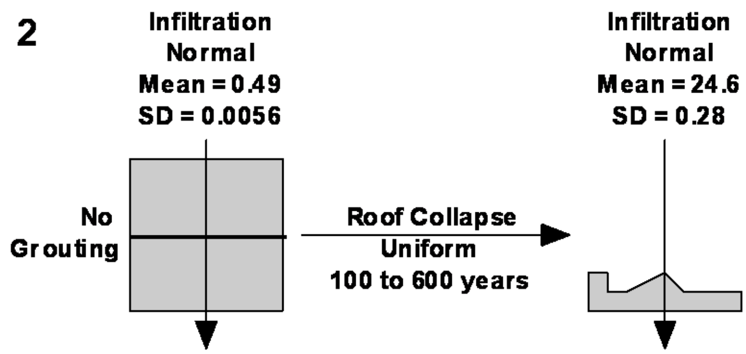


Figure 3-7 Scenario 2: No Grouting of Building 235-F

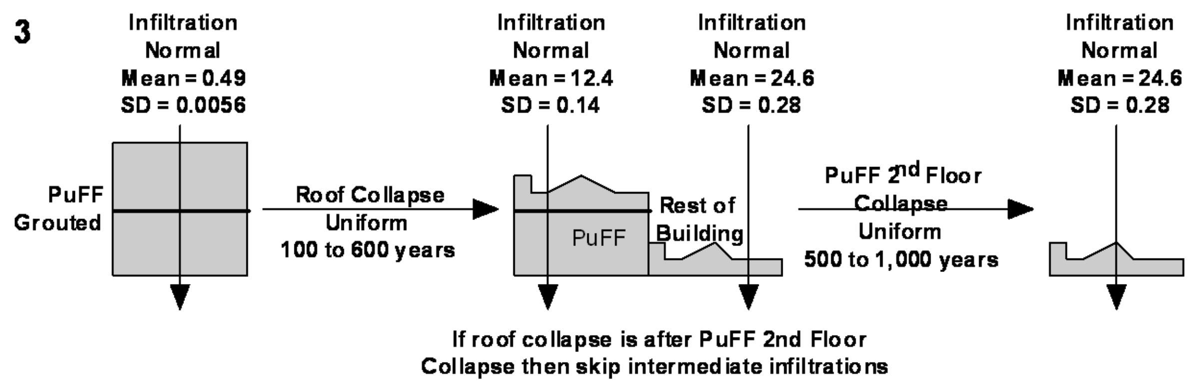


Figure 3-8 Scenario 3: Grouting PuFF Facility within Building 235-F

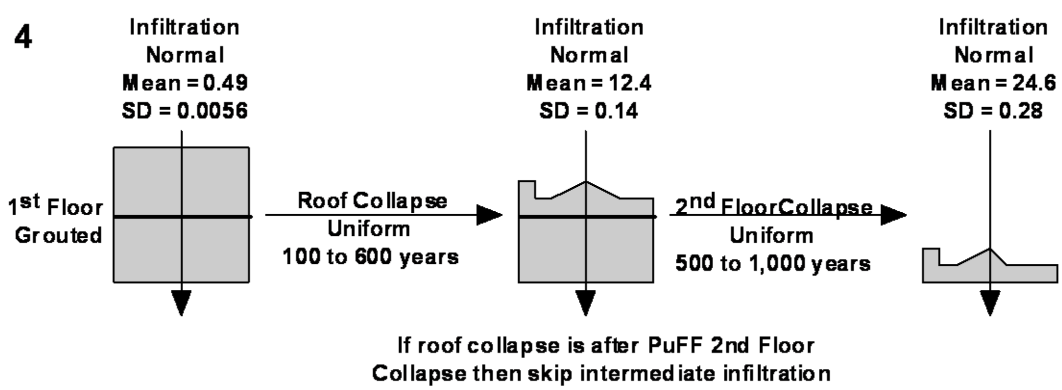


Figure 3-9 Scenario 4: Grouting the First Floor of Building 235-F

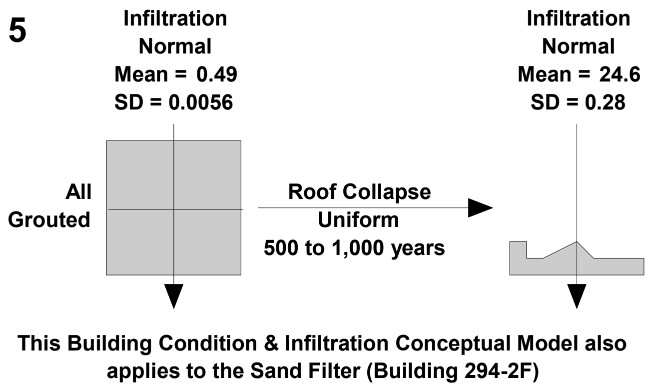


Figure 3-10 Scenario 5: Grouting All of Building 235-F

3.6 BUILDING GEOMETRY

Figure 3-11 provides the plot plan of Building 235-F and the Building 294-2F Sand Filter. The 235-F first floor plan is provided in Figure 3-12.

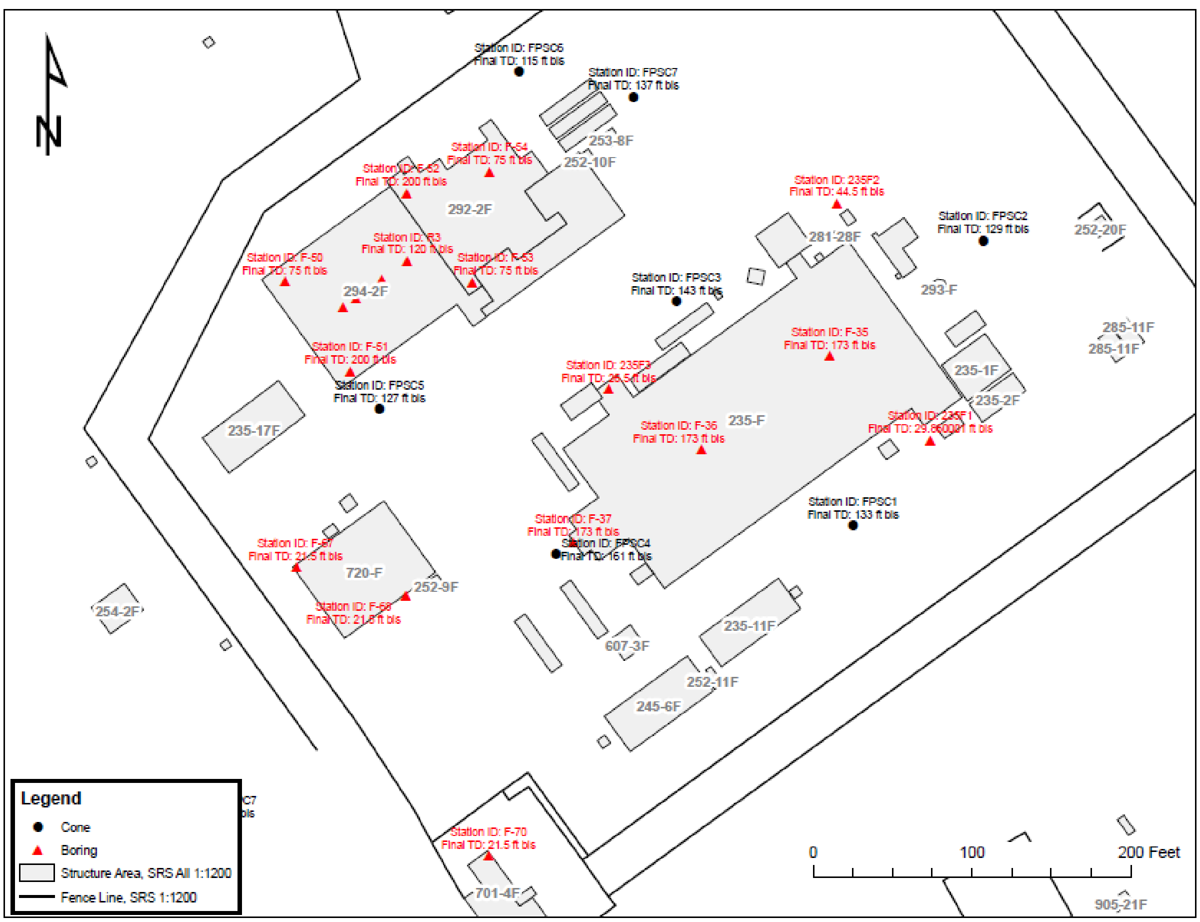


Figure 3-11 Building 235-F and Building 294-2F Sand Filter Plot Plan

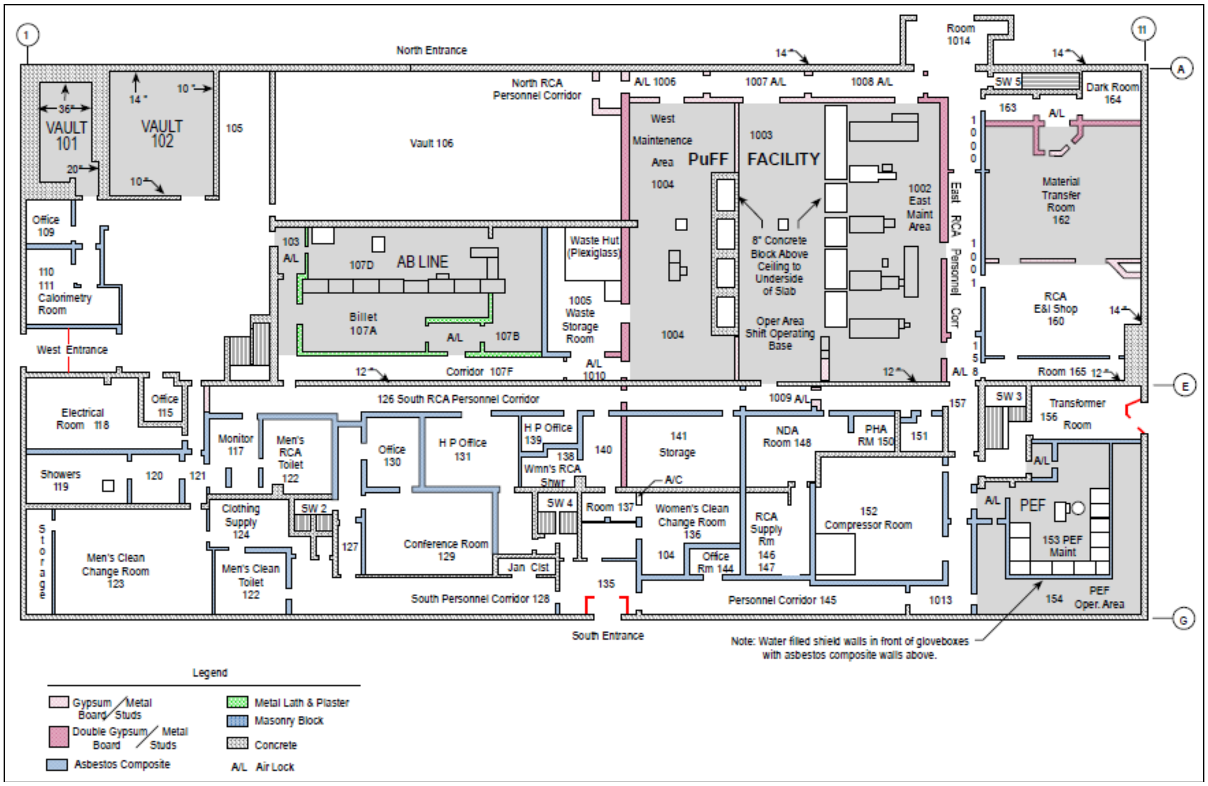


Figure 3-12 Building 235-F First Floor Plan

The following Building 235-F dimensional information will be utilized as input to the 235-F GoldSim fate and transport model (dimensions taken from Table 5.2-9 of WSRC-RP-89-575, Rev. 3 or drawings W146616, W147672, W448944, and W737960):

- The first and second floor slabs are eight inches thick.
- The roof slab is 8 inches thick.
- The thickness of grout between the top of the first floor slab and bottom of the second floor slab is 12-foot 10-inches.
- The thickness of grout between the top of the second floor slab and the bottom of the roof slab is 13-foot 4-inches.
- The entire 235-F footprint is 24,158 ft^2 (108.66' by 222.33').
- The footprint of the entire PuFF facility is 3,715 ft^2 ((30'×55') + (12'×55') + (25'×55')).
- The footprint of the PuFF Process Cells 1-5 is 1,650 ft^2 (30'×55' excluding operating area between Cells 1-5 and 6-9).
- The footprint of the PuFF Process Cells 6-9 is 1,350 ft^2. (25'×55' excluding operating area between Cells 1-5 and 6-9).
- The footprint of the Actinide Billet Line is 1,020 ft^2 (((37'×12') – (12'×6')) + ((50'×12') + (12'×4'))).
- The footprint of the rest of 235-F is 19,423 ft^2.

The following Building 294-2F Sand Filter dimensional information will be utilized as an input parameter to the 235-F GoldSim fate and transport model (dimensions taken from drawings W725656 and W726276):

- The minimum floor slab thickness is six inches.
- The sand filter bed is 8-foot 2-inches thick.
- The typical thickness of grout between the top of the sand and the underside of the roof is 9-foot 6-inches (7-foot minimum clearance to the bottom of the T-beam web plus 2-foot 6-inches to bottom of the T-beam flange).
- The minimum roof slab thickness is 1 foot.
- The footprint of 294-2F Sand Filter is 9,628 ft^2 (116' by 83').

3.7 VADOSE ZONE

For the purposes of assigning distribution coefficients (K_ds) to soils, Kaplan 2010 has divided soils into the following two categories:

- Clayey sediment is "conceptualized as a subsurface sediment containing a clay and silt content 25 to 45 wt-%, the mineralogy composed primarily of kaolinite, hydroxyl interlayered vermiculite, quartz, gibbsite, goethite, and hematite (most notable about its mineralogy is that it contains very low concentrations of 2:1 clays, such as smectites and vermiculites); organic matter concentration is low (<0.01 wt-%); pH is 5.5; and the sediment is covered with Fe-oxides, giving it a reddish color."
- Sandy sediment is "conceptualized to have identical properties as the" clayey soil "except the clay and silt content was <25 wt-%. Most of the sorption experiments from which data was considered for the look-up tables came from sandy sediments with clay and silt concentrations appreciably <25 wt-%, closer to 8 to 12%. The pH is 5.5, there is low organic matter concentrations, and the sediment tends to have a yellowish color derived from Fe-oxide coatings (most noticeably, goethite)."

Li 2004 produced a geotechnical baseline for the 235-F Expanded Storage Capacity project site, which is located just northwest of Building 235-F within the 235-F fence. Figure 3-11 provides the location of cone penetration tests and boring used by Li 2004 to produce this geotechnical baseline. Based upon Li 2004 a representation of the vadose zone beneath Building 235-F has been developed. Li 2004 divided the vadose zone into the following layers:

- <u>TR1 Layer:</u> The TR1 layer is the Upland Unit (Altamaha formation) with the dominant soil classification being clayey to silty sands (SC to SM per the Unified Soil Classification system). Of the fifteen sieve analyses available from the Upland Unit within the 235-F fence (see Li 2004 Table 3-6), eleven would be classified as clayey sediment and four as sandy sediment per the division provided by Kaplan 2010 for assignment of K_ds.
- <u>TR1A Layer:</u> The TR1A layer is part of the Tobacco Road formation with the dominant soil classification being poorly sorted sands and clayey sands (SP and SC).

Of the six sieve analyses available from the TR1A portion of the Tobacco Road formation within the 235-F fence (see Li 2004 Table 3-6), two would be classified as clayey sediment and four as sandy sediment per the division provided by Kaplan 2010 for assignment of K_ds.

- TR2A Layer: The TR2A layer is also part of the Tobacco Road formation. It is distinguished from the overlying TR1A layer by an increased cone penetrometer tip resistance and decreased friction ratio, indicating that it contains more sand than the overlying TR1A layer. This is confirmed by the available sieve analyses. Of the five sieve analyses available from the TR2A portion of the Tobacco Road formation within the 235-F fence (see Li 2004 Table 3-6), all four would be classified as sandy sediment per the division provided by Kaplan 2010 for assignment of K_ds.
- TR2B Layer: The TR2B layer is part of the Dry Branch formation and laboratory classification tests performed from an adjacent site indicate that this layer consists of sands with minor amounts of clay and silts. Thus this layer would be classified as sandy sediment per the division provided by Kaplan 2010 for assignment of K_ds. At 235-F the groundwater table is within the TR2B layer and is at an average elevation of 226 ft-msl ± 7 feet (see Li 2004 Figure 3-3).

The Tan Clay (designated layer TR3/4 by Li 2004) is located beneath the water table at 235-F under all projected water table conditions, and it consists predominantly of clays and sandy clays (probably classified as CL in both cases). The Tan Clay would be classified as clayey sediment per the division provided by Kaplan 2010 for assignment of K_ds.

Li 2004 developed an idealized stratigraphy of the 235-F Expanded Storage Capacity project site (see Li 2004 Figure 5-1). This idealized stratigraphy has been modified based upon the Li 2004 Section A-A layer thickness beneath 235-F (see page D-3 of Li 2004) in order to provide a 235-F specific vadose zone idealized stratigraphy. Figure 3-13 provides the resulting 235-F vadose zone stratigraphy. The Figure 3-13 vadose zone stratigraphy includes the average layer thickness and variation, layer identification, soil type relative to the division provided by Kaplan 2010 for assignment of K_ds, and the average elevation. The division of sediment type (i.e. sandy or clayey) for layers TR1 and TR1A are based upon the fraction of sieve analyses indicating each soil type. Layer TR2A and TR2B are assigned the sandy sediment type primarily due to the description of these layer provided by Li 2004.

Based upon Figure 13, the most likely, minimum, and maximum thicknesses of clayey and sandy sediments within the vadose zone have been developed for average, low, and high water tables as shown in Table 3-18. The average, low, and high water tables are represented by infiltrations of 14.5, 9.7, and 19.5 inches/year, respectively, based upon the General Separations Area PORFLOW groundwater flow model (WSRC 2005). A 1,000-year vadose zone thickness distribution has been developed by ratio with the 1000-year generic background infiltration of Table 3-15 (i.e. mean of 15 inches/year with a standard deviation of 0.17 inches/year) as shown in Table 3-19. Because the water table will always be in sandy sediment, the distribution of the vadose zone clayey sediment thickness is simply based upon the Table 3-18 most likely, minimum, and maximum values. It has been assumed that the minimum and maximum values represent a three standard deviation variance from the most likely value as shown in Table 3-19. The clayey and sandy sediment thicknesses are conversely related to one another. That is as the clayey layer thickness increases for a particular water table condition, the sandy layer thickness must decrease so that the two thicknesses add up to the vadose zone thickness for that water table condition. The Table 3-19 sandy sediment distribution has been developed based upon this relationship with the clayey sediment. Within the 235-F GoldSim fate and transport model, the following are selected as shown:

- the infiltration is randomly selected,
- the vadose zone thickness is selected based upon the negative of the standard deviation of the selected infiltration,
- the clayey sediment thickness is randomly selected, and
- the sandy sediment thickness = vadose zone thickness - clayey sediment thickness.

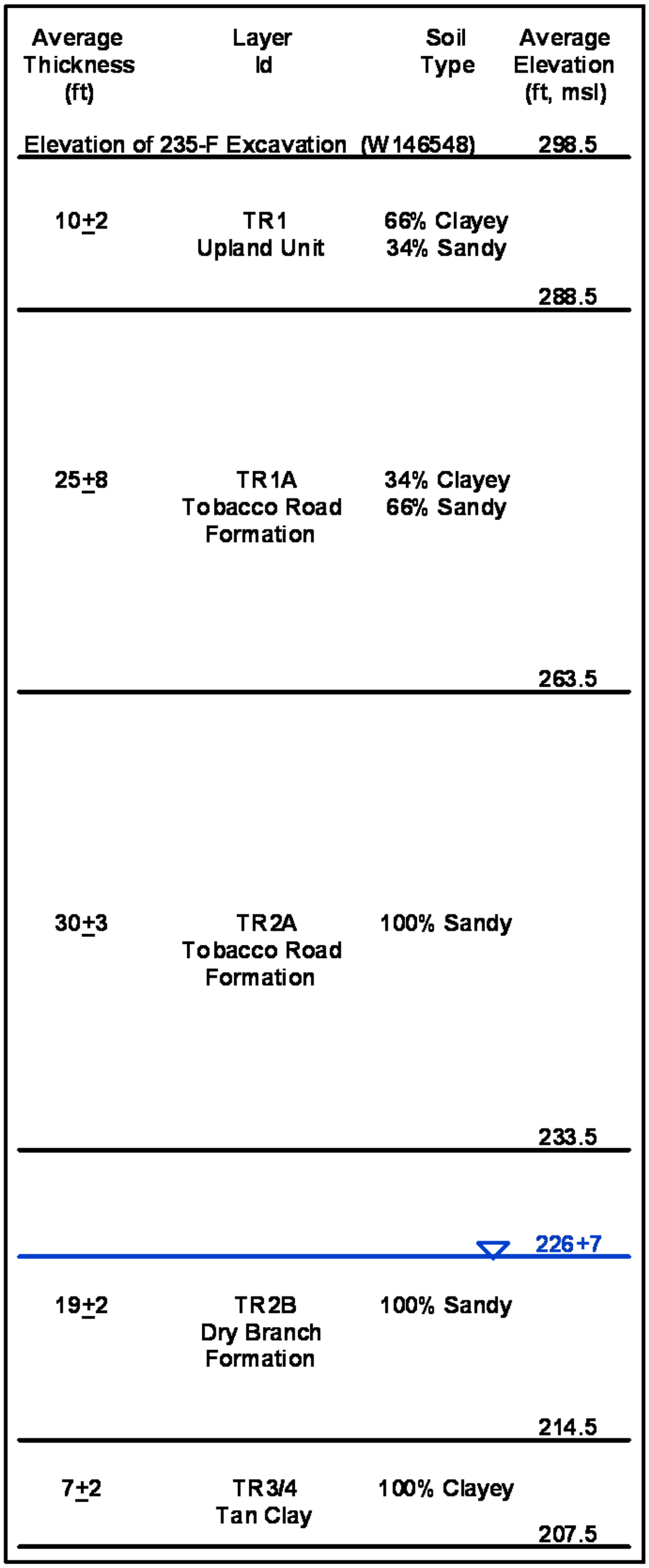


Figure 3-13 Building 235-F Vadose Zone Stratigraphy (Based upon Li 2004)

Table 3-18 Vadose Zone Sediment Thicknesses (Most Likely, Minimum, and Maximum)

Water Table Condition	GSA-Wide Infiltration (in/yr)	Vadose Zone Thickness (ft)	Clayey Sediment Thickness (ft)			Sandy Sediment Thickness (ft)		
			Most Likely	Min.	Max.	Most Likely	Min.	Max.
Average	14.5	72.5	35	25	45	37.5	27.5	47.5
Low	9.7	79.5	35	25	45	44.5	34.5	54.5
High	19.5	65.5	35	25	45	30.5	20.5	40.5

Table 3-19 1000-Year Average Vadose Zone, Clayey Sediment, and Sandy Sediment Thickness Distributions

Statistical Parameter	15 in/yr GSA-Wide Infiltration (in/yr)	Vadose Zone Thickness (ft)	Clayey Sediment Thickness (ft)	Sandy Sediment Thickness [1] (ft)
Distribution	Normal	Normal	Normal	Normal
Mean	15	72.5	35	37.5
Standard Deviation	0.17	0.23	3.33	3.56
Minimum (-3σ)	14.49	71.8	25	26.8
Maximum (+3σ)	15.51	73.2	45	48.2

Note to Table 3-19:

1 While a distribution for the sandy sediment is provided, the sandy sediment thickness within the model is calculated as the difference of the vadose zone thickness and the clayey sediment thickness.

3.8 AQUIFER

Groundwater flow and transport from 235-F to Upper Three Runs was evaluated within the SRS Composite Analysis (CA) (SRNL 2010) by Hamm et al. 2009. Figure 3-14 provides a plot plan of groundwater flow and transport within the Upper Three Runs Aquifer to its outcrop within Upper Three Runs. Hamm et al. 2009 developed the Table 3-20 aquifer flow path parameters for 235-F, which has been utilized as the basis for aquifer input data for the 235-F GoldSim fate and transport model.

1,000-year sandy sediment and clay sediment pore velocity distributions have been developed by ratio with the 1000-year generic background infiltration of Table 3-15 (i.e. mean of 15 inches/year with a standard deviation of 0.17 inches/year) as shown in Table 3-21. The nominal sandy sediment and clayey sediment flow lengths have been utilized as a constant, because the nominal length is least for sandy sediment and there is very little difference in the lengths for clayey sediment. The sandy sediment and clayey sediment travel time distributions are based upon the associated lengths and velocities.

Within the 235-F GoldSim fate and transport model the aquifer flow path parameters are selected as follows:

- The infiltration is randomly selected,
- The sand and clay travel times are selected based upon the negative of the standard deviation of the selected infiltration, and
- The sand and clay pore velocities are calculated from the sand and clay length divided by the sand and clay travel times, respectively.

The SRS CA only evaluated concentrations within site streams and therefore did not require the cross-sectional areas of the plumes within the groundwater in order to determine groundwater concentrations. Therefore the cross-sectional area of flow from the 235-F footprint for the nominal case of the GSA flow model (Flach 2004) was determined for purposes of the 235-F GoldSim fate and transport modeling. Figure 3-15 provides the 235-F building footprint. 1,000 streamlines from this footprint were projected onto the flow field of the nominal case of the GSA flow model resulting in the flow field plot plans shown in Figure 3-14 and Figure 3-16. Figure 3-16 is a close-up of the 235-F footprint showing the streamlines and the location of the 0-m boundary, which is at the downgradient edge of 235-F and perpendicular to the average flow direction. The aquifer flow path cross-section at the 0-m boundary resulting from the 1,000 streamlines from the 235-F footprint is shown in Figure 3-17. This 2325 square foot area represents the area from which groundwater concentrations of contaminants originating from 235-F are determined.

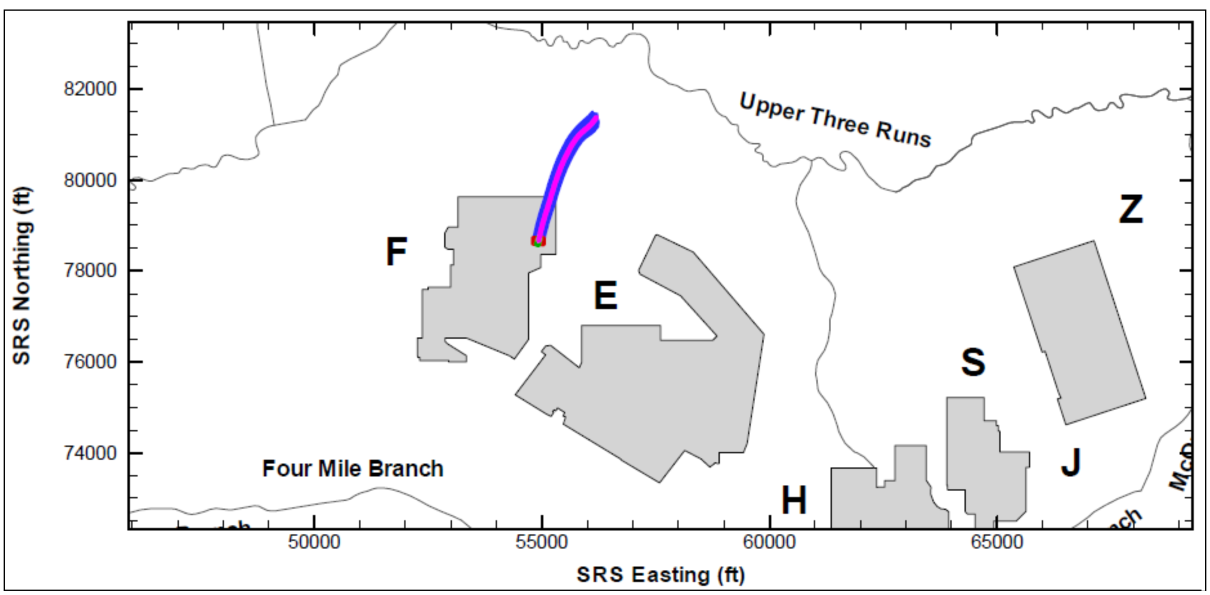


Figure 3-14 Building 235-F Groundwater Flow and Transport Plot Plan

Table 3-20 Building 235-F Aquifer Flow Path Parameters (Hamm et al. 2009)

GSA Flow Model	GSA-Wide Infiltration (in/yr)	Sand Pore Velocity (ft/yr)	Clay Pore Velocity (ft/yr)	Sand Flow Length (ft)	Clay Flow Length (ft)	Sand Travel Time (yr)	Clay Travel Time (yr)
Nominal	14.5	222.48	18.74	3119.71	17.31	14.02	0.92
Fast	19.5	516.49	26.16	3168.76	15.46	6.14	0.59
Slow	9.7	60.20	7.15	4545.31	12.82	75.51	1.79

Table 3-21 Building 235-F Aquifer Flow Path Distributions

Statistical Parameter	15 in/yr GSA-Wide Infiltration (in/yr)	Sand Pore Velocity (ft/yr)	Clay Pore Velocity (ft/yr)	Sand Length (ft)	Clay Length (ft)	Sand Travel Time (yr)	Clay Travel Time (yr)
Distribution	Normal	Normal	Normal	Constant	Constant	Normal	Normal
Mean	15	222.48	18.74	3119.71	17.31	14.02	0.92
Standard Deviation	0.17	9.66	0.24			0.54	0.01
Minimum (-3σ)	14.49	193.49	18.01			12.41	0.89
Maximum (+3σ)	15.51	251.47	19.47			15.63	0.95

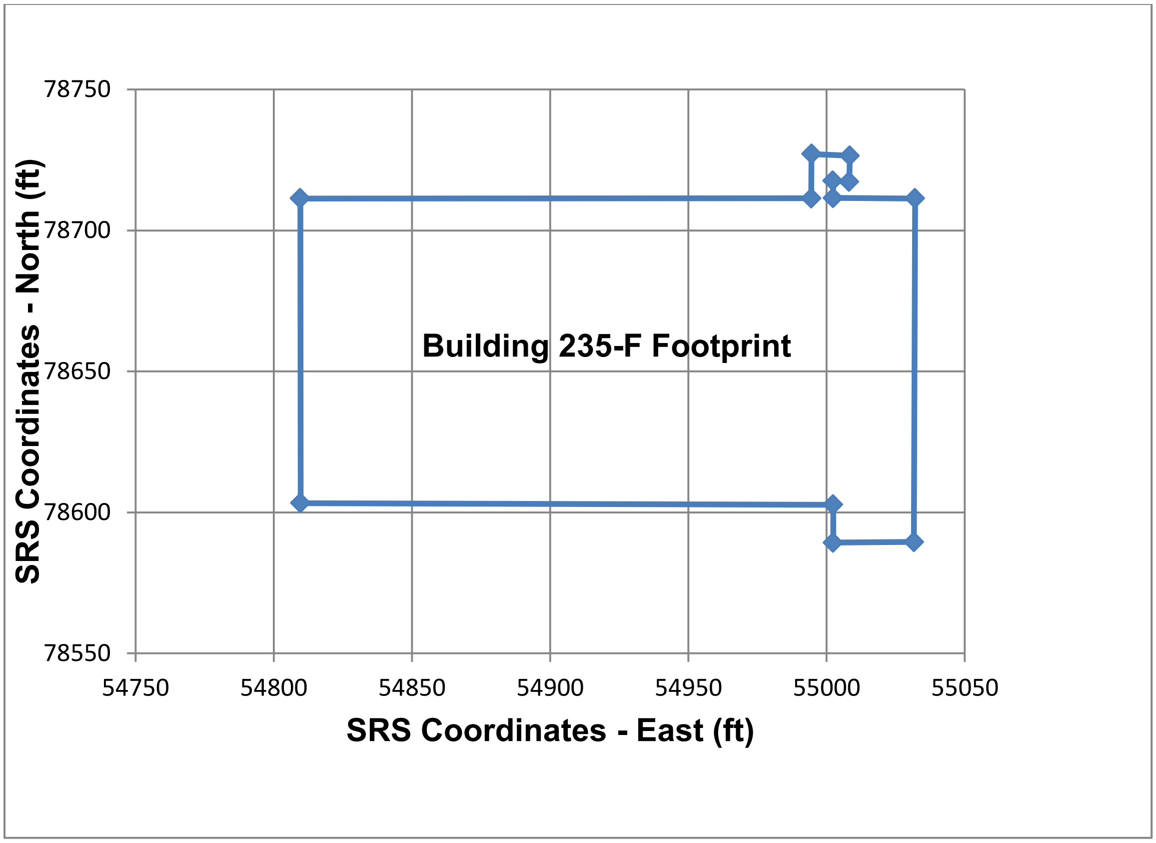


Figure 3-15 235-F Footprint

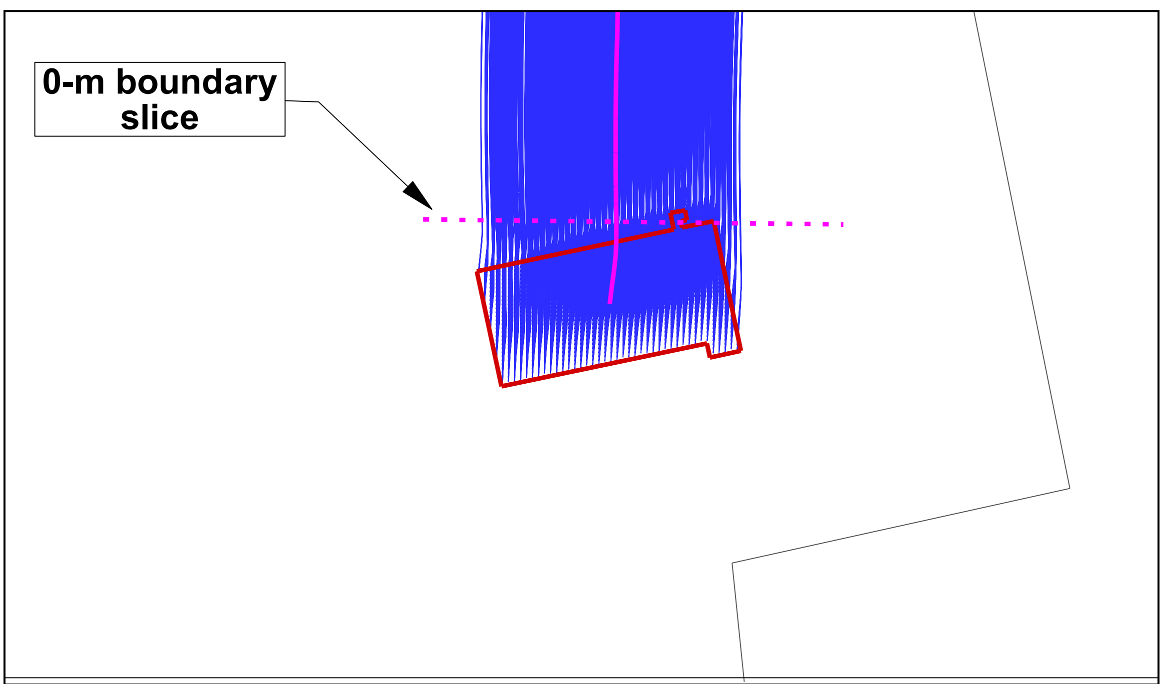


Figure 3-16 Building 235-F 0-m Boundary Location

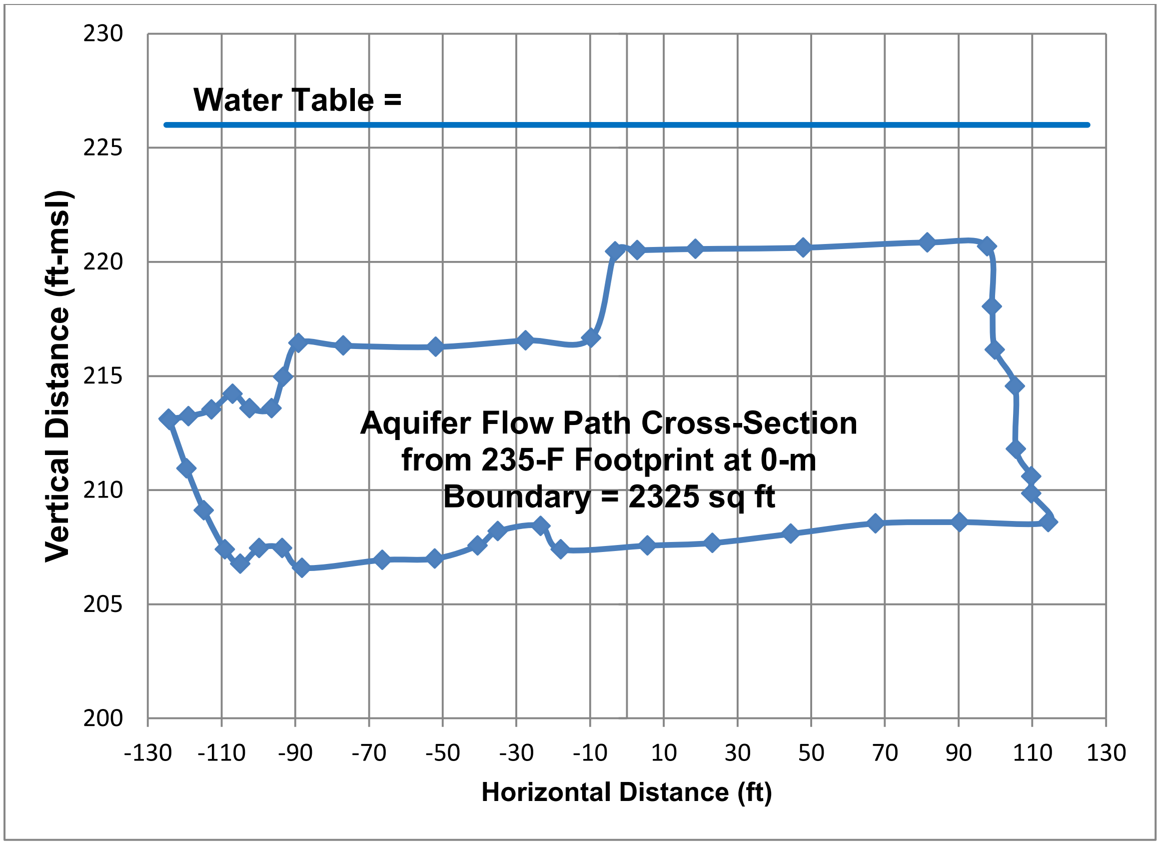


Figure 3-17 Aquifer Flow Path Cross-Section at 0-m Boundary

3.9 DISTRIBUTION COEFFICIENTS AND MATERIAL PHYSICAL PROPERTIES

The 235-F building environment, the vadose zone beneath 235-F, and the aquifer zone to the discharge point are conceptualized as consisting of oxidizing cement and sandy and clayey sediments. Distribution coefficients (Section 3.9.1) and material physical properties (Section 3.9.2) for these materials are required as input to the 235-F GoldSim fate and transport model. Additional lead properties that impact the source release from lead shielding (Section 3.9.3) are also required as input to the 235-F GoldSim fate and transport model.

3.9.1 Distribution Coefficients

Distribution coefficients (K_ds) for these materials will be assigned based primarily upon Kaplan 2010, and modified with work subsequent to Kaplan 2010 including Seaman and Kaplan 2010, Kaplan 2011, Almond et al. 2012, and Powell et al. 2010.

Kaplan 2010 has divided sediments into the following two categories for provision of K_ds:

- Clayey sediment is "conceptualized as a subsurface sediment containing a clay and silt content 25 to 45 wt-%, the mineralogy composed primarily of kaolinite, hydroxyl interlayered vermiculite, quartz, gibbsite, goethite, and hematite (most notable about its mineralogy is that it contains very low concentrations of 2:1 clays, such as smectites and vermiculites); organic matter concentration is low (<0.01 wt-%); pH is 5.5; and the sediment is covered with Fe-oxides, giving it a reddish color."

- Sandy sediment is "conceptualized to have identical properties as the" clayey soil "except the clay and silt content was <25 wt-%. Most of the sorption experiments from which data was considered for the look-up tables came from sandy sediments with clay and silt concentrations appreciably <25 wt-%, closer to 8 to 12%. The pH is 5.5, there is low organic matter concentrations, and the sediment tends to have a yellowish color derived from Fe-oxide coatings (most noticeably, goethite)."

Kaplan 2010 provides K_ds for oxidizing cementitious materials based upon the following three stages of cementitious material aging:

- The first stage is the Young Cementitious Solids Environment that is assumed to last 50 pore volume exchange cycles. "The 1st Stage occurs immediately after the cement hardens and infiltrating water passes through it. The cement porewater is characterized as having a high pH (>12), high ionic strength, and high concentrations of potassium and sodium. The high concentrations of these monovalent cations result from the dissolution of alkali impurities in the clinker phases. Hydration continues during the 1st Stage with the formation of calcium-silicate-hydrate gels (a common shorthand for this gel is C-S-H, which is a CaO-SiO_2-H_2O amorphous material that hardens and constitutes "cement") and Portlandite [$Ca(OH)_2$]. The composition of the cement pore fluid is at equilibrium with Portlandite during this time."
- The second stage is the Moderately-aged Cementitious Solids Environment that is assumed to last 500 pore volume exchange cycles due to the slow dissolving characteristic of the low-carbonate SRS groundwater when in contact with cementitious solids. During the 2nd Stage, "the soluble salts of the alkali metals are all dissolved and washed out of the cement solids. The pH of the cement pore water is controlled at a value of ~12 by the solubility of portlandite. The calcium-silicate-hydrate gel and portlandite are the major solid phases present." … "The total dissolved calcium is 20 mM, the pH is strongly buffered at pH ~12, and the silica concentration is very low, <0.03 mM/L. The flux of water must dissolve all the slightly soluble portlandite before the leachate chemistry changes."
- The third stage is the Aged Cementitious Solids Environment that is assumed to last 7000 pore volume exchange cycles, because the SRS groundwater is low in carbonate concentrations. "In the 3rd Stage, the portlandite has been fully dissolved/reacted and the solubility or reactions of calcium-silicate-hydrate gel with the infiltrating water controls the pH of the cement porewater/leachate." … "The ionic strength of the cement leachate during this period is relatively low and its pH drops to ~10 and lower over long times. Solution calcium concentrations decrease to 1- to 5-mM and silica concentrations increases to 2- to 6-mM."

Kaplan 2010 also provides cementitious leachate-impacted sediment correction factors for sediment within the vadose zone beneath concrete structures such as 235-F. The cementitious leachate-impacted sediment environment is defined as clayey or sandy sediment between a cementitious waste form or structure and the aquifer. A "1-m high cementitious slab would be expected to alter the buffering capacity all the way down to the water table during the early stages of concrete aging (1st Stage). The altered chemistry would remain during the first two stages of concrete aging (1st and 2nd Stages). Once this high pH front reached the aquifer it would be rapidly diluted and likely have negligible influence on subsequent radionuclide sorption. This environment will have a nominal pH of 10.5 and an elevated ionic strength >10 mM dominated by hydroxide and Ca^{+2} ions."

Kaplan 2010 also provides K_ds for reducing cementitious materials, however this is not applicable to 235-F, because blast furnace slag was not used in the 235-F concrete and it is not anticipated that reducing grout will be utilized in the deactivation and decommissioning (D&D) of 235-F. Correction factors are also provided for the presence of cellulose degradation products (CDP). Due to the 235-F massive concrete construction and the planned In-Situ Disposal (ISD) end state, which may involve grouting all or portions of 235-F, very little cellulose will be associated with the building's end state, therefore the CDP correction factor is not applicable.

The following modifications to the recommended K_ds provided in Kaplan 2010 have been made based upon subsequent work:

- Seaman and Kaplan 2010 provided site-specific K_ds for thallium and uranium in cementitious materials and Savannah River Site (SRS) sediments based upon laboratory testing that was not previously available within Kaplan 2010. This resulted in somewhat higher recommended thallium and uranium K_ds.
- Kaplan 2011 further evaluated neptunium K_d values as a function of pH, and concluded that a greater cementitious leachate-impacted sediment correction factor was applicable to neptunium and protactinium than previously published in Kaplan 2010.
- Almond et al. 2012 conducted a critical literature review and statistical analysis of SRS sediment plutonium K_d values that was not previously available within Kaplan 2010. This resulted in a slightly higher recommended K_d value for plutonium in sandy sediment.
- Powell et al. 2010 and Kaplan 2011 provided site-specific K_ds for radium in SRS sediments based upon laboratory testing that was not previously available within Kaplan 2010. This resulted in a slightly higher recommended K_d values for radium in SRS sediment.

Table 3-22 and Table 3-23 provide the K_ds within cementitious materials and sediment, respectively, for the elements pertinent to the 235-F fate and transport modeling based upon Kaplan 2010, Seaman and Kaplan 2010, Kaplan 2011, Almond et al. 2012, and Powell et al. 2010. Table 3-23 also provides the apparent solubilities of each of the elements in an oxidizing cementitious material environment. This is provided in case solubility limits are associated with the release of radionuclides in the 235-F environment.

The following provides information on the applicability of the K_ds provided within Table 3-22 and Table 3-23 (appropriate references associated with the values are provided within the tables):

- The Table 3-22 K_ds apply to Building 235-F itself as follows:
  - The best young oxidizing cement K_ds apply for the first 50 pore volume exchange cycles through the 235-F concrete and grout.
  - The best middle oxidizing cement K_ds apply for the next 500 pore volume exchange cycles through the 235-F concrete and grout.
  - The best old oxidizing cement K_ds apply for the next 7000 pore volume exchange cycles through the 235-F concrete and grout.
- At the end of 7550 pore volume exchange cycles through the 235-F concrete and grout, the completely degraded 235-F concrete and grout is then assigned the best sand K_ds of Table 3-23. Also at the end of 7550 pore volumes the completely degraded 235-F concrete is assigned sandy sediment properties per Table 3-28 rather than the previously assigned intact concrete properties of Table 3-27; whereas the grout maintains constant physical properties throughout time as provided in Table 3-27.
- The Table 3-23 K_ds apply to the vadose zone beneath 235-F, based upon the sediment characteristics of the vadose zone as follows:
  - The best sand CemLech K_ds and best clay CemLech K_ds apply to the vadose zone for the first 550 pore volume exchange cycles through the 235-F concrete and grout.
  - Thereafter the best sand and clay K_ds apply to the vadose zone.
- The Table 3-23 best sand K_ds and best clay K_ds apply to the aquifer zone, based upon the sediment characteristics of the aquifer zone.

Based upon the measurement of K_d variability within sediment, Kaplan 2010 determined that K_d distributions should be considered log-normal with the following 95% confidence levels. Almond et al. 2012 confirmed previous assumptions that K_d distributions within cementitious environments should be the same as that of sandy sediment environments.

- Sandy Sediment Environments and Cementitious Environments
  - Standard deviation = $0.375 \times K_d$
  - "Min" = $0.25 \times K_d$
  - "Max" = $1.75 \times K_d$
- Clayey Sediment Environments
  - Standard deviation = $0.25 \times K_d$
  - "Min" = $0.5 \times K_d$
  - "Max" = $1.5 \times K_d$

As indicated above Almond et al. 2012 conducted a critical literature review and statistical analysis of SRS sediment plutonium K_d values that was not previously available within Kaplan 2010. This analysis resulted in a revision to the recommended K_d distribution for plutonium in SRS sediment. Table 3-24 provides the recommended input for the Weibull distribution for the Pu K_d values. The Weibull distribution input for the CemLech conditions is based upon applying the cement leachate impact factor for plutonium (i.e. 2) to the minimum and mean-miniumum for the best sand K_d and best clay K_d, respectively, and leaving the Weibull slope the same.

The distributions provided by Kaplan 2010 and confirmed by Almond et al. 2012 shown above will be used for the sediment K_ds for all elements except plutonium. The Table 3-24 distribution will be used for the plutonium sediment K_ds.

As outlined in Section 3.2.3, a coating/paint used on the interior of 235-F, Amercoat 33, contained PCBs. The fate and transport modeling of the 235-F PCBs has been performed identical to that performed by Council 2009 for the R-Area Reactor Building as follows:

- A single polychlorinated biphenyl (PCB) constituent is used to represent all PCB congeners.
- Degradation of PCBs is not considered.
- For PCBs, the best-estimate value of K_d (927 L/kg) in natural sediments (A/AA Horizon and TZ) was calculated as the organic-carbon partition coefficient (K_{oc} = 309,000 L/kg) times the site specific organic carbon fraction (foc = 0.003). The conservative K_d values were assumed to be one third of this best estimate (Table 3-25). Sorption of PCBs is assumed to be negligible in concrete and grout due to minimal organic carbon presence.
- The best-estimate and conservative K_d values are used to define normally distributed stochastic model inputs. For each modeled element and environment, the mean (and default) K_d is the best estimate K_d and the standard deviation is the difference between the best-estimate and conservative K_d values. This means that the best-estimate K_d is the median value in the distribution and approximately 84% of the distribution is above the conservative value. If, during Monte Carlo simulations, the sampled K_d value is less than zero, it is reset to zero.
- PCB source release from the coating/paint will not be considered in the model due to the lack of applicable source release information (i.e. degradation of the coating/paint, diffusion of PCBs out of the paint, and/or solubility constraints).

Table 3-22 235-F Oxidizing Cementitious Material Kd Values (Kaplan 2010)

Element	**Best Young Oxidizing Cement K_d** (mL/g)	**Best Middle Oxidizing Cement K_d** (mL/g)	**Best Old Oxidizing Cement K_d** (mL/g)	**Young Oxidizing Cement Apparent Solubility** (10E-x)	**Middle Oxidizing Cement Apparent Solubility** (10E-x)	**Old Oxidizing Cement Apparent Solubility** (10E-x)
Ac	6000	6000	600	-11	-8	-7
Am	6000	6000	600	-11	-8	-7
At	8	15	4	NA	NA	NA
Bi	6000	6000	600	-11	-8	-7
Fr	2	20	10	NA	NA	NA
Np	10000	10000	5000	-13	-13	-7
Pa	10000	10000	5000	-13	-13	-7
Pb	300	300	100	-7	-7	-6
Po	300	300	100	-7	-7	-6
Pu (combo)	10000	10000	2000	-12	-12	-7
Ra	100	100	70	-6	-6	-6
Rn	0	0	0	NA	NA	NA
Th	10000	10000	2000	-12	-12	-7
Tl [1]	150	150	150	NA	NA	NA
U [1]	1000	1000	100	5.00E-06	5.00E-05	-6

Note to Table 3-22:

[1] Seaman and Kaplan 2010

Table 3-23 235-F Sediment Kd Values

Element	Best Sand K_d (mL/g)	Best Clay K_d (mL/g)	Best Sand CemLech K_d (mL/g)	Best Clay CemLech K_d (mL/g)	Reference
Ac	1100	8500	1650	12750	Kaplan 2010
Am	1100	8500	1650	12750	Kaplan 2010
At	0.3	0.9	0	0.1	Kaplan 2010
Bi	1100	8500	1650	12750	Kaplan 2010
Fr	10	50	10	50	Kaplan 2010
Np	3	9	60	180	Kaplan 2010 for sediment itself & Kaplan 2011 for CemLech
Pa	3	9	60	180	Kaplan 2010 for sediment itself & Kaplan 2011 for CemLech
Pb	2000	5000	6400	16000	Kaplan 2010
Po	2000	5000	4000	10000	Kaplan 2010
Pu (combo)	650	5950	1300	11900	Kaplan 2010 for clay sediment & Almond et al. 2012 for sand sediment
Ra	25	185	75	555	Powell et al. 2010 & Kaplan 2011
Rn	0	0	0	0	Kaplan 2010
Th	900	2000	1800	4000	Kaplan 2010
Tl	25	70	25	70	Seaman and Kaplan 2010
U	300	400	900	1200	Seaman and Kaplan 2010

Table 3-24 Recommended Pu Kd Distributions (Almond et al. 2012)

Distribution	Minimum (mL/g)	Weibull Slope	Mean-Minimum (mL/g)
Best Sand Kd	100	0.56	650
Best Clay Kd	100	0.56	5950
Best Sand CemLech Kd	200	0.56	1300
Best Clay CemLech Kd	200	0.56	11900

Table 3-25 PCB Sorption Coefficients (Council 2009)

Sand		Clay		Concrete Stage 1		Concrete Stage 2		Concrete Stage 3	
Best Est.	Con.	Best Est.	Con.	Best Est.	Con.	Best Est.	Con.	Best Est.	Con.
927	309	927	309	0	0	0	0	0	0

3.9.2 Material Physical Properties

235-F GoldSim fate and transport modeling requires the nominal value and distribution of the following porous media properties for cementitious materials and sediments:

- Porosity,
- Dry bulk density,
- Particle density,
- Saturation, and
- Tortuosity.

Drawing W146263 shows that the 235-F concrete was to develop a minimum 2,500 psi compressive strength in 28 days and references DuPont Specification 3019 Section BA. Drawing W448313 shows that the 235-F concrete was to be Class C per concrete specification SB6U. Concrete specification SB6U provides a minimum Portland cement content for footings, walls, slabs, beams, and columns ranging from 520 to 610 pounds per cubic yard. This cement content is consistent with concrete formulations that develop compressive strengths from 3,000 to 4,000 psi. Specification SB6U does not address the use of cementitious materials other than cement such as fly ash, blast furnace slag, or silica fume; therefore it is assumed that the 235-F concrete is ordinary concrete with a compressive strength around 3,000 psi (i.e. it is oxidizing concrete and does not contain fly ash, blast furnace slag, or silica fume, which tend to improve the concrete properties). Based upon this assumption, the 235-F concrete properties will be represented by non-reducing, low-quality concrete as outlined in Phifer et al. 2006 (i.e. E-Area CIG Concrete Mats).

It is assumed that the dry area placement zero bleed flowable fill (i.e. grout) that was utilized in the deactivation and decommissioning of the R-Area and P-Area reactor buildings would also be utilized in the D&D of Building 235-F (SRNS 2009), if the building is grouted up. Table 3-26 provides the formulation for two of these grouts (PR-ZB-FF and PR-ZB-FF-8) along with the formulation for a similar material (Controlled Low Strength Material (CLSM) mix EXE-X-P-O-X) for which material properties have previously been determined (Dixon and Phifer 2006; Phifer et al. 2006). The grouts and CLSM have a similar content of cementitious materials (i.e. 650 lbs/yd^3 of cement and fly ash combined) and water (i.e. 53 to 66 gal/yd^3). The grouts should have improved concrete properties over that of the CLSM, due to the higher cement content and lower water content. Therefore the previously determined properties of the CLSM will be conservatively used to represent the grout.

Table 3-27 provides the porosity, dry bulk density, particle density, saturation, and tortuosity nominal value and distributions for the 235-F concrete and grout to be used in D&D of 235-F. This data has been extracted from Phifer et al. 2006, Dixon and Phifer 2006; Phifer and Dixon 2009, and Sappington and Phifer 2005 as outlined in the notes to the table. As outlined in Section 3.9.1 at the end of 7550 pore volumes the completely degraded 235-F concrete is assigned sandy sediment properties per Table 3-28 rather than the previously assigned intact concrete properties of Table 3-27; whereas the grout maintains constant physical properties throughout time as provided in Table 3-27.

Building 235-F sediments are divided into the following four categories consistent with the treatment of distribution coefficients (K_ds) and the presence of both vadose and saturated zones:

- Vadose Zone Sandy Sediments,
- Vadose Zone Clayey Sediment,
- Saturated Sandy Sediments, and
- Saturated Clayey Sediments.

Estimates of porosity, dry bulk density, particle density, saturation, and tortuosity nominal values and distributions were developed for these four categories of sediment within Phifer and Dixon 2009. This data, which is provided in Table 3-28 , will be utilized for the 235-F sediments.

Table 3-26 Potential Building 235-F Grout Formulations

Mix	Cement (lbs/yd^3)	Fly Ash (lbs/yd^3)	Water (gal/yd^3)	Sand (lbs/yd^3)	Aggregate (lbs/yd^3)
PR-ZB-FF	150	500	63	2,318	0
PR-ZB-FF-8	150	500	53	1,799	800
EXE-X-P-O-X	50	600	66	2,515	0

Table 3-27 Building 235-F Concrete and Flowable Fill Properties

			Distribution Type	Argument 1	Argument 2	Argument 3	Argument 4
			Constant data	Value			
			Truncated normal	Mean	Standard Deviation	Minimum (-3σ)	Maximum ($+3\sigma$)
Material	Property	Units	Triangular	Minimum	Most Likely	Maximum	
235-F Intact Concrete	Porosity		Truncated normal	0.221	0.013	0.172	0.250
	Dry Bulk Density	g/cm3	Truncated normal	2.060	0.100	1.760	2.360
	Particle Density	g/cm3	Truncated normal	2.610	0.150	2.160	3.060
	Not Grouted up Saturation		Triangular	0.51	0.74	0.94	NA
	Grouted up Saturation		Constant data	1.000	NA	NA	NA
	Tortuosity		Triangular	0.011	0.050	0.217	
235-F Grout	Porosity		Truncated normal	0.328	0.009	0.301	0.355
	Dry Bulk Density	g/cm3	Truncated normal	1.78	0.029	1.69	1.87
	Particle Density	g/cm3	Truncated normal	2.65	0.010	2.62	2.68
	Saturation		Triangular	0.843	0.858	0.873	
	Tortuosity		Triangular	0.17	0.25	0.36	NA

Notes to Table 3-27:

- 235-F intact concrete mean porosity, dry bulk density, particle density, and tortuosity were taken from Phifer and Dixon 2009 Table 1.
- Under conditions where the interior of 235-F is not grouted up it is assumed that the concrete saturation would be that of concrete exposed to the atmosphere. The range of saturation of concrete exposed to the atmosphere has been estimated from data produced by Sappington and Phifer 2005.
- Under conditions where the interior of 235-F is grouted up it is assumed that the concrete would be saturated similar to conditions underground (Phifer and Dixon 2009).
- 235-F Flowable Fill mean porosity, dry bulk density, and particle density were taken from Phifer et al. 2006 Table 6-47 as that of E-Area CLSM. The standard deviation, minimum, and maximum values of porosity (Table 6-52), dry bulk density (Table 6-53), and particle density (Table 6-54) were also taken as that of E-Area CLSM from Phifer et al. 2006. This data was derived from testing conducted by Dixon and Phifer 2006.
- 235-F Flowable Fill hydraulic properties are more similar those of clayey sediments than other cementitious materials; therefore the Flowable Fill saturation will be taken as that of clayey soil from Phifer and Dixon 2009 Table 1.
- 235-F Flowable Fill tortuosity distribution was calculated from the effective diffusion coefficient (D_e) distribution for E-Area CLSM presented in Phifer et al. 2006 Table 6-59 (minimum, most likely, and maximum) per the following equation $\tau = D_e/D_m$, where D_m = molecular diffusion coefficient in water taken as 1.6e-05 cm/s (Phifer et al. 2006 Section 5.2.5).
- NA = not applicable

Table 3-28 Building 235-F Sediment Properties

Material	Property	Units	Distribution Type	Argument 1	Argument 2	Argument 3	Argument 4
			Constant data	Value			
			Truncated normal	Mean	Standard Deviation	Minimum (-3σ)	Maximum (+3σ)
			Triangular	Minimum	Most Likely	Maximum	
Vadose Zone Sandy Sediment	Porosity		Truncated normal	0.380	0.008	0.360	0.400
	Dry Bulk Density	g/cm^3	Truncated normal	1.650	0.022	1.590	1.710
	Particle Density	g/cm^3	Truncated normal	2.660	0.006	2.640	2.680
	Background Saturation (15 in/yr infiltration)		Triangular	0.662	0.683	0.705	NA
	Tortuosity		Triangular	0.227	0.500	1.000	NA
Vadose Zone Clayey Sediment	Porosity		Truncated normal	0.370	0.011	0.340	0.400
	Dry Bulk Density	g/cm^3	Truncated normal	1.680	0.028	1.600	1.760
	Particle Density	g/cm^3	Truncated normal	2.670	0.010	2.640	2.700
	Background Saturation (15 in/yr infiltration)		Triangular	0.843	0.858	0.873	NA
	Tortuosity		Triangular	0.202	0.331	0.557	NA
Saturated Sand	Porosity		Truncated normal	0.250	0.009	0.225	0.276
	Dry Bulk Density	g/cm3	Truncated normal	1.040	0.024	0.968	1.112
	Particle Density	g/cm3	Truncated normal	1.390	0.006	1.373	1.407
	Saturation		Constant data	1.000	NA	NA	NA
	Tortuosity		Triangular	0.202	0.331	0.557	NA
Saturated Clay	Porosity		Truncated normal	0.250	0.009	0.225	0.276
	Dry Bulk Density	g/cm^3	Truncated normal	1.040	0.024	0.968	1.112
	Particle Density	g/cm^3	Truncated normal	1.390	0.006	1.373	1.407
	Saturation		Constant data	1.000	NA	NA	NA
	Tortuosity		Triangular	0.176	0.250	0.368	NA

Notes to Table 3-28:

- Data obtained from Phifer and Dixon 2009 Table 1.
- NA = not applicable

3.9.3 Lead Sheet Corrosion Source Release

As outlined in Section 3.2.2, lead shielding was utilized throughout 235-F on cells, gloveboxes and cabinets. Source release of the 235-F lead has been performed identical to that performed by Council 2009 for the R-Area Reactor Building as follows:

- "Based on the range of lead corrosion measurements in soil and water environments as reported in the ASM International Handbook on material corrosion (Alhassan, 2005), the median (and deterministic) lead corrosion rate used in the model is 5 μm/yr. A log-normal distribution is used with a geometric standard deviation of 3.2. This allows for an order of magnitude variation in either direction (within the 5th and 95^{th} percentile) which is appropriate given the large degree of uncertainty associated with this corrosion rate."
- "The fractional mass degradation rate, in units of 1/time, is calculated for each object shape in GoldSim by multiplying the lead corrosion rate (5 μm/yr (1.9685×10^{-4} in/yr) deterministic/median value) by (initial) surface area and dividing by (initial) volume."
- "It is worth noting that low-solubility and/or insoluble lead salts are likely to form from corrosion, which would (a) decrease lead mobility, and (b) probably limit the corrosive attack by development of a protective film. These mechanisms are not accounted for in the model."

Subsequent to lead source release, lead transport is modeled utilizing the lead K_ds provided in Table 3-22 and Table 3-23 as appropriate.

3.10 UPPER THREE RUNS

As outlined by Hamm et al. 2009 groundwater transport from 235-F discharges to Upper Three Runs (UTR). As shown in Figure 3-18 (from Wike et al. 2006), UTR is gauged near Highway 278 (Station 02197300; Station 01 in Figure 3-18), at SRS Road C above the confluence with Tims Branch (Station 02197310; Station 02 in Figure 3-18), and at SRS Road A about three miles above the confluence of Upper Three Runs Creek with the Savannah River (Station 02197315; Station 03 in Figure 3-18). The closest UTR gaging station downgradient of the discharge of groundwater from 235-F to UTR is Station 02 (see Figure 3-18). Jones 2009 provided an average annual flow rate of 209 cfs at UTR Station 02 based upon data from 1975 to 2001. Shine 2009 determined the distribution of the 1,000-year mean flow rate at UTR Station 03 based upon data from 1975 to 2001. Shine determined that the 1,000-year mean flow rate distribution was normal with a mean of 236 cfs and a standard deviation of 1.35 cfs. The standard deviation of the of the 1,000-year mean flow rate at UTR Station 02 has been estimated for use within the 235-F GoldSim fate and transport model by proportion ($(209/236) \times 1.35 = 1.20$). For UTR Station 02 this results in a normal distribution with a mean flow rate of 209 cfs and a standard deviation of 1.20 cfs for use within the 235-F GoldSim fate and transport model. Table 3-29 provides this information in tabular format.

UTR Gauging Stations:
- 01) near New Ellenton (Hwy 278)
- 02) above Road C at SRS
- 03) at Road A at SRS

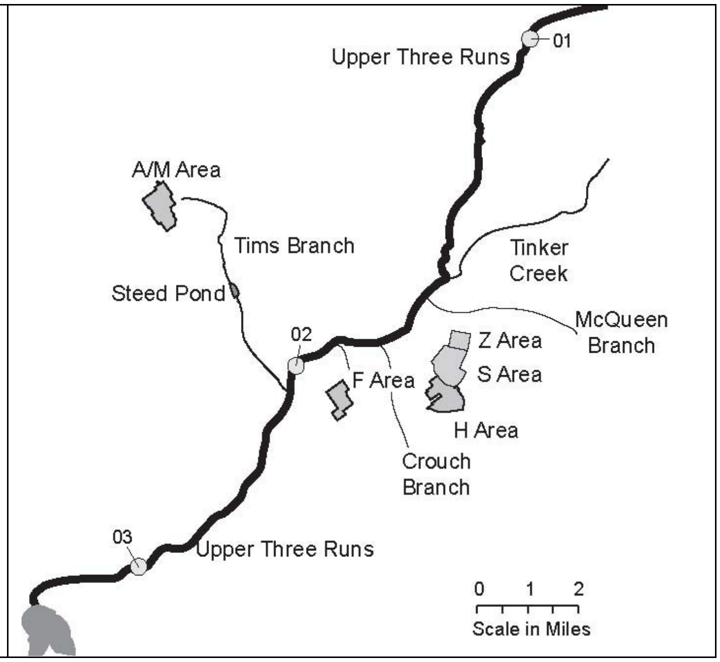


Figure 3-18 UTR Gauging Stations (Wike et al. 2006)

Table 3-29 UTR Station 02 Flow Summary

Condition	Distribution Type	Mean (cfs)	Standard Deviation (cfs)
UTR Station 02 Flow	normal	209	1.20

4.0 235-F GOLDSIM FATE AND TRANSPORT MODEL

This section describes the fate and transport model used to support in-situ closure of the 235-F Facility and/or reduction of radioisotope inventory of the facility. The model simulates contaminant release from four process areas (PuFF cells 1-5, PuFF cells 6-9, ABL, and the rest of the building (RoB)) and the 239-F sand filter. In addition, it simulates the contaminant release as though all the contaminants were dumped on the surface on the ground. It simulates the fate and transport through the vadose zone and the aquifer zone to the surface stream. See Figure 4-1 for the overall conceptual structure of the model. The model is designed as a stochastic[4] model, and as such it can provide both deterministic and stochastic (probabilistic) results. In addition to radioisotopes the model provides the ability to assess the fate and transport of elemental lead (Pb), which is present as shielding, and PCBs.

The model was developed within the GoldSim programming environment. GoldSim provides the ability to run both deterministic runs, a single realization at specific conditions, and stochastic runs, which consists of a sufficient number of realizations to provide meaningful statistics with input parameters being varied by specified probability distributions. The results of a stochastic run, consisting of multiple realizations, can be used in a sensitivity analysis which can be used to determine to which parameters the model is most sensitive, and, if the model is a reasonable representation of the real world, where the biggest changes can be implemented.

This section provides a detailed description of the 235-F fate and transport model. A general overview will be given, then, each component of the model will be examined. GoldSim model elements will be indicated by *italics*.

[4] "Stochastic is synonymous with "random." The word is of Greek origin and means "pertaining to chance" (Parzen 1962, p. 7). It is used to indicate that a particular subject is seen from point of view of randomness. Stochastic is often used as counterpart of the word "deterministic," which means that random phenomena are not involved. Therefore, stochastic models are based on random trials, while deterministic models always produce the same output for a given starting condition." From http://mathworld.wolfram.com/Stochastic.html

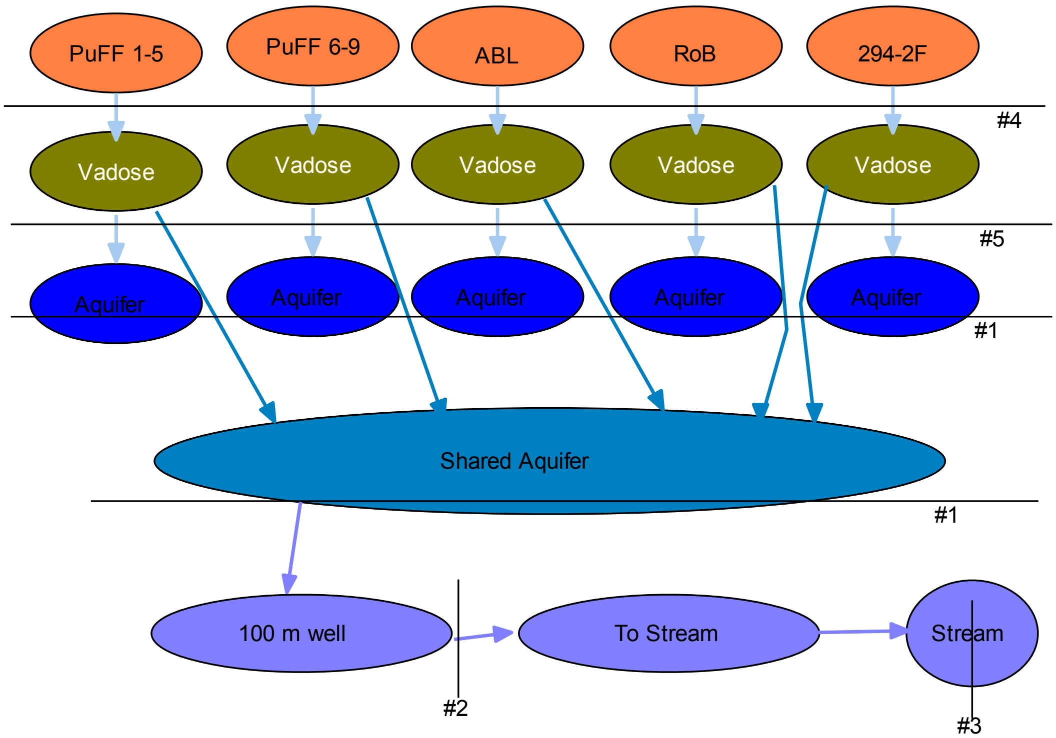


Figure 4-1 Conceptual Model[5]

4.1 MODEL DESIGN

This model's design is based on lessons learned from previous modeling efforts. It is intended to be as efficient and as fast running as possible. Its design is fairly streamlined except for one instance. GoldSim does not have the ability to handle *n*-dimensional arrays. As such, rather than having concise looping the model is forced into an object oriented programming approach where objects are specified numerous times. While this makes the model both somewhat slower and certainly larger, it adds to its clarity so the tradeoff is worthwhile.

In the *Sources* container (Figure 4-2), each source is treated as a *SubSystem*. Each source draws its data from containers outside of it but otherwise is not coupled to the other subsystems. When originally coded, the sources were modeled as closed containers. While this permitted the model to run, it took the model about 2 minutes to initialize which was thought to be rather long when a single realization takes about 20 seconds. By using the *SubSystem* construct the model now initializes in about 15 seconds. Note that a *SubSystem* is a specialized *Container*. One might notice in Figure 4-2 that each container has a small box with a "+" inside and that some of the containers are opened and some are closed. Closed containers are quite useful in that they can "see" outside, but nothing can "see" in unless it is allowed to. *SubSystem* is treated as a closed *Container*. In this manner, the five source subsystems, *PuFF1_5, PuFF6_9, ABL, RoB*, and *SandFilter* are essentially copies of each other, i.e., they contain many of the same element names. In this manner one may construct

[5] Numbers (#) denote assessment points

a model in which the structure of similar elements is consistent. If one were to reference element A from the *SubSystem PuFF1_6* in container *PbLeaching*, it would be referenced as *PuFF1_6.A* to distinguish it from *PuFF6_9.A* or *ABL.A*

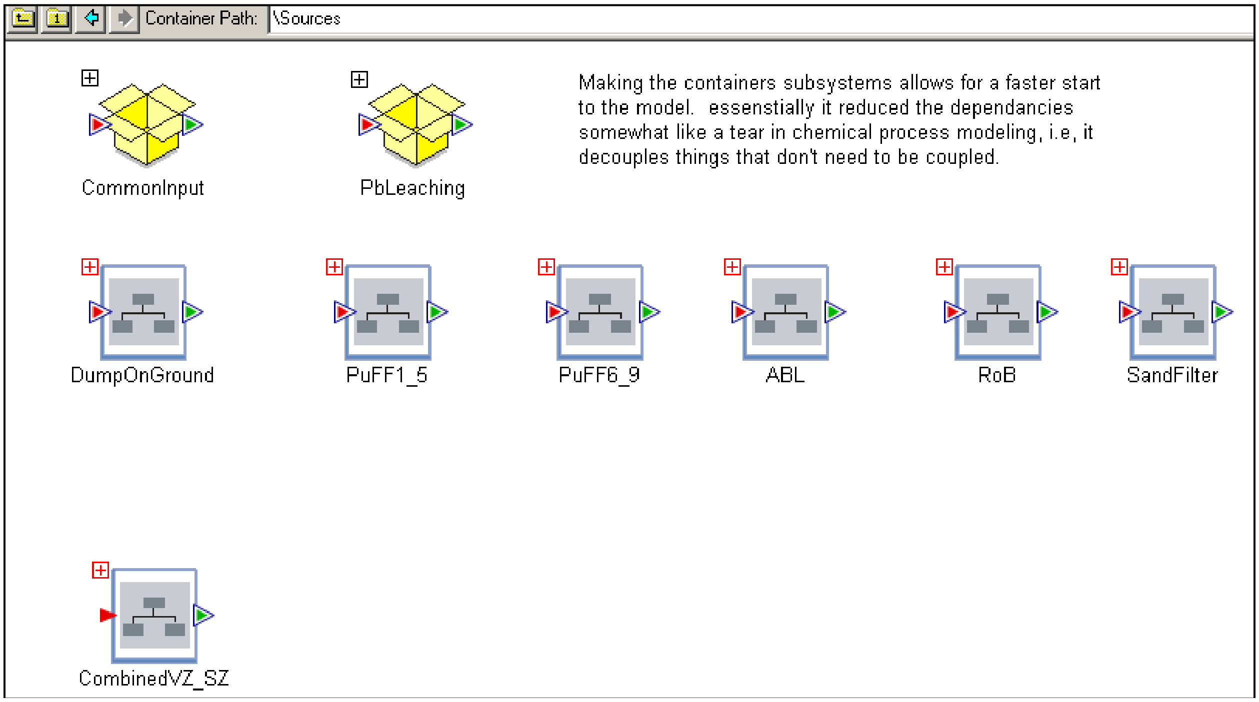


Figure 4-2 *Sources* sub-containers

The model is based on the assumption that short-lived (<3 years) daughter products are in secular equilibrium with parents. As such, there exist two groups of radionuclides, those used in the transport calculation and those used for the dose/MCL/PRG calculations with the transport group being a subset of the dose group. The transport group is what is defined by the *Species* element.

The model began as a modified version of a previous model. As such, there still might exist some elements which are extraneous to the 235-F fate and transport model. While it may be desirable to remove all these elements so as to minimize confusion, time constraints have limited the "clean-up". These extraneous elements are not deleterious to the 235-F model, just unaesthetic.

4.2 MODEL OVERVIEW

At its top level, the model consists of ten “sections”, referred to in GoldSim as “containers”. These containers, which will be examined in detail in following sections, as shown in Figure 4-3 are:

- *Material* – contains the specifications of the contaminants, materials properties, etc.
- *References* – copies of some of the germane references
- *ConceptualModels* – copies of the conceptual model diagrams
- *Miscellaneous* – various useful general parameters
- *Inventory* - contains the basis inventory and uncertainties
- *Events* – contains a single event, the number of years the inventory is decayed
- *Sources* – contains the transport and dose/MCL/PRG containers for each process area
- *Outputs* – collects some outputs of interest from *Sources*
- *SensitivityAnalysis* – collects data needed to perform sensitivity analyses
- *DashBoards* – contains the dashboard used to drive the Player version of the model.

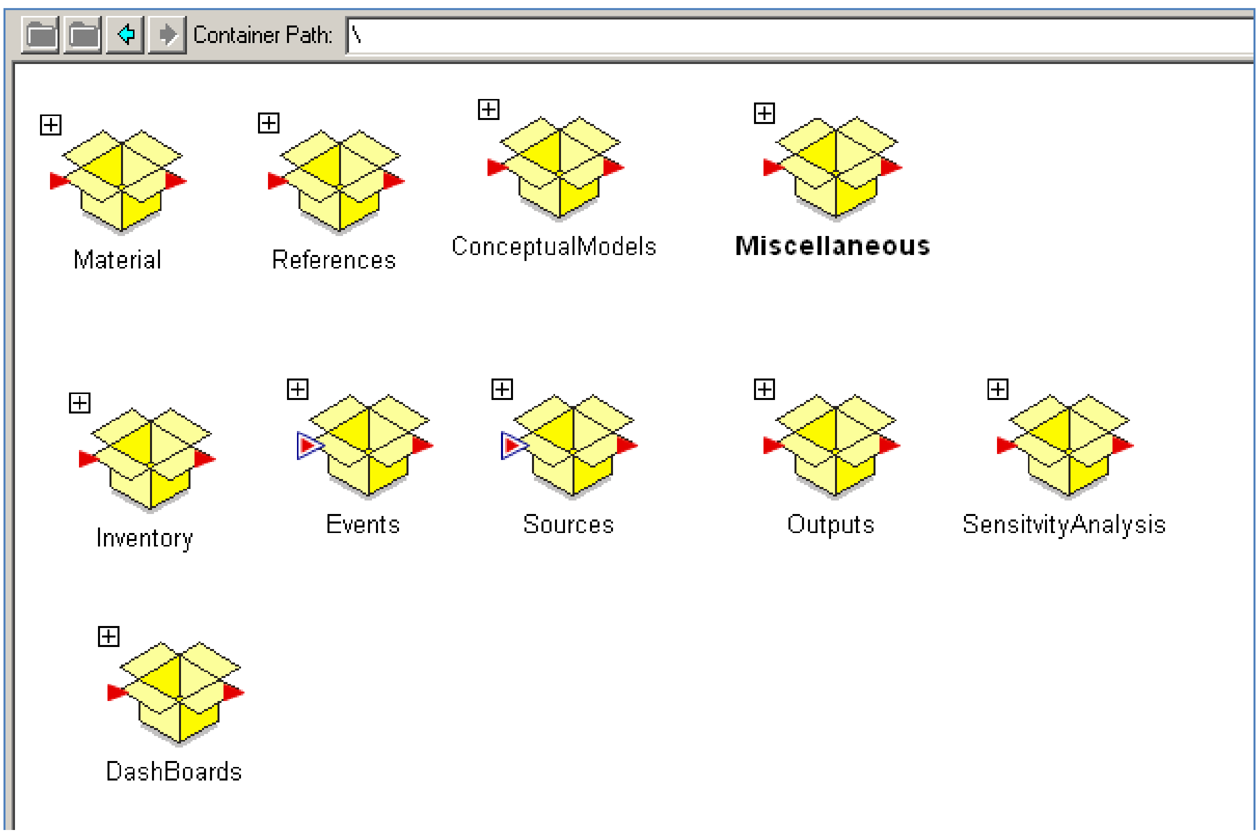


Figure 4-3 Top-level model

4.3 MODEL LABELS

Table 4-1 shows the Row Labels uses in the model. These labels are used for both vector and matrix construction. The labels are:

- *AssessmentPt*: values corresponding to locations in Figure 3-1
- *ChemElements*: used in the K_d determinations
- *DoseSpecies*: the two columns represent all the radionuclides included in the dose/MCL/PRG calculations
- *Outs*: a convenient grouping for outputs, same as *Process* with the addition of *All*
- *Process:* process lines/buildings
- *Species:* radionuclides and chemicals used in the transport calculation
- *Uranium:* the three radionuclides of uranium with MCL/PRGs.

Table 4-1 Model Row Labels (Indices)

AssessmentPt	ChemElements	DoseSpecies	DoseSpecies	Outs	Process	Species	Uranium
A1	Ac	Ac225	Po210	PuFF1	PuFF1_5	Ac227	U234
A2	Am	Ac227	Po212	PuFF6	PuFF6_9	Am241	U235
A3	At	Ac228	Po213	ABL	ABL	Np237	U238
A4	Bi	Am241	Po214	RoB	RoB	Pa231	
A5	Fr	At217	Po215	SandFilter	SandFilter	Pb210	
	Np	Bi210	Po216	All		Pu238	
	Pa	Bi211	Po218			Pu239	
	Pb	Bi212	Pu238			Pu240	
	Po	Bi213	Pu239			Pu241	
	Pu	Bi214	Pu240			Pu242	
	Ra	Fr221	Pu241			Ra226	
	Rn	Fr223	Pu242			Ra228	
	Th	Np237	Ra223			Th229	
	Tl	Pa231	Ra224			Th230	
	U	Pa233	Ra225			Th232	
		Pa234m	Ra226			U233	
		Pb209	Ra228			U234	
		Pb210	Rn219			U235	
		Pb211	Rn220			U236	
		Pb212	Rn222			U238	
		Pb214	Th227			Pb	
			Th228			PCB	
			Th229				
			Th230				
			Th231				
			Th232				
			Th234				
			Tl207				
			Tl208				
			Tl209				
			U233				
			U234				
			U235				
			U235m				
			U236				
			U238				

4.4 CONTAINER DESCRIPTIONS

This section contains detailed descriptions of the containers shown in Figure 4-3. It will follow the hierarchy of each container in its description.

4.4.1 *Material Container*

The content of the *Material* container is shown in Figure 4-5. It defines the transport species and the liquid and solid material transport properties for those species. It also defines the material properties for the porous media (solids material) and fluid. In this model the only fluid is water.

- *Species* Master Species element: defines the radionuclides and stable species (Pb and PCB) used in the transport calculation.
- *Water* Reference Fluid element: defines the properties of the flowing medium, water.
- *HalfLives* Data element which gives the half-lives of all radionuclides (transport and dose) as specified in Table 3-12. It is referenced by *Species* and the *Dose* modules.
- *Retardation_Switch* Data element: Allows for retardation to be turned on or off. For the purposes of this model it is assumed that retardation is always used but allows for the possibility that one may wish to run the model without retardation.
- *xSoil* Solid element: These elements are used to define the porous media used by the model as specified in Tables 3-27 and 3-28. Their names should be self-explanatory.
- *Grout* Solid element: defined porous medium properties of grout as specified in Table 3-27.
- *UTRSolid* Solid element: defines the porous medium properties for the Upper Three Runs (UTR) portion of the model as specified in Table 3-28.
- *FirstStage* Stochastic element: number of pore flushes to transition to second stage.
- *SecondStage* Stochastic element: number of pore flushes to transition to third stage.
- *ThirdStage* Stochastic element: number of pore flushes to transition to final stage.
- *FirstTransition* Expression element: set to *FirstStage*
- *SecondTransition* Expression element: set to *SecondStage*
- *ThirdTransition* Expression element: set to *ThirdStage*

4.4.1.1 Distribution Coefficient (Kd) Containers

The K_d containers internal structure is a holdover from previous modeling efforts. The structure is similar for all except *PCB_Kd*. K_ds are defined for chemical or elemental species with each isotope of an element having the same K_d as specified in Tables 3-22, 3-23, 3-24, and 3-25. For the 235-F model, the germane components are (as seen in Figure 4-6):

- *Kd_Median* Data element: defines median K_d values for *ChemElements*
- *GDS* Expression element: defines Geometric Standard Deviation for *ChemElements* as
  ```
  If( 0.375 * Kd_Median  * UnitKd < 1.001* ElementsOnes then
  ElementsOnes else 0.375 * Kd_Median  * UnitKd)
  ```
- *Kd_Dist* Stochastic element: defines a truncated log-normal distribution (Figure 4-4) for *ChemElements*
- *Pu* Stochastic element: defines a Weibull distribution for plutonium (Figure 4-7)
- *Value_Species* Data element: defines the K_d values for *Species*, i.e. ^{238}Pu's K_d is set equal to Pu's.

- *Kd* Selector element: defines the K_ds used for *Species* (transport) with retardation either on or off
- *Kd_SandySoil_DoseSpecies* Selector element: defines K_ds used in the dose module with retardation either on or off

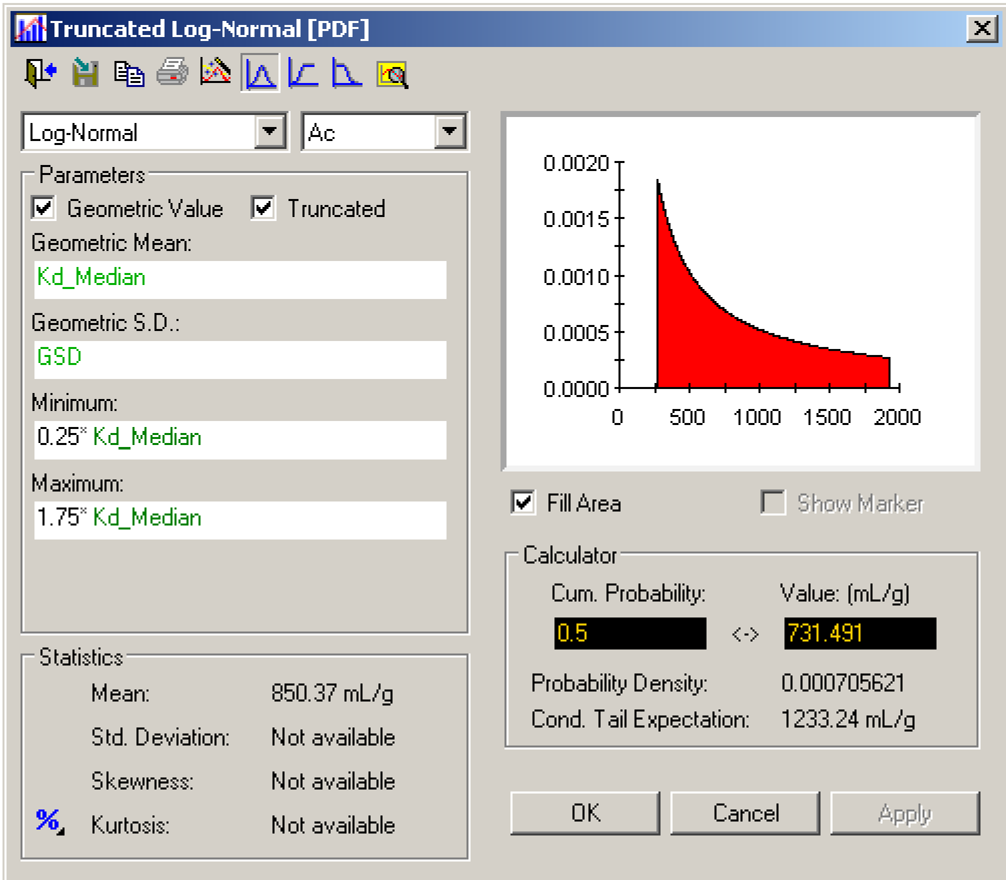


Figure 4-4 Example Truncated Log-Normal Distribution

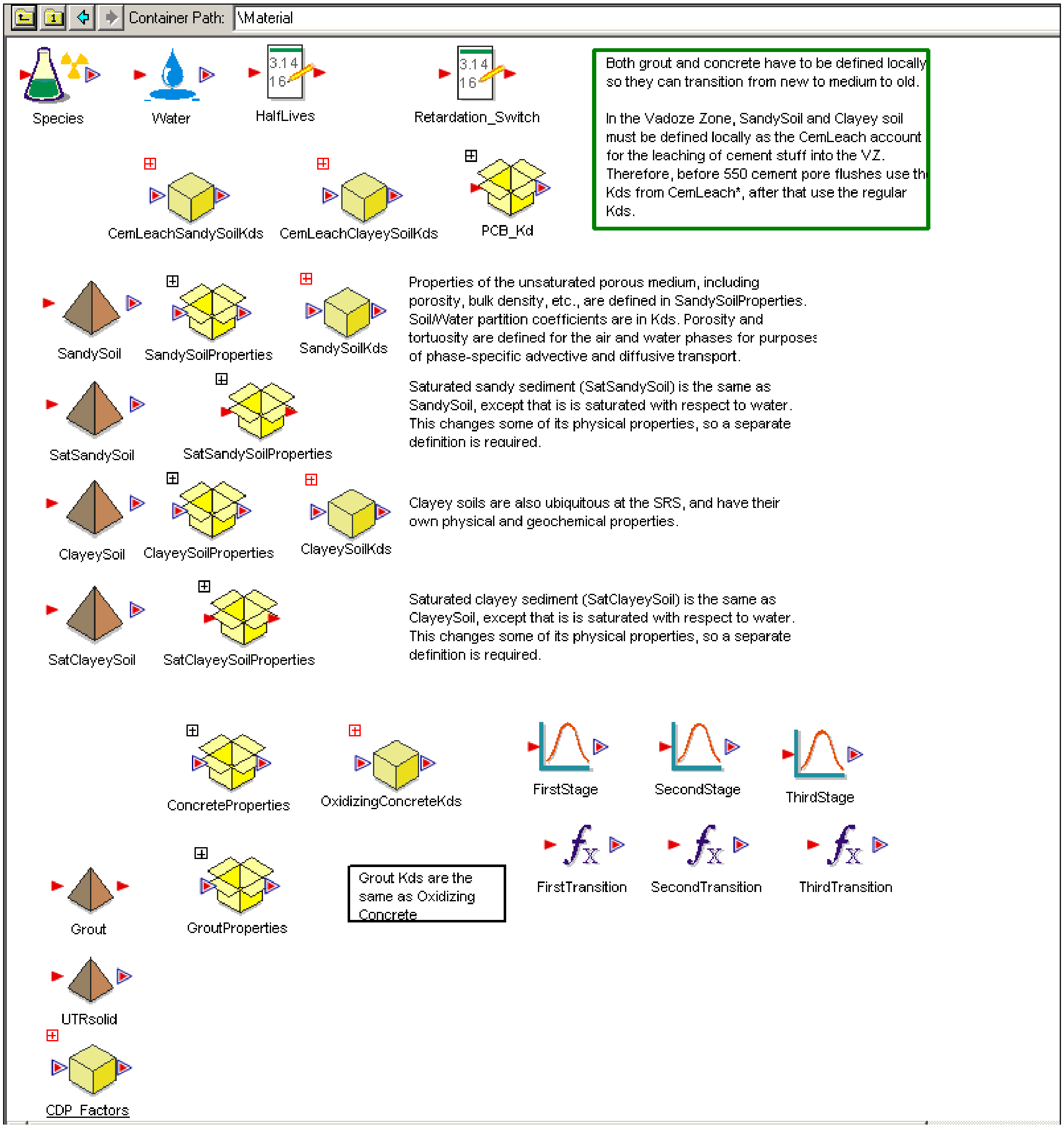


Figure 4-5 *Material* Container

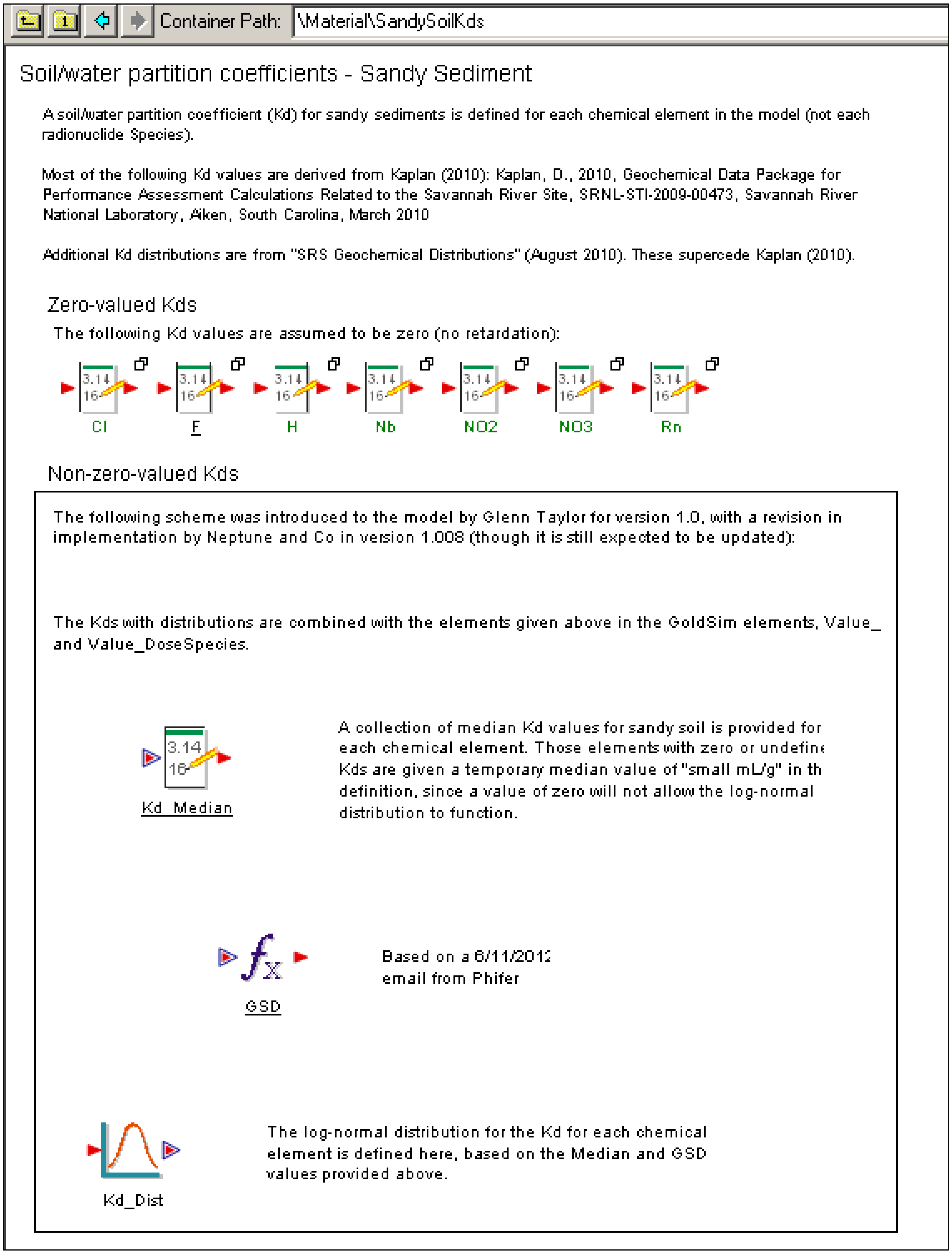


Figure 4-6 Example K_d Container, Part 1

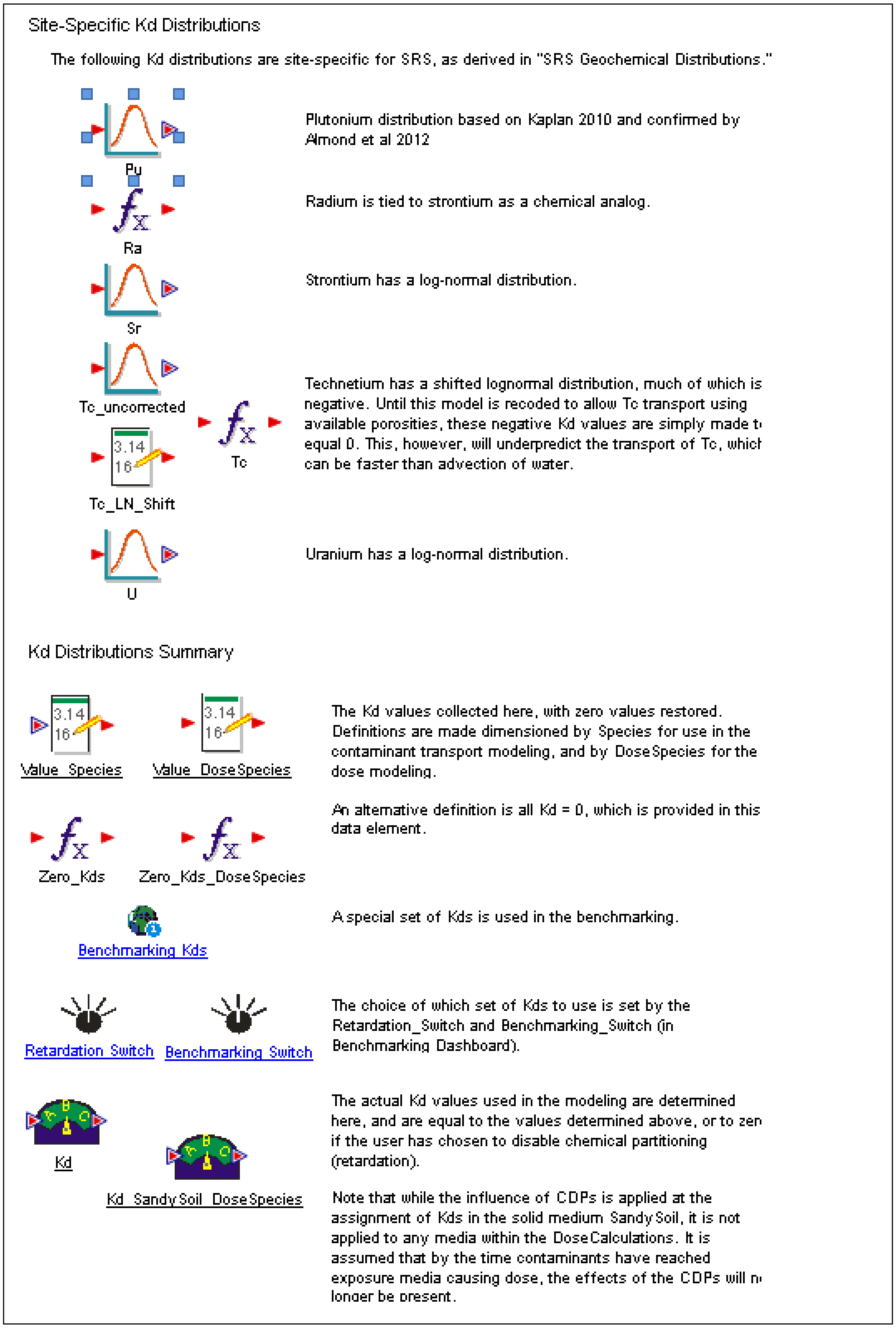


Figure 4-7 Example K_d Container, Part 2

4.4.1.2 PCB_Kd Container

The available data for the PCB Kd value was presented as a mean and a standard deviation as specified in Table 3-25. As can be seen in Figure 4-8, the distribution allows for negative values. One could have used a truncated normal distribution, but that would bias the PDF, moving the mean and other moments. Therefore, the distribution as input as shown and a Selector element was used to assure that $K_d \geq 0$ ml/g.

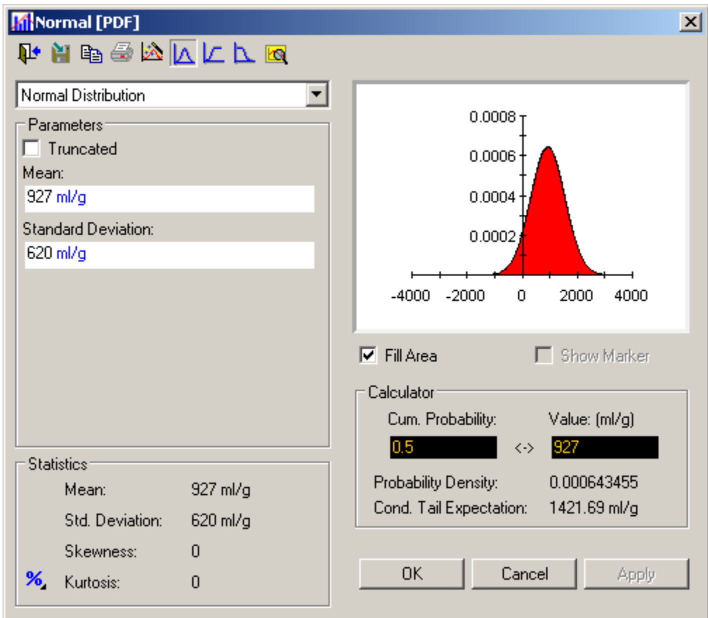


Figure 4-8 PCB K_d Distribution

4.4.1.3 xSoilProperties Containers

These containers define the physical characteristics of the porous media as specified in Table 3-23. So that the characteristic are not over specified, the *WaterSat_x*, the water saturation of the porous medium, is defined as *WaterContent_x/Porosity_x*. This paradigm was used because it is thought that the Water Content of a porous medium would be the measured parameter rather than its saturation. *WaterContent_x* and *Porosity_x* are both stochastic elements. The *SatxSoilProperties* are identical to the *xSoilProperties* with the exception of the *WaterSat_x* being set to 1.

4.4.1.4 CDP_Factors Container

This container defines the Cellulose Degradation Product factors applied to the distribution coefficients. There are no cellulosic materials in the 235-F facility, therefore these factors as not used in this model. The container is a legacy element and figures in the logical structure of the K_d model. It was more efficient to leave it in the model than to rewrite the logic when leaving it in the model has no effect on the results.

4.4.2 *References* Container

Contains copies of some of floor plans and a graphic ^{238}Pu decay chain.

4.4.3 *ConceptualModels* Container

Contains several different versions of graphical descriptions of the conceptual model.

4.4.4 *Miscellaneous* Container

Contains some useful global constants.

4.4.5 *Inventory* Container

This container sets the starting inventories as specified in Tables 3-4, 3-6, and 3-9, with starting being the inventories as of 1981.

- *Inventory_1981* Data element: A matrix, *Species* x *Process,* which defines the most probable starting inventory. *Process* is a vector of (*PuFF1_5, PuFF6_9, ABL, RoB, SandFilter*), each of the sources.
- *xUncert* Stochastic elements: defines the uncertainty associated with the different inventories. RoB is specified by three different uncertainties which are radionuclide specific.
- *X_start_inv* Expression elements: adjusts the 1981 inventory by the appropriate uncertainties. PuFF cells 1-5, PuFF cells 6-9, and ABL use the same uncertainty for all radionuclides and therefore can be specified by a simple function. RoB has different uncertainties for different radionuclides and is therefore specified as a data element where each member of an array can be defined individually. These values are used in Decay cells (see Section 4.4.7.3.1 for an example).
- *PCB_Inv* Stochastic element: defines the starting PCB inventory

4.4.5.1 Starting Spreadsheet Container

Contains a copy of the starting inventories and associated uncertainties. The spreadsheet is the same as Table 3-4 with a slightly different format. Note that in the *Inventory* container the inventories are as of 1981. Decayed inventories are calculated in each of the source containers.

- *Inventory_1981* Data element: A matrix, *Species* x *Process,* which defines the most probable starting inventory. *Process* is a vector of (*PuFF1_5, PuFF6_9, ABL, RoB, SandFilter*), each of the sources.

4.4.6 *Events* Container

This contains elements used to determine the amount of time the 1981 inventory is decayed before the transport calculation starts.

- Decay Years Stochastic element: defines the number of years to decay the 1981 inventory. This distribution ranges from 32 to 44 years, which are equivalent to years 2013 and 2025 respectively. This was specified in this manner so that the simulation could begin at year 0.
- Move Inventory Triggered Event element: defines an event, based on *DecayYears*, which initiates an inventory move from the *DecayCell* to the *WasteCell* (see Section 4.4.7.3.4 for an example). This type of element is used as it forces a time step when it becomes true.

4.4.7 *Sources* Container

This contains the heart of the model. As shown in Figure 4-9 there are seven subsystem containers, one for each source. Each subsystem can be thought of as a stand-alone in that it can function without any of the other subsystems. As mentioned earlier, the subsystem construct allows for a much faster initialization. The two containers not treated as subsystems, *CommonInput* and *PbLeaching*, provide information to each of the subsystems.

PuFF1_5, PuFF6_9, ABL, and *RoB* are identical in construction with the appropriate references. Therefore, a detailed exposition of only PuFF1_5 will be included.

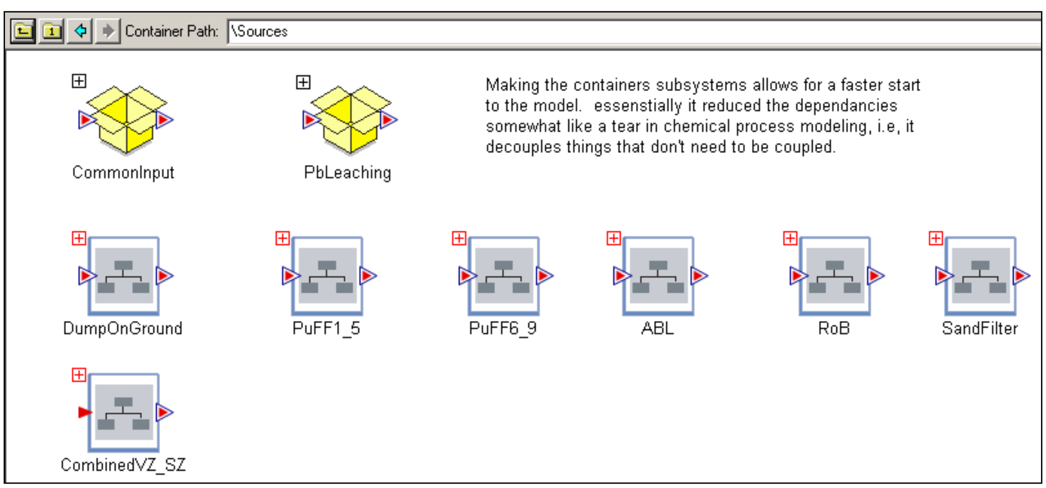


Figure 4-9 Sources Container

4.4.7.1 PbLeaching Container

Leaching of the lead shielding is solely of function of time. Therefore, it does not matter which scenario any of the sources are following as the leaching is always the same. The elements of this container are *Vector[Process]* as each process (source) has different thicknesses of shielding.

- *PbLeach* Stochastic element: sets the leach rate in µm/yr as a log-normal distribution.
- *PbLeachedRate* Expression element: converts the leach rate from distance/year to mass/year.
- *PbUnleachedMass* Reservoir element: used to determine when all the lead shielding has been leached. Its initial value is the starting mass of lead. There is no addition rate. The withdrawal rate is set to *PbLeachedRate* if *DecayYears* has elapsed, i.e., no leaching before building infiltration begins. The lower bound is set to 0 so that no leaching is calculated if there is no mass left. The withdrawal rate (*PbUnleachedMass.Withdrawal_Rate[x])* is used in the *Source* subsystems to set a lead addition rate to the process.
- *PbThickness* Data element: a vector by *Source* of lead shielding thickness
- *PbSurfaceArea* Data element: a vector by *Source* of lead shielding area
- *PbVolume* Data element: a vector by *Source* of lead shielding volume
- *PbDensity* Data element: density of elemental lead
- *PbInitialMass* Expression element: a vector by *Source* of *PbVolume* times *PbDensity*

4.4.7.2 CommonInput Container

This contains elements referenced by the *Source* subsystems which are the same for all the subsystems.

- *SD* Stochastic element: Rather than defining a number of stochastic elements, and the desire to have a consistent variance in the interrelated parameters, this element chooses a standard deviation to apply to all appropriate elements. It is defined as a normal distribution with a range of -3 to 3. It applies to *InfiltrationRate_x, SZ_xVelocity*, and *VZ_Thickness.*

  The issue with this construct is that the variables mentioned above are not stochastic elements and therefore do not show up in the sensitivity analysis. To ameliorate this issue, corresponding stochastic elements are used which take on the value of the variables. GoldSim does not allow a reference in a Discrete Distribution so a Uniform distribution is used. That requires an upper bound higher than the lower so the elements are set up such that the lower bound is the variable value, such as *SZ_ClayVelocity* and the upper limit is 0.01 * *SZ_ClayVelocity.*
- The vadose zone thickness calculation is somewhat convoluted. Its total thickness varies with the infiltration which affects the water table. It consists of two layers, clayey and sandy. The clayey soil sits on top of the sandy soil and is unaffected by the water table. Hence, the clayey soil thickness is allowed to vary independently of the infiltration.

- *VZ_Thickness* references *SD* and is the total VZ thickness (clayey + sandy) using the algorithm described in Section 4.4.7.2.2.
- The clayey layer's thickness is chosen by the *Clayey_VZ_Thickness* stochastic element, using the mean and standard deviation to its left.
- Finally, the sandy layer's thickness it calculated by element *Sandy_VZ_Thickness* by differencing *VZ_Thickness* and *Clayey_VZ_Thickness*.
- *VZ_Thickness_Stoch* Stochastic element: explained in *SD* bullet above
- Note that there is a negative correlation between infiltration and sandy layer thickness in that as the infiltration increases the water table increases therefore the sandy layer thickness decreases.

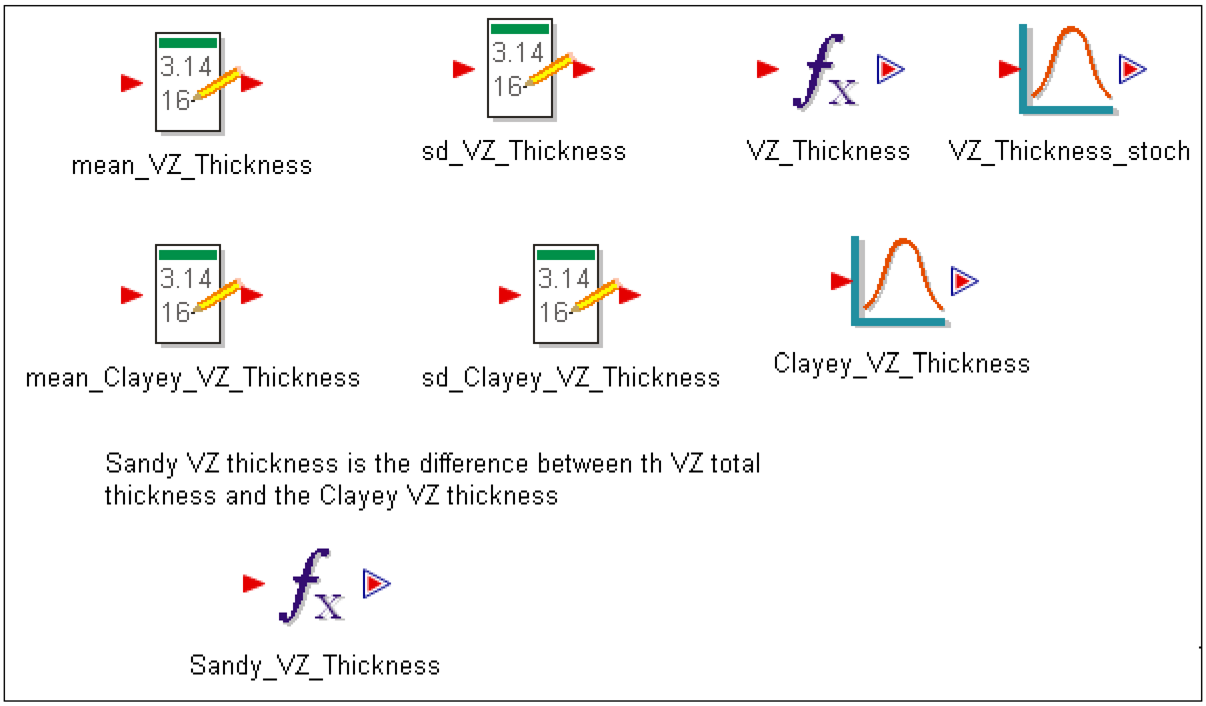


Figure 4-10 Vadose Zone Thickness Calculation

- *SZ_Thickness* Stochastic element: As described in Section 3.8, a flow area perpendicular to the saturated zone flow was derived from PORFLOW simulations (Figure 3-17). This area was used to compute a SZ thickness based on the 235-F building length. The computed thickness was about 10.2 ft. *SZ_Thickness* is defined by a uniform distribution between 8 and 12 ft.
- *DispersivityUncert* Stochastic element: The SZ dispersivity was modeled as a stochastic element in order that it could be included in the sensitivity analysis. It is defined by a triangular distribution with a minimum of 0, most likely of 0.1 and maximum of 0.3. A rule of thumb for dispersivity is 10% (or 0.1) of the length and that is why the most likely value was chosen.
- *UTR_Flow* Stochastic element: flow in Upper Three Runs (UTR) is defined by a normal distribution and is independent of infiltration.

- *Pb_MCL* Data element: the MCL for elemental lead (shielding)
- *PCB_MCL* Data element: the MCL for PCBs

4.4.7.2.1 *FlowReference* Container

Contains copies of the different flow scenarios, similar to Table 3-15, Table 3-16, and Table 3-17.

4.4.7.2.2 *Infiltration* Container

This container computes the infiltration rates for the various scenarios as specified by Table 3-15, Table 3-16, and Table 3-17. Figure 4-11shows an example of the calculation. By using this algorithm one is assured that a consistent series of flows will be used within a single realization.

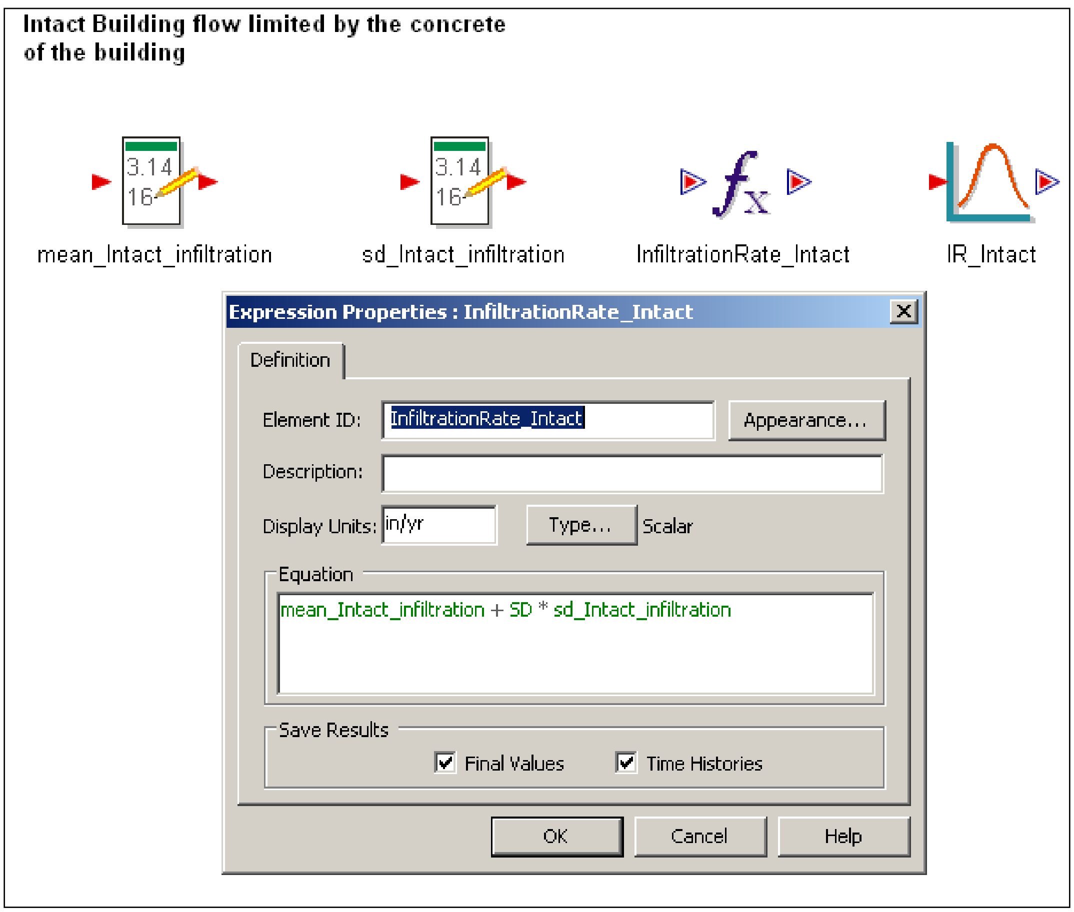


Figure 4-11 Infiltration Calculation Example

4.4.7.2.3 Saturated Zone Velocity

The saturated zone velocities are all based on the assumption that in these types of simulation the travel time is the most important parameter in that decay and in-growth control the dose/MCL/PRG. PORFLOW models are typically set up so that rather than having a mixture of clay and sand, the clay is segregated into its own zone. This then gives an SZ of clayey soil and sandy soil. Mean travel times and standard deviations are obtained from PORFLOW simulations and are used to calculate the velocity as specified in Table 3-21. *SZ_ClayVelocity* and *SZ_SandVelocity* (Figure 4-12) reference *SD* so that all the infiltration parameters are consistent.

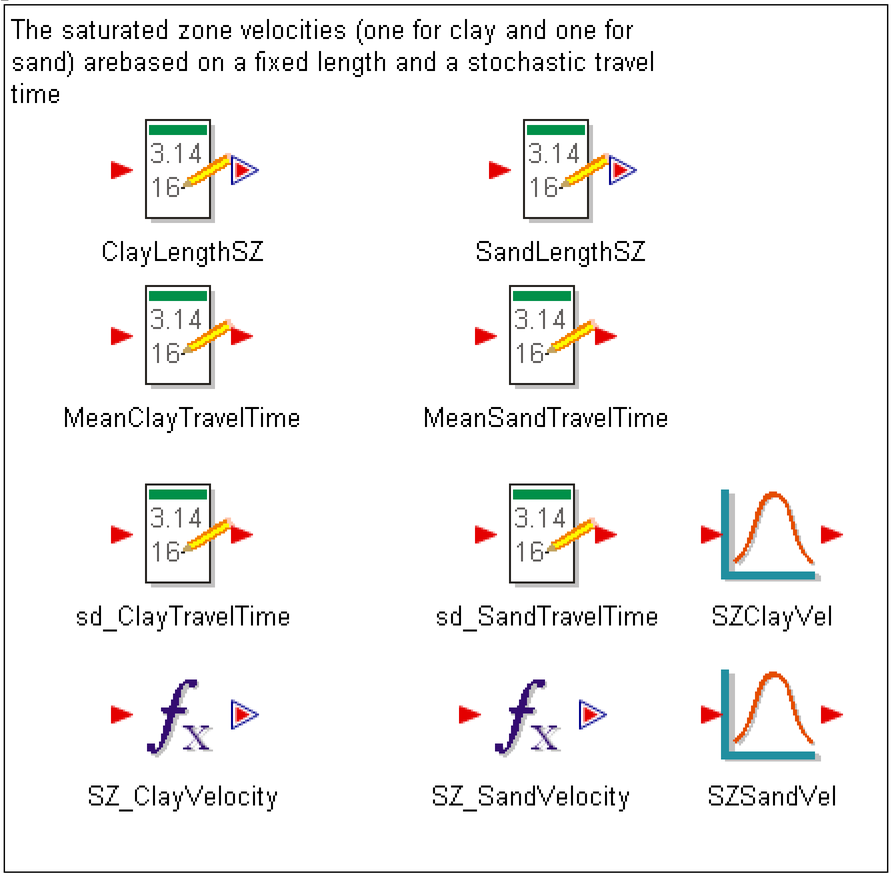


Figure 4-12 SZ Velocity Calculation

4.4.7.2.4 Number of saturated zone sand cells

Figure 4-13 shows the calculation of the number of sand cells used in the saturated zone. These cells are modeled as Aquifer elements and as such are capable of having any number of cells which are generated dynamically.

- *Number_SZ_SandCells* is defined by a Data element with the number of cells based on a noding sensitivity study (see Section 4.4.11.1. The construct shown in the figure as developed so that *Number_SZ_SandCells* could be easily changed to a stochastic element.

- *NearWellDistanceFraction* is the fraction of distance to the 100 m well to the total distance.
- *Distance_NearWellToStream* is the distance from the 100 m well to the stream.
- *NumCellsNearWell* is the rounded product of *NearWellDistanceFraction* and *Number_SZ_SandCells* giving the number of cells from 235-F to the 100 m well.
- *NumCellsSandSZ* is the difference between *Number_SZ_SandCells* and *NumCellsNearWell* giving the number of cells between the 100 m well and the stream.

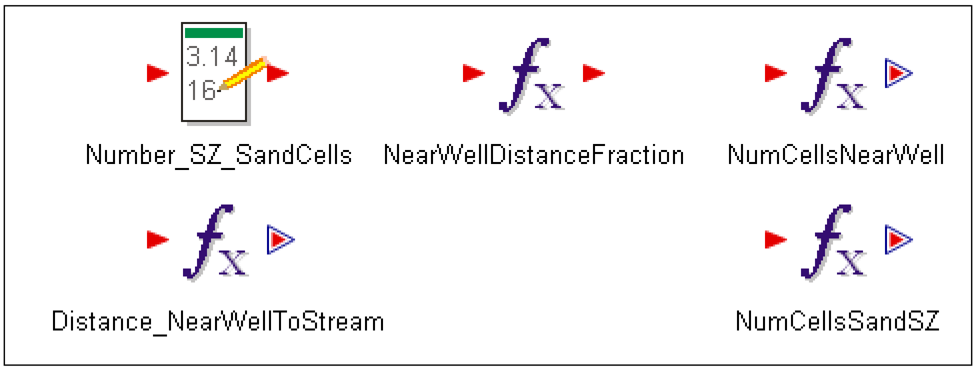


Figure 4-13 Number of SZ sand cell calculation

4.4.7.2.5 ***BuildingParameters* Container**

This contains parameters associated with roof and floor collapses of 235-F as specified in Table 3-16.

- *BuildingReference* Container shows a copy of the reference for the events in this *BuildingParameters*.
- *NoGroutCollapseTimeRoof* Stochastic element is the time when an unsupported roof collapses. It is used in the "no grout" and the "1st floor grouted" scenarios.
- *GroutCollpaseTime2ndFloor* Stochastic element defines when the second floor collapses. It is used in all "grout" scenarios. In the case of the 2nd floor being grouted it is also used as the time of roof collapse.
- *CollapseTime2ndFloor* Selector element is necessary because *NoGroutCollapseTimeRoof* and *GroutCollpaseTime2ndFloor* overlap in the period of 500-600 years. That is, depending on the values selected by the two stochastic elements the first floor could collapse before the second floor. As this makes no sense, the selector elements assures that the 1st floor does not collapse before the 2nd floor. The 1st floor collapse will always be at least one time step after the 2nd floor collapse.
- The two Expression elements shown in Figure 4-14 shift the timings selected by the above two stochastic elements by DecayTime, i.e., the "collapse" clock does not begin running until flow is occurring. The two Status elements are used to simplify

the expressions which are dependent on the collapses. They are set to “True” if the collapse times are exceeded.

- *GroundSlabThickness* Data element defines the thickness of the ground slab for 235-F.
- *FirstFloorHeight* Data element: the distance between the top of the ground slab and the bottom of the second floor.
- *SecondFloorHeight* Data element: the distance between the top of the second floor slab and the roof slab.

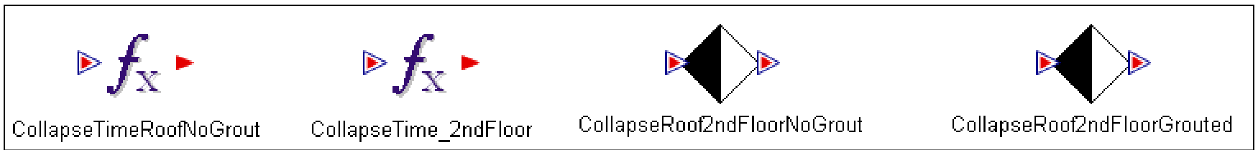


Figure 4-14 Collapse Time Shift

4.4.7.3 PuFF1_5 Subsystem

Figure 4-15 shows the top level of the PuFF1_5 subsystem. A Subsystem is treated as a closed container therefore all variables names are local to the subsystem. Variables must be exposed if they are referenced outside the subsystem.

- *FlowArea* Expression element: Computes the flow area perpendicular to the SZ flow. It assumes a projection of the footprint and is the product of *Length* and *SZ_Thickness*..
- *Length* Data element: length of the source.
- *Width* Data element: width of the source.
- *Area* Expression element: computes the product of *Width* and *Length* to give the footprint area.
- *AreaRatio* Expression element: computes the fraction of total building area of a source by dividing *Area* by *TotalBuildingArea.*

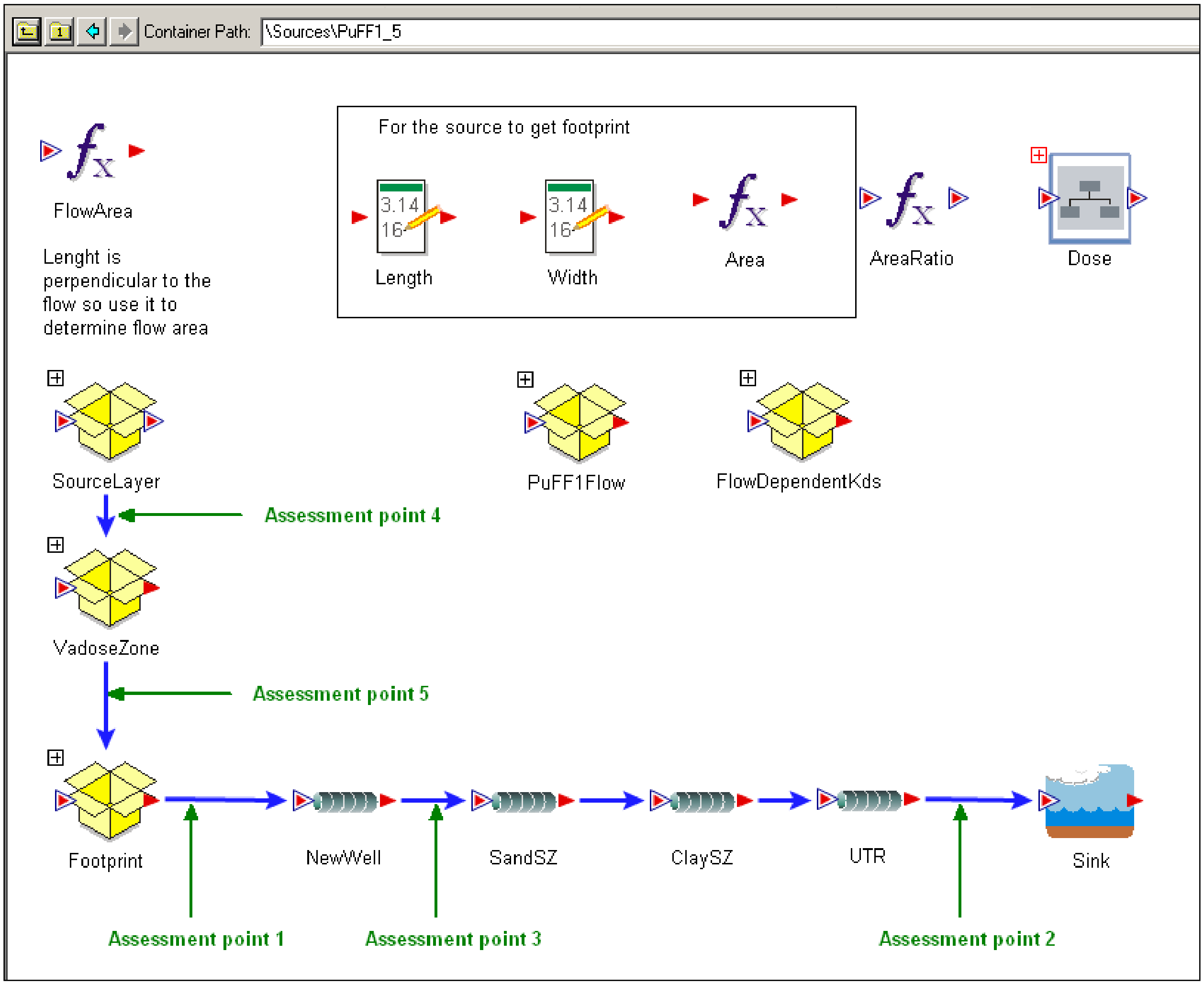


Figure 4-15 Top level of PuFF1_5 Subsystem

4.4.7.3.1 *SourceLayer* Container

The elements of the container are shown in Figure 4-16.

- *DecayCell* Cell Pathway element: receives the 1981 inventory and decays it until it is transferred to *WasteZone*.
- *Decon* Data element: linked to the dashboard (see Section 4.4.10), set to True if there is decontamination of the source.
- *DeconFrac* Data element: linked to the dashboard (see Section 4.4.10), sets the amount of inventory to be removed. It is assumed that the same fraction of all radionuclides are removed.
- *DeconInv* Selector Element: If *Decon* is true it multiplies the masses in *DecayCell* by (1-*DeconFrac*), giving the amount of inventory left after decontamination. If *Decon* is false it is set to the masses in *DecayCell*.

- *DecayedInventory* Discrete Change element: used to move the mass from *DecayCell* (via *DeconInv*) to *WasteZone*. It is triggered when *MoveInventory* becomes True.
- *PCBInv* Data element: a vector by *Species*, it sets the starting PCB inventory as the product of *PCB_Inv* and *AreaRatio.*
- *PCBInventory* Discrete Change element: Moves the *PCBInv* to *WasteZone* when *MoveInventory* becomes True.
- *WasteThickness* Stochastic element: defines the thickness of the waste zone. The waste thickness is rather arbitrary and was chosen so that the contaminants were not released in a single time step. It is defined by a uniform distribution between 1 and 6 inches. It is thought that any contamination remaining in the facility will be surface contamination.
- *WasteCellVolume* Expression element: the product of *WasteThickness* and *Area*
- *FS_Volume* Expression element: the volume of floor slab computed as *Area* times *GroundSlabThickness.*
- *PBLeachIn* Selector element: if simulation time (*ETime*) is greater than *DecayYears* it is set to *PbUnLeachedMass.Withdrawal_Rate[PuFF1_5]*, else it is set to 0 g/yr.
- *WasteZone* Cell Pathway element: defines the waste zone based on the parameters listed above. As shown in Figure 4-17, the leached lead shielding is put in the cell as an "Input Rate" while the radionuclide and PCB inventories are added as discrete changes of mass. Note that in the vector construct of "Input Rate",

```
vector(if(row=21,PbLeachIn, 0 g/yr))
```

- "row=21" defines the location of lead within the *Species* vector. If the species vector is reordered the location of lead will change and the index will be incorrect. I have yet to find a good way to get around this GoldSim constraint. Flow is *VZFlux*.
- *FloorSlab* Cell Pathway element: defines the concrete pad beneath the waste zone. Flow is *VZFlux*.
- *MassOut* Integrator element: integrates the mass flux leaving the waste zone for the vadose zone.
- *PCBMassError* Expression element: used in the time step sensitivity (see Section 4.4.11.2. Only the final value is meaningful.

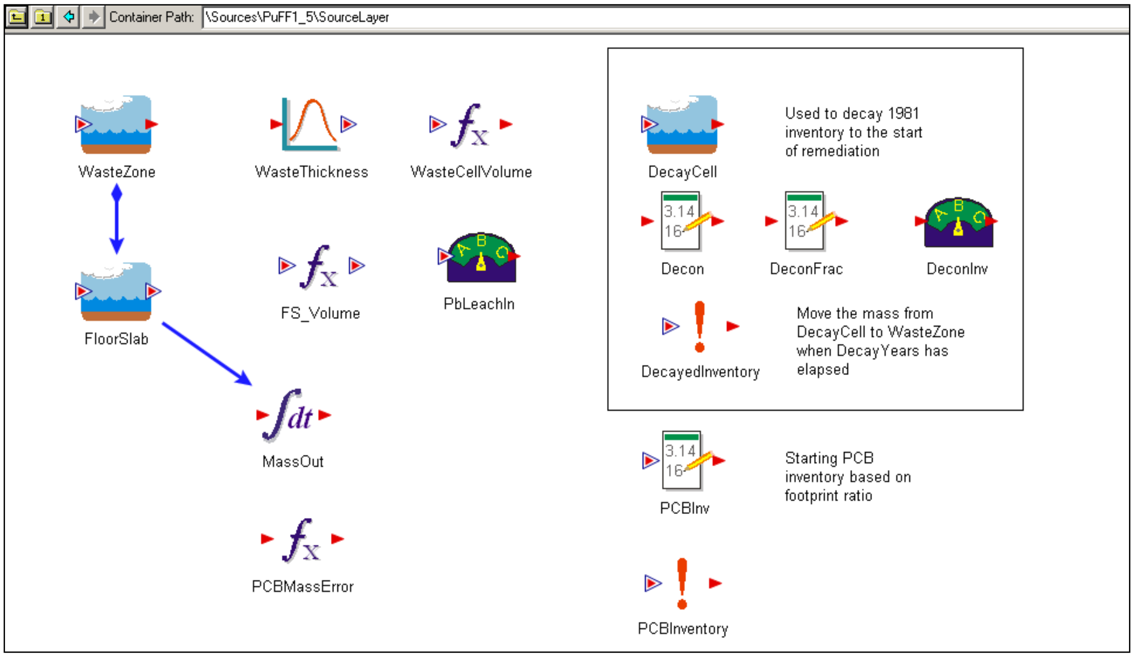


Figure 4-16 *SourceLayer* Container

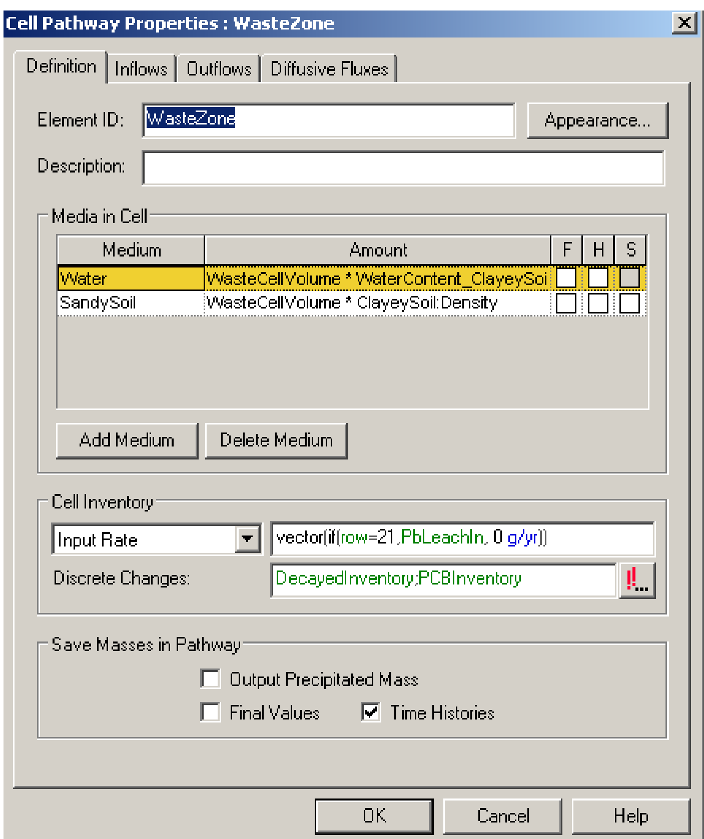


Figure 4-17 *WasteZone* Cell Pathway Element

4.4.7.3.2 *VadoseZone* Container

The vadose zone (Figure 4-18) consists of a clayey layer on top of a sandy layer. The layers are defined by Aquifer elements so that the noding can be easily changed.

- *NumberOfClayCells* Data element: number of Cell Pathways used by the appropriate Aquifer element.
- *NumberOfSandCells* Data element: number of Cell Pathways used by the appropriate Aquifer element.
- *VZFlux* Expression element: the volumetric flow rate, the product of *VZFlow* and *Area.*
- *FootprintFlux* Expression element: *VZFlux* divided by *NumberOfFootprintCells,* used to divvy the flow up evenly among the Cell Pathway element which represent the SZ under the source.
- *ClayeyVZ* Aquifer Pathway element: defines the Cell Pathways used to define this part of the VZ. It is dynamically expanded into the *NumberOfClayCells* at execution (see Figure 4-19). The "Dispersivity" is somewhat confusing as the expansion into a number of Cell Pathways will introduce its own degree of dispersion. "Dispersion" makes more sense, or at least is easier to grasp, for a Pipe element in that a Pipe element's solution is a transfer function, not difference equations. Its flow is *VZFlux*.
- *SandyVZ* Aquifer Pathway element: defines the Cell Pathways used to define this part of the VZ. Its outflow is *FootprintFlux* with an outflow to each of the *Footprint* container's Cell Pathways.

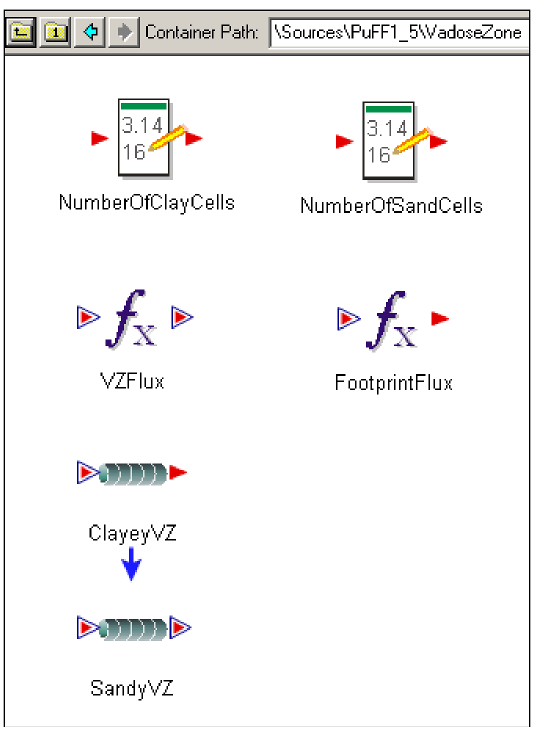


Figure 4-18 *VadoseZone* Container

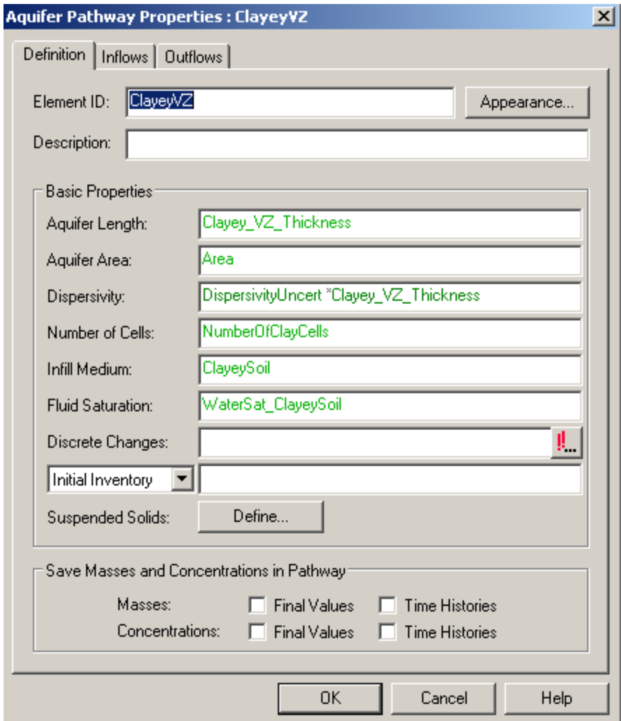


Figure 4-19 Aquifer element

4.4.7.3.3 <u>*Footprint* Container</u>

This container represents the SZ region directly under the facility/source (see Figure 4-20). It receives its flow from *SandyVZ*. *FPOut* is where Assessment Point 1 obtains its concentrations.

- *CellNet_Gen1* Cellnet Generator element: An Aquifer element could not be used as each Cell Pathway receives flow from *SandyVz* rather than just the inlet cells. The cell net generator is a convenient way to generate the cells as it automatically does all the flow connections between the generated cells. Where it is not quite so convenient is that it allows only numerical data for distances, not links. Therefore, I went into each Cell Pathway and inserted *FPCellVolume* in place of the cellnet generated numerical value.
- *NumberofFootprintCells* Data element: number of cell in the footprint. Cannot be referenced by the Cellnet Generator but is reference by *FPCellVolume*.
- *FPCellVolume* Expression element: the volume of a footprint cell given by:
  *Area * VZ_Thickness / NumberOfFootprintCells*

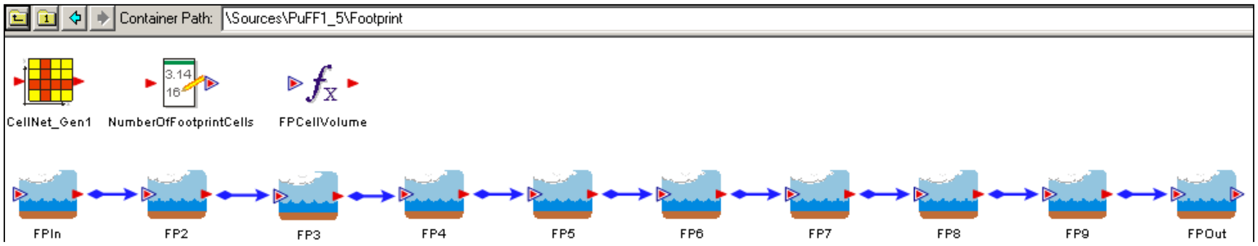


Figure 4-20 *Footprint* Container

4.4.7.3.4 *NearWell* Aquifer element

This element represents the SZ from the edge of the building to the 100 m well. Its outlet concentrations are used for Assessment Point 3.

4.4.7.3.5 *SandSZ* Aquifer Element

This element represents the sandy saturated soil distance from the 100 m well to the creek.

4.4.7.3.6 *ClaySZ* Aquifer Element

This element represents the clayey saturated soil distance from the 100 m well to the creek.

4.4.7.3.7 *UTR* Aquifer Element

This element represents Upper Three Runs creek outfall. Its outlet concentrations are used for Assessment Point 2.

4.4.7.3.8 *Sink* Cell Flowpath element

This is the subsystem's flow sink.

4.4.7.3.9 *PuFF1Flow* Container

The contents of this container (see Figure 4-21) determine the vadose zone flow.

- *Grouted* Data element: a logical variable linked to the Dashboard. If true the source is grouted. If the 1st floor or the entire building is grouted elements. *RoB.RoB1stFloorGrouted* or *RoB.RoBBothFloorsGrouted*, respectively, are used rather than the local *Grouted*.
- *VZFlow* Selector element: determines the VZ flow (infiltration rate). Figure 4-22 shows the logic used. Note that the order of the conditions in the Selector element is

very important as the code parses the conditions in order listed and stops as soon as a True condition is met. All the variables referenced in the conditions are Logical.

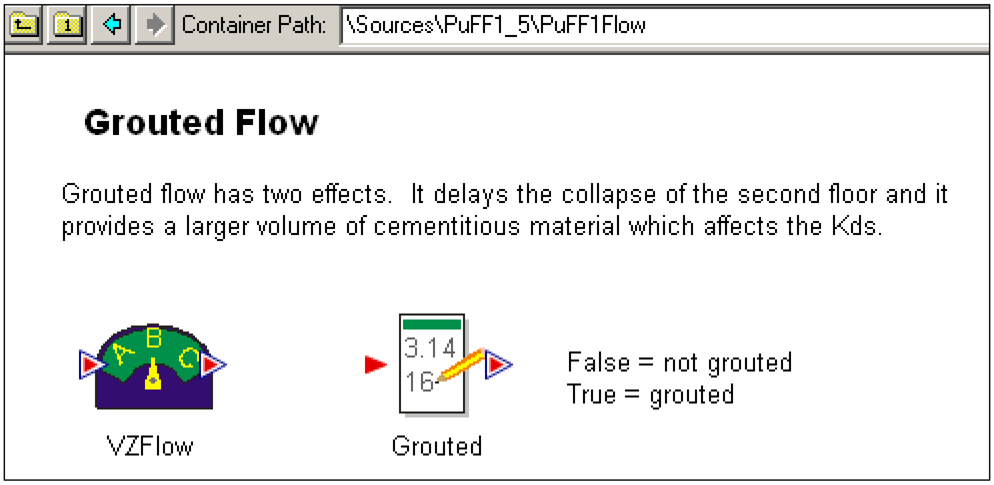


Figure 4-21 VZ Flow Determination

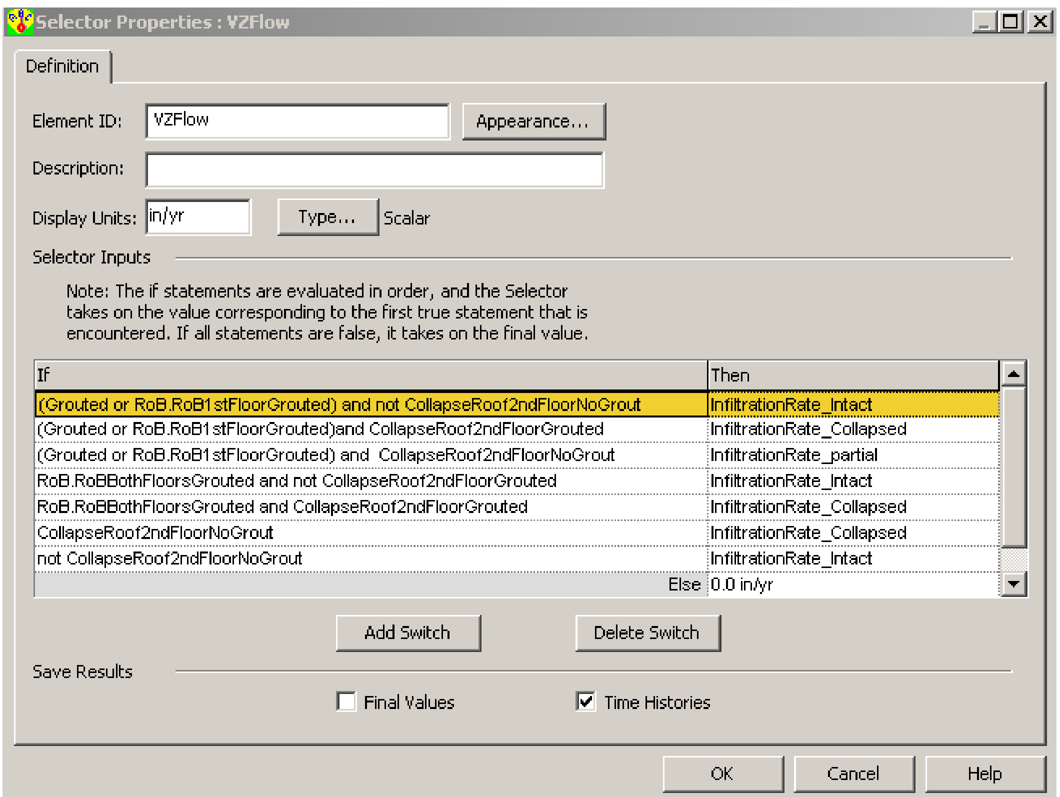


Figure 4-22 VZ Flow selection logic

4.4.7.3.10 *FlowDependentKds* Container

The K_ds in the model change based on the number of pore flushes of the cementitious materials. The amount of cementitious material can vary based on the scenario selected. Because each Source can simultaneously be run with different scenarios, the behavior of the K_ds is source dependent. Therefore, each Source has locally defined materials. (See Figure 4-23.) The transport calculation begins at the top of the waste zone. Therefore, one will see concrete but not grout K_ds being modified. The effect of adding grout, etc. to the model is that it delays the time of transition from one set of K_ds to another.

- *PoreVolume* Selector element: calculates the pore volume based on scenario selected. Note that the 1st and 2nd floor slabs are the same thickness so in the scenarios where the 2nd floor slab comes into play the floor slab volume used in 2 * *FS_Volume*. (See Figure 4-24).
- *FlowThruPores* Integrator element: calculates the integrated volume of water which has flowed through the pores.
- *NumberofFlushes* Expression element: calculates the number of pore volume flushes by dividing *FlowThruPores* by *PoreVolume.*
- *ConcreteKds* Selector element: picks which set of concrete K_ds to use depending on the condition met (see Figure 4-25) Note that if one were to look for element *OxidizingConcreteKds.NewKd* one would not find it. Instead, one must open the properties of *OxidizingConcreteKds* container and click on the "Exposed Outputs" tab. This will show that the NewKd is an alias for *OxidizingConcreteKds\New_Concrete_Kds\Kd.*
- *SandyKds* Selector element: picks which set of sandy soil K_ds to use depending on the condition met (see Figure 4-25).
- *ClayeyKds* Selector element: picks which set of clayey soil K_ds to use depending on the condition met (see Figure 4-25).
- *ConcreteSlab* Solid element: local concrete material definition which get its K_ds from *ConcreteKds.*
- *SandySoil* Solid element: local sandy soil material definition which get its K_ds from *SandyKds.*
- *ClayeySoil* Solid element: local clayey soil material definition which get its K_ds from *ClayeyKds.*

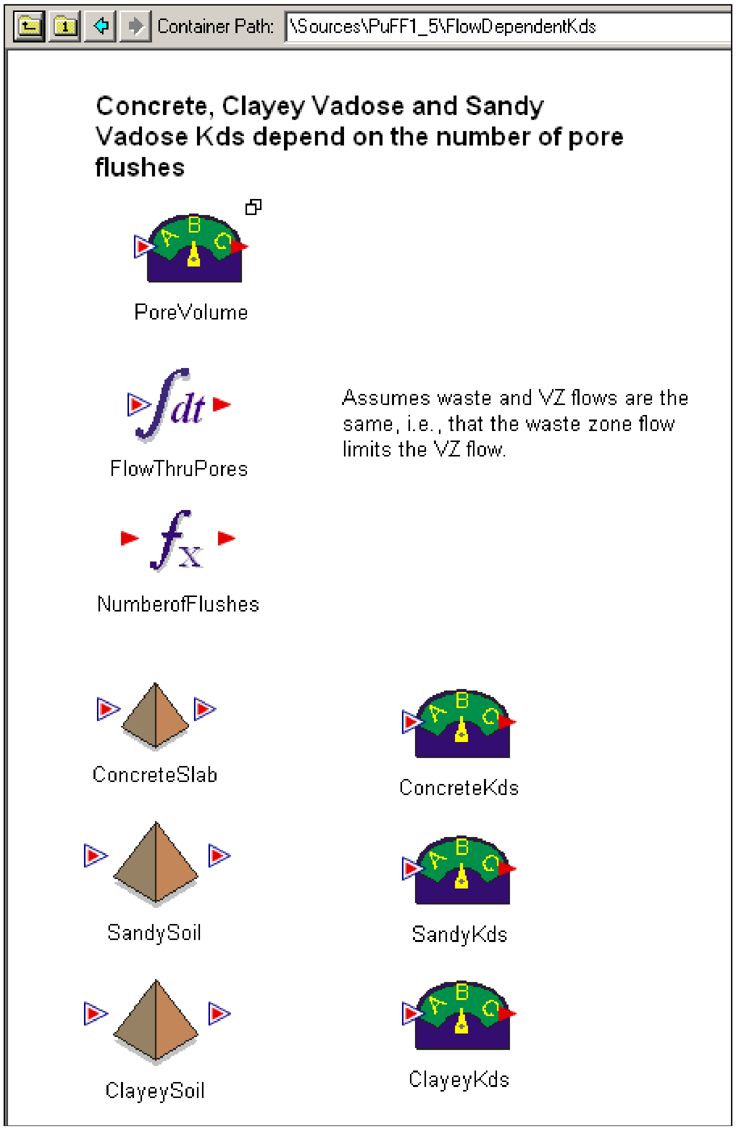


Figure 4-23 Flow dependent K_ds

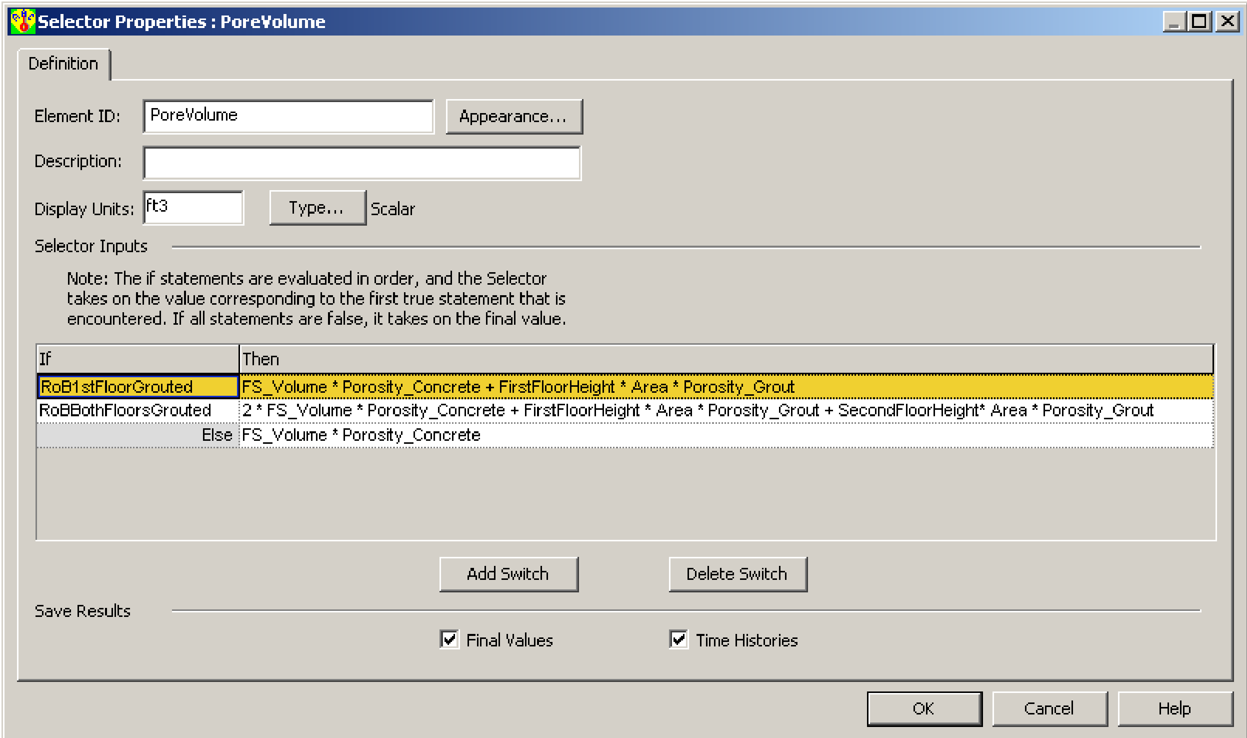


Figure 4-24 Example Pore volume calculation

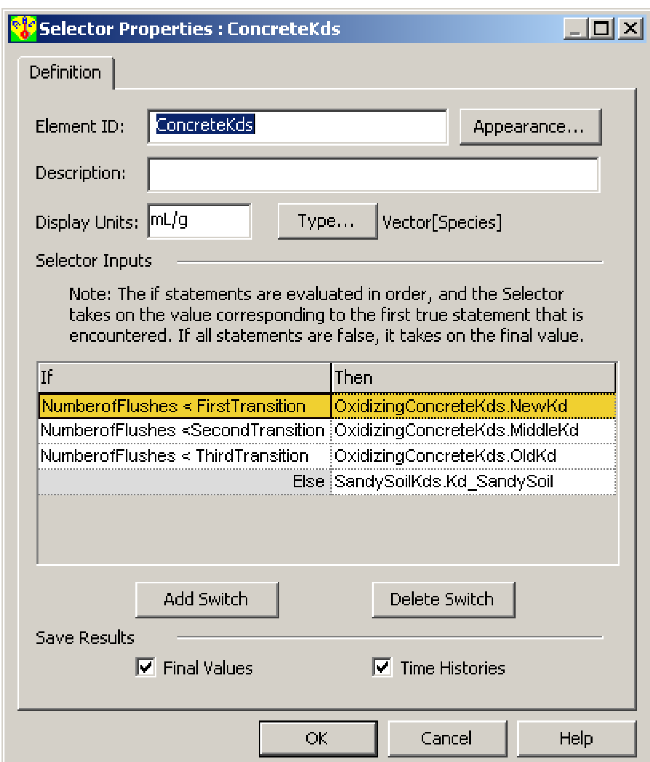


Figure 4-25 Flow dependent K_d determination example

4.4.7.3.11 *Dose* Subsystem container

This subsystem contains the dose/MCL/PRG calculations. It is described in detail in (Perona et al, 2009) so only germane modifications will be discussed in this section. The dose module was designed so that it could be used as a "drop-in" subsystem to any model (assuming the species lists match). It's only connection with the rest of the model is the concentrations passed to it by the transport calculation. In this section, the hierarchical construct heretofore used will be forsaken as the layers become too deep. The top level of the Dose subsystem is shown in Figure 4-26.

- *AssessmentPointx_conc* Expression element: is a vector by *Species* which gets the appropriate concentrations and converts them mass to activity.
- *InputConc_x* Expression element: combines the *AssessmentPointx_conc*s into a matrix of *Species* by *AssessmentPoint* as shown in Figure 4-27. These matrices are passed into *Dose_Module* . For example, in *Dose_Module InputConc_DrinkWater* is converted from *Species* to *DoseSpecies* by Data element *DoseSpecies_DrinkingWater.*

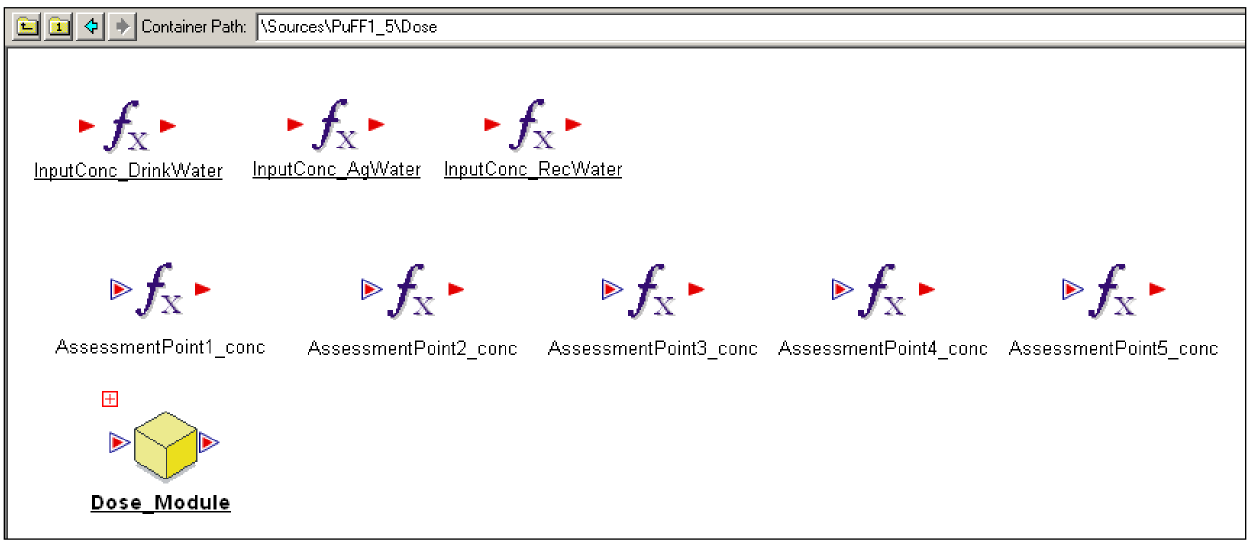


Figure 4-26 Top level *Dose* Subsystem

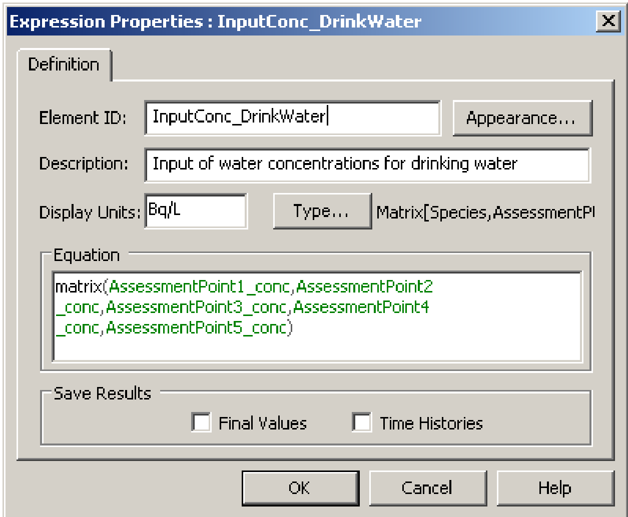


Figure 4-27 Creation of dose water concentration matrix

4.4.7.3.12 *Dose_Module* Container

This contains the dose/MCL/PRG calculations. Other than container *MCL_Comparisons*, the only changes to this container (and sub-containers) were expanding what were vectors by *Species* to matrices *Species* by *AssessmentPoint.*

4.4.7.3.13 *MCL_Comparisons* Container

This container provides the output of most interest to ACP and the comparison to the reference standards provided in Table 3-10 and Table 3-11. Extensive comments regarding evaluations of PA parameters are holdovers from previous analyses. Unfortunately, this text is not very germane to the analysis requested by ACP. To alleviate some of this confusion, *Outputs* container (see Section 4.4.8 provides a summary of outputs of interest. Following are the items of interest for this analysis.

- *Radium_MCL* Data element: the radium MCL of 5 pCi/L
- *Radium_Conc* Expression element: a vector by *AssessmentPoint* of the sum of ^{226}Ra and ^{228}Ra concentrations
- *Radium_Conc_Max* Extrema element: a vector by *AssessmentPoint* of the maximum *Radium_Conc* during a realization
- *NetAlpha_MCL* Data element: the alpha MCL of 15 pCi/L
- *NetAlpha_Fraction* Data element: a vector by Dose Species of the alpha branching fractions
- *ApplyAlphaMask* Container: picks the alpha's of interest for this analysis
    - *NetAlphaMask* Data element: a vector by *DoseSpecies*, 0 if not a species of interest, 1 if of interest

- *Alpha*X Expression element: a vector by *DoseSpecies* for each assessment point (see Figure 4-28)

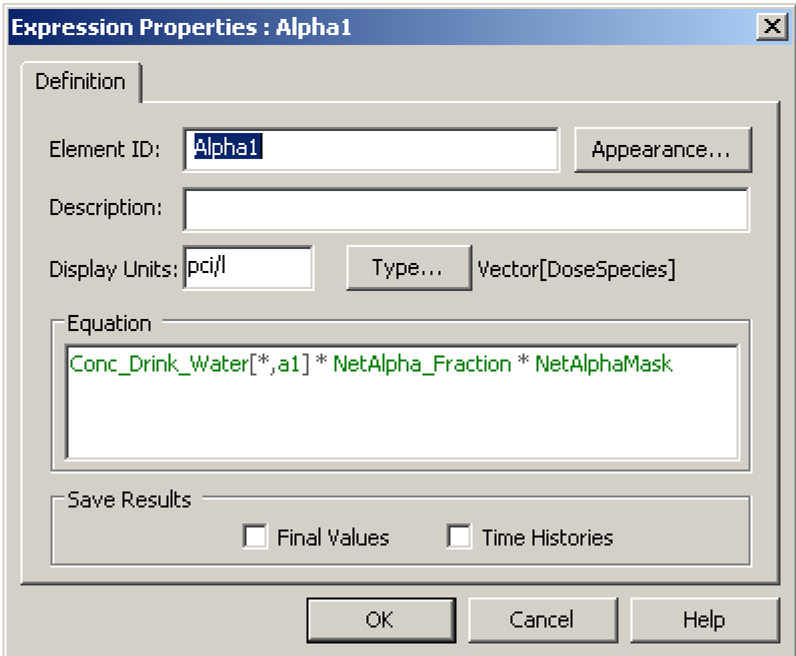


Figure 4-28 Alpha Concentration Calculation

- *NetAlpha_Conc_byRad* Expression element: a matrix of *DoseSpecies* by *AssessmentPoint* made by combining the *Alpha*X's from above giving the drinking water concentration of net alpha (see Figure 4-29)

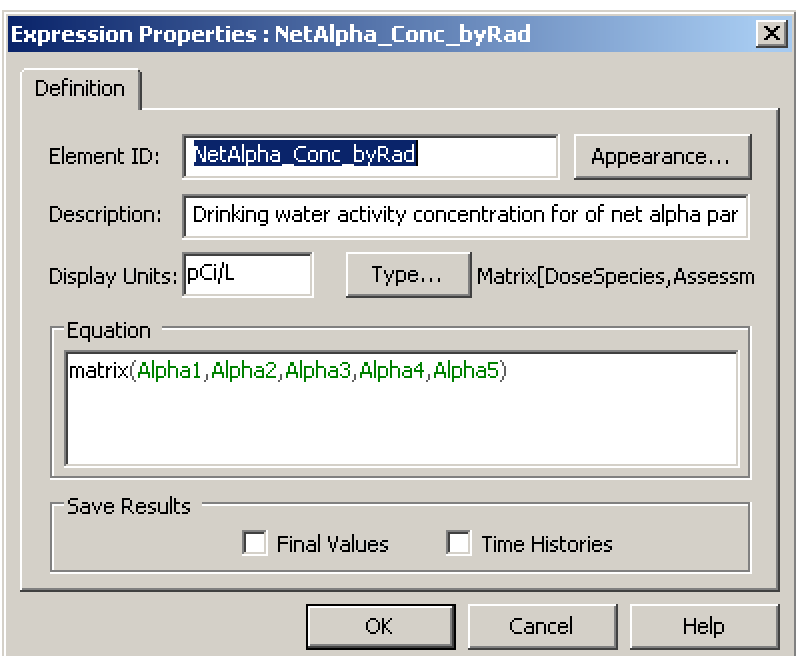


Figure 4-29 Net Alpha Concentration matrix

- *BetaGamma_MCL* Data element: the beta/gamma MCL of 4 mREM/yr. Table 3-10 shows Pa-233 as the only beta/gamma of interest.
- *BetaGamma_DCF* Data element: vector by DoseSpecies of the dose conversion factors for beta/gamma. In order to keep the previous construct of the dose module, a DCF had to be calculated in order to be consistent with the methodology used to determine the MCL. Table 3-10 gives an MCL of 300 pCi/L as equivalent to 4 mREM/yr for Pa-233. Dividing the MCL by the dose equivalent gives a DCF of 0.01333 (mREM/yr)/(pCi/L).
- *ApplyBGMask* Container: the same functionality as *ApplyAlphaMask* but to beta/gamma
- *BetaGamma_Dose_byRad* Expression element: a matrix of *DoseSpecies* by *AssessmentPoint*
- *Total_BetaGamma_Dose* Expression element: a vector by *AssessmentPoint* of the columnar sum of *BetaGamma_Dose_byRad* . In this case, with there being only one beta/gamma species *BetaGamma_Dose_byRad* and *Total_BetaGamma_Dose* give the same result.
- *Total_BetaGamma_Dose_Max* Extrema element: a vector by *AssessmentPoint* giving the maximum value of *Total_BetaGamma_Dose* for a realization.
- *Uranium_MCL* Data element: a vector by *Uranium* of the three uranium MCLs shown in Table 3-10 in μg/L.
- *U234_Isotope_conc* Expression element: a vector by *AssessmentPoint* of ^{234}U concentrations
- *U235_Isotope_conc* Expression element: a vector by *AssessmentPoint* of ^{235}U concentrations
- *U238_Isotope_conc* Expression element: a vector by *AssessmentPoint* of ^{238}U concentrations
- *PRGs* Data element: a vector by *DoseSpecies* of the PRGs given in Table 3-10.
- *PRG_Max* Extrema element: as PRGs are given in terms of concentration, a matrix of *DoseSpecies* by *AssessmentPoint* of *Conc_Drink_Water* maxima.
- *PRG_Compare_A*x Expression element: PRGs are different for each radionuclide so an easy method to assess if any PRG were exceeded was desired. A vector by *DoseSpecies* comparing concentrations at an assessment point to the PRGs. If a PRG is exceeded the element is set to 1, otherwise it is set to zero (see Figure 4-30).
- *PRG_over_1_A*x Array View element: provides a visual representation of the results of *PRG_Compare_A*x (see Figure 4-31). An exceedance occurred if a bar's value is one. Since it is difficult to tell which radionuclide exceeded its PRG, one should click on the "Table View" button and do a quick scan to see which radionuclide(s) did exceed the PRGs.
- *Pb_Conc* Data element: a vector by *AssessmentPoint* of elemental lead concentrations
- *Pb_MCL_Comp* Expression element: a vector by *AssessmentPoint* of *Pb_Conc* divided by *Pb_MCL*. If a result is greater than 1 then the MCL was exceeded at the assessment point.
- *PCB_Conc* Data element: a vector by *AssessmentPoint* of elemental lead concentrations.

- *PCB_MCL_Comp* Expression element: a vector by *AssessmentPoint* of *PCB_Conc* divided by *PCB_MCL*. If a result is greater than 1 then the MCL was exceeded at the assessment point.

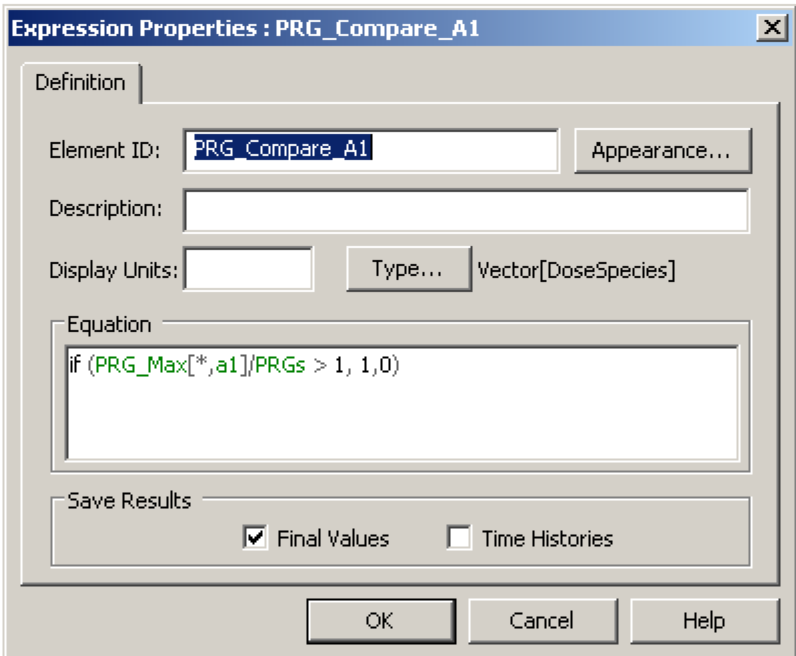


Figure 4-30 PRG comparison at an assessment point

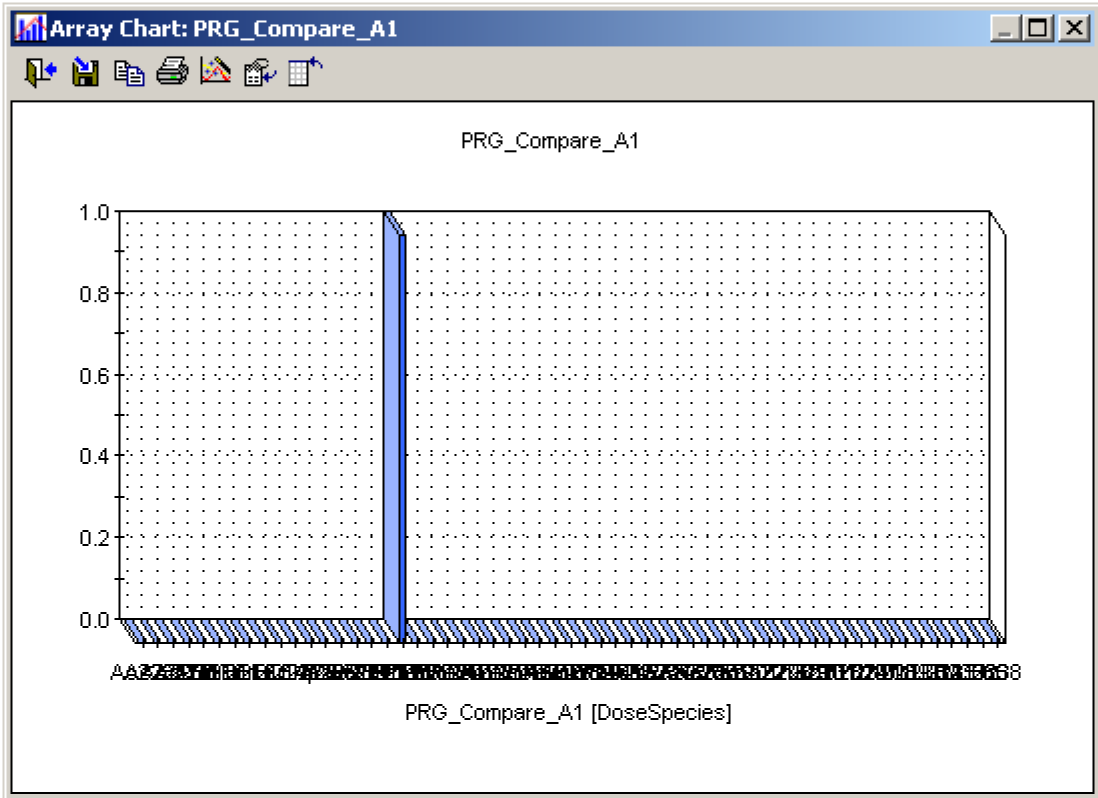


Figure 4-31 Visual representation of PRG exceedance

4.4.7.4 Puff6_9 Subsystem container

This is the same as *Puff1_5* subsystem except that data specific to PuFF cells 6-9 are used. These data are source dimensions, scenario flags, and inventory.

4.4.7.5 ABL Subsystem container

This is the same as *Puff1_5* subsystem except that data specific to the ABL are used. These data are source dimensions, scenario flags, and inventory.

4.4.7.6 RoB Subsystem container

This is the same as *Puff1_5* subsystem except that data specific to the RoB are used. These data are source dimensions, scenario flags, and inventory.

4.4.7.7 SandFilter Subsystem container

This is the same as *Puff1_5* subsystem, except that data specific to the sand filter are used. These data are listed below.

- *PoreVolume* Selector element: pore volume is based on either floor slab thickness plus grout thickness or floor slab thickness only (in *SandFilterFlow* container).
- *GroutThickness* Data element: thickness of the grout, used by *PoreVolume* (in *FlowDependentKds* container).
- *WasteThickness* Stochastic element: the waste thickness, defined as the thickness of the sand layer, is known. The element is defined by a Discrete distribution of a single value.

4.4.7.8 CombinedSources Subsystem container

Because the model is based on a linear K_d model, a simple multiplier can be used to scale the results. In this case the multiplier is an area ratio, the ratio of the source to 235-F's total footprint. Note that this multiplier does not apply to the sand filter. Also, even though the sand filter is down-gradient of the 235-F building it is included in Assessment Point 1. The top level of the subsystem is shown in Figure 4-32. As of this writing only the three assessment points of most interest have been coded. At Assessment Points 1 and 2 the interest is in MCLs/PRGs. At Assessment Point 3 the interest is in dose. All the elements shown in Figure 4-33 are calculated similarly as illustrated by the *RaMCLComp* expanded element. Container *AP1* and Container *AP2* are the same except that they do not include the water dose elements.

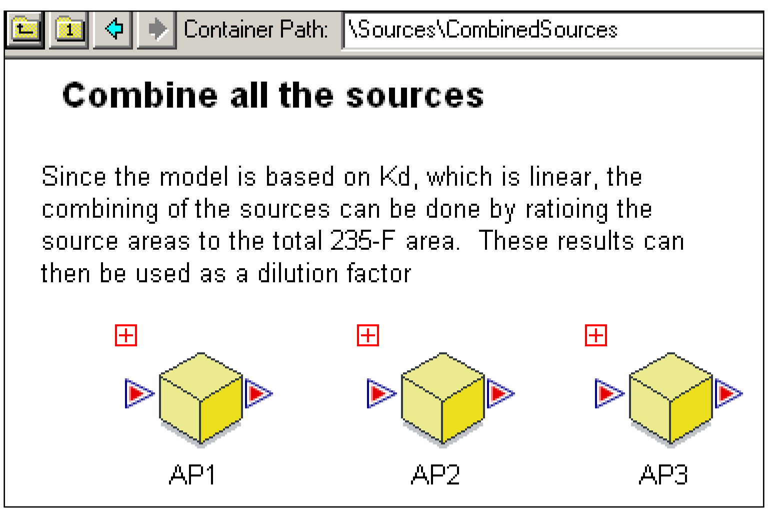


Figure 4-32 *CombinedSources* Top Level

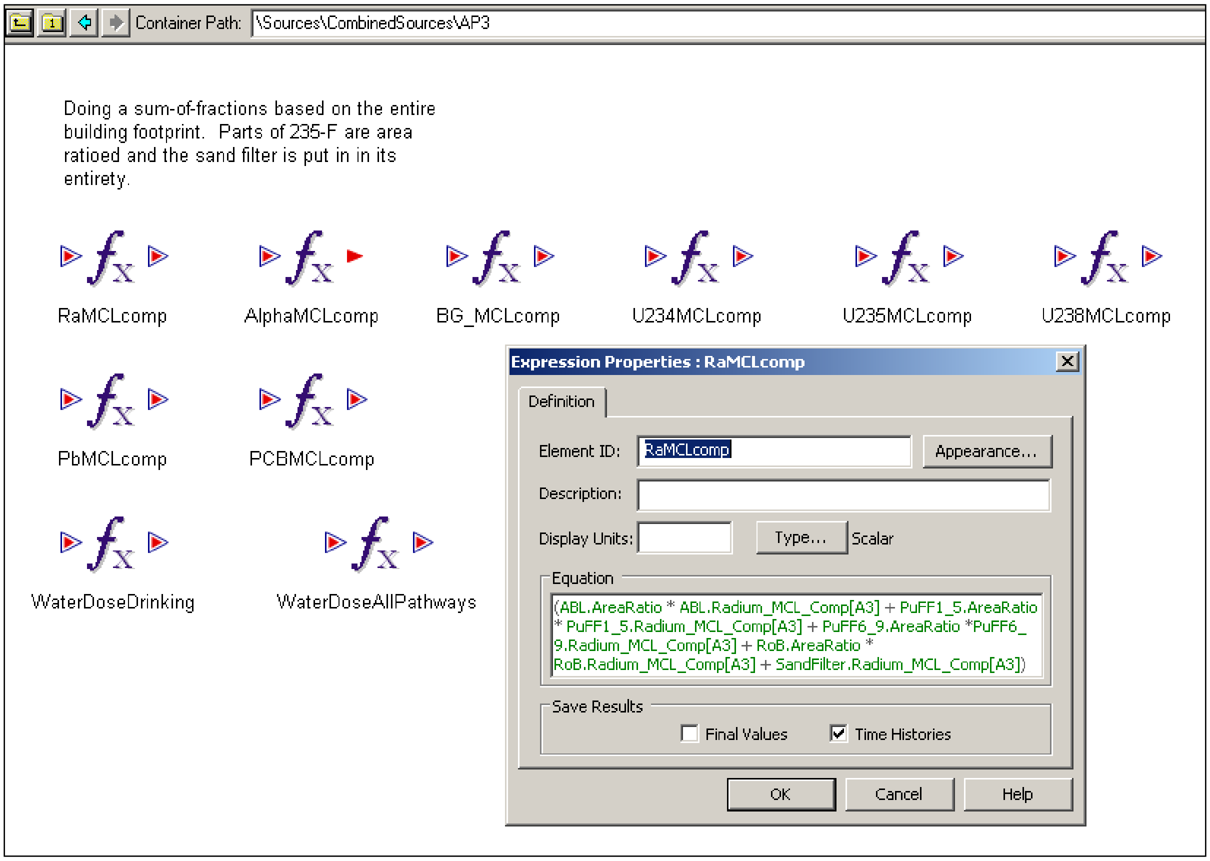


Figure 4-33 Combined source example

4.4.7.9 DumpOnGround Subsystem

This is truly a standalone subsystem. Its purpose is to simulate the disappearance of the 235-F building structure with all the contaminants being deposited on the ground in the former buildings footprint. This is thought to represent a "worst" case in that no engineered barriers are available to contain the waste. The only difference is that its waste zone consists of only a clayey soil layer rather than a layer of contaminants intermingled with cement above the floor slab.

4.4.8 *Outputs* Container

This contains the outputs thought to be most commonly used. Radium will be used for the denouement, all other are computed similarly. The radium outputs will be explained. The outputs for the other components of interest are basically the same.

- *RaMCL_fractions_A1* Data element: a vector by *Outs*, it is essentially the components of the totals from *CombinedSources* in a format so that the individual contributions can be assessed. For example, the PuFF1_5.Radium_MCL_Comp[A1] has already been normalized so this is an area weighted fraction.

- *RaMCL_A1* Expression element: multiplies the fractions by the MCL.
- *RaMCL_5pci_plot_A1* Time History element: displays the results of *RaMCL_A1*. Only the last realization will be displayed for a stochastic run.
- *Ra_MCL_Median_Values* Time History element: displays the median values of *RaMCL_A1* from a stochastic run. Although it looks like *RaMCL_5pci_plot_A1* it uses a different Style which allows the Median to be shown.
- *RaMCL_SOF_A1* Time History element: shows the fractions of the MCL. If any value is greater than 1, the limit has been exceeded. This is the same as *RaMCL_5pci_plot_A1* scaled by the MCL.

4.4.9 *SensitivityAnalysis* Container

This contains the elements necessary for GoldSim to perform its sensitivity analysis (Figure 4-34). The independent variables contained in *stochastics* will be the same regardless of what dependent variable is selected. The sensitivity analysis will present results regarding that independent variable. Presently the model contains the two parameters which exceed their respective dose/MCL/PRG limits. Although, as shown in Section 5.4.1, radium actually peaks at Assessment Point 3 rather than Assessment Point 1, running the sensitivity analysis for Assessment Point 1 gives an accurate indication of the importance of the independent variables to the dependent variable. It should be noted that "final" values are saved at 1000 and 10,000 years and the end of the simulation (i.e. 100,000 years). Sensitivity analysis can be run for any time for which final values are saved.

- *stochastics* Multi Variate element: contains all stochastic elements used in the transport portion of the model as the independent variables (the Input Variables of the element). It does not contain the stochastic elements of the *Dose* subsystems.
- *Ra_PuFF1_AP1* Maxima element: a dependent (output) variable used by *stochastics*.
- *Pb210Max_PuFF1_AP1* Expression element: a dependent (output) variable used by *stochastics.*

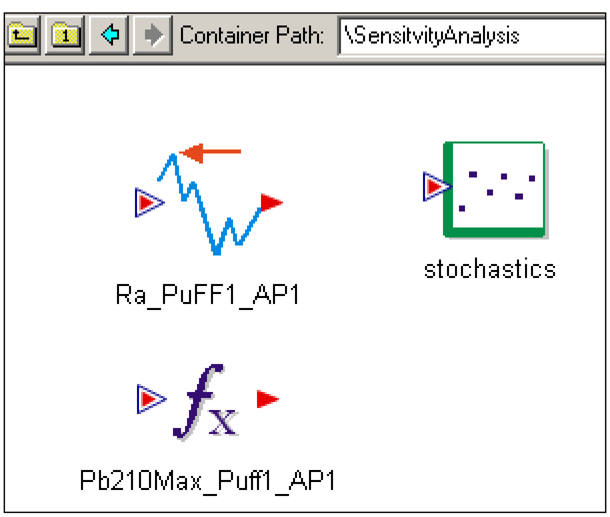


Figure 4-34 *SensitivityAnalysis* Container

4.4.10 *DashBoards* Container

The dashboard (Figure 4-35) is designed to provide a convenient and graphical way to set up the scenarios the model is capable of running. In the GoldSim Player version of the model it is the user interface with the model. The dashboard does some input checking so that conflicting scenarios are not allowed. One rather irritating feature of GoldSim is that the checkboxes remember their last setting. Even if the default option is set in the element definition, it is ignored. One must always be vigilant of which boxes are checked. The Player version opens to this as the splash screen.

- *Grout PuFF East* Checkbox: sets the flag for grouting of PuFF cells 1-5. Checked is True.
- *Grout PuFF West* Checkbox: sets the flag for the grouting of PuFF cells 6-9. Checked is True.
- *Grout ABL*: sets the flag for the grouting of ABL. Checked is True.
- *Grout 1st floor* Checkbox: sets the flag for grouting of the entire first floor (*PuFF1-5, PuFF6-9, ABL, RoB*) regardless of the individual source flags. Checked is True.
- *Grout Entire Building* Checkbox: set flag for grouting the first and second floors regardless of the individual source flags. Checked is True.
- *Decon PuFF Cells 1-5* Checkbox: sets the flag which activates the corresponding Input Edit Box. Allows for the reduction of contaminants in PuFF Cells 1-5. Checked is True.
- Input Edit Box: allows for values 0-1. It is the fraction of waste removed from a source.
- *Decon PuFF Cells 6-9* Checkbox: same as above for PuFF cells 6-9.
- *Decon ABL* Checkbox. Same as above for ABL.
- *Run* Button: runs the simulation.
- *go to Results* Hyperlink: takes the user to the *Outputs* container.
- *go to PuFF1 flow* Hyperlink: takes the user to the *VZFlow* container of *PuFF1_5.*

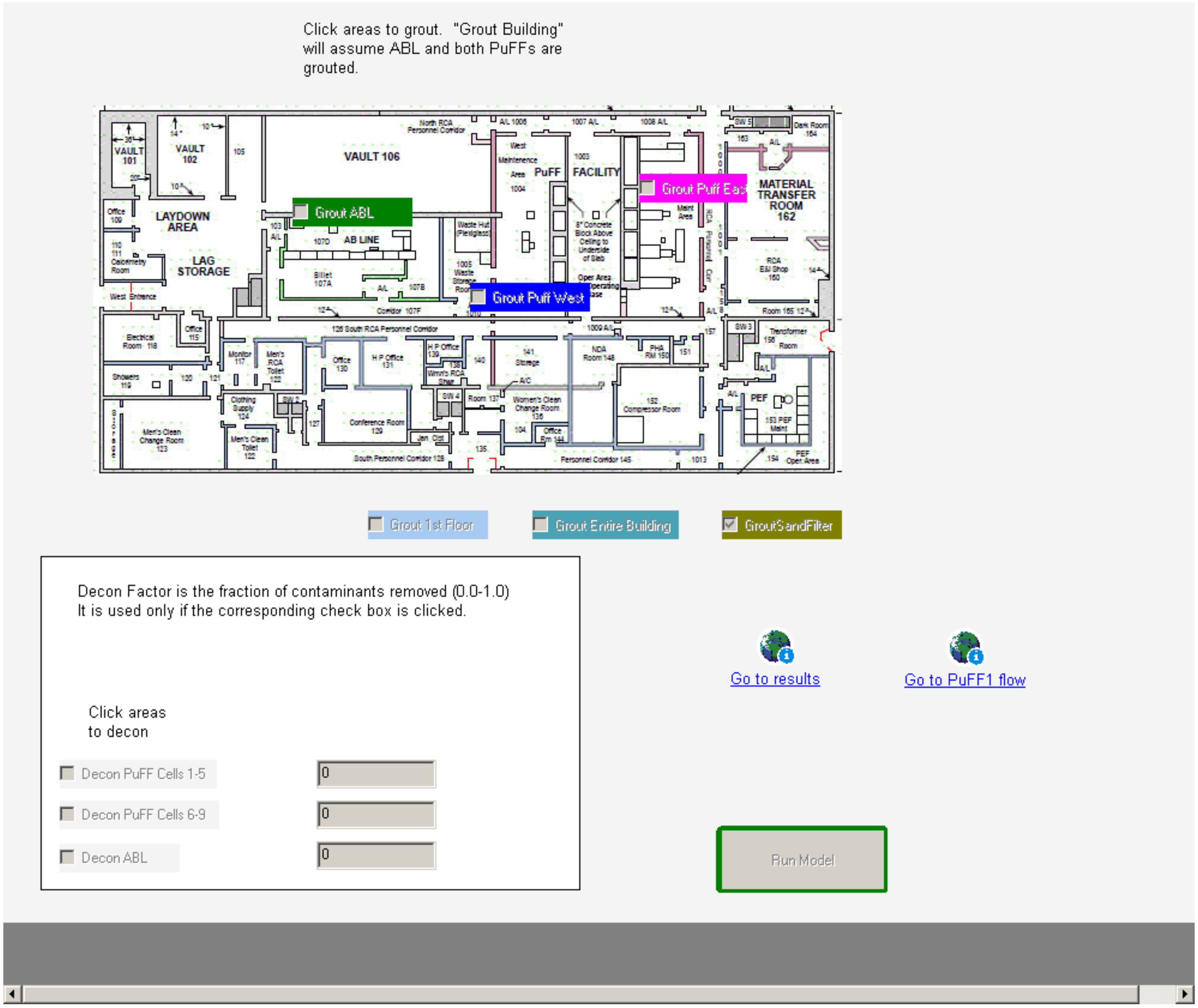


Figure 4-35 Dashboard

4.4.11 Modeling Sensitivities

Two modeling sensitivities were assessed, time steps and saturated zone noding

4.4.11.1 Noding Sensitivity

The noding sensitivity was done to assess how many Cell Pathway cells are needed to achieve an accurate solution. It was done by comparing a Pipe element's solution to an Aquifer element's solution. A Pipe element uses an analytic solution so its result is taken to be the "truth". The dispersion used for the Pipe element is the rule-of-thumb value of 1 percent of the length. Pipe elements give a slower solution and depending on boundary conditions can give inaccurate results so it is recommended to use Cell Pathway elements rather than Pipe elements in most cases.

Figure 4-36 shows that 20 cells do not provide a sufficiently good comparison for the saturated zone length of 3120 ft. Figure 4-37 shows that the 50 cells provide a good match.

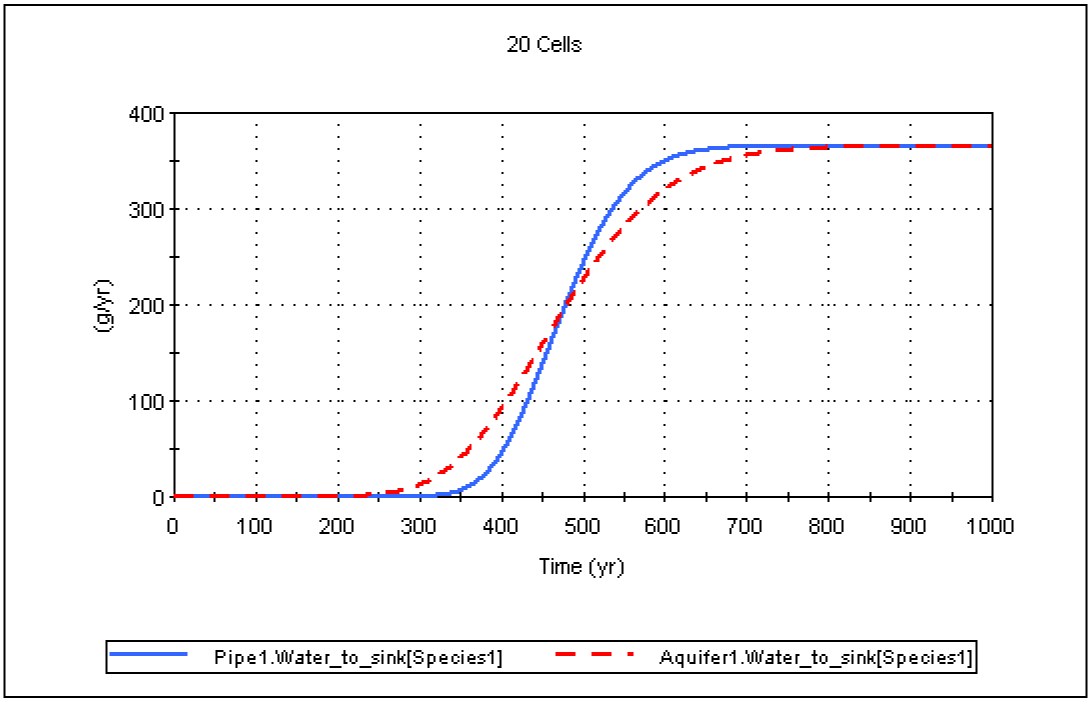


Figure 4-36 Saturated Zone 20 Cells

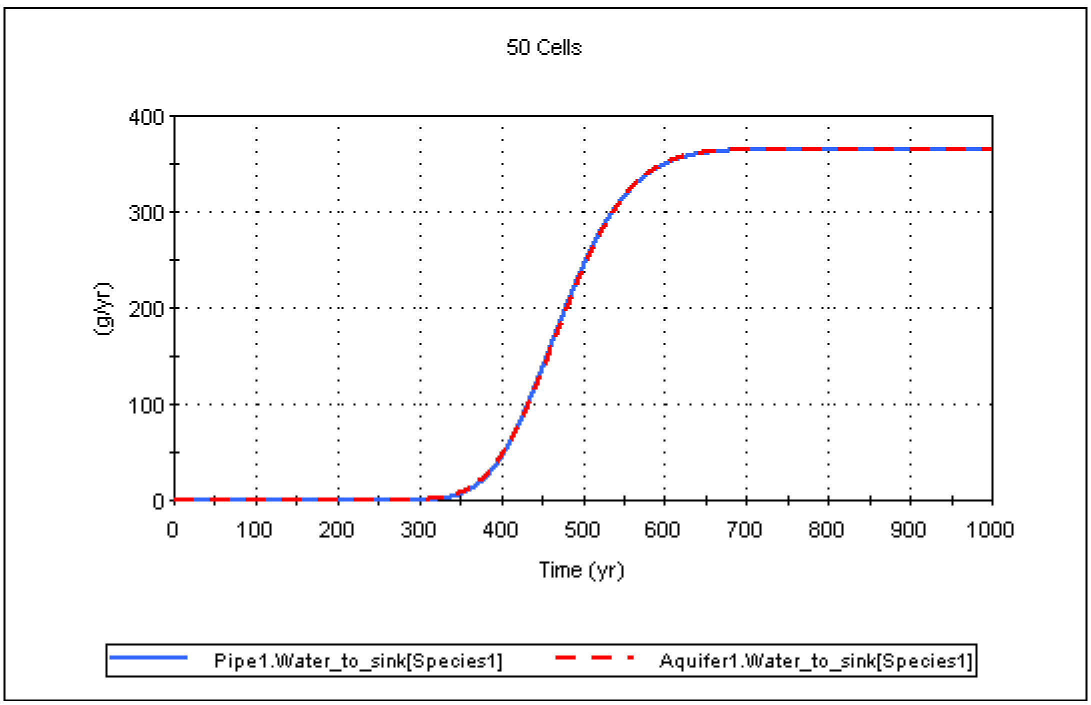


Figure 4-37 Saturated Zone 50 Cells

Figure 4-38 shows the results of using 20 cells for the vadose zone length of 70 ft. Figure 4-39 shows that 50 cells provides a good match. I found it curious that both saturated and vadose zones are convergent at 50 cells. I believe that has to do with the definition of the dispersion, which is a linear function of the pathway length.

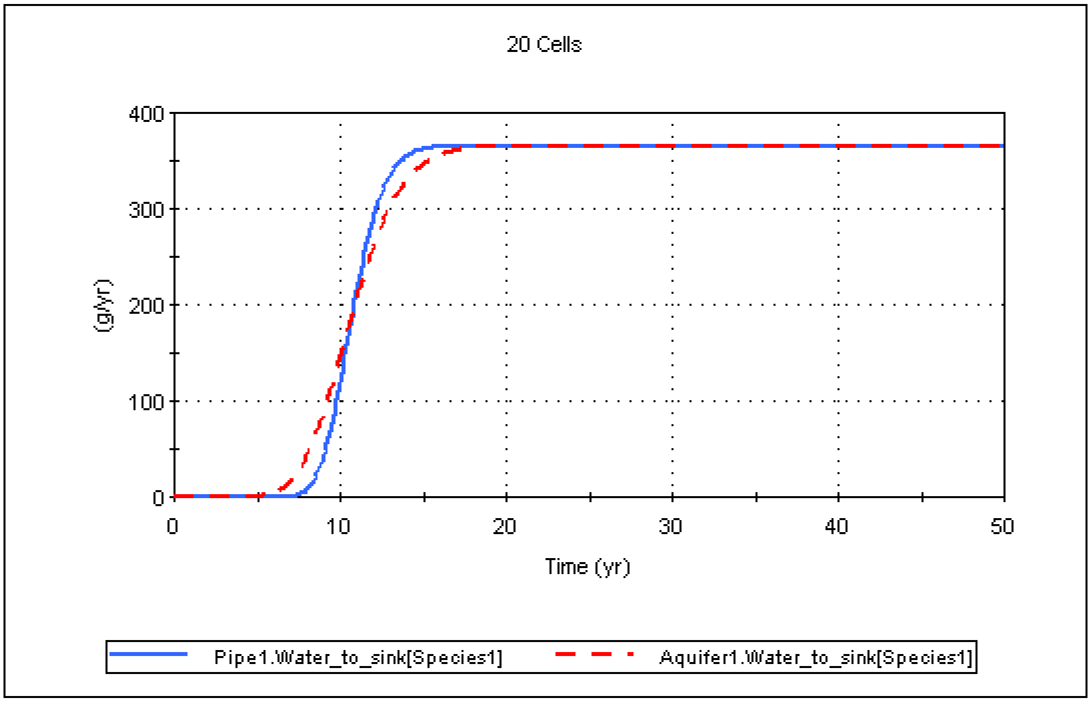


Figure 4-38 Vadose Zone 20 cells

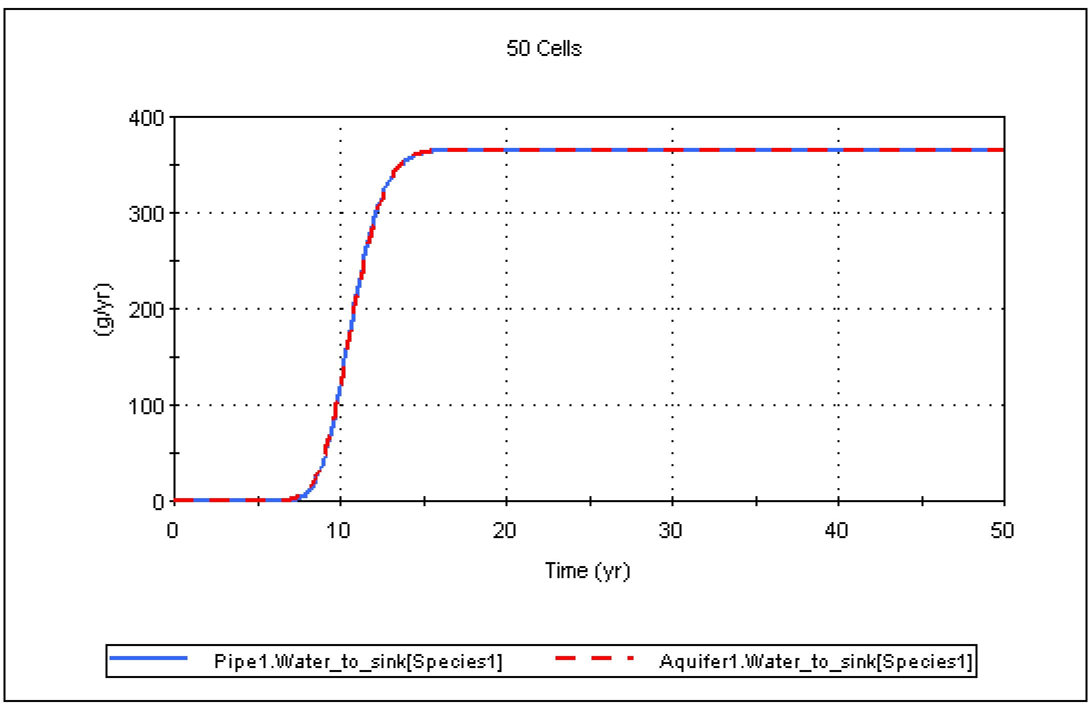


Figure 4-39 Vadose Zone 50 cells

4.4.11.2 Time Step Sensitivity

The time step sensitivity was accomplished by looking at the mass error of a stable species, in this case PCB. The mass error is calculated in *Sources\PuFF1_5\SourceLayer*.

MassOut Integrator element: integrates the mass leaving the floor slab
PCBMassError Expression element: *Massout* divided by the initial PCB mass.

All the PCB has left the source zone by 5000 years so the final value of *PCBMassError* gives the final mass error. By adjusting the time steps a mass error of about 0.3% was obtained which is considered more than sufficient for this analysis.

The time steps used for all cases are shown in Figure 4-40.

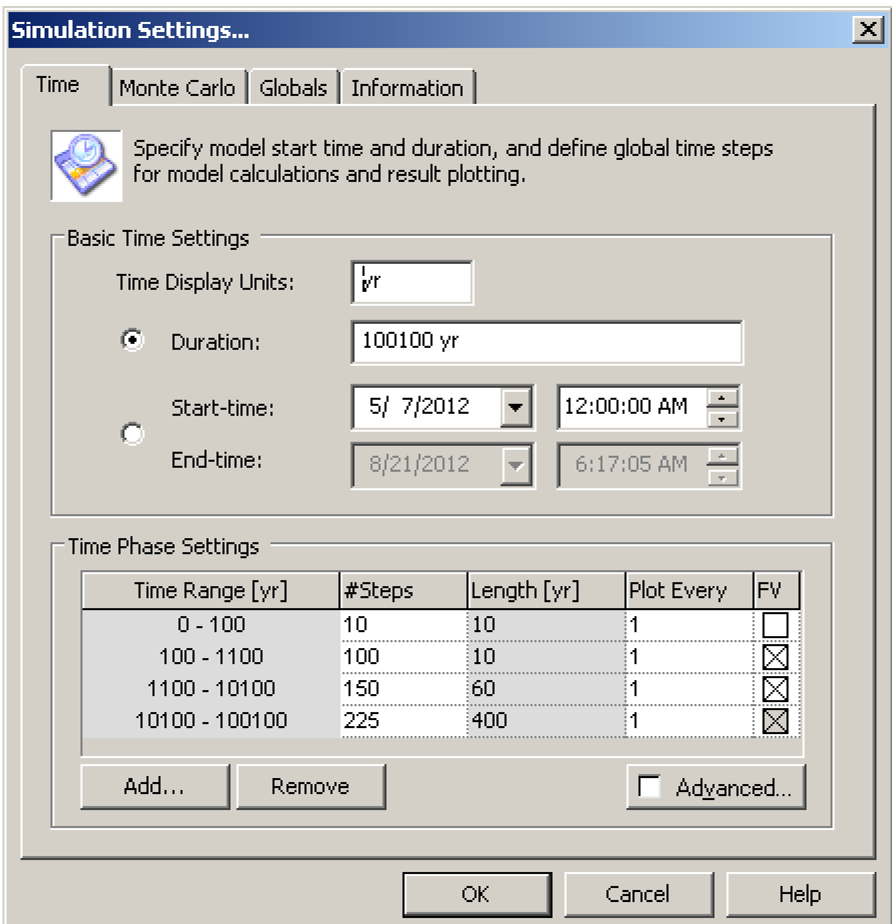


Figure 4-40 Time steps used for runs

Important: all calculations in this document are carried out at high precision. Figure 4-41 shows this setting which is found in Model\Options of the main menu bar.

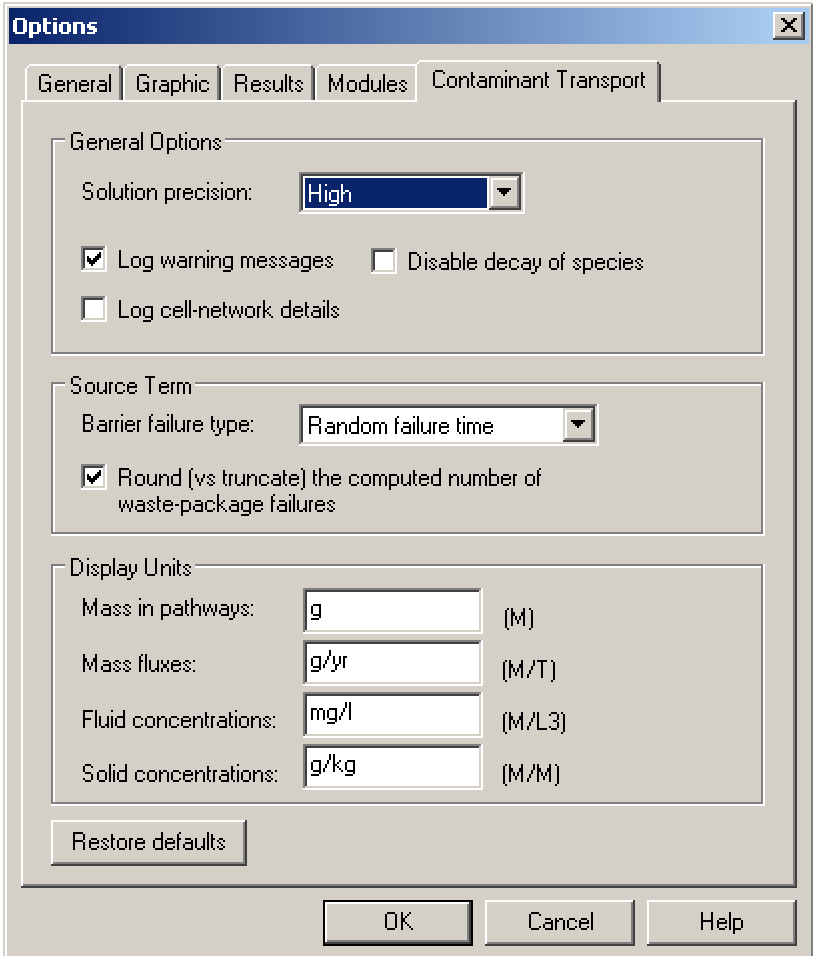


Figure 4-41 Setting Solution Precision to High

5.0 RESULTS

5.1 RESULTS SUMMARY

Table 5-1 and Table 5-2 provide a summary of the results of the MCLs and PRGs while Table 5-3 provides a summary of the dose. Details for the various scenarios can be seen in Appendices A-I. The generic (inventory on ground surface) and precipitation (infiltration equated to the annual average precipitation of 49.14 inches/year) scenarios are viewed as extreme scenarios for comparative purposes only. The results show that some MCLs and PRGs are exceeded at the edge of the building (Assessment Point 1) for all scenarios except those with a sufficient amount of inventory removed. A very interesting result is that grouting has basically no effect on the contaminant concentration and is actually deleterious. No limits were exceeded at Upper Three Runs creek (Assessment Point 2).

Only three limits were exceeded in the first 100,000 years at the edge of the building (Assessment Point 1) in any of the 1,000 realizations, the Radium (Ra-226 + Ra-228) MCL, the Alpha MCL, and the Pb-210 PRG. All of these are members of the Pu-238 decay chain. For convenience, the Pu-238 decay chain is shown in Figure 5-1.

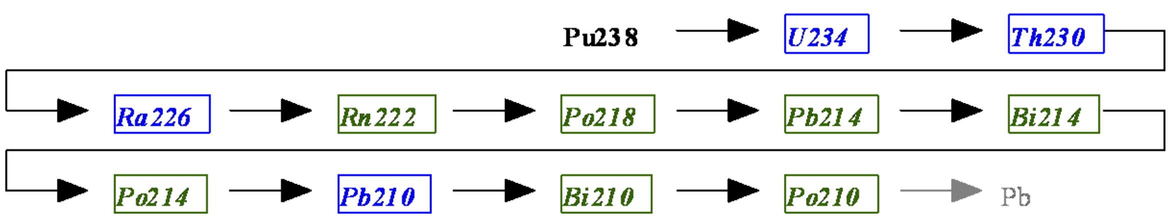


Figure 5-1 Pu-238 Decay Chain

The only contaminant which did not peak within 100,000 years was elemental lead. A deterministic run for elemental lead was run beyond 100,000 years in order to determine its peak. The imputed peak mean of the elemental lead concentration approached 40% of its MCL at 186,000 years at the edge of the building (Assessment Point 1).

Table 5-1 and Table 5-2 report results for each MCL and the only PRG which was exceeded (i.e. Pb-210). Each limit has two columns. The first is the fraction of the 1,000 realizations which exceeded the limit (this can be viewed as the probability of exceeding the limit). The second column is the Median value of the variable. Only the Pb-210 PRG is shown, because none of the other PRGs were exceeded in any of the 1,000 realizations (see Table 3-10 for a listing of the other radionuclides with PRGs that were not exceeded). Median values which exceed the limit are highlighted. Table 5-3 shows that the DOE dose limit (i.e. 25 mrem/yr) was not exceeded for any of the scenarios or realizations.

The results are based on 1000 realizations and the Figure 3-17 aquifer flow path cross-section emanating from the entire 235-F footprint, unless otherwise notated.

Table 5-1 Summary at Edge of Building 235-F (Assessment Point 1) Comparisons with Limits over 100,000 years

D&D Scenario	Ra-226+Ra-228[1] (5 pCi/L)		Alpha[3] (15 pCi/L)		Beta-Gamma (4 mrem/yr)		U-234 (10 pCi/L)		U-235 (0.47 pCi/L)		U-238 (10 pCi/L)		Lead[8] (15 ug/L)		PCBs (0.5 ug/L)		Pb-210 PRG[6] (0.06 pCi/L)	
	Frac[7]	Median[4]	frac	Median[4]	frac	Median[4]	frac	Median[4]	frac	Median[4]	frac	Median[4]	frac	Median[4]	frac	Median[4]	frac	Median[4]
Generic[5]	-	**24.6**	-	12.9	-	0.04	-	**11.1**	-	4e-4	-	7e-8	-	-	-	-	-	**1.7**
No action	0.88	**9.2**	0.2	6.1	0	0.01	0	0.006	0	2.E-05	0	1.E-08	0	3.5	0	6.00E-05	0.54	0.07
Grout PuFF cells 1-5	0.9	**9.2**	0.18	6.1	0	0.01	0	0.006	0	2.E-05	0	1.E-08	0	3.5	0	6.00E-05	0.54	0.07
Grout PuFF cells 6-9	0.89	**9.2**	0.2	6.1	0	0.01	0	0.006	0	2.E-05	0	1.E-08	0	3.5	0	6.00E-05	0.56	0.07
Grout 1st floor	0.9	**9.1**	0.17	4.2	0	0.01	0	0.006	0	2.E-05	0	1.E-09	0	3.5	0	6.00E-05	0.56	0.07
Grout Entire building	0.9	**9.1**	0.17	4.2	0	0.01	0	0.006	0	2.E-05	0	1.E-09	0	3.5	0	6.00E-05	0.54	0.07
Decon[2] 60%	0.37	4.3	0.10	5.0	0	0.01	0	0.005	0	9e-6	0	6e-9	0	3.5	0	6.00e-05	0.27	0.03
Decon[2] 75%	0.14	3	0.07	4.6	0	0.01	0	0.005	0	7.E-06	0	5.E-09	0	3.5	0	6.00E-05	0.11	0.023
Decon[2] 95%	0	1.3	0.005	4	0	0.01	0	0.005	0	3.E-06	0	2.E-09	0	3.5	0	6.00E-05	0.0	0.009
Precipitation	0.64	**5.9**	0.44	13.2	0	0.03	0	0.004	0	1.9e-6	0	9.1e-10	0.04	8.0	0	4e-08	0.40	0.048

Notes for Table 5-1:

1 Limits for each standard are provided in parenthesis below the standard. The first column for each standard (**Frac**) shows the fraction of realizations which exceeded the limit. The second column of each limit shows the Median value from the stochastic analyses (except for the generic scenario, which was performed as a deterministic simulation, where the maximum value is shown).

2 The Decon scenarios refer to the amount of contaminant removed from PuFF cells 1-5, with no other action.

3 Primary contributors to peak are Th-230 (≈90%) and Po-210 (≈10%).

4 Median of the maximum values of the realizations. Highlighted values exceed their standard.

5 Maximum results of a deterministic simulation.

6 Pb-210 is the only radionuclide to exceed its PRG in any of the simulations.

7 Fraction of realizations exceeding the limit. For example, for the "No Action" case 883 realizations out of the 1,000 realizations exceeded the Radium MCL (5 pCi/L) resulting in a fraction of 0.88.

8 The imputed peak mean of the elemental lead concentration approached 40% of its MCL at 186,000 years.

Table 5-2 Summary at Upper Three Runs (Assessment Point 2) Comparisons with Limits over 100,000 years

D&D Scenario	Ra-226+Ra-228[1] (5 pCi/L)		Alpha[3] (15 pCi/L)		Beta-Gamma (4 mrem/yr)		U-234 (10 pCi/L)		U-235 (0.47 pCi/L)		U-238 (10 pCi/L)		Lead (15 ug/L)		PCBs (0.5 ug/L)		Pb-210 PRG[6] (0.06 pCi/L)	
	Frac[7]	Median[4]	frac	Median[4]	frac	Median[4]	frac	Median[4]	frac	Median[4]	frac	Median[4]	frac	Median[4]	frac	Median[4]	frac	Median[4]
Generic[5]	-	3e-3	-	5e-4	-	2e-6	-	2e-4	-	1e-8	-	1e-12	-	-	-	-	-	
No action	0	2e-4	0	7e-4	0	8e-8	0	8e-6	0	2e-9	0	2e-13	0	1e-14	0	3e-12	0	2.7e-6
Grout PuFF cells 1-5	0	2e-4	0	7e-4	0	8e-8	0	8e-6	0	2e-9	0	2e-13	0	1e-14		3e-12	0	2.7e-6
Grout PuFF cells 6-9	0	2e-4	0	7e-4	0	8e-8	0	8e-6	0	2e-9	0	2e-13	0	1e-14	0	3e-12	0	2.7e-6
Grout 1st floor	0	2e-4	0	7e-4	0	3e-8	0	8e-6	0	2e-9	0	2e-13	0	1e-14	0	3e-12	0	2.7e-6
Grout Entire building	0	2e-4	0	7e-4	0	5e-8	0	8e-6	0	2e-9	0	2e-13	0	1e-14	0	3e-12	0	2.6e-6
Decon[2] 60%	0	1.5e-4	0	4.5e-4	0	7.6e-8	0	4.8e-6	0	1.3e-9	0	1.3e-13	0	1e-14	0	3e-12	0	1.7e-6
Decon[2] 75%	0	1e-4	0	4e-4	0	7e-8	0	4e-6	0	1e-9	0	1e-13	0	1e-14	0	3e-12	0	1.4e-6
Decon[2] 95%	0	1e-4	0	3e-4	0	7e-8	0	3e-6	0	1e-9	0	8e-14	0	1e-14	0	3e-12	0	1.0e-6
Precipitation	0	2e-4	0	7e-4	0	9e-8	0	4e-3	0	2e-9	0	9e-10	0	2e-11	0	4e-11	0	2.6e-6

Notes for Table 5-2

1 Limits for each standard are provided in parenthesis below the standard. The first column for each standard (**Frac**) shows the fraction of realizations which exceeded the limit. The second column of each limit shows the Median value from the stochastic analyses (except for the generic scenario, which was performed as a deterministic simulation, where the maximum value is shown).

2 The Decon scenarios refer to the amount of contaminant removed from PuFF cells 1-5, with no other action.

3 Primary contributors to peak are Th-230 (≈90%) and Po-210 (≈10%).

4 Median of the maximum values of the realizations. No values exceed their standard.

5 Maximum results of a deterministic simulation.

6 Pb-210 is the only radionuclide to exceed its PRG in any of the simulations.

7 Fraction of realizations exceeding the limit. No realizations exceeded the limits at UTR.

Table 5-3 Peak-mean Total Dose at 100 m Down Gradient from Edge of Building 235-F (Assessment Point 3) over 100,000 years (25 mrem/yr limit)

D&D Scenario	Frac[1]	Median
Generic	-	-
No action	0	15.8
Grout PuFF cells 1-5	0	16.0
Grout PuFF cells 6-9	0	15.8
Grout 1st floor	0	16.0
Grout Entire building	0	16.0
Decon 60%	0	7.1
Decon 75%	0	4.5
Decon 95%	0	2.1
Precipitation	0	14.3

Note for Table 5-3
[1] Fraction of realizations exceeding the limit. No realizations exceeded the limit.

Table 5-4 shows the maximum mean (see Section 5.2 as to why the mean is more applicable than the median) values of radium concentrations during three time intervals. This is the mean of the maximum value for each realizations regardless of the time at which it occurs. This shows that the effect of grouting is apparent during the first 1,000 years, but after that its effect is not seen, at least in the first two significant figures. The radium MCL is only exceeded after 10,000 years for those scenarios that do not involve inventory removal and only at the edge of Building 235-F. Table 5-5 shows the maximum mean alpha concentration during the three time periods. Even though a number of realizations exceeded the limit at the edge of the building, except for the extreme and non-physical "Precipitation" case, none of the means exceeded the limit. Table 5-6 shows the maximum mean Pb-210 concentration during the three time periods. The Pb-210 PRG, like the radium MCL, is only exceeded after 10,000 years for those scenarios that do not involve inventory removal and only at the edge of Building 235-F.

Note that a complete suite of all figures for each scenario is in the appropriate appendix.

Table 5-4 Maximum Ra Mean Concentration during 3 Time Intervals

MCL = 5 pCi/L	Edge of 235-F Building (Assessment Point 1) (pCi/L)			Upper Three Runs (Assessment Point 2) (pCi/L)		
D&D Scenario	**0 to 1,000 years**	**1,000 to 10,000 years**	**10,000 to 100,000 years**	**0 to 1,000 years**	**1,000 to 10,000 years**	**10,000 to 100,000 years**
Generic[1]	1.5e-4	4.8	**24.6**[2]	7.3e-19	7.5e-5	2.7e-3
No action	5.8e-3	4.1	**10.4**	1.4e-11	1.5e-5	2.5e-4
Grout PuFF cells 1-5	1.6e-3	4.1	**10.3**	3.8e-12	1.5e-5	2.5e-4
Grout PuFF cells 6-9	5.8e-3	4.1	**10.4**	1.3e-11	1.5e-5	2.5e-4
Grout 1st floor	1.2e-3	4.1	**10.3**	3.4e-15	1.5e-5	2.5e-4
Grout Entire building	4.2e-4	4.0	**10.2**	8.7e-17	1.5e-5	2.3e-4
Decon 60%	1.1e-3	1.8	4.7	2.8e-11	9.5e-6	1.6e-4
Decon 75%	1.7e-3	1.26	3.3	6.2e-12	7.9e-6	1.3e-4
Decon 95%	6.6e-4	0.51	1.4	4.3e-12	6.1e-6	1.0e-4
Precipitation	8.3e-2	5.0	**6.7**	2.7e-10	2.2e-5	2.5e-4

Notes for Table 5-4
1 Deterministic run
2 Values exceeding the 5 pCi/L MCL are highlighted

Table 5-5 Maximum Mean Alpha Concentrations during 3 Time Intervals

MCL =15 pCi/L	Edge of 235-F Building (Assessment Point 1) (pCi/L)			Upper Three Runs (Assessment Point 2) (pCi/L)		
D&D Scenario	**0 to 1,000 years**	**1,000 to 10,000 years**	**10,000 to 100,000 years**	**0 to 1,000 years**	**1,000 to 10,000 years**	**10,000 to 100,000 years**
Generic[1]	12.9	2.1	0.025	2.7e-4	4.6e-4	4.7e-5
No action	2.3	9.1	11.9			
Grout PuFF cells 1-5	2.1	7.8	13.3	4.3e-11	4.5e-5	7.4e-4
Grout PuFF cells 6-9	2.3	9.1	11.9	1.5e-10	4.6e-5	7.4e-4
Grout 1st floor	2.9e-5	5.2	8.4	1.0e-13	4.5e-5	7.4e-4
Grout Entire building	1.2e-5	5.8	9.2	2.8e-15	4.5e-5	1.5e-5
Decon 60%	2.2	6.0	7.3			
Decon 75%	2.2	5.3	6.7	7.0e-11	2.4e-5	3.1e-4
Decon 95%	2.1	4.3	4.6	5.0e-11	1.8e-5	6.3e-6
Precipitation	8.1	**25.1**	**27.9**[2]	2.6e-9	6.8e-5	7.4e-4

Notes for Table 5-5
1 Deterministic run
2 Values exceeding the 15 pCi/L MCL are highlighted

Table 5-6 Maximum Pb-210 Mean Concentrations during 3 Time Intervals

PRG = 0.06 pCi/L	Edge of 235-F Building (Assessment Point 1) (pCi/L)			Upper Three Runs (Assessment Point 2) (pCi/L)		
D&D Scenario	**0 to 1,000 years**	**1,000 to 10,000 years**	**10,000 to 100,000 years**	**0 to 1,000 years**	**1,000 to 10,000 years**	**10,000 to 100,000 years**
Generic[1]	1.8e-6	0.024	**0.125**	1.1e-19	7.6e-7	2.6e-5
No action	6.5e-5	0.040	**0.099**	2.5e-13	1.9e-7	3.2e-6
Grout PuFF cells 1-5	4.0e-5	0.040	**0.098**	6.8e-14	1.9e-7	3.1e-6
Grout PuFF cells 6-9	6.4e-5	0.040	**0.099**	2.5e-13	1.9e-7	3.2e-6
Grout 1st floor	3.8e-5	0.040	**0.098**	7.4e-17	1.9e-7	3.2e-6
Grout Entire building	1.9e-5	0.040	**0.096**	1.6e-17	1.8e-7	3.2e-6
Decon 60%	2.8e-5	0.018	0.044	1.4e-13	1.2e-7	2.0e-6
Decon 75%	1.9e-5	0.012	0.031	1.1e-13	1.0e-7	1.7e-6
Decon 95%	7.4e-6	0.005	0.012	7.7e-14	7.7e-8	1.3e-6
Precipitation	9.3e-4	0.049	**0.063**	4.5e-12	2.9e-7	3.2e-6

Notes for Table 5-6

1 Deterministic run

2 Values exceeding the 0.06 pCi/L PRG are highlighted

5.2 BRIEF STATISTICS DISCUSSION

The results section of this report discusses means, medians, and percentiles. Following is a brief discussion of those concepts and how and why they are appropriate.

As discussed in Section 4.0, the 235-F model was designed to be a stochastic model. Its most meaningful results are viewed best as the conglomeration of individual realizations. Many of the statistical distributions are described by a uniform distribution which means that any value within its limits is equally likely to occur as any other (maximum statistical entropy). This leads to a deterministic run not necessarily being very meaningful, but the statistical description of the results is.

The set A = [0.1, 0.2, 0.3, 0.4, 100] will be used to illustrate the statistics. The mean of the first four elements of A is (0.1 + 0.2 + 0.3 + 0.4) / 4 = 0.25. If the 5th element is included, and can be thought of as a data outlier, the mean is (0.1 + 0.2 + 0.3 + 0.4 + 100) / 5 = 22. The one outlier greatly biases the mean. A more meaningful statistic might be the geometric mean which can account for a spread in the data and not bias it so greatly for outliers. The geometric mean (*g.m.* shown below) for A would be 0.75, better but not great. The first four elements of A give a geometric mean of 0.221… showing that it is not the best descriptor of data which is of the same order of magnitude. Therefore, this report will be referring to the arithmetic mean when the term “mean” is used.

$$\boldsymbol{g.m.} = \left(\prod_{\boldsymbol{i=1}}^{\boldsymbol{n}} \boldsymbol{x_i}\right)^{\boldsymbol{\frac{1}{n}}}$$

The median is given by the following equation and basically says the value at which cumulative distribution function equals 0.5 is the median. For a symmetric distribution, such as the normal distribution, the mean and median are equal. This is not necessarily true for an asymmetric distribution.

$$median = P(X \leq m) = P(X \geq m) = \int_{-\infty}^{m} f(x)\,dx = \frac{1}{2}$$

Figure 5-2 shows the statistics for the distribution of radium results. One can see that the distribution is not symettric. The value given for “Cum. Probability” of 0.5 is 9.24706. As shown above, that value indicates the median. The mean is shown to be 10.392 so in this case the mean and median are not much different, but the mean is still higher than the median. Among other things, Figure 5-2 shows the standard deviation is about half the value of the mean which implies a fairly wide spread in the data. In set A the median is simply the middle value, 0.3, as all values are equally possible.

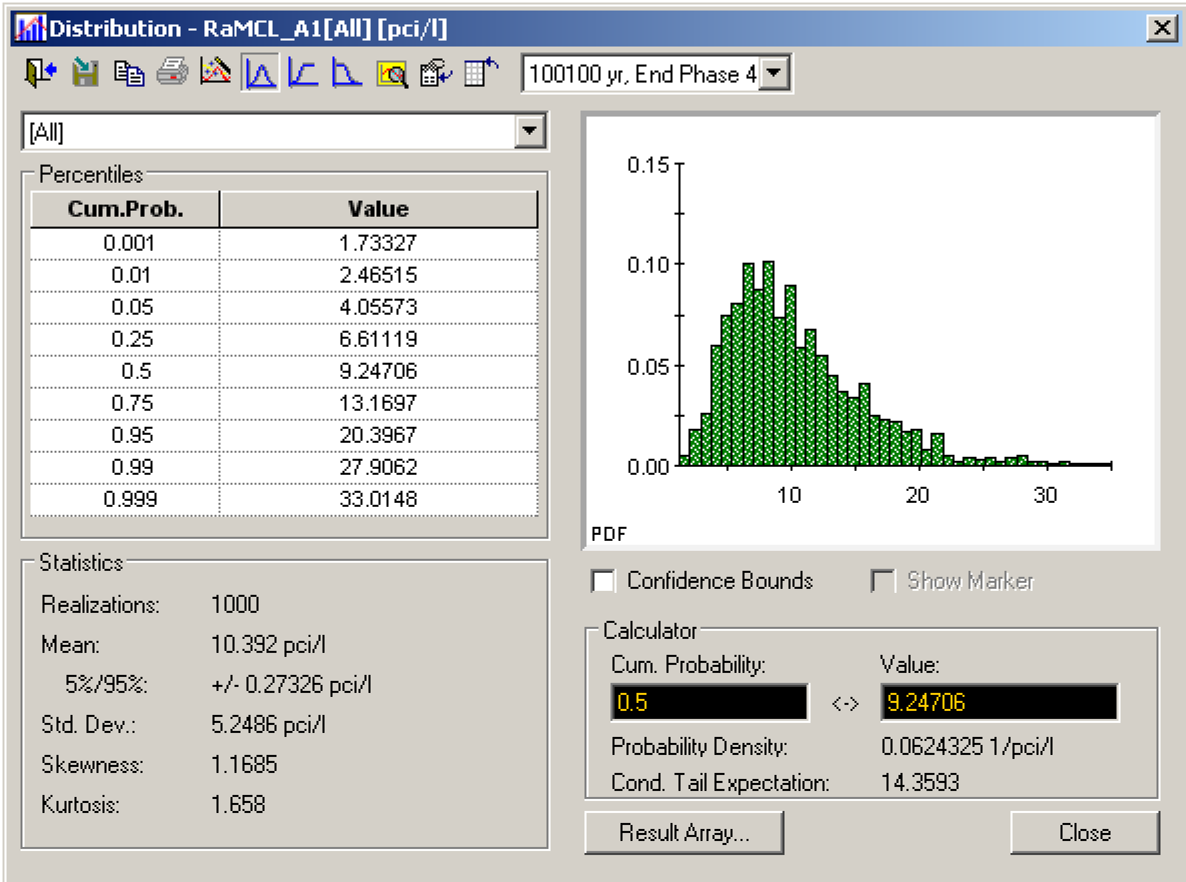


Figure 5-2 Radium result distribution statistics

Figure 5-3 shows a very skewed distribution for the alpha results. The median is 6.14411 while the mean is 11.94. The point of all this is that the Table 5-1 median values are used to go along with the column of fraction of realization exceedances. If 80% of the realizations exceed the limit, I find it more meaningful to ask where the 50-50 split is. If the mean were used one could not easily relate the mean to a 50% number as it could relate to anything in the distribution. For Figure 5-3 the mean is equivalent to 77% while Figure 5-2's mean relates to 60%. Note that in this discussion "%" could be read as "percentile".

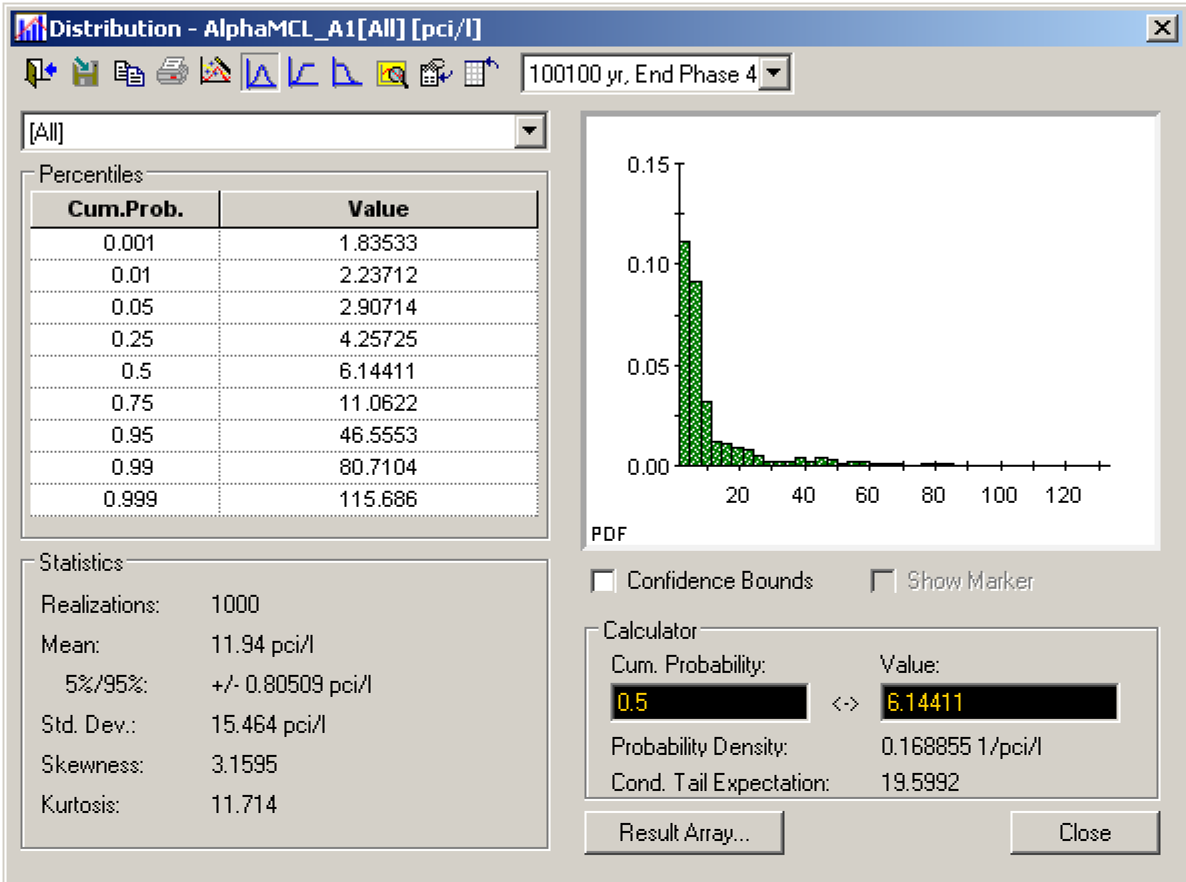


Figure 5-3 Alpha result distribution statistics

Many statistical discussions will include terms such as “1, 2, or 3σ confidence level”. This refers to the Cumulative Distribution Function (CDF), $D(x)$, which is described by

$$D(x) = P(x \leq x) = \int_{-\infty}^{x} P(\vartheta)\, d\vartheta$$

where $P(\vartheta)$ = the probability density function.

Table 5-7 shows the relationship between standard deviation (σ), CDF, and percentile. In the above equation, σ corresponds to the upper limit of integration, x, for a normalized normal distribution. At times the percentile may be referred to as a confidence level, so an 85% confidence level would be about equivalent to a 1σ distance from the mean (as the mean and median are the same for a normal distribution).

Table 5-7 Relationship between Standard Deviation, Cumulative Distribution Function, and Percentile

σ	$D(x)$	Percentile
1	0.84	84
2	0.977	98
3	0.999	99

5.3 GENERIC SCENARIO

As indicated in Section 3.5.3 the Generic Scenario assumes that the entire 235-F inventory is simply dumped on the ground over the 235-F footprint with typical background infiltration without taking into account the building itself (see Figure 3-6). The Generic Scenario's results are from a deterministic run. Lead and PCBs were not modeled for this scenario. This is not a realistic case but was run to help judge the effectiveness of engineered barriers or remedial actions. It showed Ra-226/Ra-228, U-234, and Pb-210 exceeded their limits in this extreme scenario.

5.4 NO ACTION SCENARIO

This scenario was taken as the "base" case. It showed that although several of the limits were still exceeded, the engineered barriers considered, the floor and walls, provided a good amount of attenuation. This section describes in some detail how conclusions were made using this scenario, and then give briefer discussions for the other scenarios. The figures shown in this section are similar to those shown in the appendices so comments made here are generally applicable to those in the appendices.

5.4.1 Ra-226/Ra-228 MCL

Figure 5-4 illustrates the convention used in most of the plots in the appendices. The thick blue line represents the limit. The green line represents the "building's" contribution, that is, the sum of all sources over the building footprint. The other lines represent each sources' contribution to the total. The red line represents PuFF cells 1-5, the lavender line represents RoB, the Texas burnt orange represents the sand filter, the lime green line represents PuFF cells 6-9, and the dark purple represents ABL. Unless otherwise notated, all figures show the mean values of the stochastic simulations. Except for the uranium plots, which show the time-dependent actual values rather than the maximum value up to a time, the plots show the maximum values recorded. The plots show a leveling off which implies that the value of the dependent variable has decreased below some maximum value.

The major contributors to this exceedance are the radium daughter products of Pu-238 and Pu-240 with the vast majority coming from Pu-238 (Ra-226). The RoB and sand filter supply a small fraction. Figure 5-5 shows the distribution of results for PuFF cells 1-5. While these results are available for all limits at all assessment points, only this one will be shown. With the uncertainties in this calculation one can see that the limit can be exceeded by a factor of 3. Figure 5-6 shows that the Ra concentrations at Assessment Point 3, the creek, are less than 15 of the limit. Figure 5-7 shows the distribution of the total building's radium concentration.

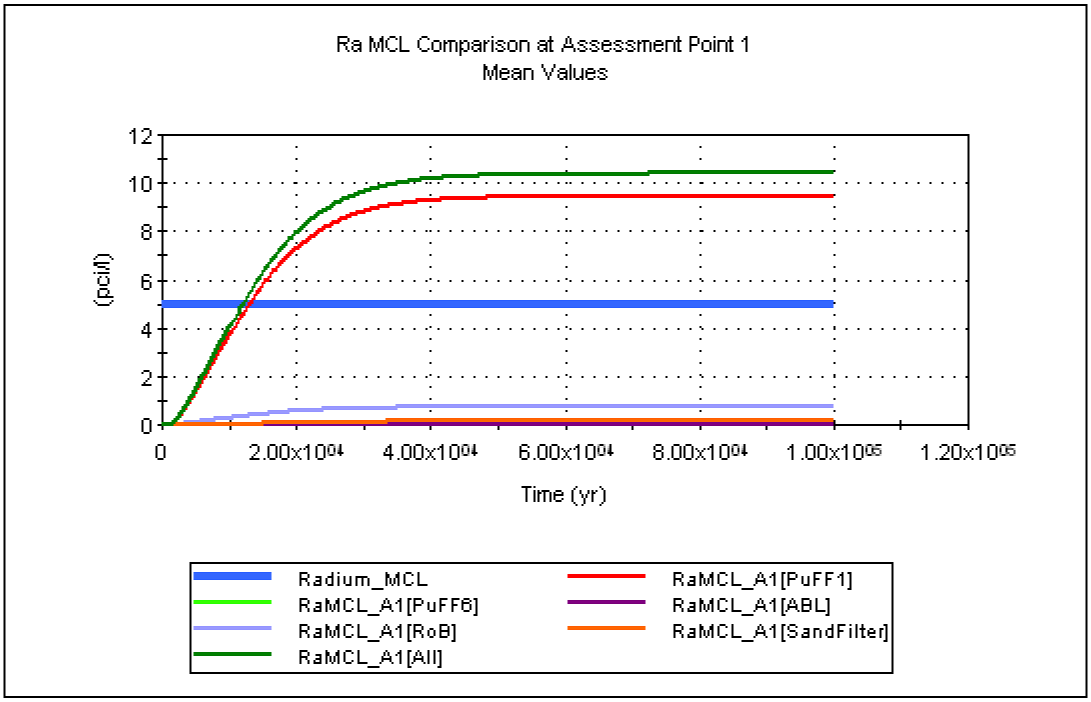


Figure 5-4 Radium MCL Assessment Point 1

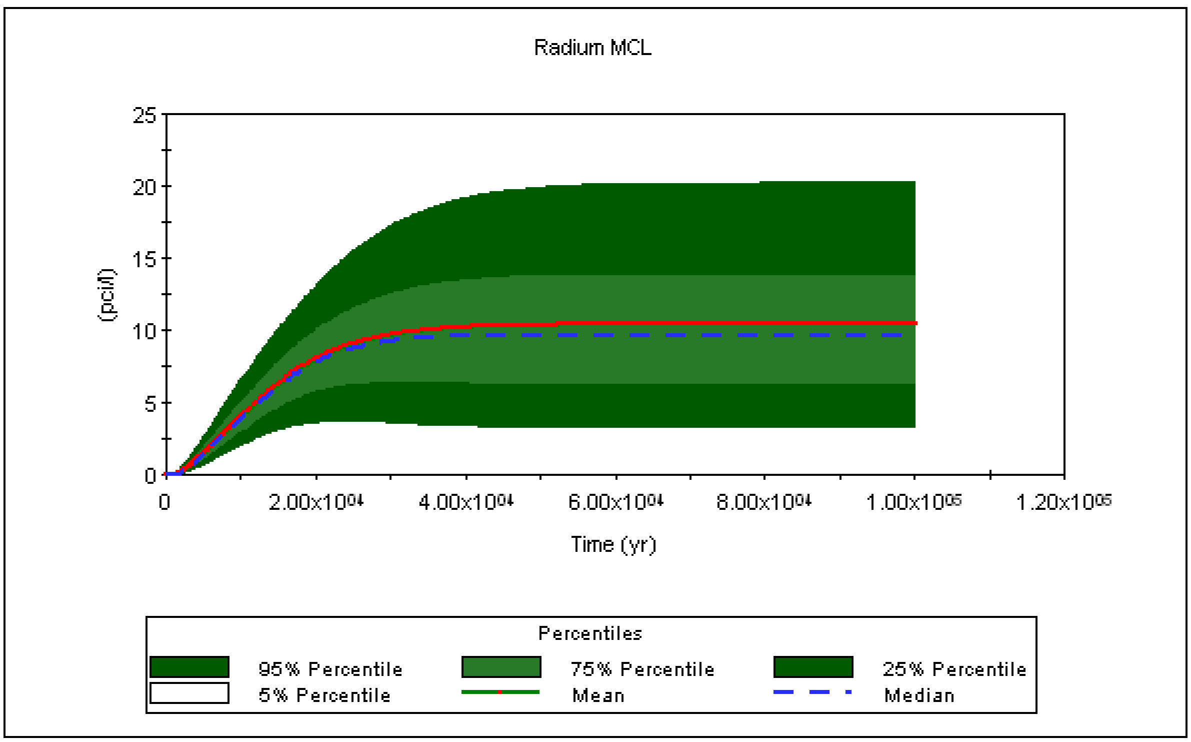


Figure 5-5 Ra Concentration at Assessment Point 1

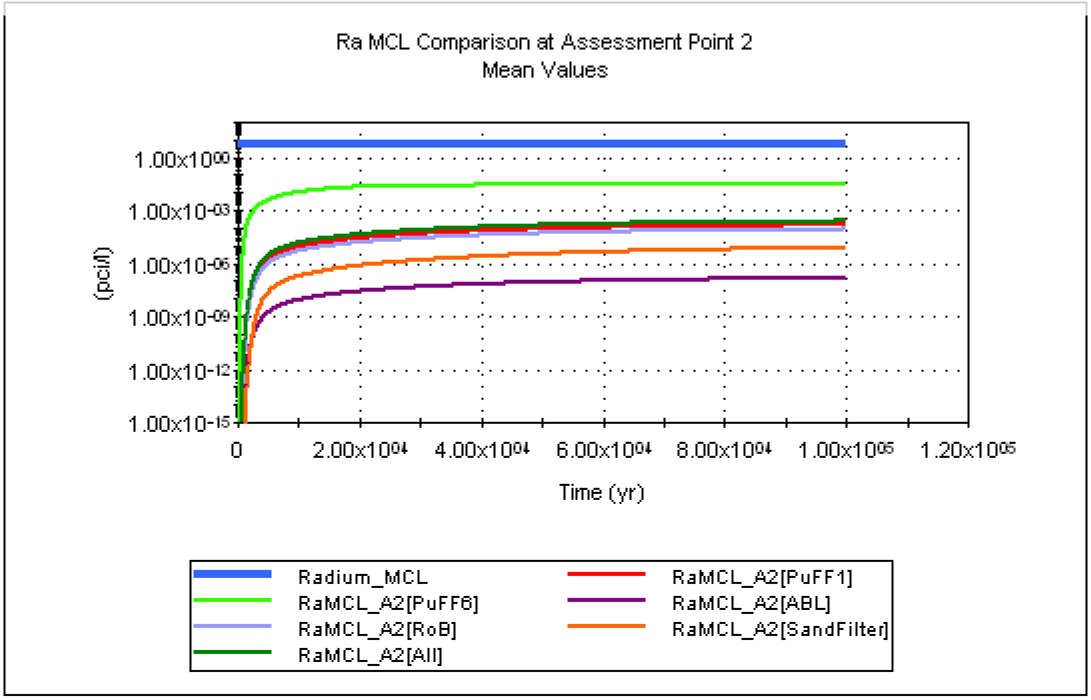


Figure 5-6 Ra MCL Assessment Point 2

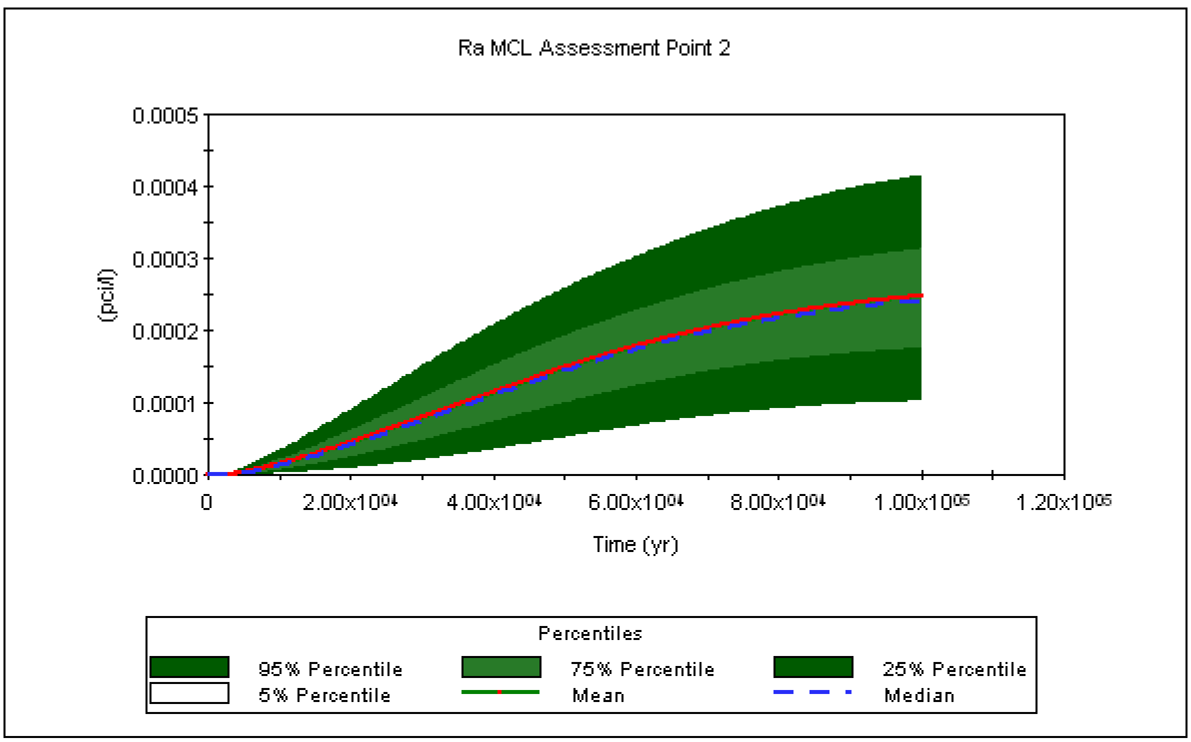


Figure 5-7 Ra Concentration Assessment Point 2

One might usually expect that the nearer one is to a source, the higher the concentration of a particular species. However, Figure 5-8 shows otherwise. The reason for this higher concentration at a farther distance is that is takes some time for the contaminants to travel to a more distant point. All during this time decay is happening so during this “delay”, there is the opportunity for the ingrowth of more Ra. In this case it is about 30 % higher. One can see that rather than peaking at around 40,000 years at Assessment Point 1, it takes an additional 20,000 years for the peak to arrive at Assessment Point 3.

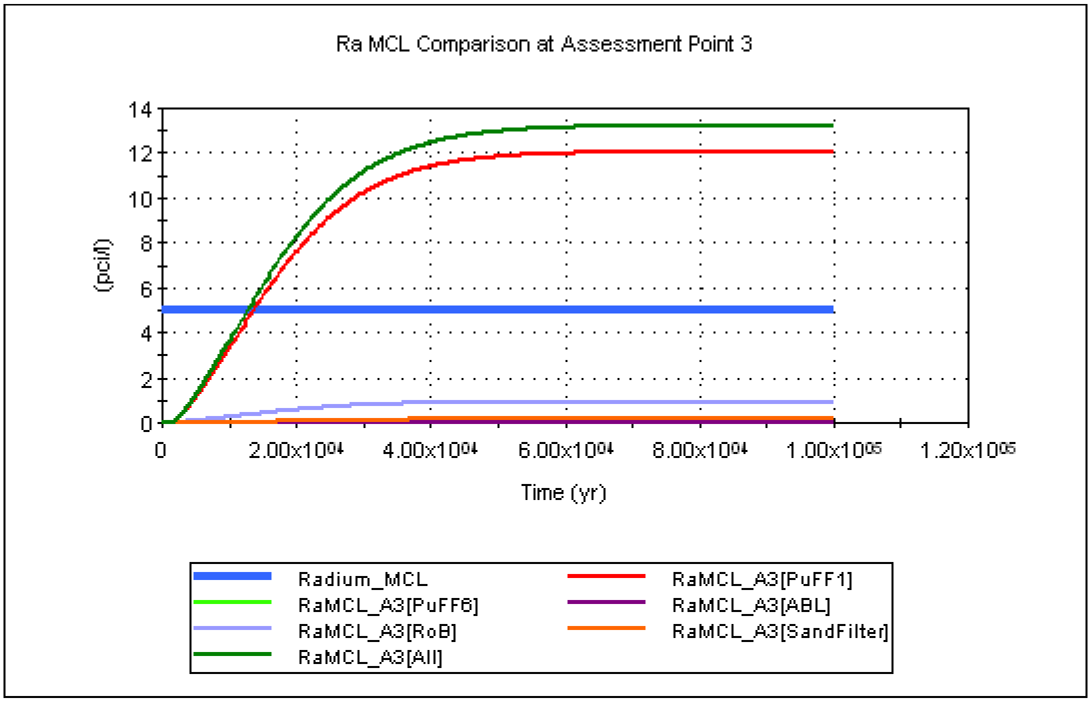


Figure 5-8 Ra MCL Assessment Point 3

5.4.2 Alpha MCL

Looking at the means shown in Figure 5-9 one would say that the MCL is not exceeded. However, one can see from Figure 5-10 that one might reasonably expect values of almost three times the limit. This illustrates the assumption of risk. If one is willing to be 80% assured that limit will not be exceeded, this would show it. (Based on Table 5-1 which shows about 20% if the realizations exceeding the limit.) It also shows that there are some large uncertainties in the alpha parameters as can be seen by the difference between the mean and the median. Only 20% of the realizations exceeded the limit, but they biased the mean upwards by factor of almost eight. The standard deviation for this simulation was about 14, which is practically the limit. If this were the limit which was controlling the D&D of 235-F, time would be well spent reducing the uncertainties.

Figure 5-11 shows that at the creek, the concentration of alphas is about four orders of magnitude less than the limit. No distribution is shown for the creek because even though the uncertainties are large, as shown by Figure 5-12, they are nowhere near as large as the many orders of magnitude the results are under the limit.

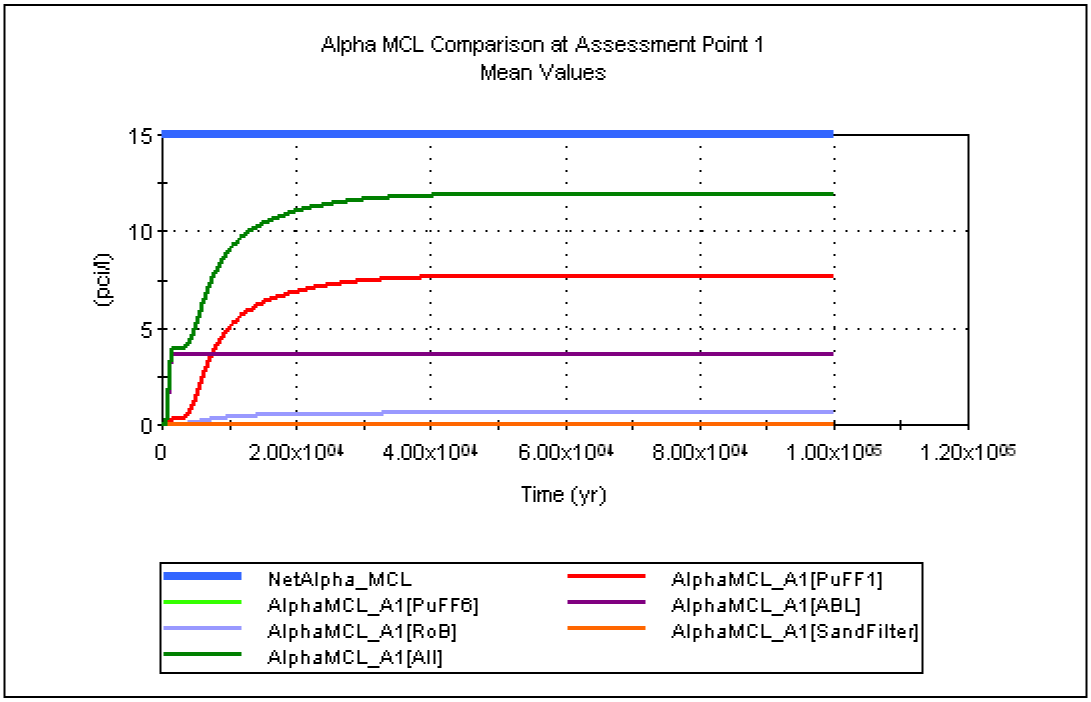


Figure 5-9 Alpha MCL at Assessment Point 1

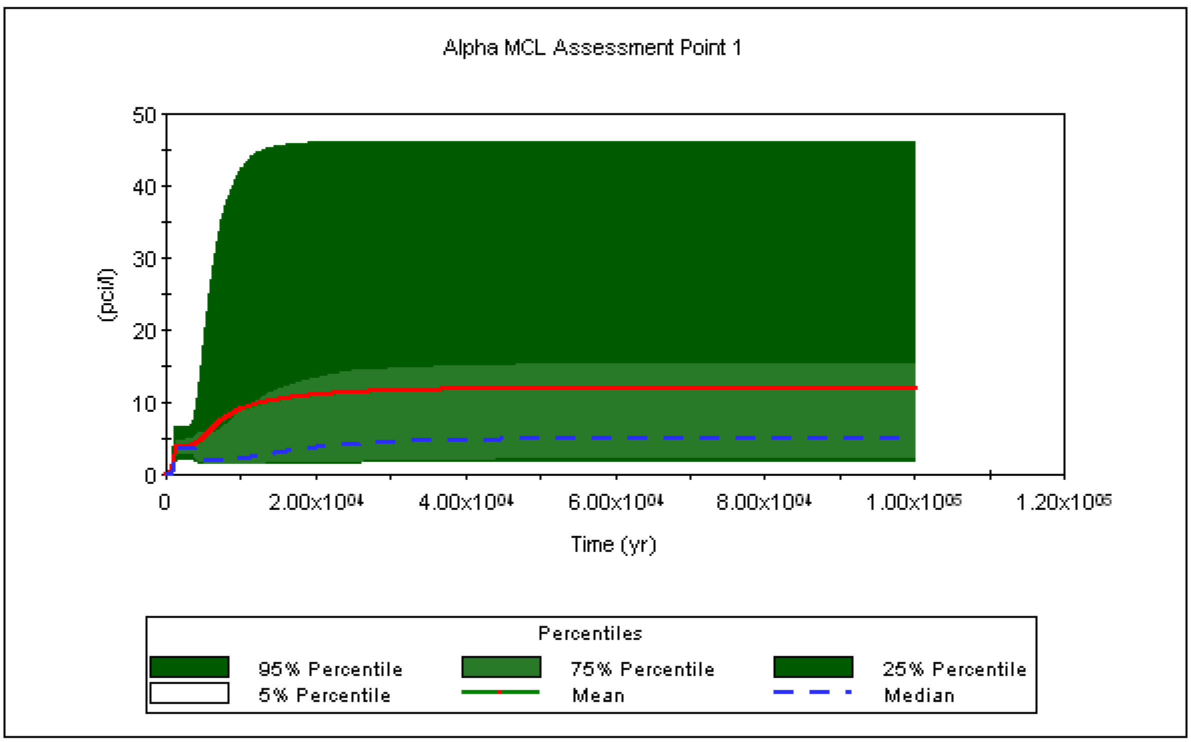


Figure 5-10 Alpha Concentration Assessment Point 1

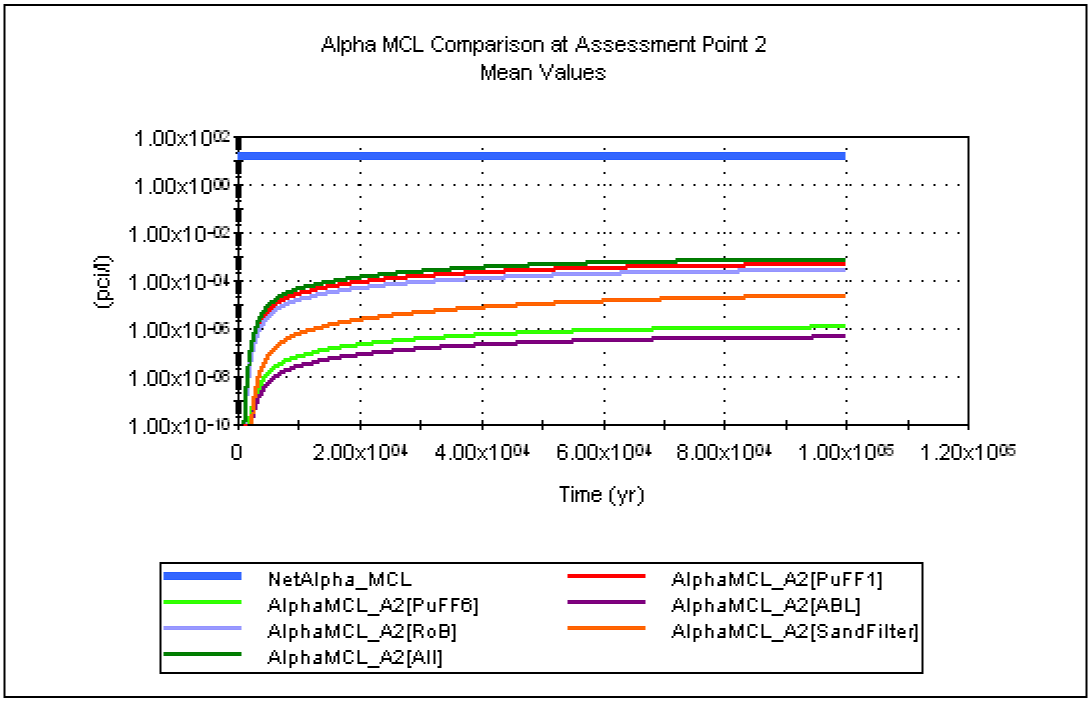


Figure 5-11 Alpha MCL at Assessment Point 2

5.4.3 Beta-Gamma MCL

With only one beta-gamma species (Pa-233) there is little beta-gamma dose. Figure 5-12 shows that at Assessment Point 1 the beta-gamma dose is about three orders of magnitude less than the limit. The dose at Assessment Point 2 is several orders of magnitude less than that.

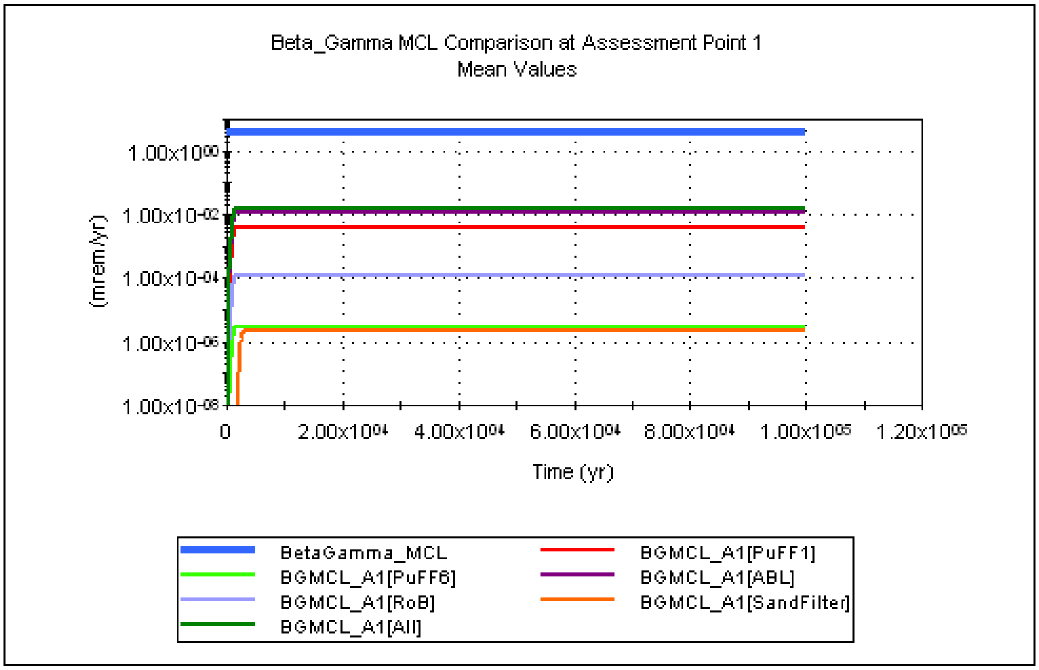


Figure 5-12 Beta-Gamma MCL at Assessment Point 1

5.4.4 U-234 MCL

Figure 5-13 shows the U-234 concentration approaching its MCL of 10 pCi/L. Figure 5-14 shows that the mean value of the total (all sources) concentration is about 60% of the 10 pCi/L limit.

Figure 5-15 shows that only a small portion of the realizations exceed the limit (can be crosschecked with Table 5-1) but because of the large uncertainties the peak can be several times the median value. It also illustrates how a large uncertainty can bias the mean away from the median. Figure 5-16 shows that the U-234 is nowhere near its limit at Assessment Point 2.

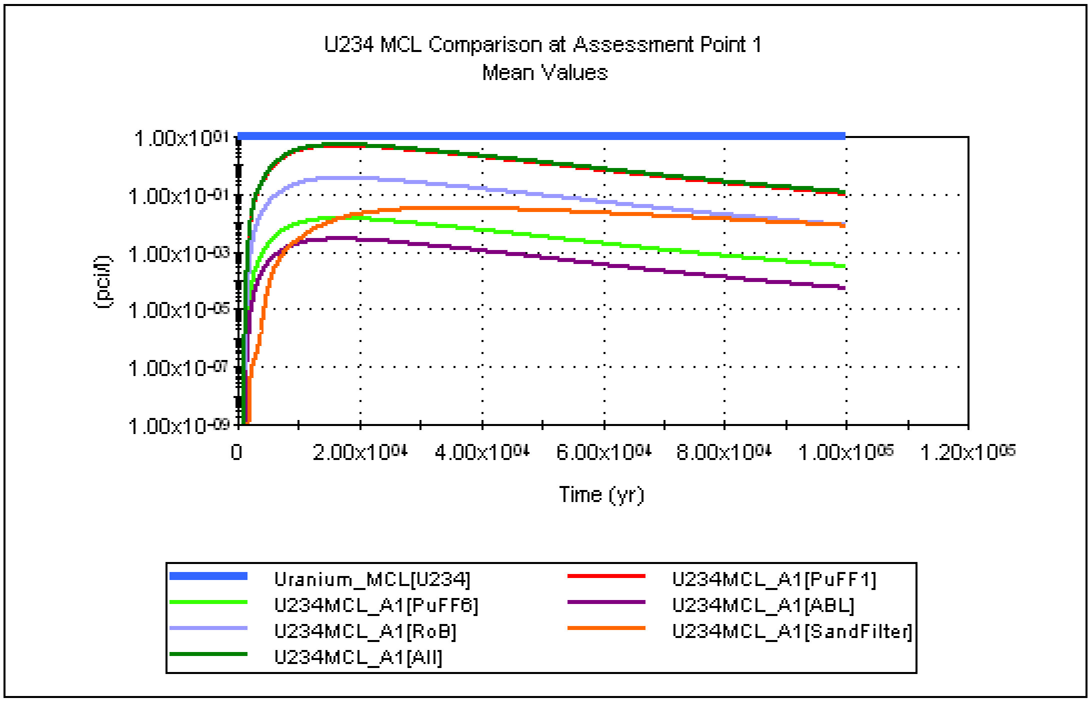


Figure 5-13 ^{234}U MCL

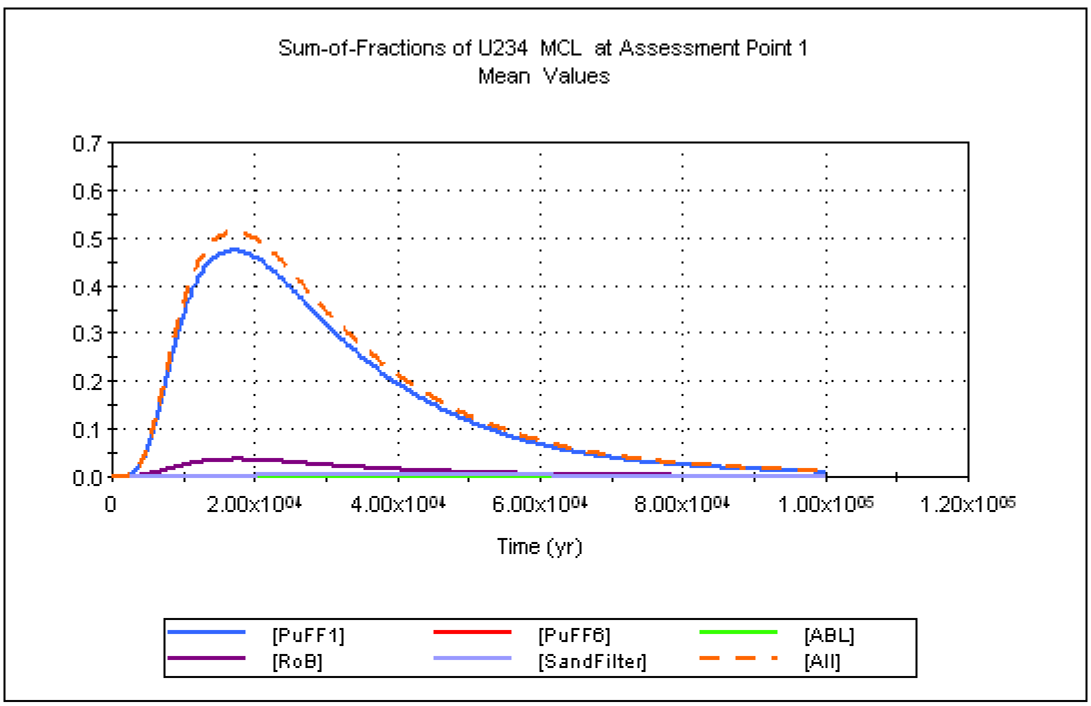


Figure 5-14 U-234 Fraction of MCL

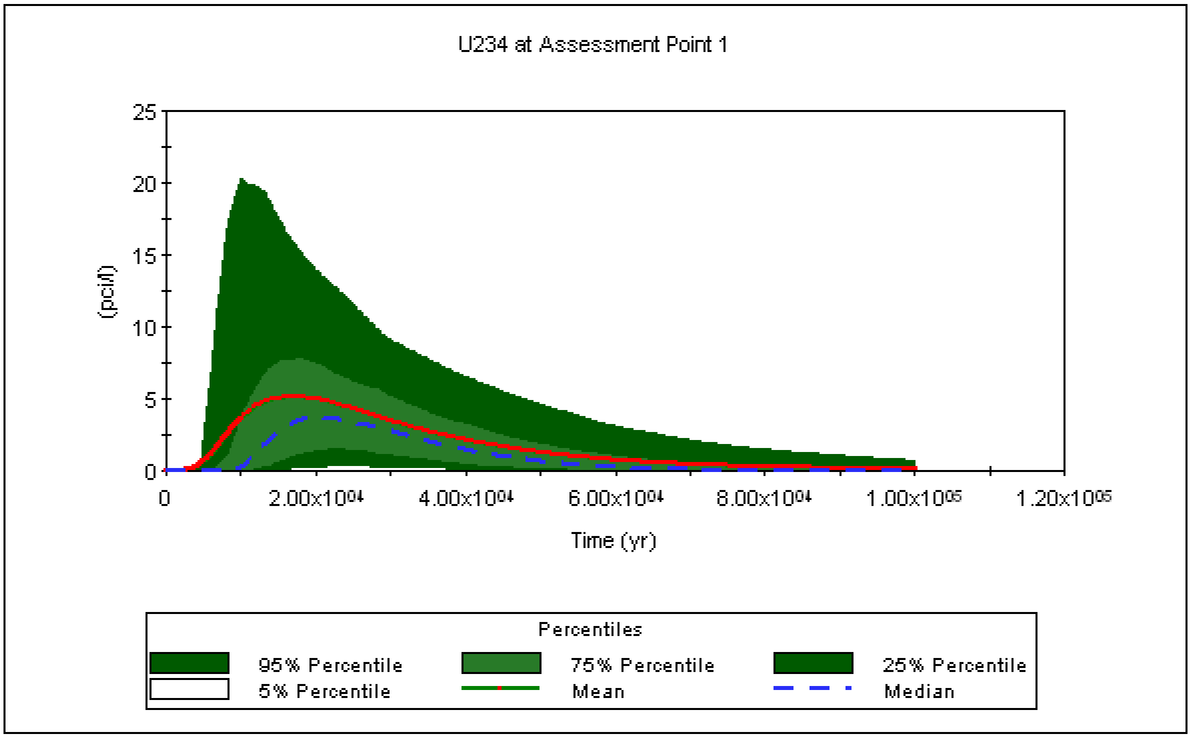


Figure 5-15 U-234 Concentration at Assessment Point 1

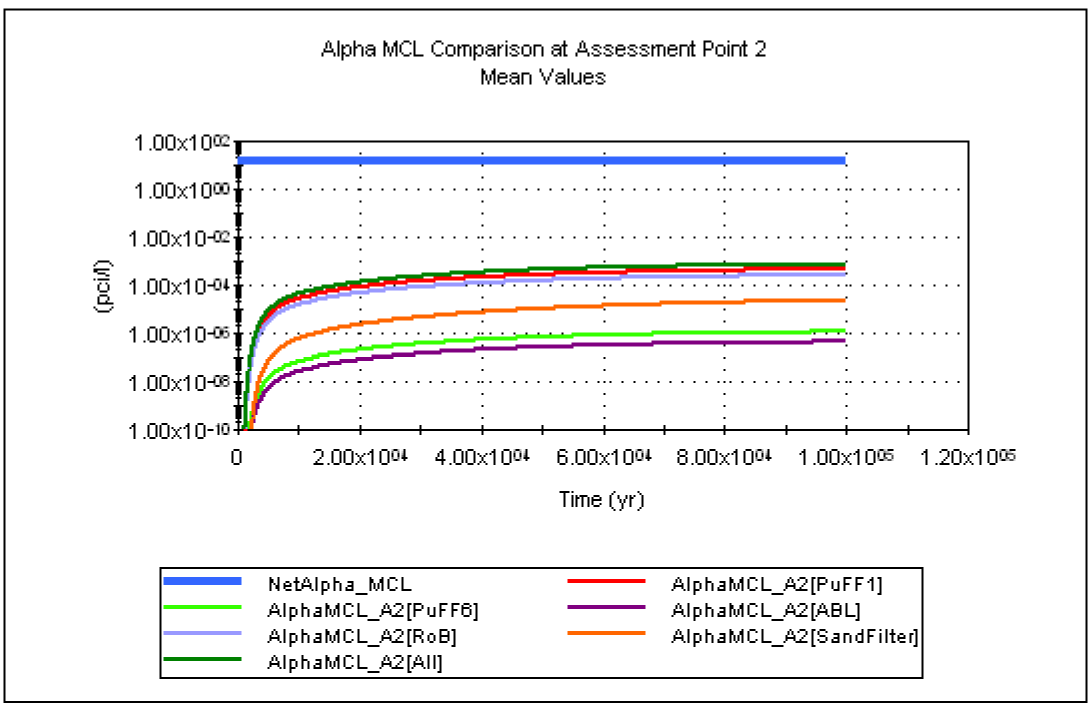


Figure 5-16 U-234 Concentration at Assessment Point 2

5.4.5 U-235 and U-238 MCLs

Figure 5-17 and Figure 5-18 show that the concentrations for U-235 and U-238 are at least four orders of magnitude below their limits. Their concentrations at Assessment Point 2 are several orders of magnitude less than these figures.

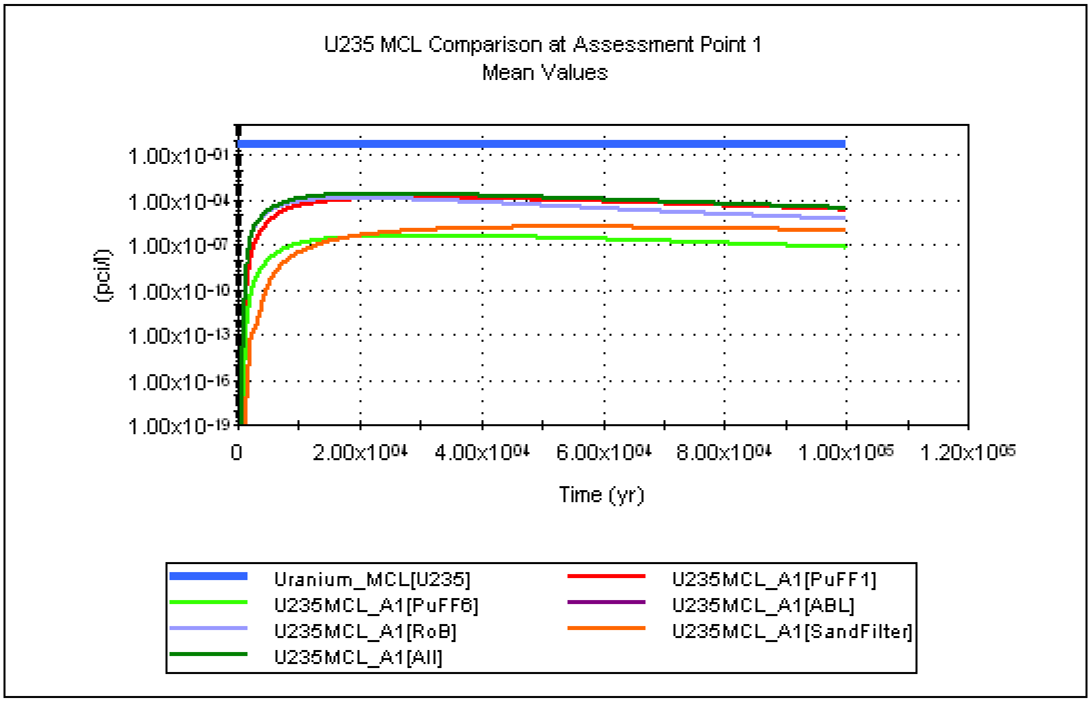


Figure 5-17 U-235 MCL at Assessment Point 1

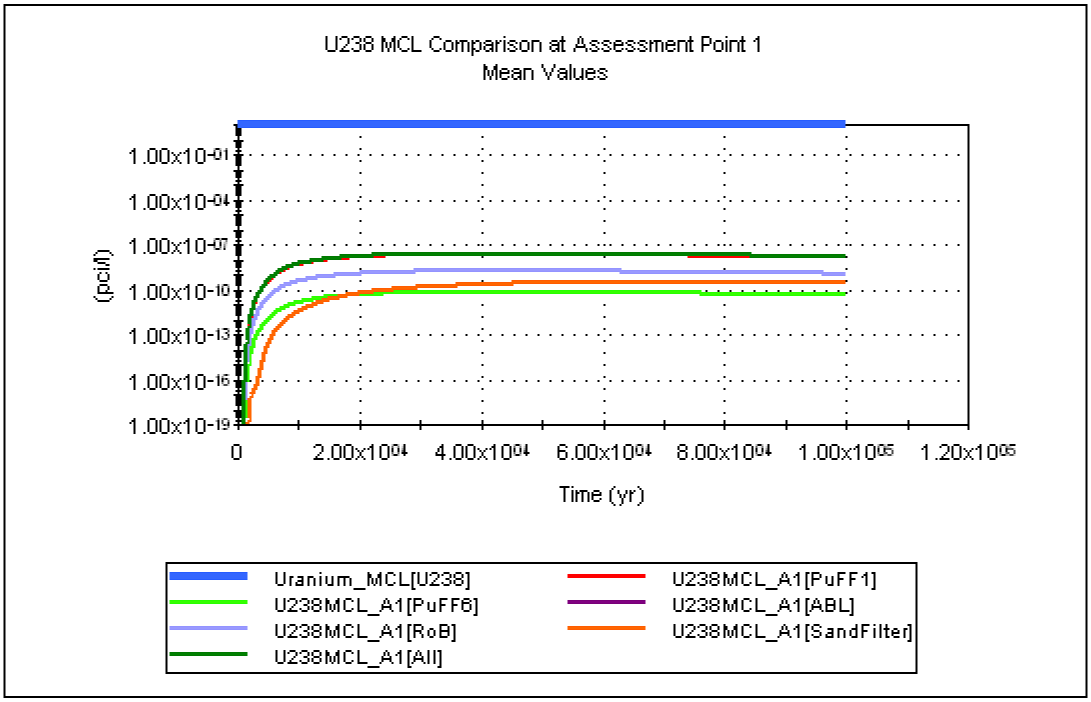


Figure 5-18 U-238 MCL at Assessment Point 1

5.4.6 Lead MCL

The fate of the lead shielding is essentially the same for all scenarios as its dissolution is based on a rate independent of any other factor. The end production of many of the decay chains happens to be lead, but that contribution is ignored due to the massive amount of lead shielding compared to the radionuclide inventory. Lead is the only species in this analysis which does not peak at the edge of Building 235-F (Assessment Point 1) within the first 100,000 years. Figure 5-19 shows a deterministic run out past the peak. The peak occurs around 186,000 years, and as the lower plot of Figure 5-19 shows, it is at slightly less than 40% of the MCL.

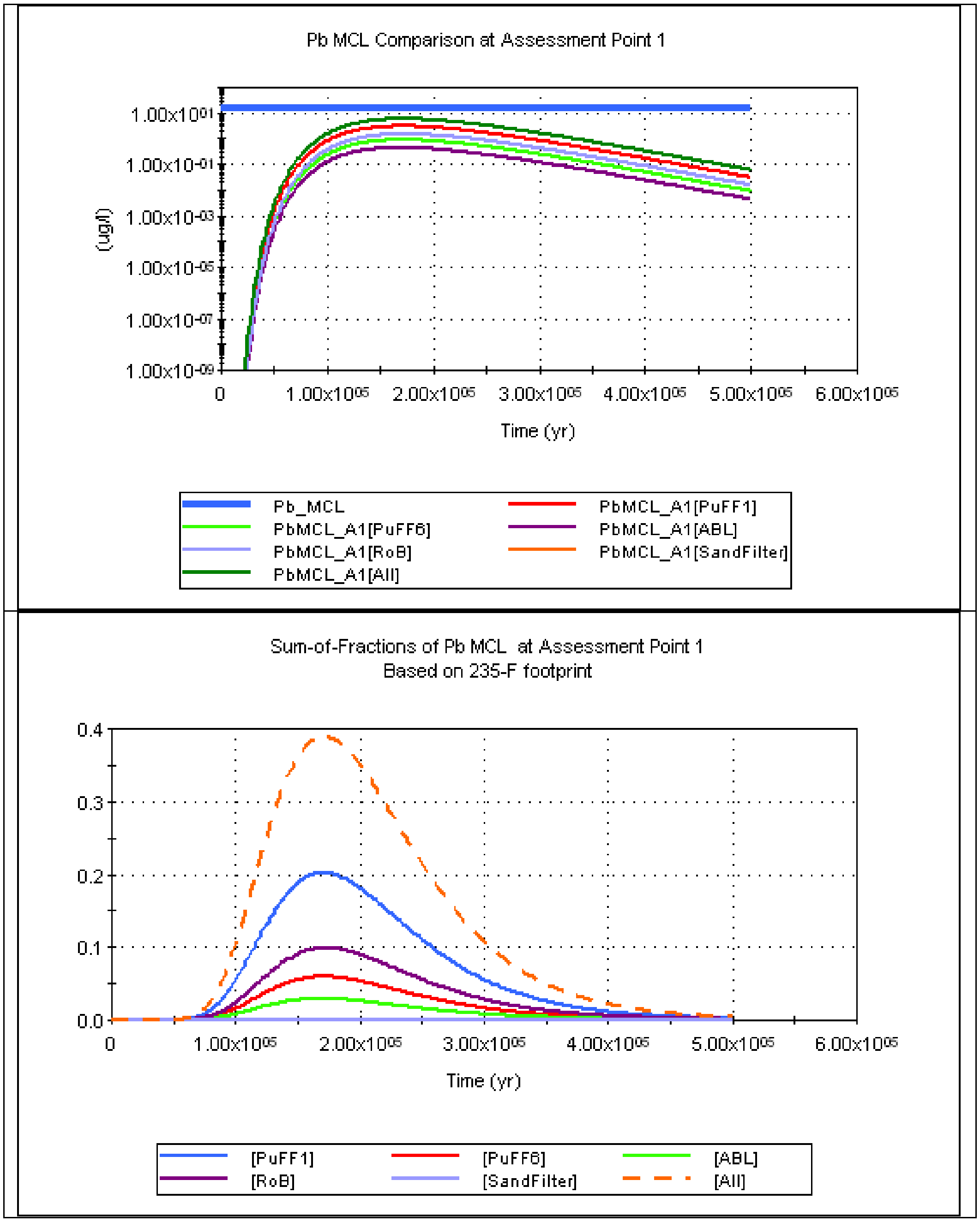


Figure 5-19 Lead run to peak, deterministic run

Figure 5-20 shows the results of a stochastic run for lead. Figure 5-21 shows that the 95th percentile is approaching the MCL of 15 µg/L. If one assumes that a linear relationship between the concentrations at 100,000 years (1.7 µg/L) and 186,000 years (5.8 µg/L) from the deterministic run can be applied to the stochastic run, then the peak mean concentration at 186,000 years would be approaching 15 µg/L and the 95th percentile concentration would be 41 µg/L. Figure 5-22 shows the lead concentration to be orders of magnitude less than its limit at Assessment Point 2.

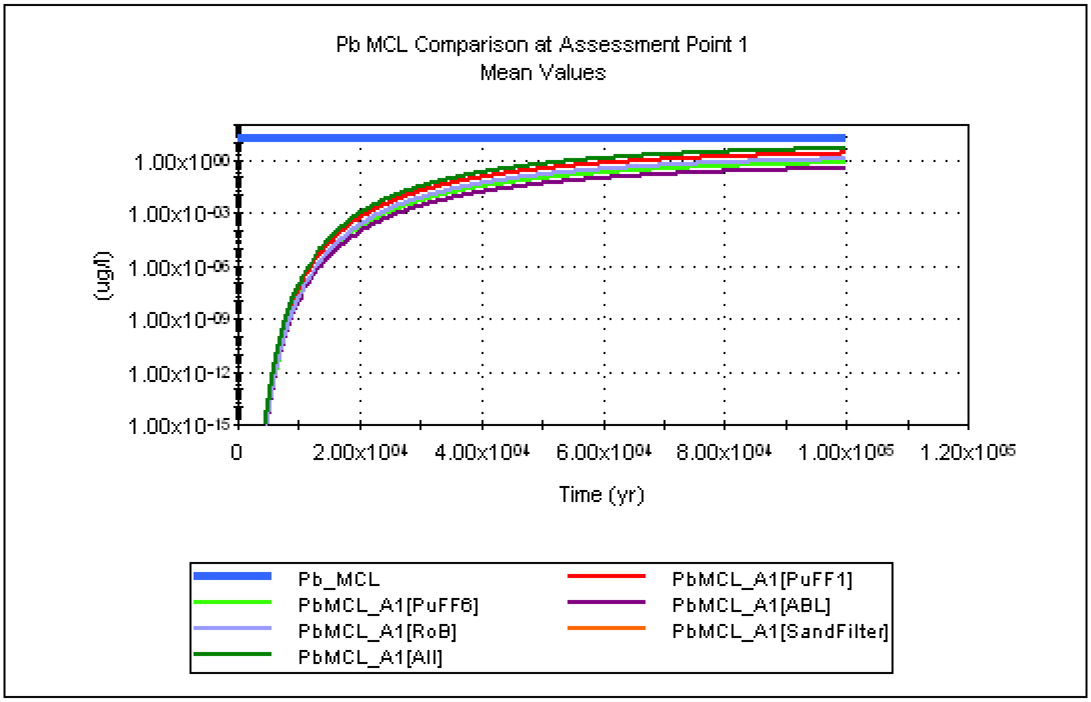


Figure 5-20 Pb MCL at Assessment Point 1

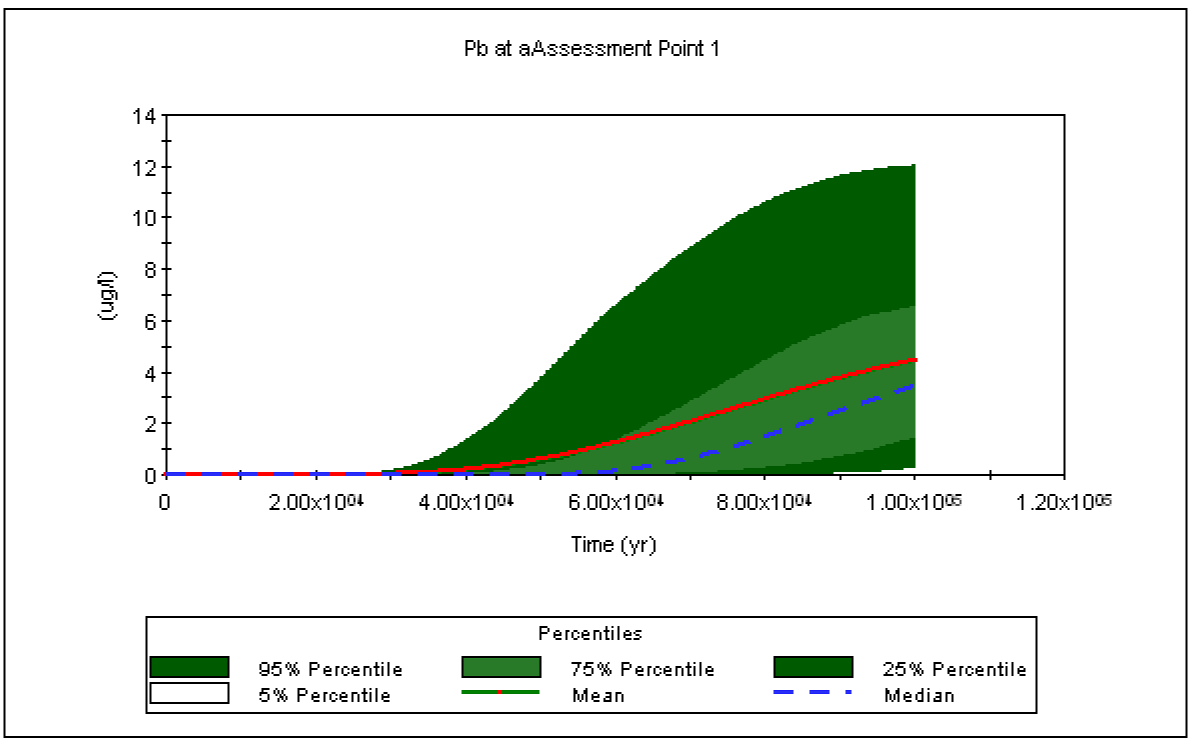


Figure 5-21 Pb distribution at Assessment Point 1

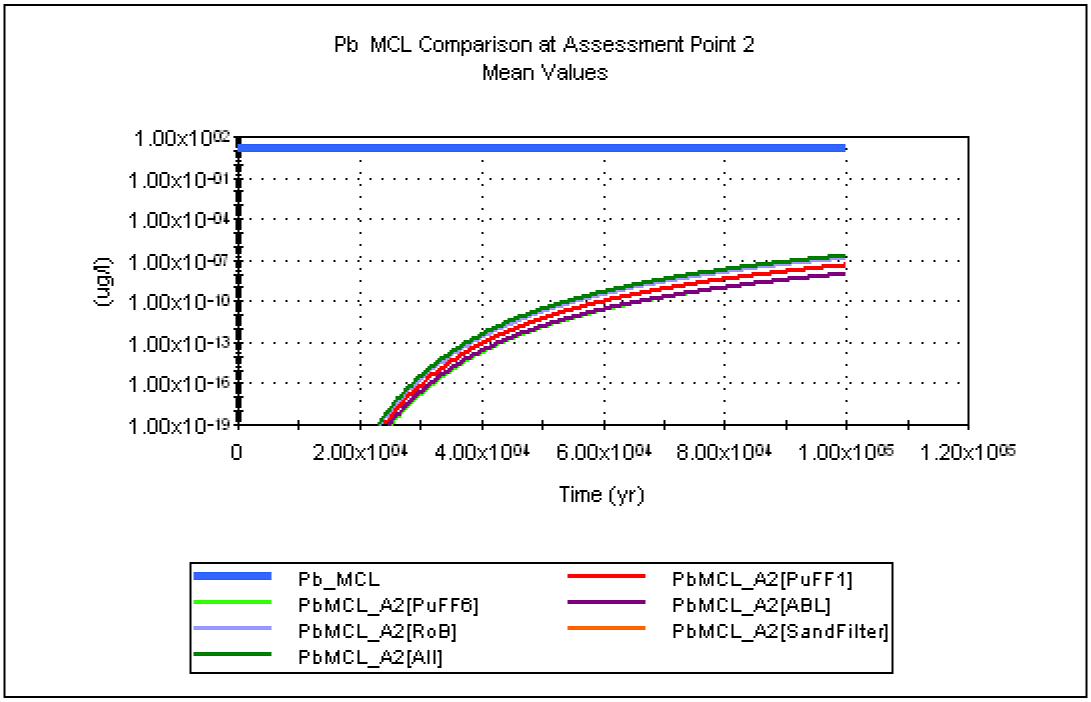


Figure 5-22 Pb MCL at Assessment Point 2

5.4.7 PCB MCL

Figure 5-23 shows the PCB concentration being about three orders of magnitude less than its MCL at Assessment Point 1. At Assessment Point 2 it is about eight orders of magnitude less than its limit (Figure 5-24).

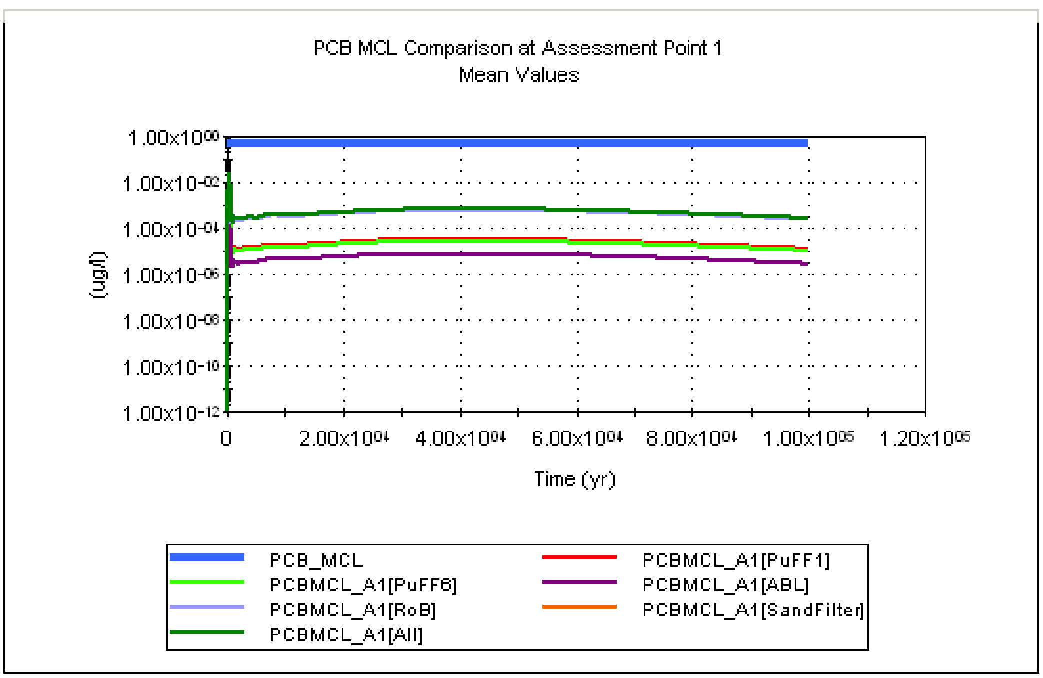


Figure 5-23 PCB MCL at Assessment Point 1

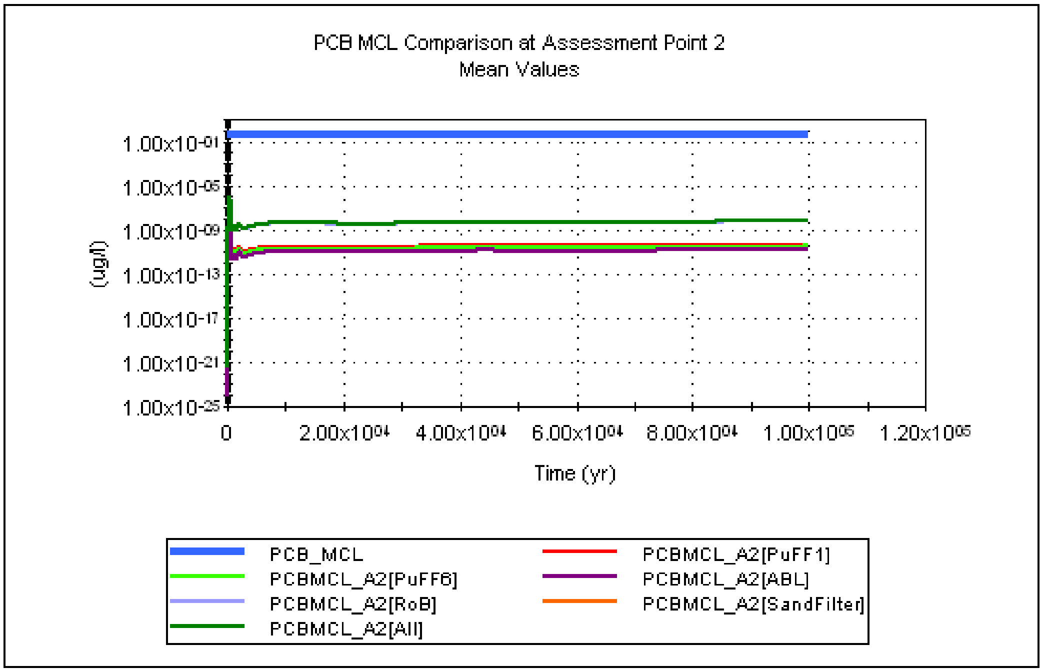


Figure 5-24 PCB MCL Assessment Point 2

5.4.8 Pb-210 PRG

Pb-210 is a concern primarily due to its very low PRG of 0.06 pCi/L. As shown in Table 3-12, Pb-210 decays by beta emission. The beta-gamma MCL is 4 mrem/yr (EPA 2009). EPA has calculated the concentration of specific radionuclides resulting in a dose of 4 mrem/yr; however Pb-210 was not among the radionuclides included (EPA 1981). The concentration of Pb-210 resulting in a dose of 4 mrem/yr has been calculated based upon DOE 2011 and the consumption of 1.86 liters of water per day. Based upon this a Pb-210 concentration of 2 pCi/L results in a dose of 4 mrem/yr. The MCL equivalent Pb-210 concentration is approximately 30 times greater than the Pb-210 PRG of 0.06 pCi/L

The NRC (NRC 1999) gives a PRG of 0.95 pCi/g for Pb-210 and around 0.77 pCi/g for Ra-226. In comparison, Table 3-10 gives a PRG value of 0.06 pCi/L for Pb-210 and a MCL of 5 pCi/L for Ra-226. The NRC values show a factor of 1.2 difference while the Table 3-10 values show a factor of almost 100.

Similarly, the NCRP (NCRP 1996) gives effective dose factors for ingestion of 8.1e-7 Sv/Bq for Pb-210 and 2.3e-7 Sv/Bq for Ra-226, a factor of about 3. Again, one must wonder why such a difference in the factors we are using.

Finally, if one looks at the dose calculated per DOE Order 435.1, one would see, from a deterministic run of the no-action option for PuFF cells 1-5, Ra-226 contributes about 81% of the dose while Pb-210 contributes about 1%. Remember that these values are based on the

PuFF cells 1-5 footprint, not the total facility footprint. These dose calculations are based on the NCRP dose factors.

5.4.8.1 Building Footprint

Figure 5-25 shows the Pb-210 concentration at Assessment Point 1, based on the Figure 3-17 aquifer flow path cross-section emanating from the entire 235-F footprint (2325 ft^2). It shows that large uncertainties proved a substantial bias to the mean in comparison with the median. The peak values are 0.099 pCi/L and 0.070 pCi/L for mean and median respectively. Both the mean and median exceed the PRG, and about 54% of the realizations exceed the PRG. Note that the maximum mean value of 0.099 pCi/L from Figure 5-26 is higher than the mean given in Figure 5-26 of 0.085 pCi/L where the figure's mean is essentially the "mean of the means".

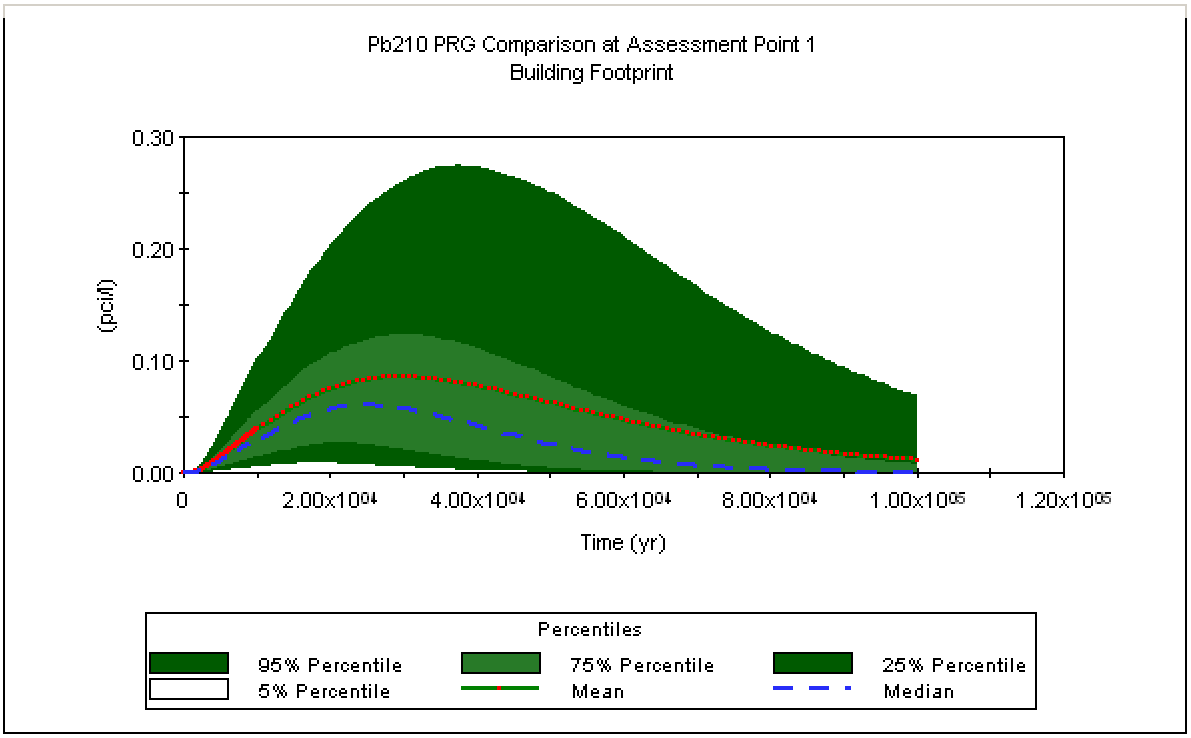


Figure 5-25 Pb-210 Concentration for Building Footprint

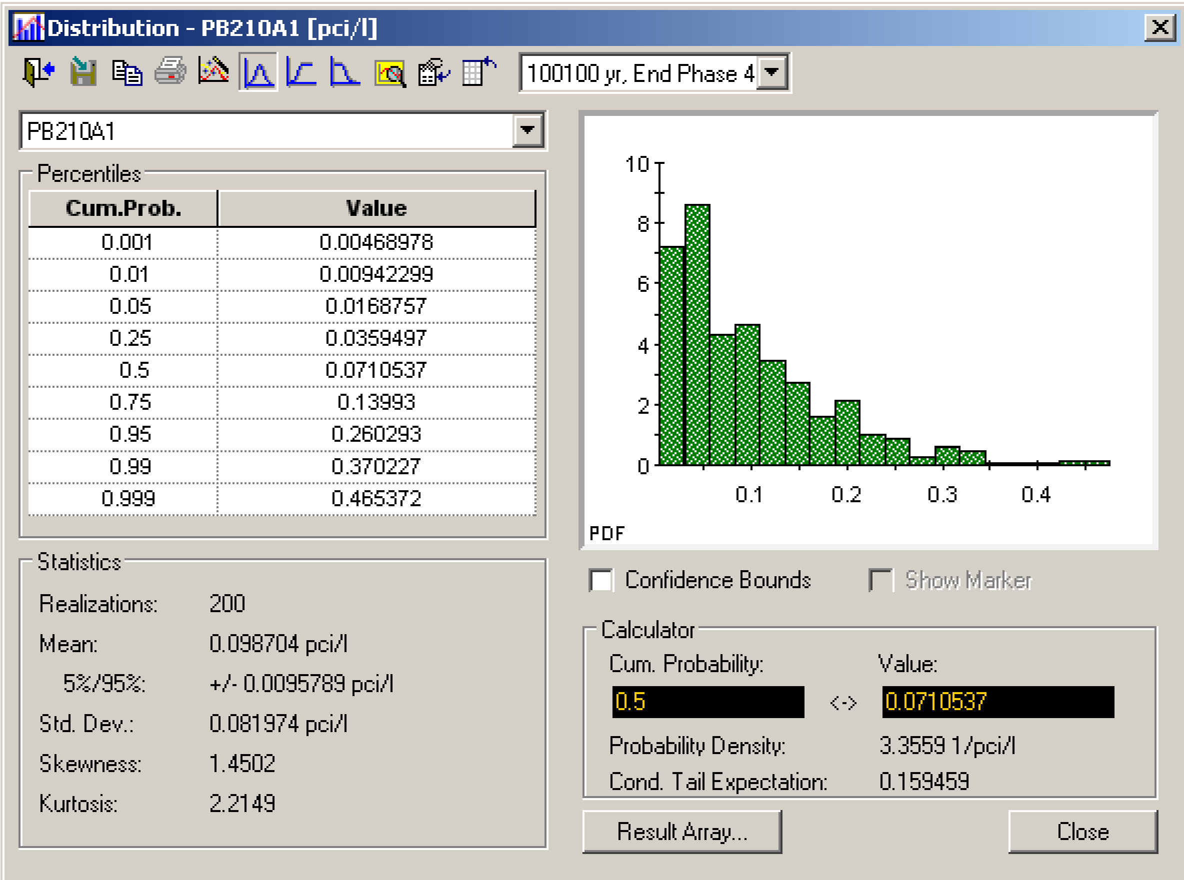


Figure 5-26 Pb-210 Cumulative Probability distribution

5.4.8.1.1 PuFF Cells 1-5 Footprint

This section illustrates the difference between using a source footprint and the building footprint. The entire 235-F footprint results in an aquifer flow path cross-section of 2325 ft^2 at the edge of the building (see Figure 3-17). Basing the results on a single sources footprint reduces the aquifer flow path cross-section by the ratio of the source footprint to the building footprint. Figure 5-27 shows the mean and median Pb-210 concentrations as calculated by the two different footprints. The 235-F building footprint values are shown as blue lines and include all sources. The PuFF Cells 1-5 footprint values are shown as green lines and include only the PuFF Cells 1-5 source. The building footprint's values are considerably lower than using the individual source's footprint.

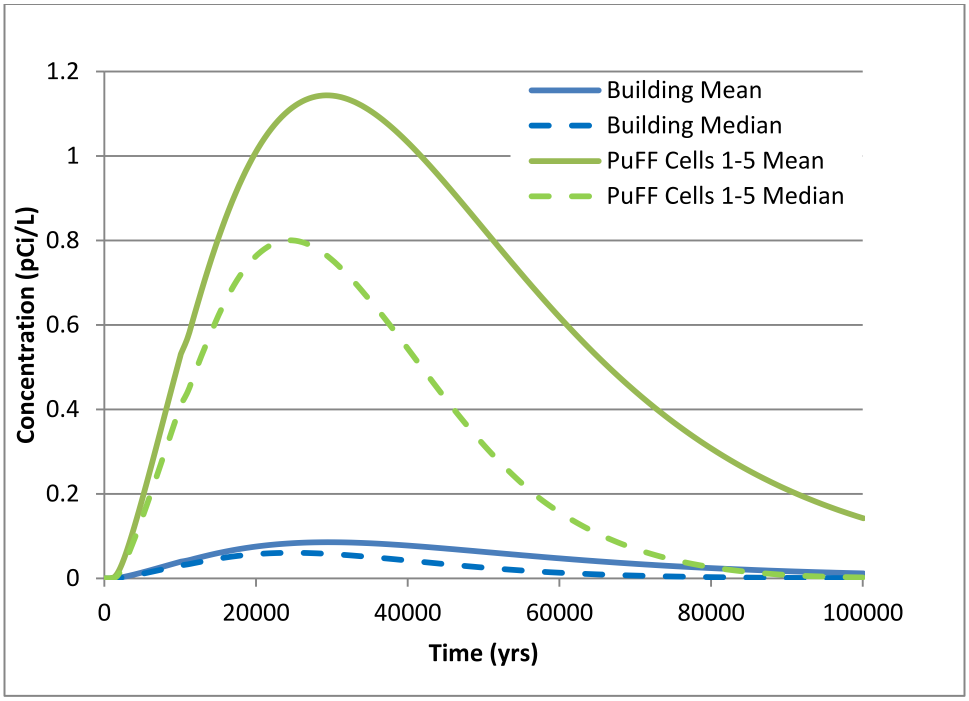


Figure 5-27 Comparison of Building and PuFF Cells 1-5 Footprints Concentrations

5.4.9 DOE Order 435.1 Dose

DOE Order 435.1 specifies that a total water dose (drinking, agricultural, and recreation) be below 25 mrem/yr at an assessment point 100 m from the facility boundary, which is Assessment Point 3. In Figure 5-28, the blue line represents the total dose, the green line the agricultural pathway dose, and the red line the drinking water pathway dose. The water recreation pathway dose is quite small and not shown. Table 5-8 shows the fractions of total dose for the major contributors. It's interesting how Po-210 shows up with about twice the contribution of Pb-210 but did not show up as exceeding any PRG or MCL.

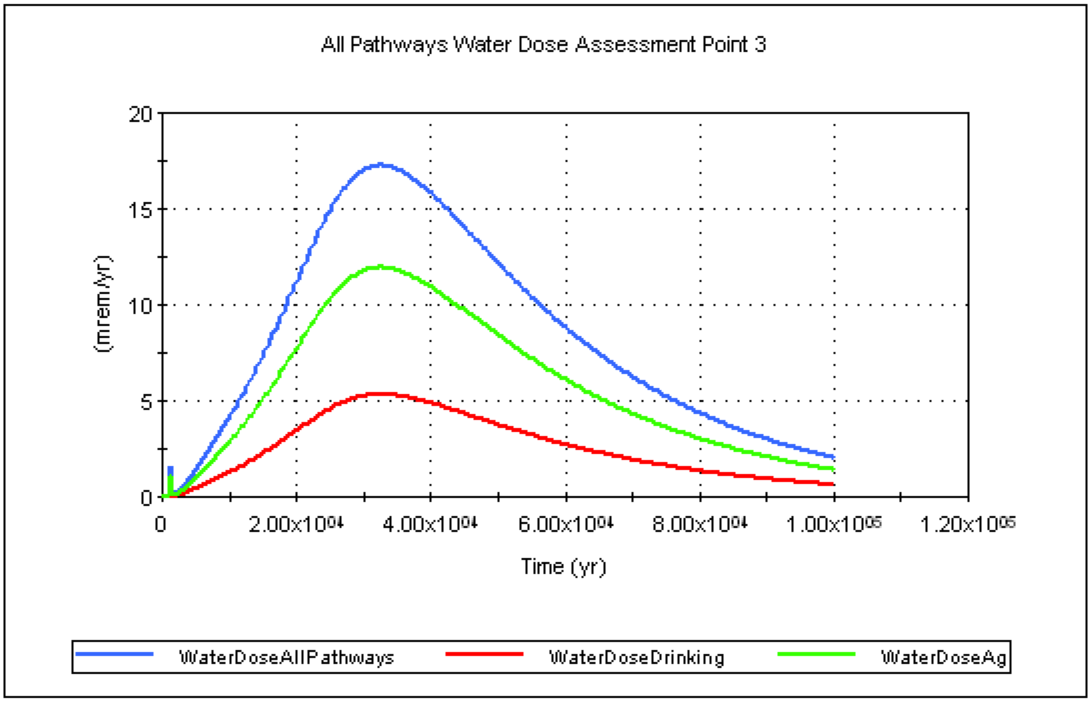


Figure 5-28 All Pathways Water dose at Assessment Point 3 (25 mrem/yr limit)

Table 5-8 Fraction of Total Dose

Radionuclide	Fraction
Pb-210	0.010
Po-210	0.018
Ra-226	0.825
Th-230	0.032
U-234	0.119

5.4.10 Sensitivity Analyses

Sensitivity analyses were performed to determine which parameters (independent variables) had the most effect on a parameter of interest (dependent variable). Explanations of the various columns in the figures can be found in Appendix J. Each time period had a different rank ordering of the Relative Importance.

5.4.10.1 Ra Sensitivity Analysis

Table 5-9 shows a summary of the top three results of the sensitivity analysis of Ra concentrations at Assessment Point 1 (edge of Building 235-F). More detailed results are presented in Appendix A. The table shows that the sensitivity analysis for each period had differing results. The earliest period shows that the Ra K_ds were most important and this implies that the mobility of Ra is the reason it is important. The Dispersivity parameter affects the timing of the arrival of contaminants and would reasonably be seen as an important parameter early in the event evolution. The middle time period shows the PuFF Cells 1-5 inventory to be the most important uncertainty parameter followed by the Ra K_ds. During this period the contaminant flux has reached quasi-equilibrium so one could reasonably expect the starting inventory to have an important effect. The second time period implies that the contaminant front arrival uncertainties have occurred during the first time period and now the amount of contaminant available is important. The third, and last, time period shows the Clayey Soil U K_d and the PuFF Cells 1-5 Inventory to have nearly the same importance. U-234 is a long lived and slow moving parent of Ra-226 so it is reasonable that long after Pu-238 has decayed completely away the movement of the remaining Ra-226 precursor is important. Similarly, the uncertainty in the initial inventory of Pu-238 implies a similar uncertainty in remaining U-234 inventory.

Table 5-9 Ra Concentration Sensitivity Analysis

0-1,000 Years		1,001-10,000 Years		10,001-100,000 years	
Uncertainty Parameter	**Relative importance**	**Uncertainty Parameter**	**Relative importance**	**Uncertainty Parameter**	**Relative importance**
Clayey Soil Ra Kd	0.341	PuFF Cells 1-5 Inventory	0.570	U Clayey Soil Kd	0.323
Sandy Soil Ra Kd	0.098	Clayey Soil Ra Kd	0.117	PuFF Cells 1-5 Inventory	0.312
Dispersivity	0.098	Sandy Soil Ra Kd	0.079	U Sandy Soil Kd	0.094

5.4.10.2 Pb-210 Sensitivity Analysis

Table 5-10 shows the sensitivity analysis of Pb-210 concentrations at Assessment Point 1 (edge of Building 235-F). It basically shows the same actors as with the Ra sensitivity analysis with the addition of the Pb K_d.

Table 5-10 Pb-210 Concentration Sensitivity Analysis

0-1,000 Years		1,001-10,000 Years		10,001-100,000 years	
Uncertainty Parameter	**Relative importance**	**Uncertainty Parameter**	**Relative importance**	**Uncertainty Parameter**	**Relative importance**
Clayey Soil Pb Kd	0.345	Clayey Soil Pb Kd	0.460	Clayey Soil Pb Kd	0.333
Dispersivity	0.121	Clayey Soil Ra Kd	0.225	Clayey Soil Ra Kd	0.202
Clayey Solid U Kd	0.074	PuFF Cells 1-5 Inventory	0.160	PuFF Cells 1-5 Inventory	0.113

5.5 GROUT SCENARIOS

The grout scenarios gave almost identical results. The grout scenarios are:

1. Grout PuFF Cells 1-5 only,
2. Grout PuFF Cells 6-9 only,

3. Grout the entire first floor,
4. Grout the entire building (first and second floors).

As mentioned earlier, the only real difference was the timing of release of the radionuclides due to differing flow rates during the first 1000 years of the simulation. Figure 5-29 shows a comparison of the Ra concentrations at Assessment Point 1 for the four grout options along with the No Action case. The figure's legend denotes what is grouted. The plots are virtually indistinguishable from each other at this scale. Therefore, there is nothing to be gained from grouting part or all of the facility. Table 5-1 shows that the maximum Ra concentrations are actually slightly greater for the grout options than the no action case. This is because grouting reduces flow in the grouted portion of the facility allowing for more ingrowth of Ra. The alpha concentrations are slightly lower for the grouted options and this is again caused by the lower flow. The primary contributor to the alpha concentration is Pu-238 which has a relatively short half-life of 87.7 years. The lower flow allows for more decay time which decreases the amount of Pu-238 available for transport once the flow increases. Another way to look at it is that less alpha (via Pu-238) leads to more Ra if the starting inventories are the same.

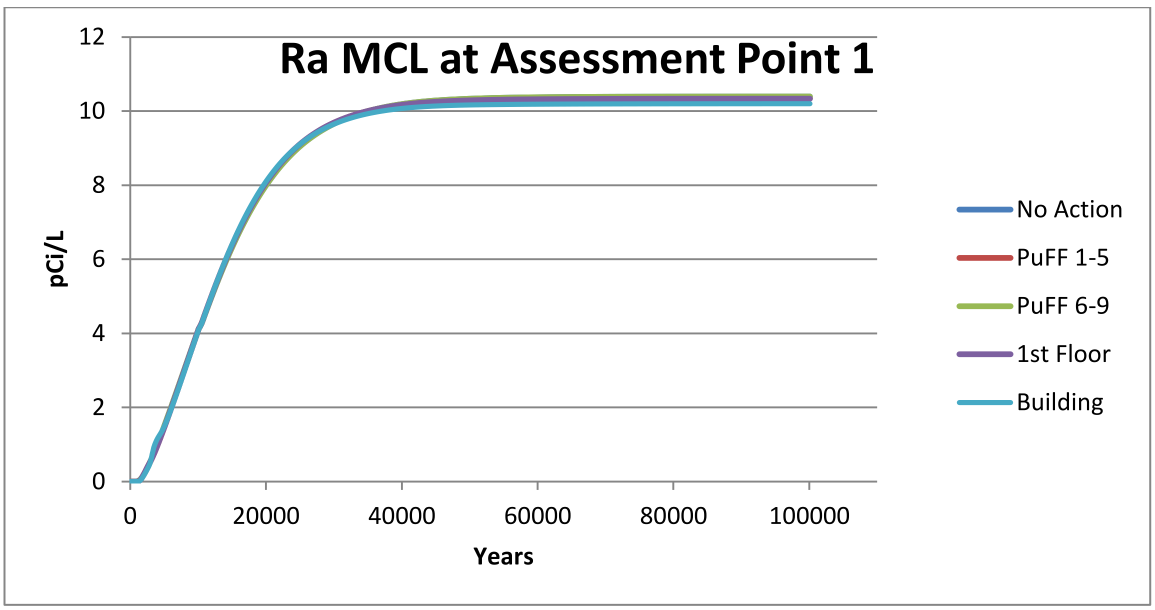


Figure 5-29 Comparison of Ra for Grout Scenarios

The first 5,000 years are shown below in Figure 5-30. It shows that if one were concerned with a performance period of 1,000 years then the grout options would have some effect on the Ra concentrations. However, the "worst" option shows that at 1,000 years the Ra concentration is still several orders of magnitude below its MCL. Again, grouting provides no benefit.

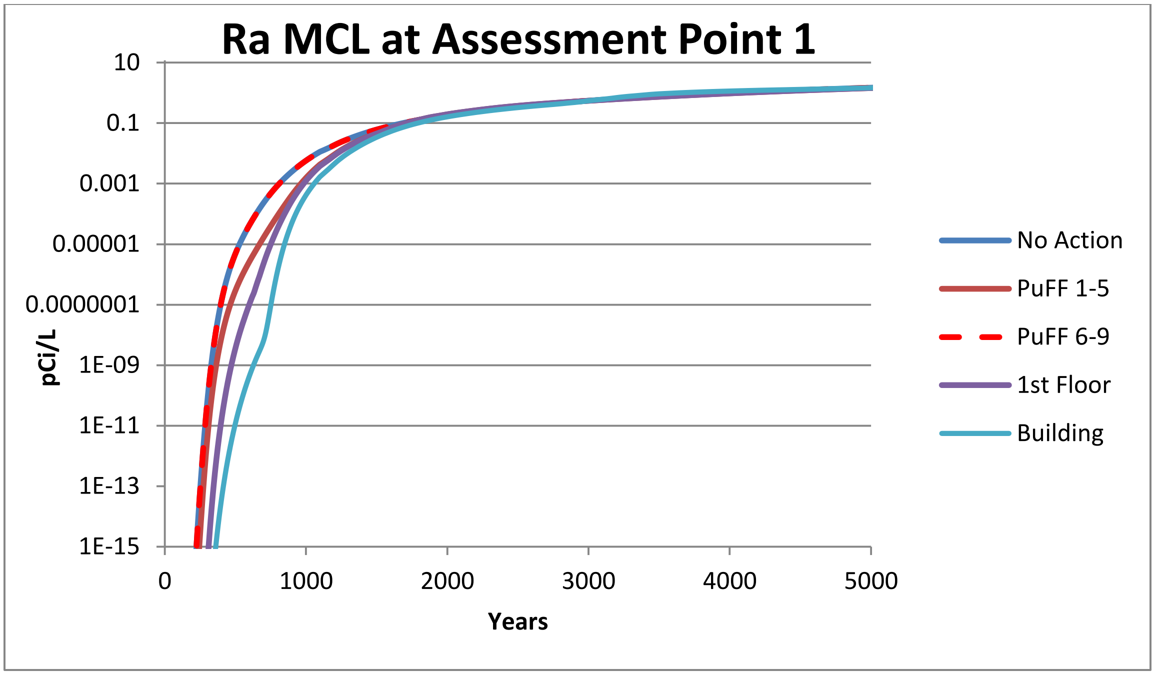


Figure 5-30 Ra MCL at Assessment Point 1, years 0-5,000

5.6 DECONTAMINATION OF PUFF CELLS 1-5

PuFF cells 1-5 contain 627 g of the total Pu-238 inventory of 659 g (i.e. 95% of the Pu-238 inventory). The one MCL and one PRG which are exceeded may be reached by decontaminating only these cells. This section assumes that all contaminants are removed to the same level not just the Pu-238 and that no other actions are taken. The amount of inventory removal is based upon the inventory at the time of removal, not the 1981 inventory. It is important to note that this report does not address the worker risk associated with decontamination versus the risk of leaving the contamination in place.

5.6.1 Removal of 60% of the inventory

Removing 60% of the PuFF cell 1-5 inventory allows the total mean Ra concentration to fall below the MCL (see Figure 5-31). Figure 5-32 shows that the limit is exceeded in about 37% of the realizations. Figure 5-33 shows that about 23% of the realizations exceeded the Pb-210 PRG. If one would like more assurance that the limit is met, more inventory must be removed.

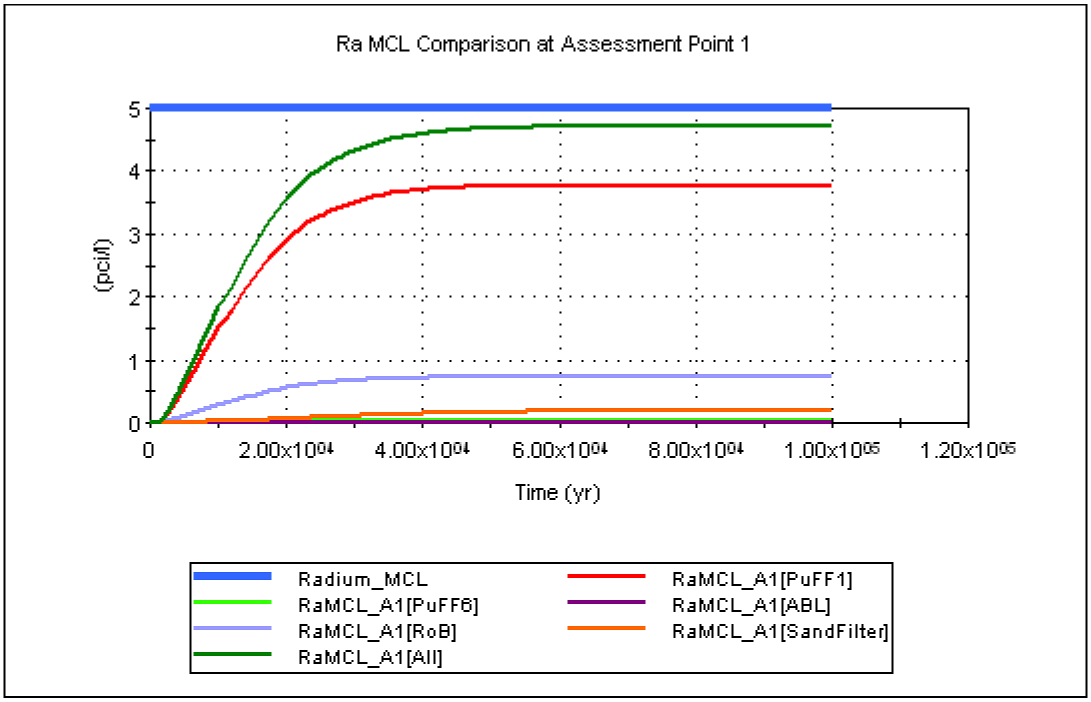


Figure 5-31 Removal of 60% of inventory Ra concentrations

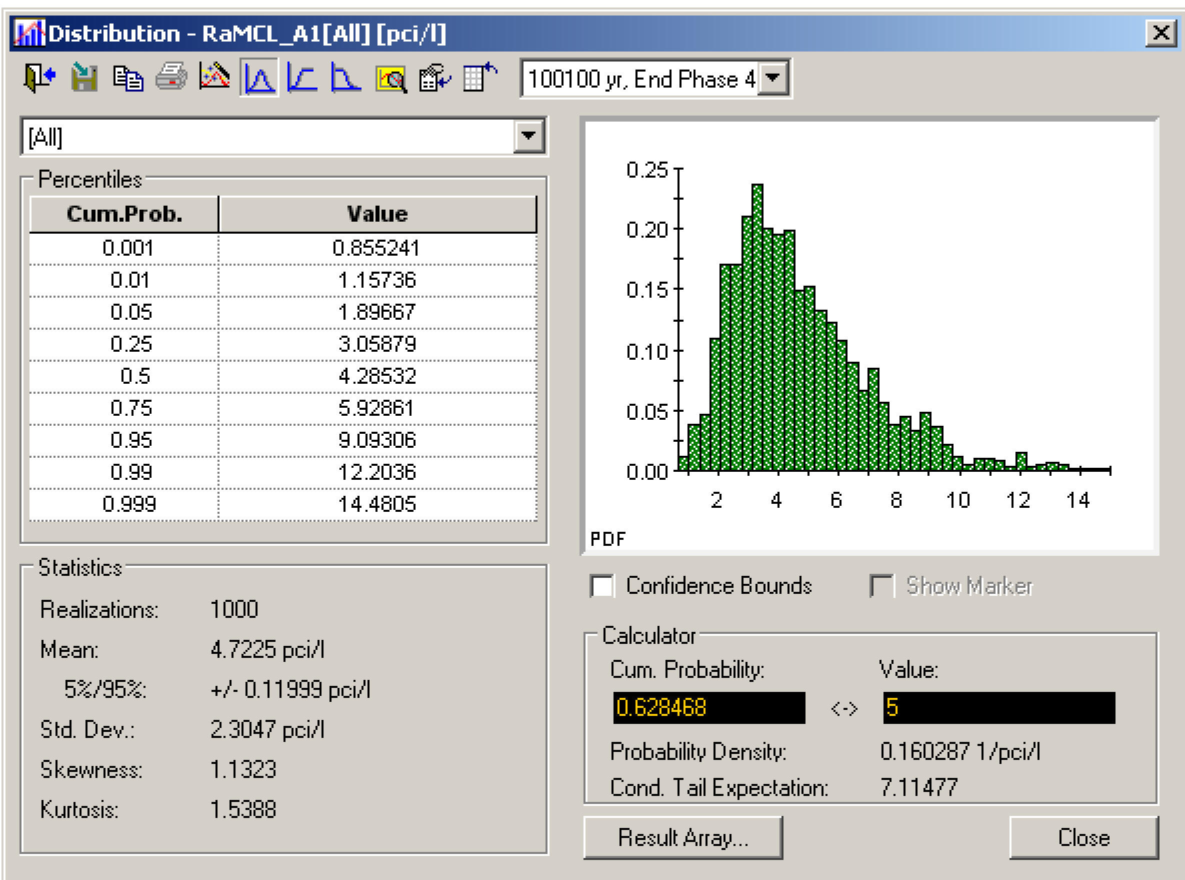


Figure 5-32 Removal of 60% of inventory Ra distribution

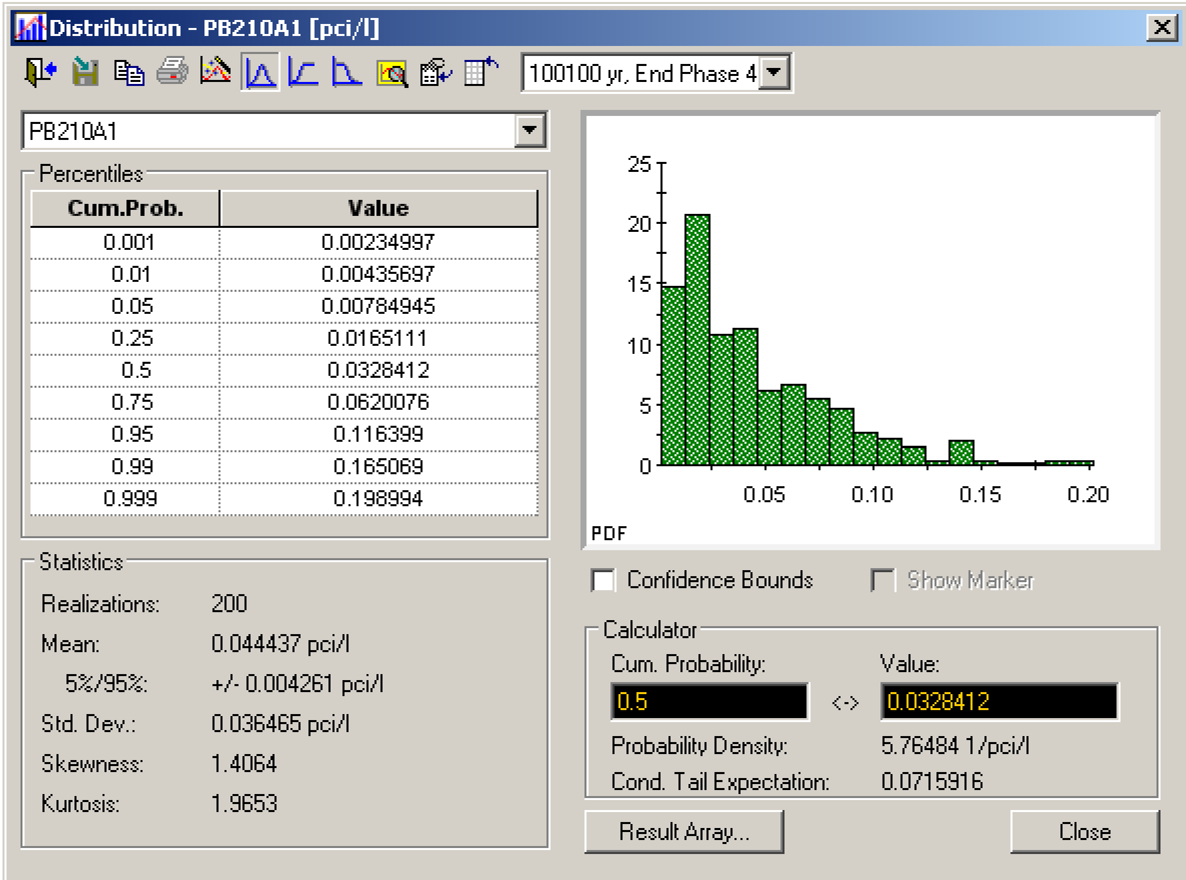


Figure 5-33 Removal of 60% of inventory Pb-210 distribution

5.6.2 Removal of 75% of the inventory

Removal of 75% of the PuFF cells 1-5 inventory allows the mean Ra concentration to be below its MCL (Figure 5-34). However, Figure 5-35 shows that this is a true statement for about 85% of the time. In other words, one can be about 85% confident that the MCL will not be exceeded. Figure 5-36 shows that about 11% of the realizations exceeded the Pb-210 PRG. If one would like more assurance that the limit is met, more inventory must be removed.

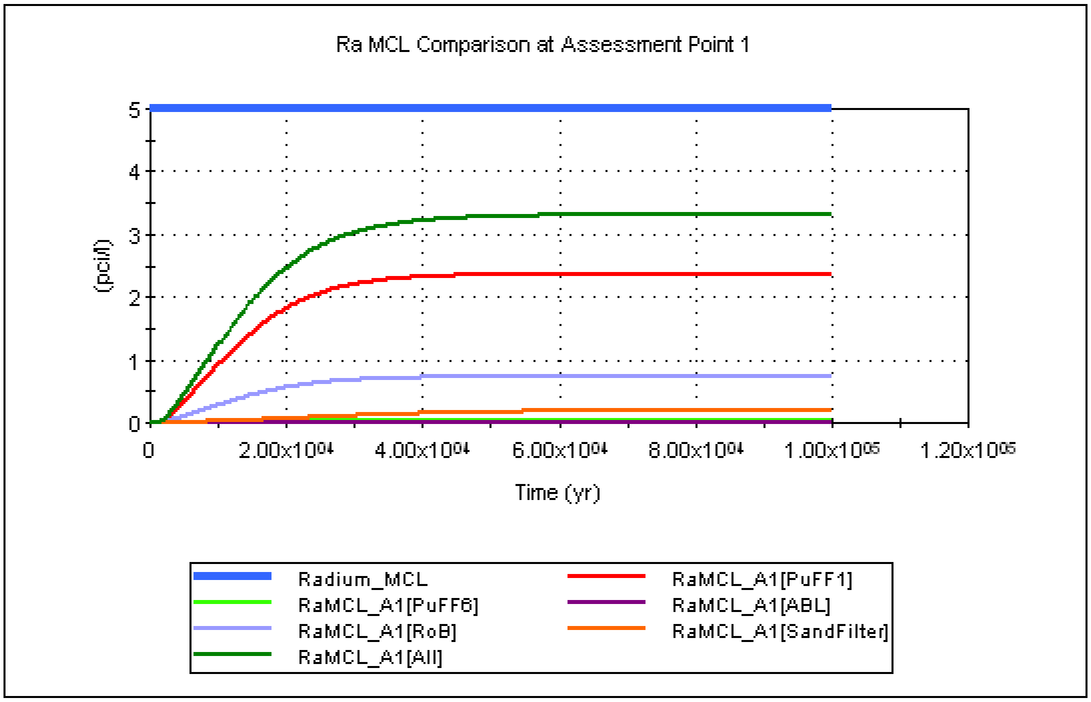


Figure 5-34 Removal of 75% of inventory Ra concentrations

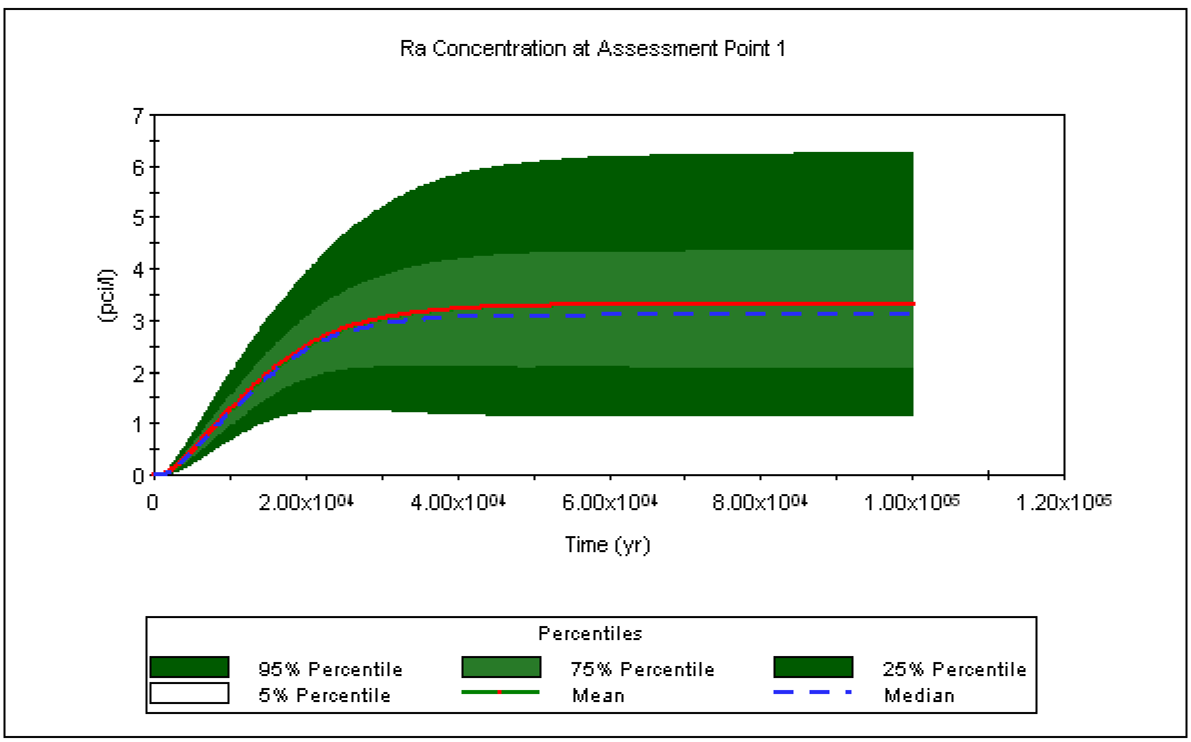


Figure 5-35 Removal of 75% of inventory Ra concentration uncertainties

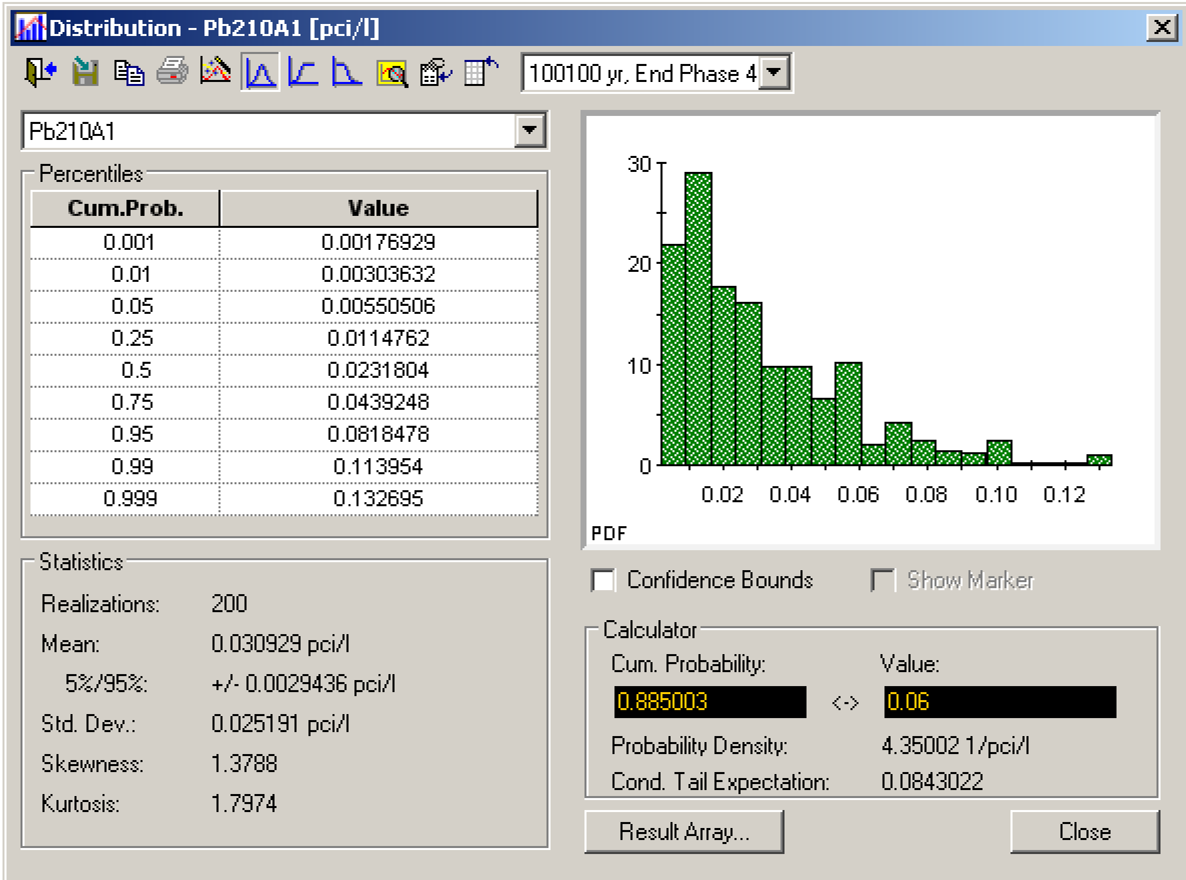


Figure 5-36 Removal of 75% of inventory Pb-210 distribution

5.6.3 Removal of 95% of the inventory

Figure 5-37 shows that if 95% of the PuFF cells 1-5 inventory is removed the mean total Ra concentration is not near the MCL. In this case, no realizations exceeded the MCL. The Pb-210 PRG was not exceeded for any realizations.

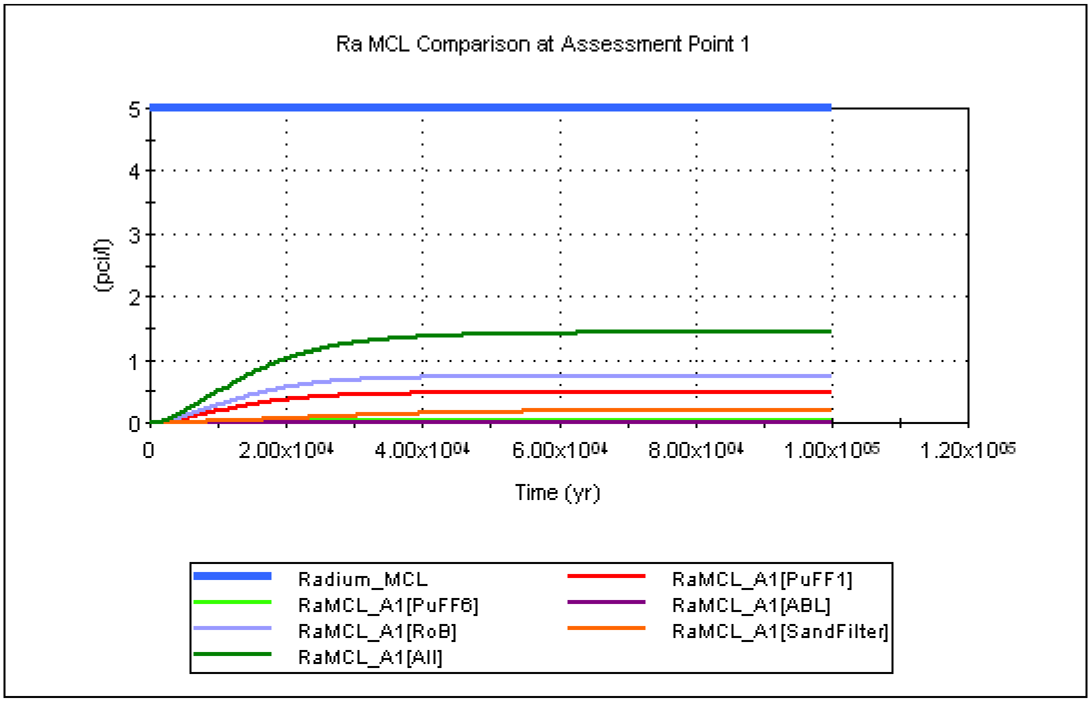


Figure 5-37 Removal of 95% of inventory Ra concentration

5.7 Pu TRANSPORT TO ASSESSMENT POINTS 4 AND 5

This discussion will refer to Pu isotopes from PuFF cells 1-5. Other sources behave similarly. Table 5-11 summarizes the results for the "no action" case which is representative of all cases. The rightmost columns refer to the final, integrated mass that passes through Assessment Points 4 and 5 over 10,000 years. Assessment Point 4 is at the bottom of the 235-F slab, and Assessment Point 5 is at the water table (see Figure 3-1).

One must remember that two different decay and transport rate processes are taking place simultaneously. The two isotopes with relatively short half-lives, Pu-238 and Pu-241, show the effect of short half-lives by having a small fraction of the initial mass crossing Assessment Point 4. Pu-239 and Pu-240, with their large masses crossing Assessment Point 4, shows the effect of the mass error (numerical uncertainty). Numerical uncertainty increases with increasing time step length and the time steps were made necessarily long due to the long duration of the simulation. Section 4.4.11.2 shows that sufficiently small time steps, such as those used for the beginning of the realizations, provided a much smaller mass error than the larger time steps at the end of the simulation. All peaks, except elemental Pb, occurred during this smaller time step period.

Figure 5-38 shows that the majority of the masses were released during the first 2,000 years. The figure shows the integrated mass so that when the curve levels off it means no more mass is passing the boundary.

Table 5-11 Pu Isotopes Transport

Isotope	Half Life (years)	Mean Initial mass[1] (g)	Mean Final mass AP 4 (g)	Final mass AP 5 (g)
Pu-238	87.7	495	7.0	0
Pu-239	24,110	127	129	1.8e-16
Pu-240	6564	18	17	1.2e-17
Pu-241	14.5	0.3	1e-6	0
Pu-242	375,000	1.5	1.5	2.6e-16

Note for Table 5-11
[1] Mean accounts for uncertainties in 1981 mass (±46%) and starting time of event.

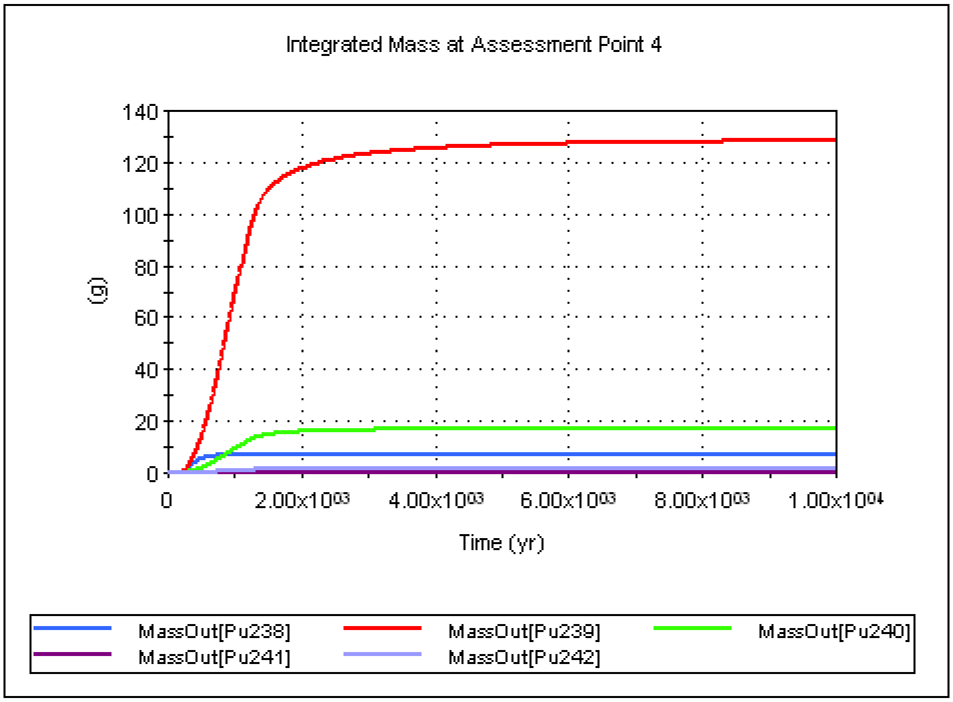


Figure 5-38 Pu Integrated Masses at Assessment Point 4

6.0 REFERENCES

Alhassan, Safaa J., 2005, Corrosion of Lead and Lead Alloys. ASM Handbook, Volume 13B: Corrosion: Materials (S.D. Cramer and B.S. Covino Jr., editors), ASM International, p. 195-204.

Almond, P. M., Kaplan, D. I., and Shine, E. P. 2012. Variability of Kd Values in Cementitious Materials and Sediments, SRNL-STI-2011-00672, revision 0, Savannah River National Laboratory, Aiken, SC. January 2012.

August 2010 Radionuclide Preliminary Remediation Goals (PRGs) (http://erdweb.srs.gov/eng/riskassess.html)

Bracken, D., Freeman, C., Wenz, T., and Gunn, C. 2009. Review of SRS PUFF Cell Holdup Calculations, Chief of Nuclear Safety Technical Paper, Volume 2, U.S. Department of Energy, Washington, DC. October 2009.

Carey, S. 2005. Low Activity Waste (LAW) Vault Structural Degradation Prediction, TCLC-E-00018, Rev. 0. Westinghouse Savannah River Company, Aiken, South Carolina. October 27, 2005.

Carey, S. 2008. Long Term Assessment of 105-P Structure for In-Situ D&D Alternatives, T-CLC-P-0000$, August 6, 2008.

Carey, S. 2009. Long Term Assessment of 105-R Structure for In-Situ D&D Alternatives, T-CLC-R-00002, January 8, 2009.

Council, G. W. 2008. Tier 2 Constituent Transport Analysis for the P-Area Reactor Building (U), ERD-EN-2008-0051, Revision 1, Savannah River Nuclear Solutions, Aiken, SC. September 2008.

Council, G. W. 2009. Constituent Transport Analysis for the R Area Reactor Building (U), ERD-EN-2008-0060, Revision 0, Savannah River Nuclear Solutions, Aiken, SC. April 2009.

Dixon, K. L. and Phifer, M. A. 2006. Hydraulic and Physical Properties of Cementitious Materials used at the Component-in-Grout Waste Trenches and the Intermediate Level Vault, WSRC-CP-2006-00033, Revision 0, Washington Savannah River Company, Aiken, South Carolina. August 2006.

DOE 1997. DOE Standard Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports, DOE-STD-1027-92, Change Notice Number 1. U.S. Department of Energy, Washington, D.C. September 1997.

DOE 2011. DOE Standard - Derived Concentration Technical Standard, DOE-STD-1196-2011, U.S. Department of Energy, Washington, D.C. April 2011.

DuPont 1983. Concrete – Certified Ready-Mixed and Special, Standard Engineering Specification SB6U, November 1983.

EPA 1981. Radioactivity in Drinking Water, Appendix III, United States Environmental Protection Agency, January 1981, pages 72-74.

EPA 2009. National Primary Drinking Water Regulations, EPA 816-F-09-004, United States Environmental Protection Agency, Washington, D.C. May 2009.

Hamm, L. L., Smith, F. G. III, Phifer, M. A., and Collard, L. B. 2009. Savannah River Site Composite Analysis: Aquifer Flow Path Parameters, SRNL-STI-2009-00438, Rev. 0, Savannah River National Laboratory, Aiken, SC. August 2009. [OUO]

NCRP 1996. Screening Models for Releases of Radionluclides to Atmosphere, Surface Water, and Ground, NCRP Report No. 123, National Council on Radiation Protection and Measures, January 1996.

ICRP 2008. Nuclear Decay Data for Dosimetric Calculations. ICRP Publication 107. Ann. International Commission on Radiological Protection (ICRP) 38 (3).

Jones, W. E. and Phifer, M. A. 2007. E-Area Low-Activity Waste Vault Subsidence Potential and Closure Cap Performance (U), WSRC-TR-2005-00405, Washington Savannah River Company, Aiken, SC. Augusta 2007.

Jones, W. E. 2009. Savannah River Site Surface Water Flow Rates for Composite Analysis Dose Calculations, SRNL-STI-2009-00077, Savannah River National Laboratory, Aiken, SC, January 2009.

Kaplan, D. I. 2010. Geochemical Data Package for Performance Assessment Calculations Related to the Savannah River Site, SRNL-STI-2009-00473, Savannah River National Laboratory, Aiken, SC. March 15, 2010.

Kaplan, D. I. 2011. Estimated Neptunium Sediment Sorption Values as a Function of pH and Measured Barium and Radium Kd Values, SRNL-STI-2011-00011, Savannah River National Laboratory, Aiken, SC. January 13, 2011.

Li, W. T. 2004. 235-F Expanded Storage Capacity Project Geotechnical Baseline and Evaluation (U), K-ESR-F-00013, Revision 1, Westinghouse Savannah River Co., Savannah River Site, Aiken, SC. July 2004.

NRC 1999. Residual Radioactive Contamination from Decommissioning: Parameter Analysis, NUREG/CR-5512, Vol. 3, Prepared for the Nuclear Regulatory Commission by Sandia National Laboratories, October 1999.

Perona, R., Tauxe, J., Gratson, D. 2009. Documentation of the Savannah River Site Dose Module (v1.2), Neptune and Company, Inc. July 29, 2009.

Phifer, M.A., M. A. Millings, G. P. Flach, 2006. Hydraulic Property Estimation for the E-Area and Z-Area Vadose Zone Soils, Cementitious Materials, and Waste Zones (U). WSRC-STI-2006-00198. Westinghouse Savannah River Company, Aiken, South Carolina. September 2003.

Phifer, M. A., Jones, W. E., Nelson, E. A., Denham, M. E. Lewis, M. R., and Shine, E. P. 2007. FTF Closure Cap Concept and Infiltration Estimates, WSRC-STI-2007-00184, revision 2, Washington Savannah River Company, Aiken, SC, October 2007.

Phifer, M. A. and Dixon, K. L. 2009. Material Property, Infiltration, and Saturation Estimates and Distributions, SRNL-STI-2009-00316, Savannah River National Laboratory, Aiken, SC, May 2009.

Powell, B. A., Lilly, M. A., Miller, T. J., and Kaplan, D. I. 2010. Iodine, Neptunium, Radium, and Strontium Sorption to Savannah River Site Sediments, SRNL-STI-2010-00527, Savannah River National Laboratory, Aiken, SC. September 20, 2010.

Radder, J. A. 2007. Master Engineering Calculation for 235-F Holdup Measurements, S-CLC-F-00534, Rev. 1, Washington Safety Management Solutions, Aiken, SC. February 2007.

Reed, M. B., Swanson, M. T., Gaither, S., Joseph, J. W., and Henry, W. R. 2002. Savannah River Site at Fifty, Strack, B. S., ed., Fedor, T. L., graphic designer, U.S. Government Printing Office, Washington, DC, 720 p.

Roe, B. A. 2006. Characterization Report – Building 235-F, FAMS Complex for Beryllium, Asbestos, Lead, PCBs and Holdup Assays, SDD-FAMS-2006-00007, Rev. 0, Washington Savannah River Company, Aiken, SC. September 28, 2006.

Rucker, G. 2001a. United States Environmental Protection Agency Promulgates New Maximum Contaminant Level for Uranium (U), ERTEC-2001-0001, Westinghouse Savannah River Company, Aiken, SC. February 5, 2001.

Rucker, G. 2001b. Use of Maximum Contaminant Levels for Radionuclides (U), ERTEC-2001-0002, Westinghouse Savannah River Company, Aiken, SC. February 9, 2001.

Santos, J. K. 2006. FAMS Complex Preliminary PCB Paint Characterization, SDD-2006-00213, Washington Savannah River Company, Aiken, SC. April 18, 2006.

Sappington, F. C. and Phifer, M. A. 2005. Moisture Content and Porosity of Concrete Rubble Study, WSRC-TR-2005-00054, revision 0, Westinghouse Savannah River Company, Aiken, South Carolina. October 7, 2005

Seaman, J. C. and Kaplan, D. I. 2010. Chloride, Chromate, Silver, Thallium and Uranium Sorption to SRS Soils, Sediments, and Cementitious Materials, SRNL-STI-2010-00493, Savannah River National Laboratory, Aiken, SC. September 29, 2010.

Schroeder, P. R., Lloyd, C. M., Zappi, P. A., and Aziz, N. M. 1994a. The Hydrologic Evaluation of Landfill Performance (HELP) Model User's Guide for Version 3. EPA/600/R-94/168a. Office of Research and Development, United States Environmental Protection Agency (EPA), Cincinnati, Ohio. September 1994.

Schroeder, P. R., Dozier, T. S., Zappi, P. A., McEnroe, B. M., Sjostrom, J. W., and Peyton, R. L. 1994b. The Hydrologic Evaluation of Landfill Performance (HELP) Engineering Documentation for Version 3. EPA/600/R-94/168b. Office of Research and Development, United States Environmental Protection Agency (EPA), Cincinnati, Ohio. September 1994.

Shine, E. P. 2008. Distribution of the 1,000-Year Mean of Background Infiltration in SRS Soils, SRNL-L5100-2008-00012, Savannah River National Laboratory, Aiken, SC, December 10, 2008.

Shine, E. P. 2009. Distribution of the Means of Stream Flow Rates in the Savannah river Site Vicinity Over One-Year and 1,000-Years, SRNL-L5200-2009-00009, Savannah River National Laboratory, Aiken, SC, March 9, 2009.

Soo, P. and Roberts, T. C. 1995. Corrosion Analysis of Decommissioned Carbon Steel Waste Water Tanks at Brookhaven National Laboratory, BNL-52486, Brookhaven National Laboratory, Upton, NY. July 1995.

SRNL 2010. Savannah River Site DOE 435.1 Composite Analysis, Volumes I and II, SRNL-STI-2009-00512, Revision 0, Savannah River National Laboratory, Aiken, SC. June 10, 2010.

SRNS 2009. Furnishing and Delivery of R-Area Disassembly Concrete (U), C-SPP-R-00006, revision 1, Savannah River Nuclear Solutions, Aiken, SC. November 12, 2009.

SRNS 2010. Consolidated Hazards Analysis for Surveillance and Maintenance, and for Deactivation and Decommissioning of Building 235-F, S-CHA-F-00006, Rev. 0, Savannah River Nuclear Solutions, Aiken, SC. May 2010.

SRR 2010. Performance Assessment for the F-Tank Farm at the Savannah River Site, SRS-REG-2007-00002, Revision 1, Savannah River Remediation (SRR), Aiken, SC. March 31, 2010.

SRR 2011. Performance Assessment for the H-Tank Farm at the Savannah River Site, SRR-CWDA-2010-00128, Revision 0, Savannah River Remediation (SRR), Aiken, SC. March 2011.

Technical Data Sheet for Berger Protecton Protective Coatings Linosol Chlorinated Rubber Paint (http://www.bergerpaints.com/industrial-users/products-industrial/protective-coatings/products/Berger_Chlorinated_Rubber_Coatings/DS_025_Linosol_Chlorinated_Rubber_Paint.pdf)

Technical Data Sheet for Sealocrete chlorinated rubber paint (http://www.sealocrete.com/docs/datasheet/Chlorinated%20Rubber%20Paint.pdf)

Technical Data Sheet for Teamac Chlorvar chlorinated rubber paint (http://www.teamac.co.uk/downloads/pdfs/CHLOR%20RUBBER%20DATA.pdf)

Technical Data Sheet for TriCom Coatings, Inc. chlorinated rubber coating (http://www.tricomcoatings.com/Tech%20Data%20Sheets/images/TT-P-95C%20Chlorinated%20Rubber%20Coating.pdf)

Wike, L. D., Martin, F. D., Nelson, E. A., Halverson, N. V., Mayer, J. J., Paller, M. H., Riley, R. S., Serrato, M. G., and Specht, W. L. 2006. SRS Ecology: Environmental Information Document, WSRC-TR-2005-00201, Washington Savannah River Company, Aiken, SC.

WSRC 2003a. Safety Analysis – 200 F-Area, Savannah River Site, Building 235-F, Final Safety Analysis Report (U), WSRC-RP-89-575, Rev. 3, Westinghouse Savannah River Company, Aiken, SC. January 2003.

WSRC 2003b. Savannah River Site Environmental Management Integrated Deactivation and Decommissioning Plan, WSRC-RP-2003-00233, Rev. 1, Westinghouse Savannah River Company, Aiken, SC. September 2003.

WSRC 2005. Response to Request for Additional Information on the Draft Section 3116 Determination for Salt Waste Disposal at the Savannah River Site, CBU-PIT-2005-00131, Rev. 0, Westinghouse Savannah River Company, Aiken, SC. June 30, 2005.

WSRC 2006. FAMS Decommissioning End-State Alternative Evaluation, G-AES-F-00002, Rev. 0, Washington Savannah River Company, Aiken, SC. May 2006.

WSRC 2007. Strategy and Scope of Work to Decommission 235-F Using CERCLA Remedial Process (U), SDD-2007-00017, Rev. 0, Washington Savannah River Company, Aiken, SC. February 2007.

WSRC 2008. E-Area Low-Level Waste Facility DOE 435.1 Performance Assessment, WSRC-STI-2007-00306, Revision 0. Washington Savannah River Company, Savannah River Site, Aiken, SC. July 2008.

Personal correspondence with Shawn Carey and Bill Peregoy of SRNS Design Engineering Structural Mechanics

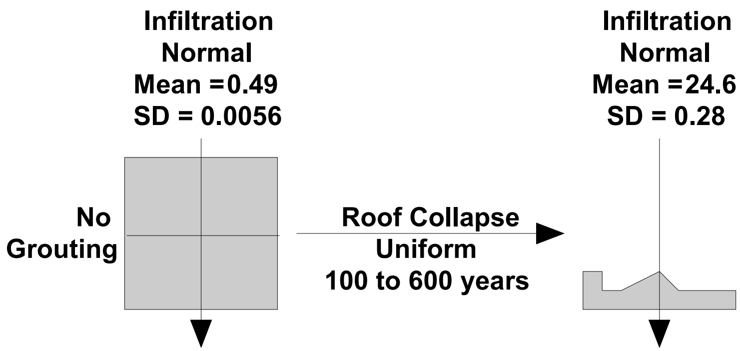
Drawing W146548

Drawing W146616
Drawing W147672
Drawing W448944
Drawing W725656
Drawing W726276
Drawing W737960

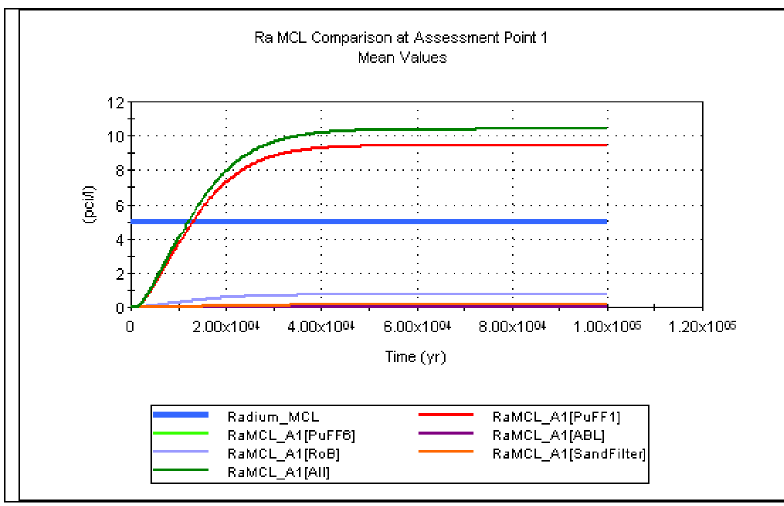
APPENDICES

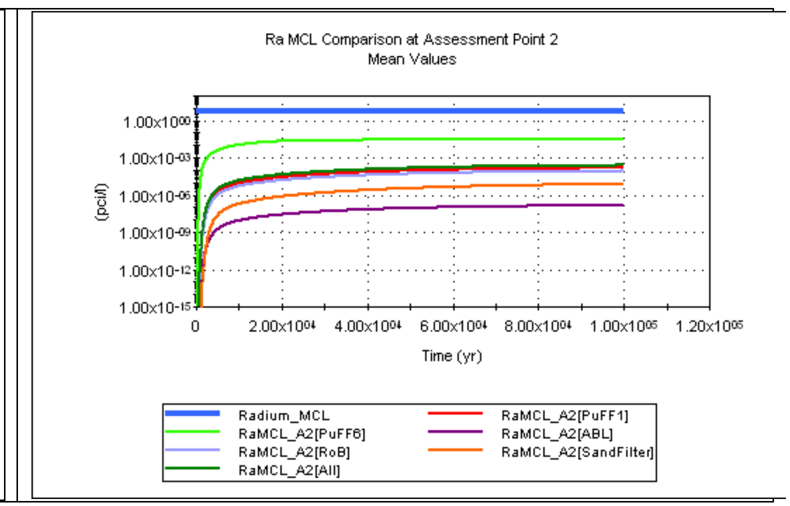
The following appendices contain figures which complete the story told above. Not all appendices contain the same figures as different things are of interest for some of the cases. A distribution plot is typically shown if the mean of an item of interest is near its limit. This provides an indication of the risk involved with that item as opposed to showing a single line which would give a pass/fail.

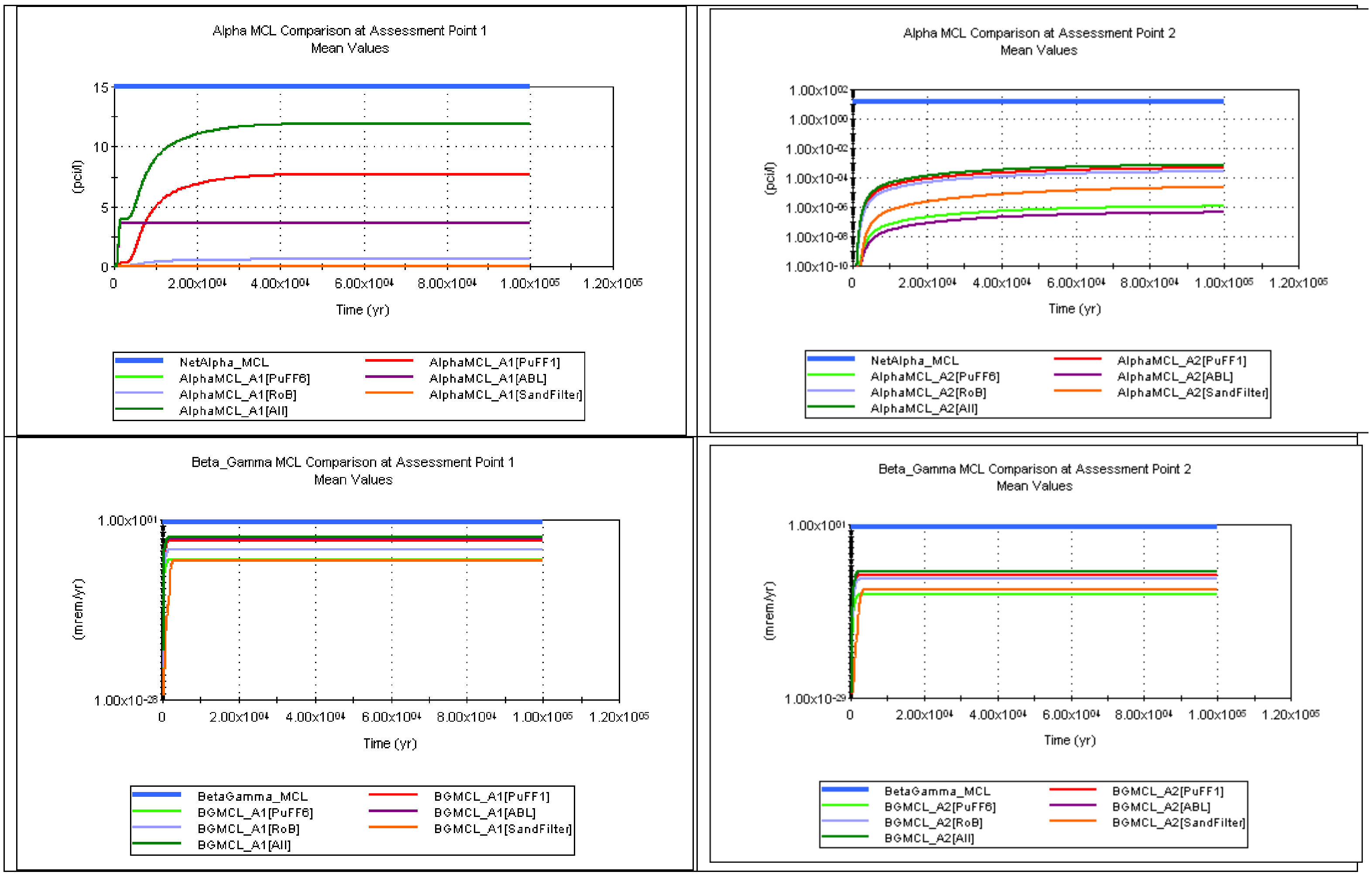
APPENDIX A NO ACTION SCENARIO

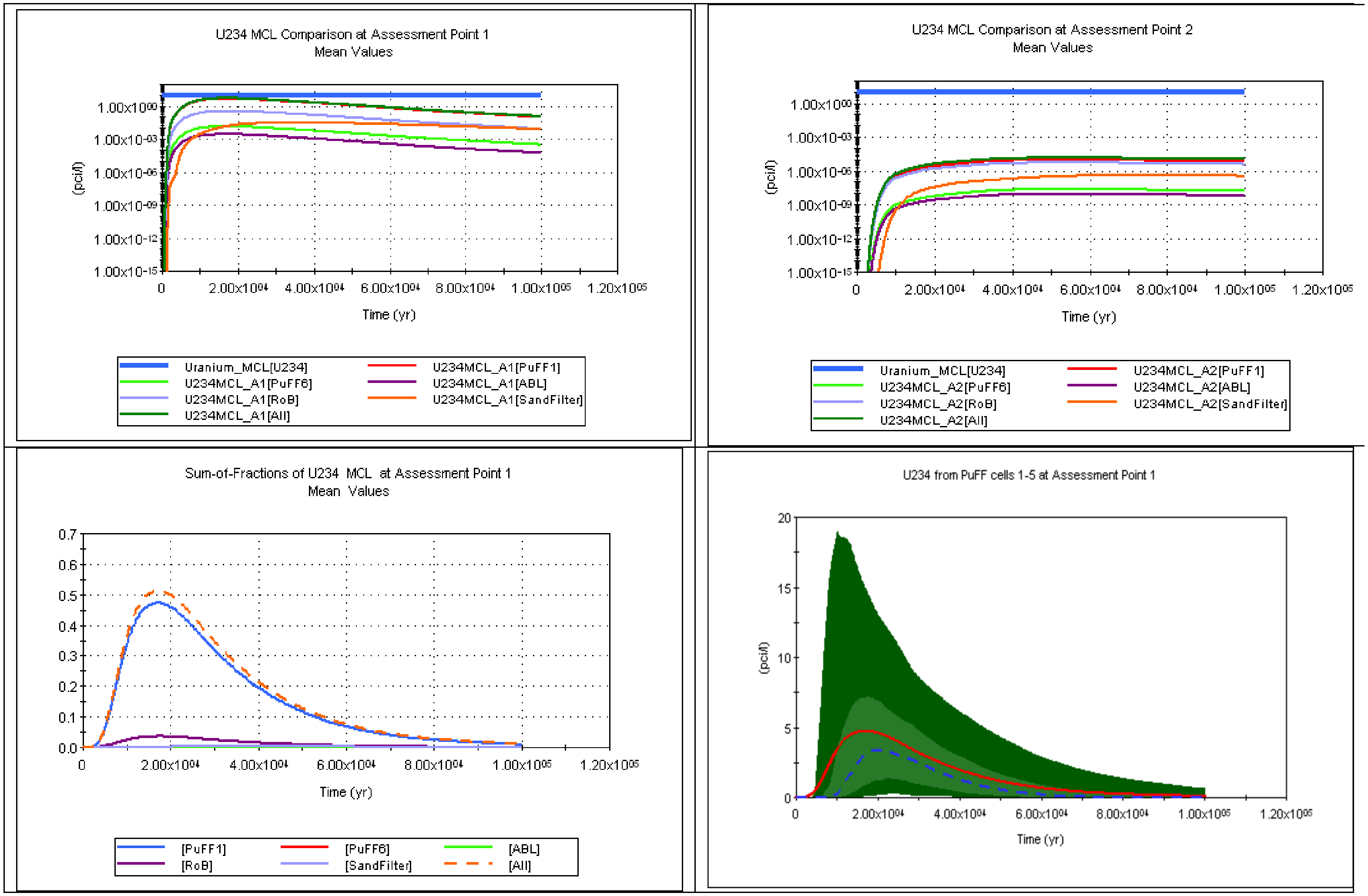


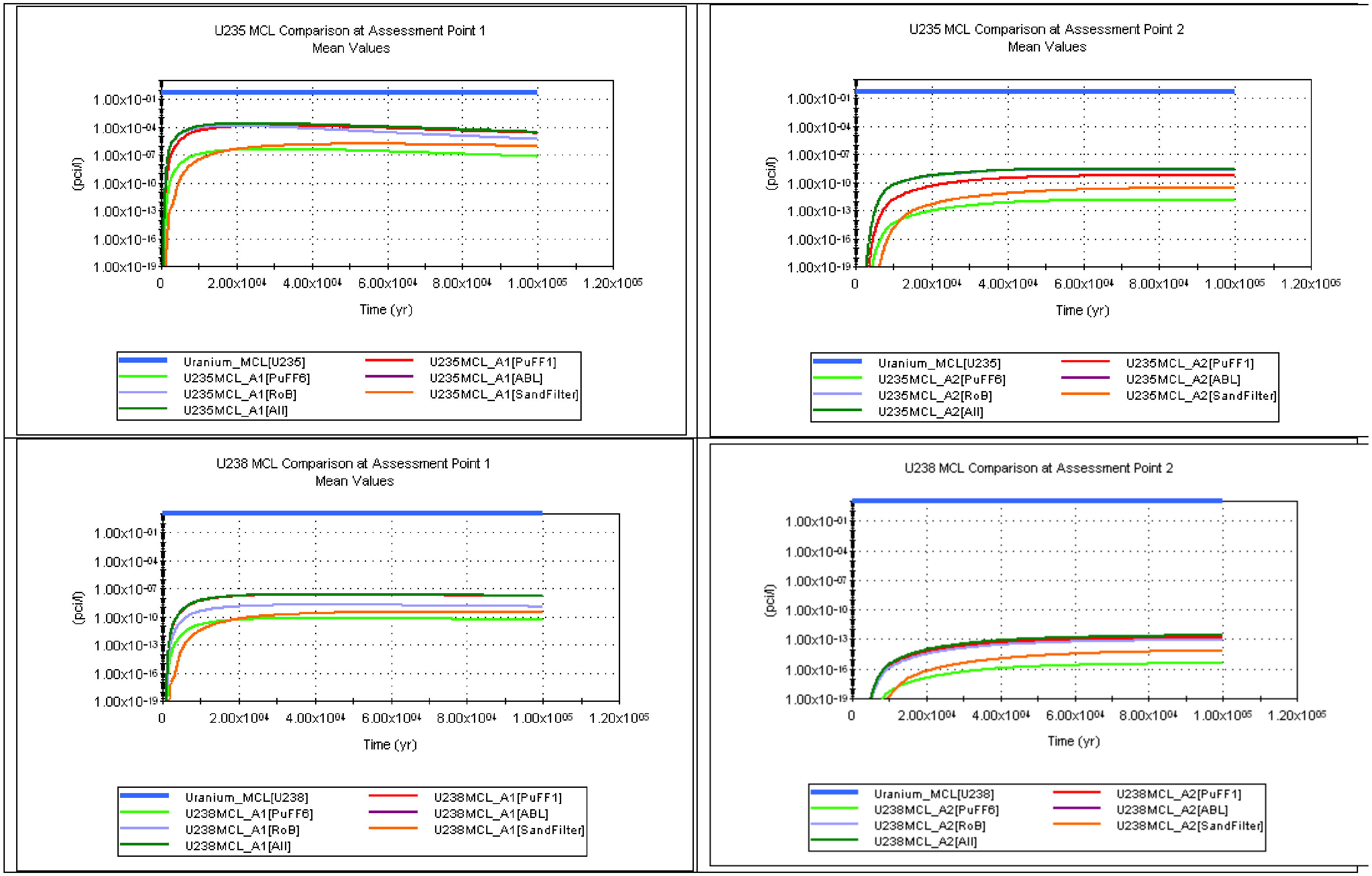
Unless otherwise noted, all plots are of mean values and are **based** upon the entire building.

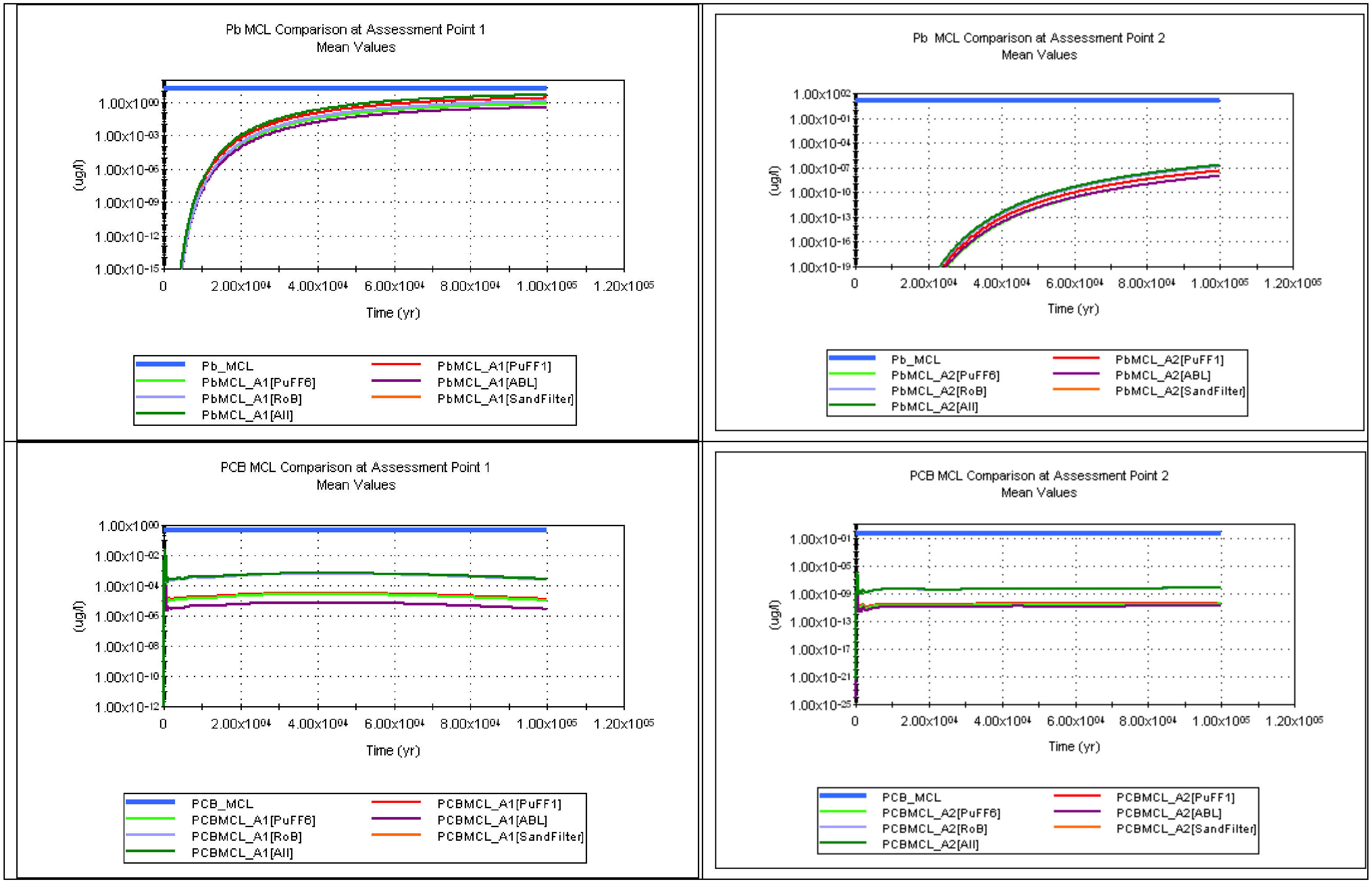




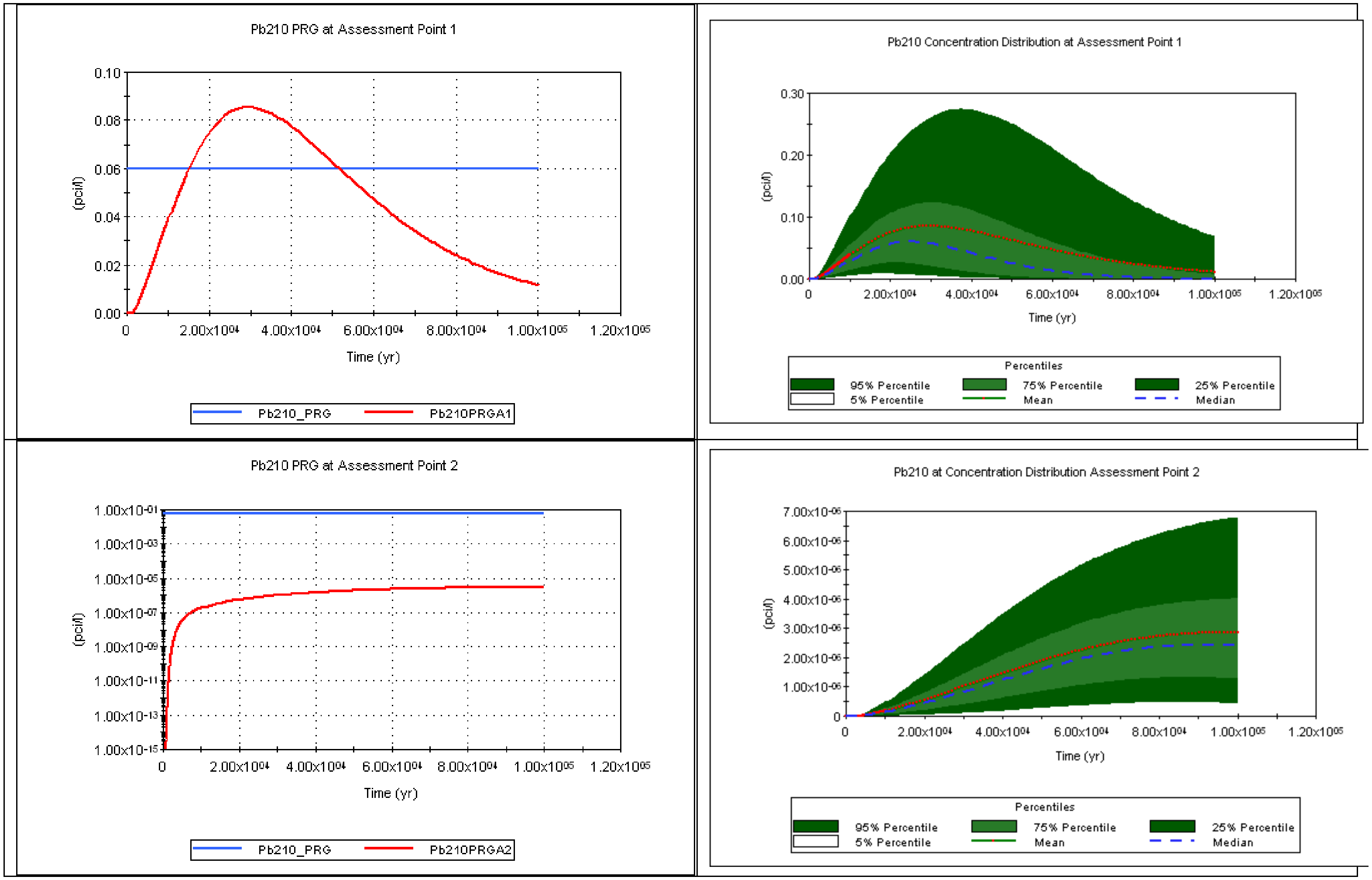

Alpha MCL Comparison at Assessment Point 1
Mean Values
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A1[PuFF6]
AlphaMCL_A1[RoB]
AlphaMCL_A1[All]
AlphaMCL_A1[PuFF1]
AlphaMCL_A1[ABL]
AlphaMCL_A1[SandFilter]
Alpha MCL Comparison at Assessment Point 2
Mean Values
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A2[PuFF6]
AlphaMCL_A2[RoB]
AlphaMCL_A2[All]
AlphaMCL_A2[PuFF1]
AlphaMCL_A2[ABL]
AlphaMCL_A2[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 1
Mean Values
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A1[PuFF6]
BGMCL_A1[RoB]
BGMCL_A1[All]
BGMCL_A1[PuFF1]
BGMCL_A1[ABL]
BGMCL_A1[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 2
Mean Values
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A2[PuFF6]
BGMCL_A2[RoB]
BGMCL_A2[All]
BGMCL_A2[PuFF1]
BGMCL_A2[ABL]
BGMCL_A2[SandFilter]

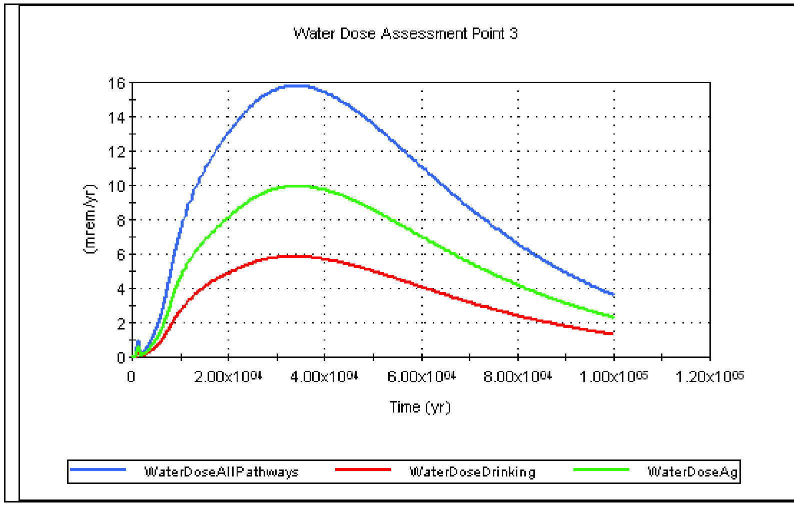

U234 MCL Comparison at Assessment Point 1
Mean Values
(pci/l)
Time (yr)
Uranium_MCL[U234]
U234MCL_A1[PuFF6]
U234MCL_A1[RoB]
U234MCL_A1[All]
U234MCL_A1[PuFF1]
U234MCL_A1[ABL]
U234MCL_A1[SandFilter]
U234 MCL Comparison at Assessment Point 2
Mean Values
(pci/l)
Time (yr)
Uranium_MCL[U234]
U234MCL_A2[PuFF6]
U234MCL_A2[RoB]
U234MCL_A2[All]
U234MCL_A2[PuFF1]
U234MCL_A2[ABL]
U234MCL_A2[SandFilter]
Sum-of-Fractions of U234 MCL at Assessment Point 1
Mean Values
Time (yr)
[PuFF1]
[RoB]
[PuFF6]
[SandFilter]
[ABL]
[All]
U234 from PuFF cells 1-5 at Assessment Point 1
(pci/l)
Time (yr)

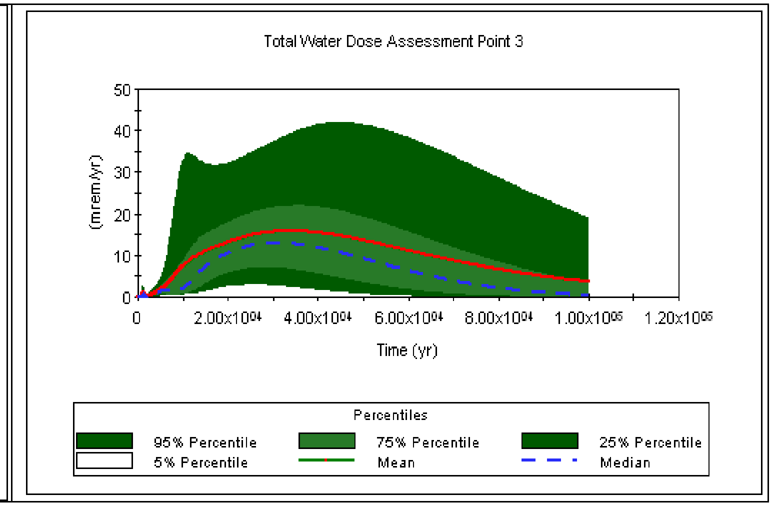

U235 MCL Comparison at Assessment Point 1
Mean Values
1.00x10-01
1.00x10-04
1.00x10-07
1.00x10-10
1.00x10-13
1.00x10-16
1.00x10-19
(pci/l)
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
Uranium_MCL[U235]
U235MCL_A1[PuFF6]
U235MCL_A1[RoB]
U235MCL_A1[All]
U235MCL_A1[PuFF1]
U235MCL_A1[ABL]
U235MCL_A1[SandFilter]
U235 MCL Comparison at Assessment Point 2
Mean Values
Uranium_MCL[U235]
U235MCL_A2[PuFF6]
U235MCL_A2[RoB]
U235MCL_A2[All]
U235MCL_A2[PuFF1]
U235MCL_A2[ABL]
U235MCL_A2[SandFilter]
U238 MCL Comparison at Assessment Point 1
Mean Values
Uranium_MCL[U238]
U238MCL_A1[PuFF6]
U238MCL_A1[RoB]
U238MCL_A1[All]
U238MCL_A1[PuFF1]
U238MCL_A1[ABL]
U238MCL_A1[SandFilter]
U238 MCL Comparison at Assessment Point 2
Uranium_MCL[U238]
U238MCL_A2[PuFF6]
U238MCL_A2[RoB]
U238MCL_A2[All]
U238MCL_A2[PuFF1]
U238MCL_A2[ABL]
U238MCL_A2[SandFilter]



Pb MCL Comparison at Assessment Point 1
Mean Values
(ug/l)
Time (yr)
Pb_MCL
PbMCL_A1[PuFF6]
PbMCL_A1[RoB]
PbMCL_A1[All]
PbMCL_A1[PuFF1]
PbMCL_A1[ABL]
PbMCL_A1[SandFilter]
Pb MCL Comparison at Assessment Point 2
Mean Values
(ug/l)
Time (yr)
Pb_MCL
PbMCL_A2[PuFF6]
PbMCL_A2[RoB]
PbMCL_A2[All]
PbMCL_A2[PuFF1]
PbMCL_A2[ABL]
PbMCL_A2[SandFilter]
PCB MCL Comparison at Assessment Point 1
Mean Values
(ug/l)
Time (yr)
PCB_MCL
PCBMCL_A1[PuFF6]
PCBMCL_A1[RoB]
PCBMCL_A1[All]
PCBMCL_A1[PuFF1]
PCBMCL_A1[ABL]
PCBMCL_A1[SandFilter]
PCB MCL Comparison at Assessment Point 2
Mean Values
(ug/l)
Time (yr)
PCB_MCL
PCBMCL_A2[PuFF6]
PCBMCL_A2[RoB]
PCBMCL_A2[All]
PCBMCL_A2[PuFF1]
PCBMCL_A2[ABL]
PCBMCL_A2[SandFilter]


Pb210 PRG at Assessment Point 1
(pci/l)
Time (yr)
Pb210_PRG
Pb210PRGA1
Pb210 Concentration Distribution at Assessment Point 1
(pci/l)
Time (yr)
Percentiles
95% Percentile
75% Percentile
25% Percentile
5% Percentile
Mean
Median
Pb210 PRG at Assessment Point 2
(pci/l)
Time (yr)
Pb210_PRG
Pb210PRGA2
Pb210 at Concentration Distribution Assessment Point 2
(pci/l)
Time (yr)
Percentiles
95% Percentile
75% Percentile
25% Percentile
5% Percentile
Mean
Median





DOE Order 435.1 dose limit is 25 mrem/yr at 100 m from facility boundary (i.e. Assessment Point 3).

Table A.1 shows the PRGs evaluated in these analyses. The column "Fraction of PRG" is the peak mean concentration at Assessment Point 1 divided by the PRG. Other than Pb-210 all other species with PRGs are at least two orders of magnitude lower in concentration than their limits. With the similarity of the other grout cases to this one, this table will not be repeated in the other appendices. The inventory removal cases produce even lower concentrations, so this table will not be reproduced for those cases. The remaining cases are unrealistic and the table will not be reproduced for those cases.

The concentrations are based on the building footprint and are taken from Assessment Point 1.

Table A-1 PRG Comparison

Species	PRG	Fraction of PRG
Ac227	2.63E-01 pCi/l	1e-34
Ac228	2.66E+01 pCi/l	4e-8
Bi210	5.93E+00 pCi/l	0.01
Bi212	7.45E+01 pCi/l	1e-8
Bi213	1.04E+02 pCi/l	1e-6
Bi214	2.76E+02 pCi/l	0.03
Fr223	7.26E+00 pCi/l	4e-10
Pb209	2.20E+02 pCi/l	6e-7
Pb210	6.01E-02 pCi/l	**1.0**
Pb211	1.29E+02 pCi/l	2e-9
Pb212	2.12E+00 pCi/l	5e-7
Pb214	1.54E+02 pCi/l	0
Pu241	3.01E+01 pCi/l	0
Ra225	4.64E-01 pCi/l	3e-4
Th231	2.39E+01 pCi/l	2e-5
Th234	2.29E+00 pCi/l	2e-8

Radium Sensitivity Analysis

This discussion will be with respect to the sum of the radium concentrations (per the MCL) as the dependent variable. The Importance Measure ranks the influence each independent variable has on the dependent variable. From Table A-2 one can see that "U" variable ID has the most effect on the radium concentration. Unfortunately the Sensitivity Analysis table does not give the full path name of the variable so if one backtracks the variable by looking at the Multi Variate Properties element one would see that variable number 44 is the clayey soil K_d for uranium. Variable 25 is the sandy soil K_d for uranium. What the table is telling us is that for the period ending at 100,100 years, by far the parameters with the most effect of the radium concentration at Assessment Point 1 are the clayey soil Kd and the PuFF cells 1-5 inventory.

Table A-2 Ra Sensitivity Analysis for Assessment Point 1, t=100100 years

Result Sensitivity Analysis

Result analyzed: Ra_PuFF1_AP1

Analysis is based on: value Phase: 100100 yr, End Phase 4

Coefficient of determination: 0.811026

	Variable ID	Correlation Coefficient	Regression Coefficient	Partial Coefficient	Importance Measure
44	U	0.550	0.529	0.743	0.323
157	PuFF1Uncert	-0.555	-0.521	-0.736	0.312
25	U	0.266	0.309	0.551	0.094
19	Kd_Dist[Th]	0.277	0.239	0.444	0.068
169	DispersivityUncert	-0.159	-0.151	-0.298	0.051
126	Kd_Dist[Rn]	-0.032	-0.021	-0.043	0.031
116	Kd_Dist[Am]	0.024	0.021	0.042	0.029
104	Kd_Dist[U]	0.010	-0.037	-0.075	0.029
66	Kd_Dist[U]	0.039	0.007	0.014	0.028
94	Kd_Dist[Fr]	0.008	0.019	0.038	0.028
108	U	0.027	0.010	0.021	0.027
105	Pu	-0.042	-0.012	-0.026	0.027
112	DryBulkDensity_Grout	-0.069	-0.001	-0.001	0.027
81	Kd_Dist[Ra]	0.019	0.004	0.008	0.027

Close Help

For the period ending at 10,100 years the PuFF cells 1-5 inventory have become extremely important (see Table A-3). This tells us that if we were looking at 10,000 years as our compliance period, working on reducing the uncertainty on the PuFF cells 1-5 inventory would have the greatest effect on the radium concentration. The second most important parameter is “Sr”. Sr is the radium surrogate for K_ds. Variable 43 is the clayey soil K_d for Ra (and Sr).

The period ending at year 1100 (see Table A-4) shows the clayey and sandy soil K_d of Ra being the most important parameter, with the clayey soil one being more than three times as important.

To sum up the sensitivity analyses, for Ra concentration at Assessment Point 1, the two most important parameters, or, those to which the Ra concentration is most sensitive, are clayey soil Ra Kd and PuFF cells 1-5 inventory. If one were interested in refining the model, these parameters would provide the biggest bang for the buck.

Table A-3 Ra Sensitivity Analysis for Assessment Point 1, t=10100 years

Result Sensitivity Analysis

Result analyzed: Ra_PuFF1_AP1

Analysis is based on: value   Phase: 10100 yr, End Phase 3

Coefficient of determination: 0.828855

	Variable ID	Correlation Coefficient	Regression Coefficient	Partial Coefficient	Importance Measure
157	PuFF1Uncert	-0.754	-0.745	-0.853	0.570
43	Sr	-0.313	-0.279	-0.524	0.117
44	U	-0.233	-0.264	-0.504	0.079
24	Sr	-0.211	-0.229	-0.443	0.050
183	IR_Partial	0.161	-0.079	-0.042	0.037
185	VZ_Thickness_stoch	-0.142	0.008	0.011	0.036
147	Kd_Dist[Tl]	0.054	0.007	0.015	0.032
91	Kd_Dist[Am]	-0.065	-0.002	-0.003	0.032
89	U	0.025	0.010	0.021	0.031
144	Kd_Dist[Ra]	0.063	0.004	0.009	0.029
61	Kd_Dist[Pu]	0.023	0.003	0.005	0.029
182	IR_Intact	0.159	-0.025	-0.013	0.029
181	IR_GSA	0.158	-0.050	-0.027	0.028
167	SD	0.171	0.392	0.063	0.028

Close   Help

Table A-4 Ra Sensitivity Analysis for Assessment Point 1, t=1100 years

Result Sensitivity Analysis

Result analyzed: Ra_PuFF1_AP1

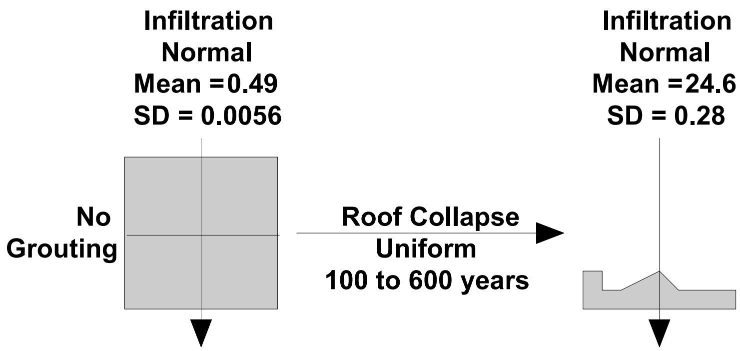
Analysis is based on: value   Phase: 1100 yr, End Phase 2

Coefficient of determination: 0.48133

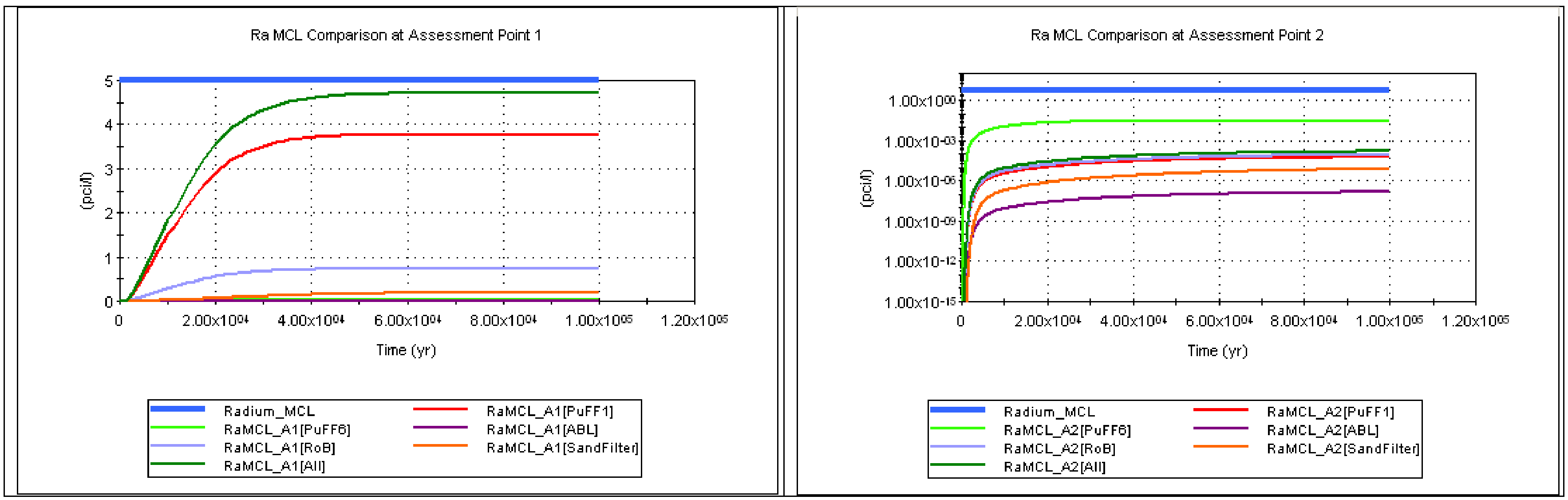
	Variable ID	Correlation Coefficient	Regression Coefficient	Partial Coefficient	Importance Measure
43	Sr	-0.461	-0.439	-0.486	0.341
24	Sr	-0.271	-0.281	-0.328	0.098
169	DispersivityUncert	0.258	0.277	0.326	0.098
147	Kd_Dist[Tl]	0.005	-0.008	-0.009	0.060
83	Kd_Dist[Th]	0.010	0.067	0.084	0.049
118	Kd_Dist[Bi]	0.035	-0.020	-0.024	0.049
133	U	0.009	0.053	0.065	0.046
57	Kd_Dist[Np]	0.021	0.013	0.016	0.044
28	Kd_Dist[At]	0.060	0.048	0.058	0.044
171	NoGroutCollapseTimeRoof	-0.137	-0.145	-0.179	0.042
34	Kd_Dist[Po]	0.009	0.046	0.056	0.039
79	Kd_Dist[Po]	0.016	0.038	0.047	0.038
25	U	0.022	0.022	0.029	0.037
59	Kd_Dist[Pb]	0.035	0.003	0.004	0.036

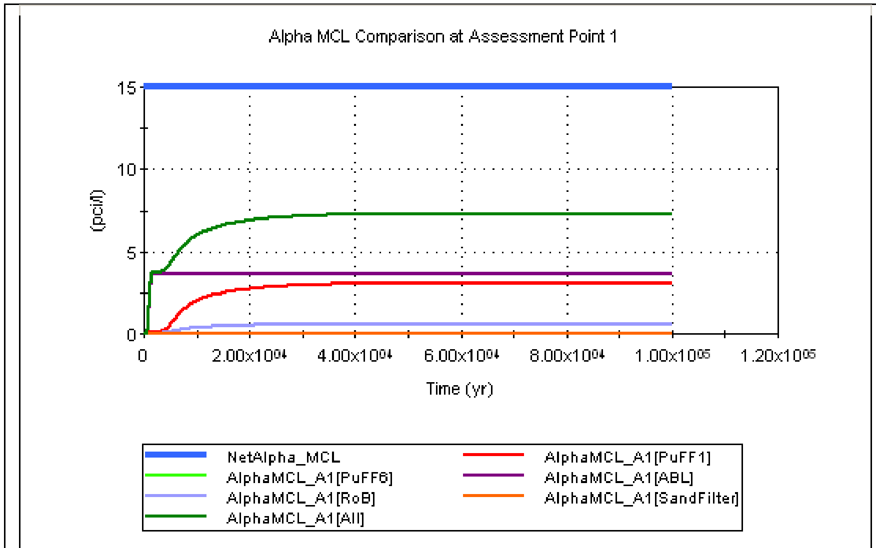
Close   Help

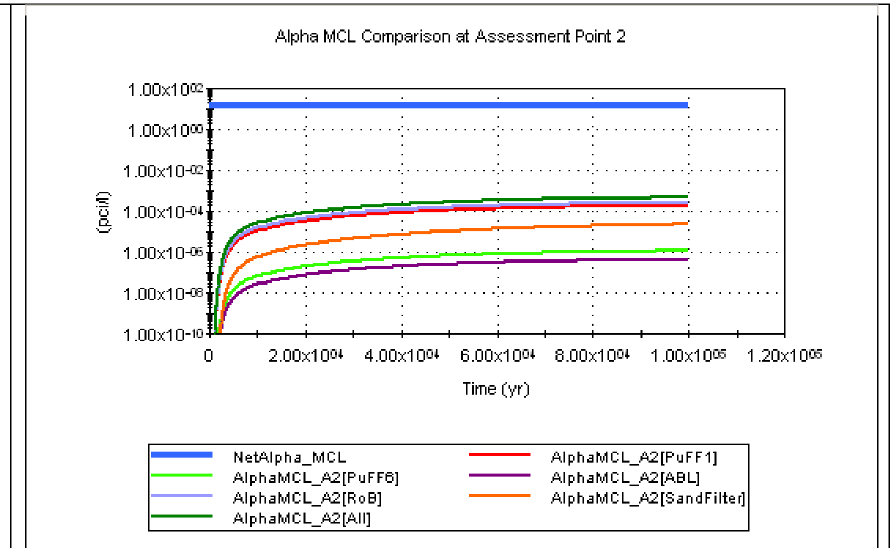
APPENDIX B REMOVE 60% OF PUFF CELLS 1-5 INVENTORY

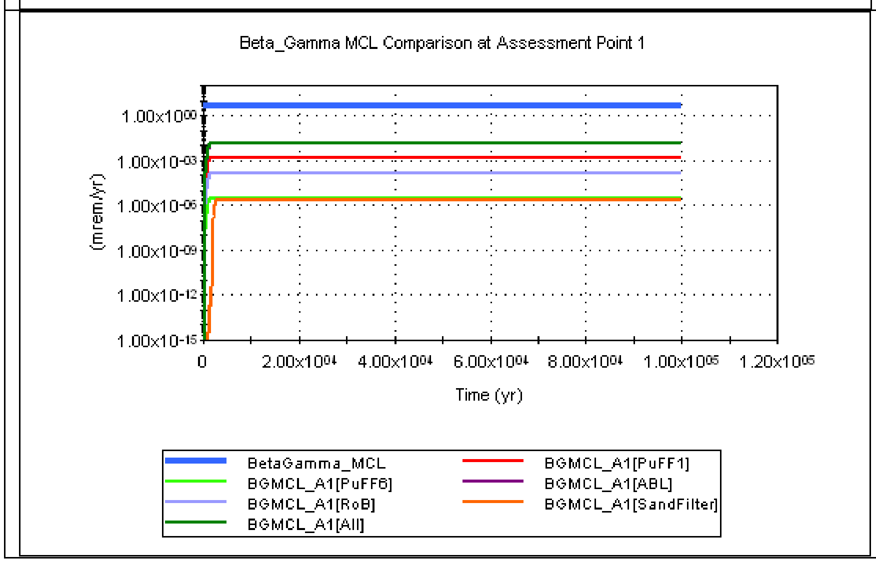


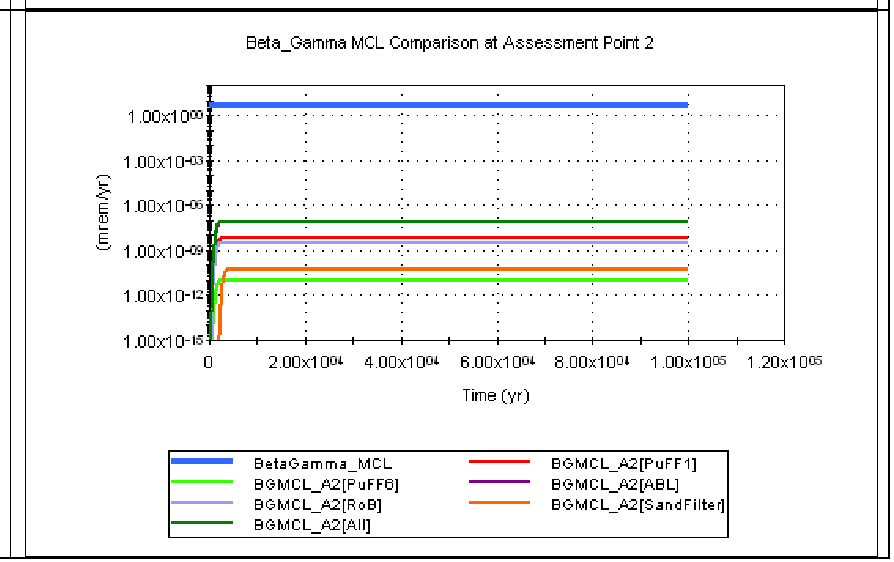
Unless otherwise noted, all plots are of mean values and are based upon the entire building.

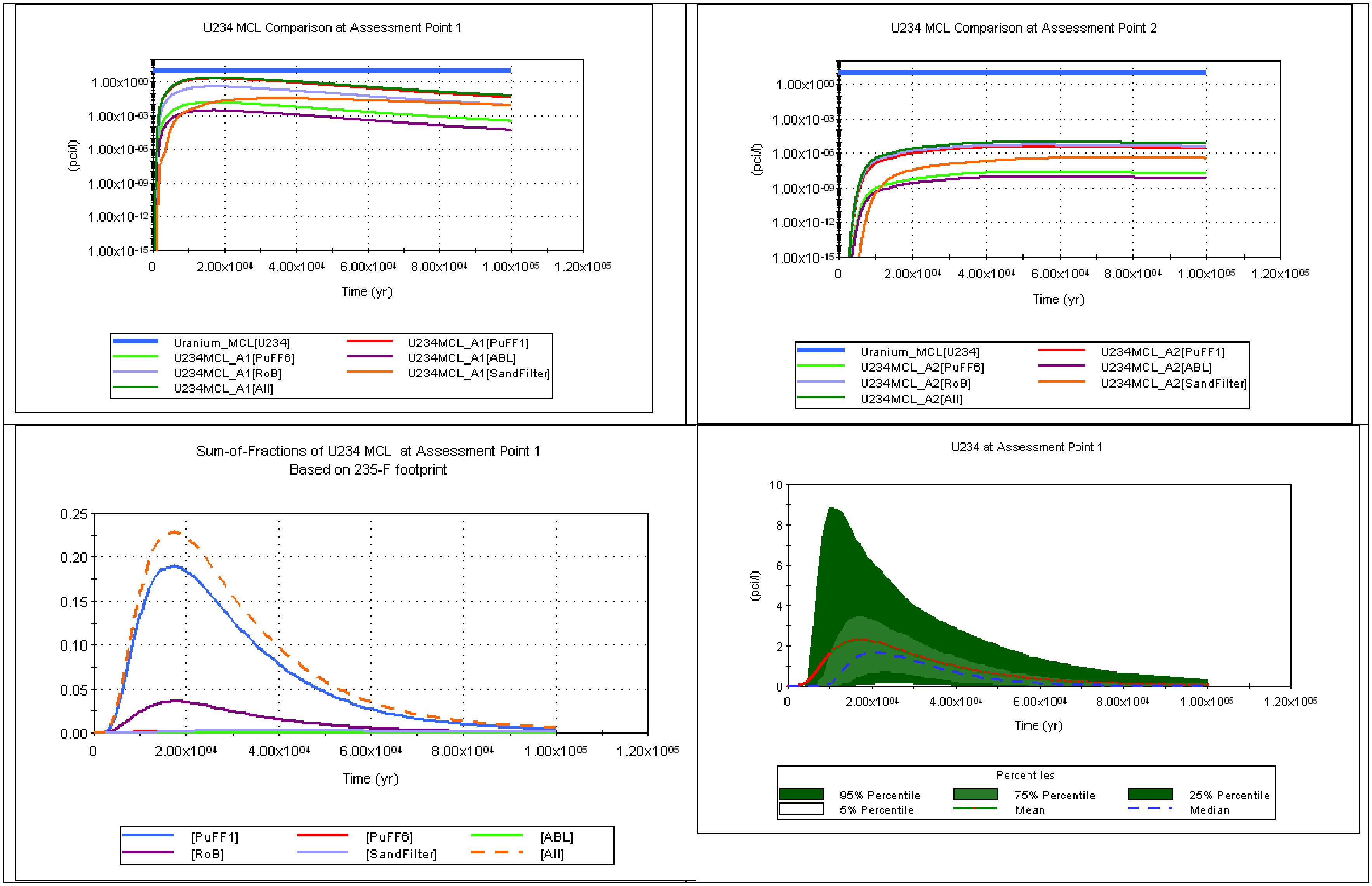


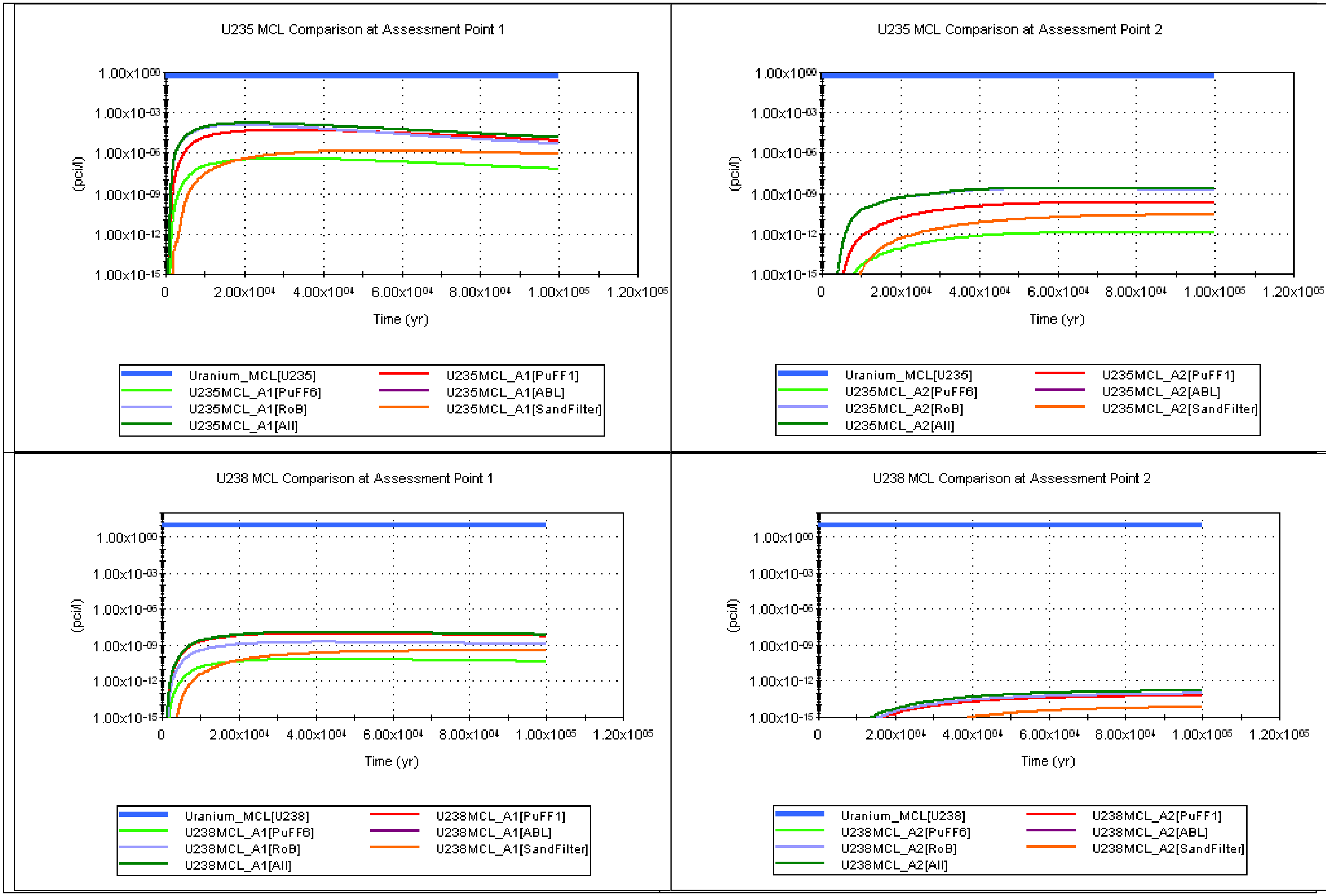

Alpha MCL Comparison at Assessment Point 1
(pci/l)
15
10
5
0
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
NetAlpha_MCL
AlphaMCL_A1[PuFF6]
AlphaMCL_A1[RoB]
AlphaMCL_A1[All]
AlphaMCL_A1[PuFF1]
AlphaMCL_A1[ABL]
AlphaMCL_A1[SandFilter]

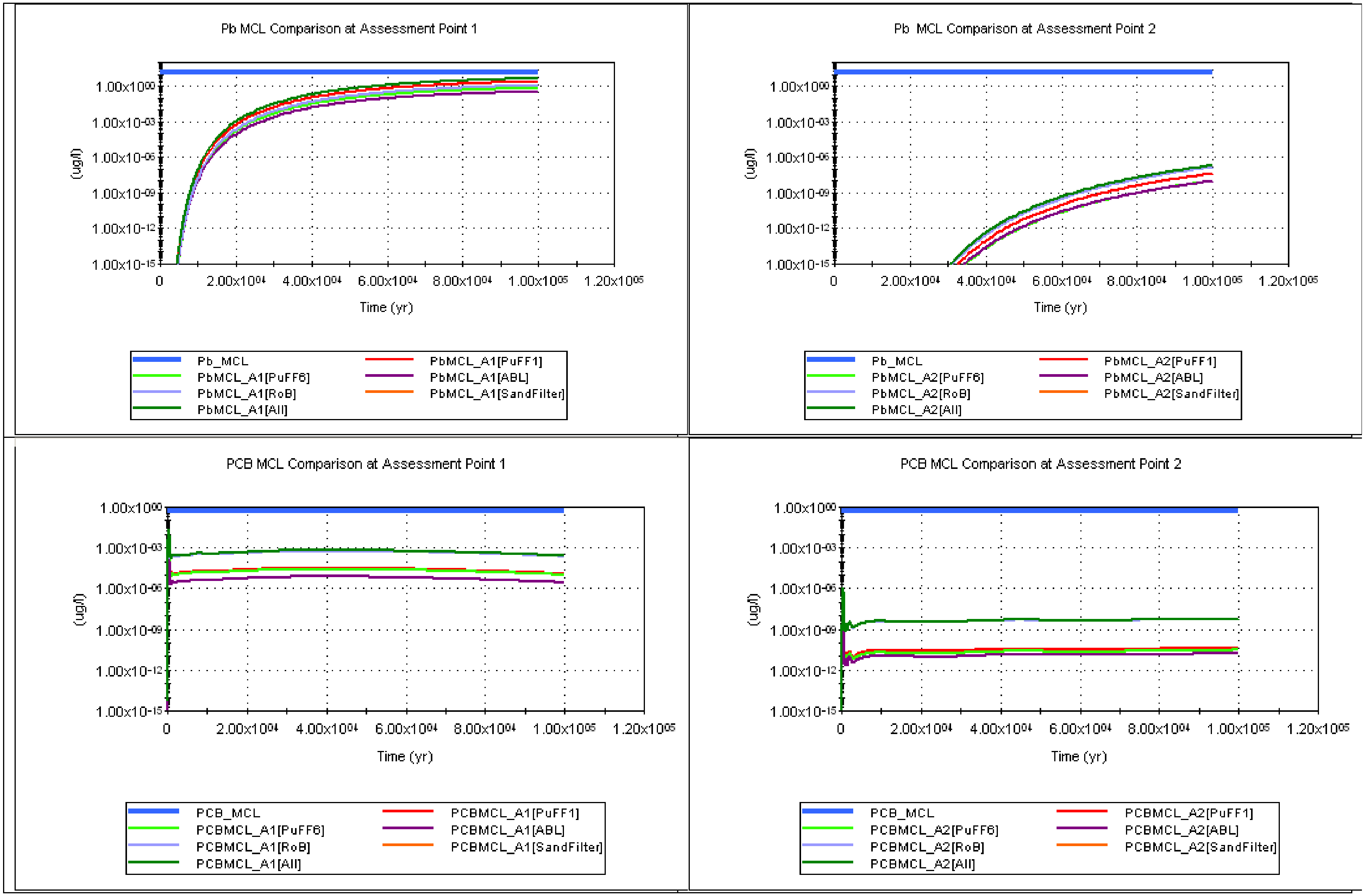

Alpha MCL Comparison at Assessment Point 2
(pci/l)
1.00x10^02
1.00x10^00
1.00x10^-02
1.00x10^-04
1.00x10^-06
1.00x10^-08
1.00x10^-10
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
NetAlpha_MCL
AlphaMCL_A2[PuFF6]
AlphaMCL_A2[RoB]
AlphaMCL_A2[All]
AlphaMCL_A2[PuFF1]
AlphaMCL_A2[ABL]
AlphaMCL_A2[SandFilter]

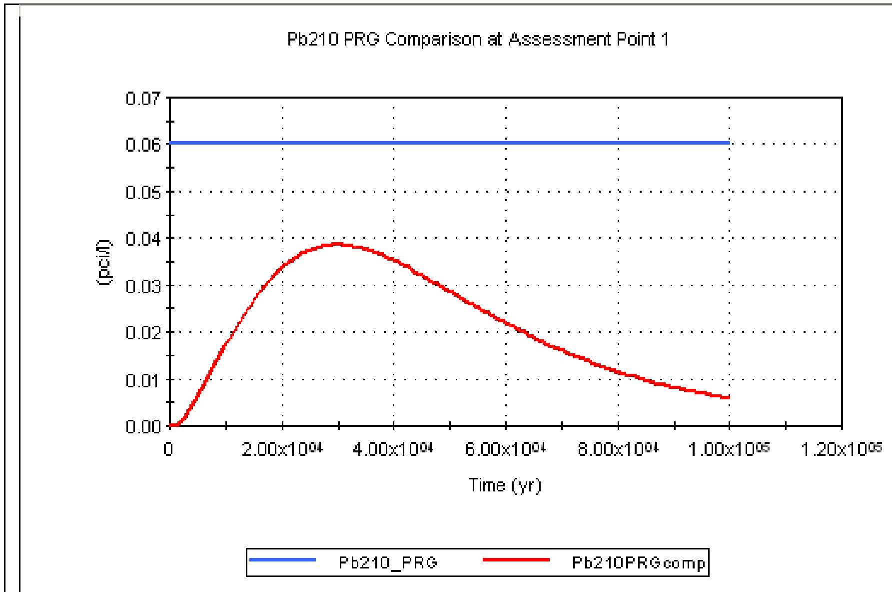

Beta_Gamma MCL Comparison at Assessment Point 1
(mrem/yr)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
BetaGamma_MCL
BGMCL_A1[PuFF6]
BGMCL_A1[RoB]
BGMCL_A1[All]
BGMCL_A1[PuFF1]
BGMCL_A1[ABL]
BGMCL_A1[SandFilter]

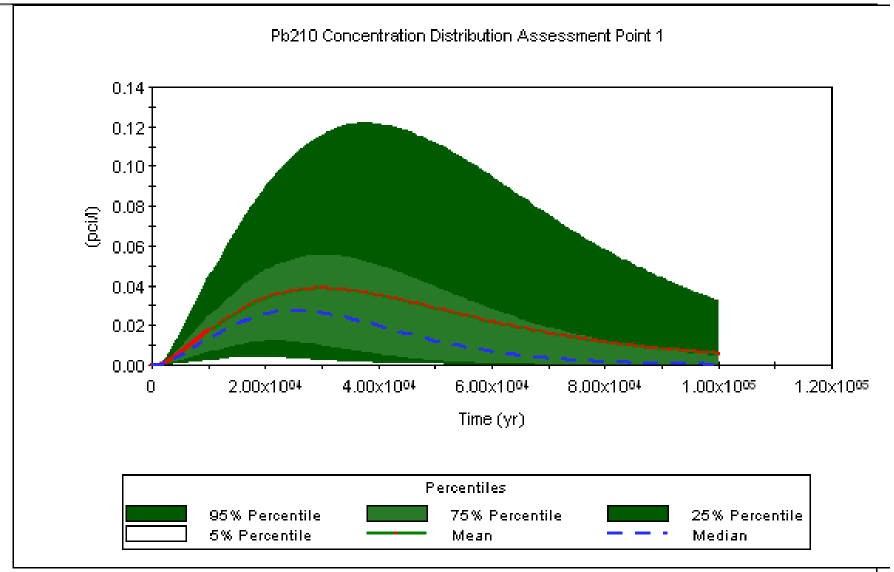

Beta_Gamma MCL Comparison at Assessment Point 2
(mrem/yr)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
BetaGamma_MCL
BGMCL_A2[PuFF6]
BGMCL_A2[RoB]
BGMCL_A2[All]
BGMCL_A2[PuFF1]
BGMCL_A2[ABL]
BGMCL_A2[SandFilter]

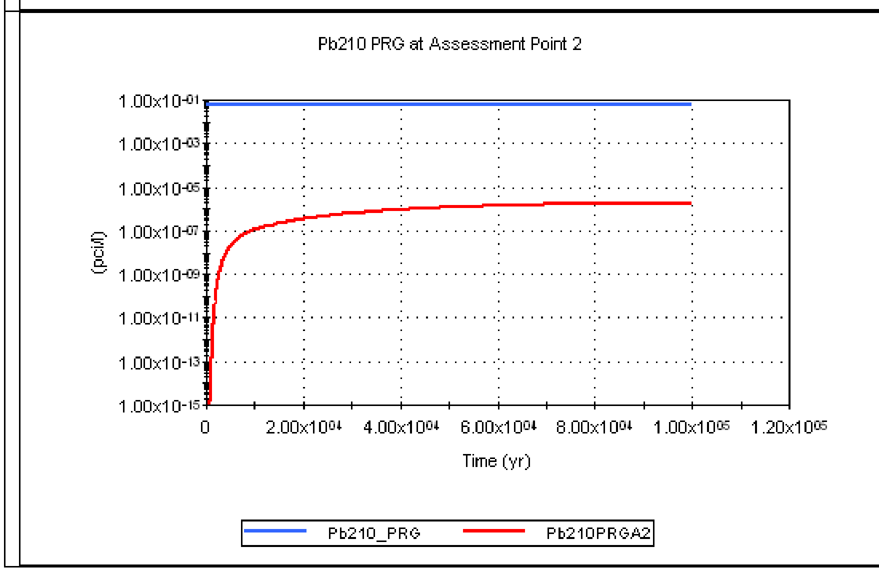

U234 MCL Comparison at Assessment Point 1
1.00x10^00
1.00x10-03
1.00x10-06
1.00x10-09
1.00x10-12
1.00x10-15
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U234]
U234MCL_A1[PuFF6]
U234MCL_A1[RoB]
U234MCL_A1[All]
U234MCL_A1[PuFF1]
U234MCL_A1[ABL]
U234MCL_A1[SandFilter]
U234 MCL Comparison at Assessment Point 2
1.00x10^00
1.00x10-03
1.00x10-06
1.00x10-09
1.00x10-12
1.00x10-15
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U234]
U234MCL_A2[PuFF6]
U234MCL_A2[RoB]
U234MCL_A2[All]
U234MCL_A2[PuFF1]
U234MCL_A2[ABL]
U234MCL_A2[SandFilter]
Sum-of-Fractions of U234 MCL at Assessment Point 1
Based on 235-F footprint
0.25
0.20
0.15
0.10
0.05
0.00
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
[PuFF1]
[RoB]
[PuFF6]
[SandFilter]
[ABL]
[All]
U234 at Assessment Point 1
10
8
6
4
2
0
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Percentiles
95% Percentile
5% Percentile
75% Percentile
Mean
25% Percentile
Median

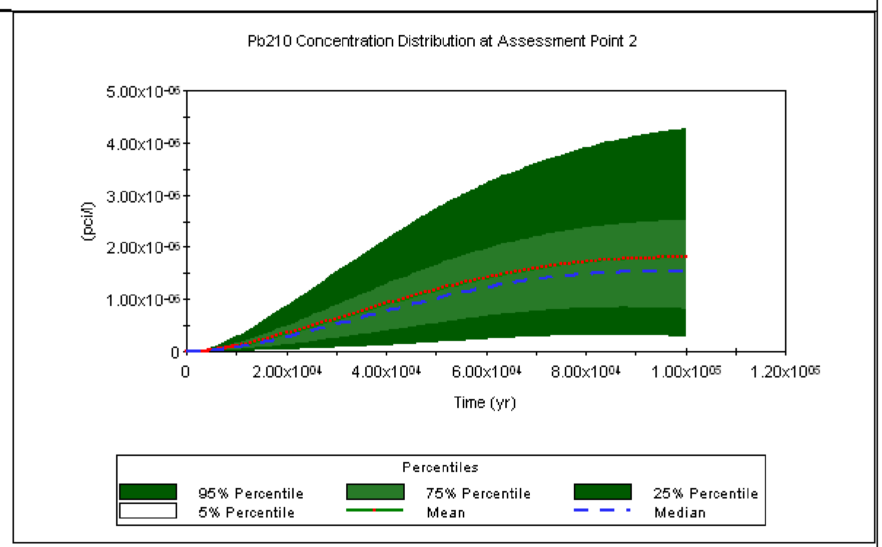

U235 MCL Comparison at Assessment Point 1
(pci/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U235]
U235MCL_A1[PuFF1]
U235MCL_A1[PuFF6]
U235MCL_A1[ABL]
U235MCL_A1[RoB]
U235MCL_A1[SandFilter]
U235MCL_A1[All]
U235 MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
Uranium_MCL[U235]
U235MCL_A2[PuFF1]
U235MCL_A2[PuFF6]
U235MCL_A2[ABL]
U235MCL_A2[RoB]
U235MCL_A2[SandFilter]
U235MCL_A2[All]
U238 MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
Uranium_MCL[U238]
U238MCL_A1[PuFF1]
U238MCL_A1[PuFF6]
U238MCL_A1[ABL]
U238MCL_A1[RoB]
U238MCL_A1[SandFilter]
U238MCL_A1[All]
U238 MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
Uranium_MCL[U238]
U238MCL_A2[PuFF1]
U238MCL_A2[PuFF6]
U238MCL_A2[ABL]
U238MCL_A2[RoB]
U238MCL_A2[SandFilter]
U238MCL_A2[All]

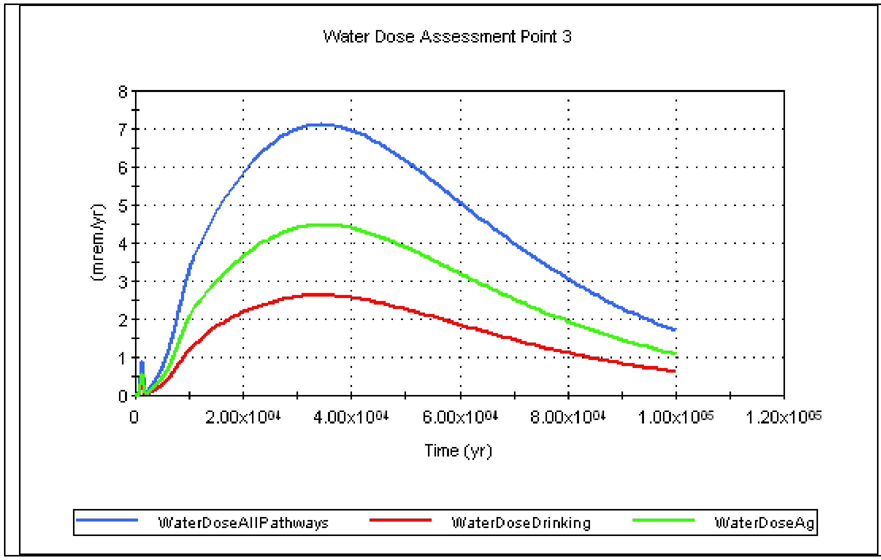

Pb MCL Comparison at Assessment Point 1
(ug/l)
1.00x10^00
1.00x10-03
1.00x10-06
1.00x10-09
1.00x10-12
1.00x10-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Pb_MCL
PbMCL_A1[PuFF6]
PbMCL_A1[RoB]
PbMCL_A1[All]
PbMCL_A1[PuFF1]
PbMCL_A1[ABL]
PbMCL_A1[SandFilter]
Pb MCL Comparison at Assessment Point 2
Pb_MCL
PbMCL_A2[PuFF6]
PbMCL_A2[RoB]
PbMCL_A2[All]
PbMCL_A2[PuFF1]
PbMCL_A2[ABL]
PbMCL_A2[SandFilter]
PCB MCL Comparison at Assessment Point 1
PCB_MCL
PCBMCL_A1[PuFF6]
PCBMCL_A1[RoB]
PCBMCL_A1[All]
PCBMCL_A1[PuFF1]
PCBMCL_A1[ABL]
PCBMCL_A1[SandFilter]
PCB MCL Comparison at Assessment Point 2
PCB_MCL
PCBMCL_A2[PuFF6]
PCBMCL_A2[RoB]
PCBMCL_A2[All]
PCBMCL_A2[PuFF1]
PCBMCL_A2[ABL]
PCBMCL_A2[SandFilter]

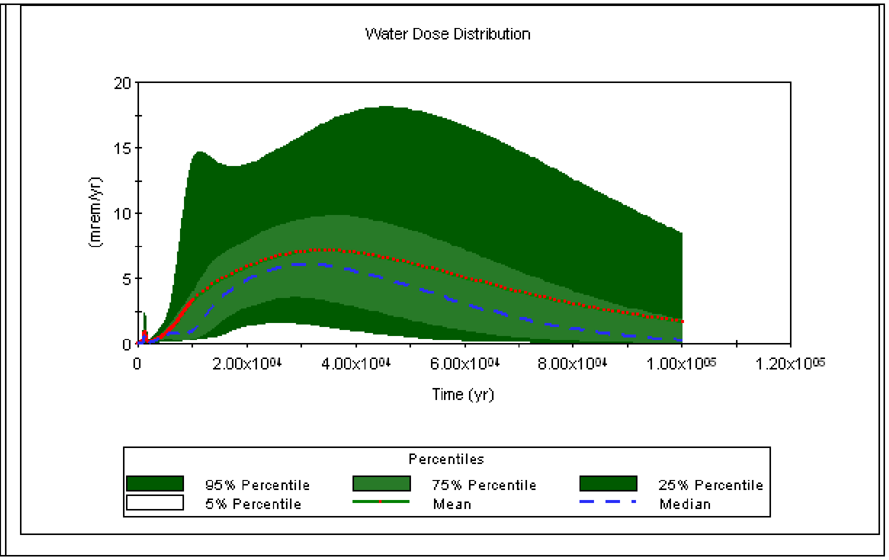

Pb210 PRG Comparison at Assessment Point 1
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Pb210_PRG
Pb210PRGcomp


Pb210 Concentration Distribution Assessment Point 1
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Percentiles
95% Percentile
5% Percentile
75% Percentile
Mean
25% Percentile
Median


Pb210 PRG at Assessment Point 2
1.00x10^-01
1.00x10^-03
1.00x10^-05
1.00x10^-07
1.00x10^-09
1.00x10^-11
1.00x10^-13
1.00x10^-15
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Pb210_PRG
Pb210PRGA2

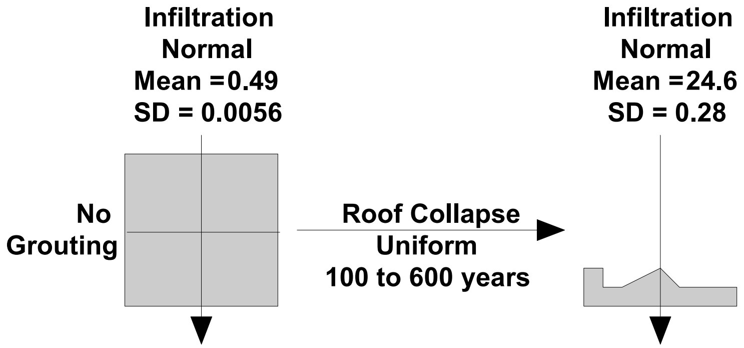

Pb210 Concentration Distribution at Assessment Point 2
5.00x10^-06
4.00x10^-06
3.00x10^-06
2.00x10^-06
1.00x10^-06
0
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Percentiles
95% Percentile
5% Percentile
75% Percentile
Mean
25% Percentile
Median



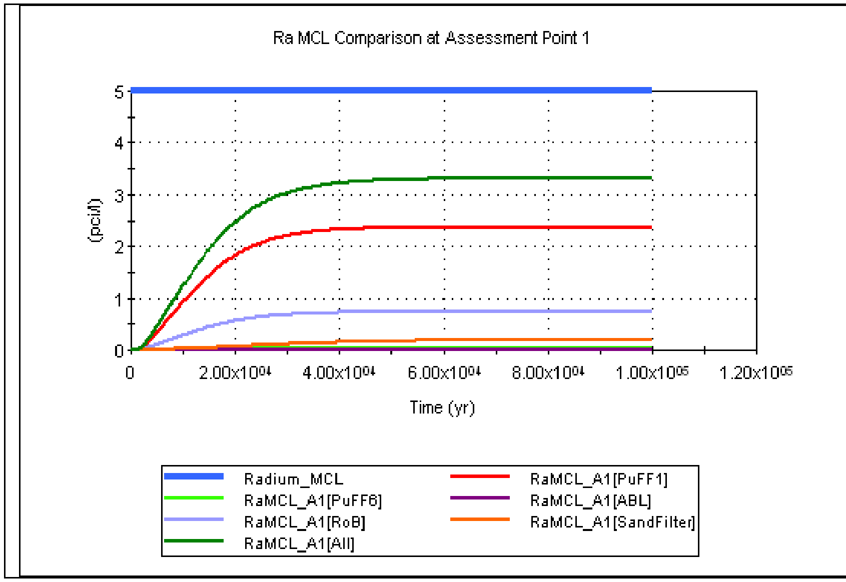


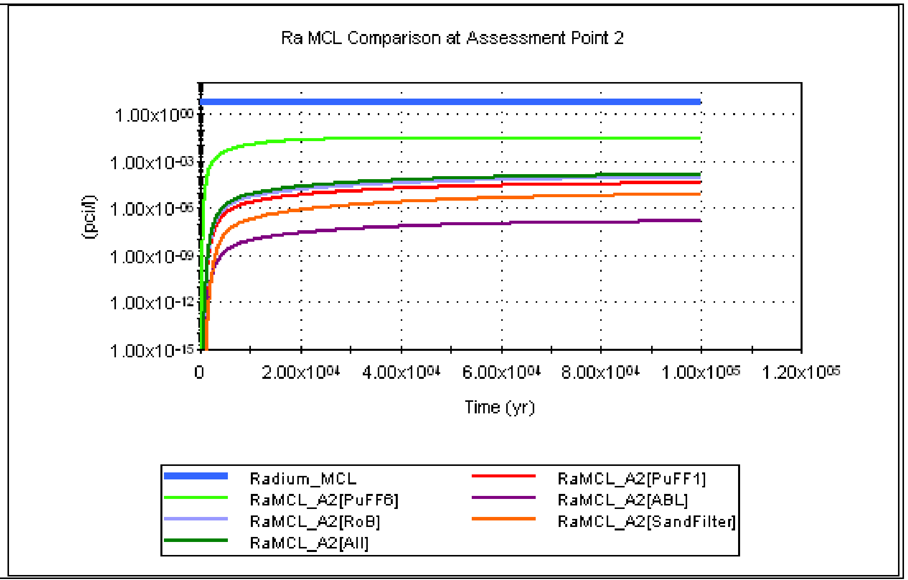
DOE Order 435.1 dose limit is 25 mrem/yr at 100 m from facility boundary (i.e. Assessment Point 3).

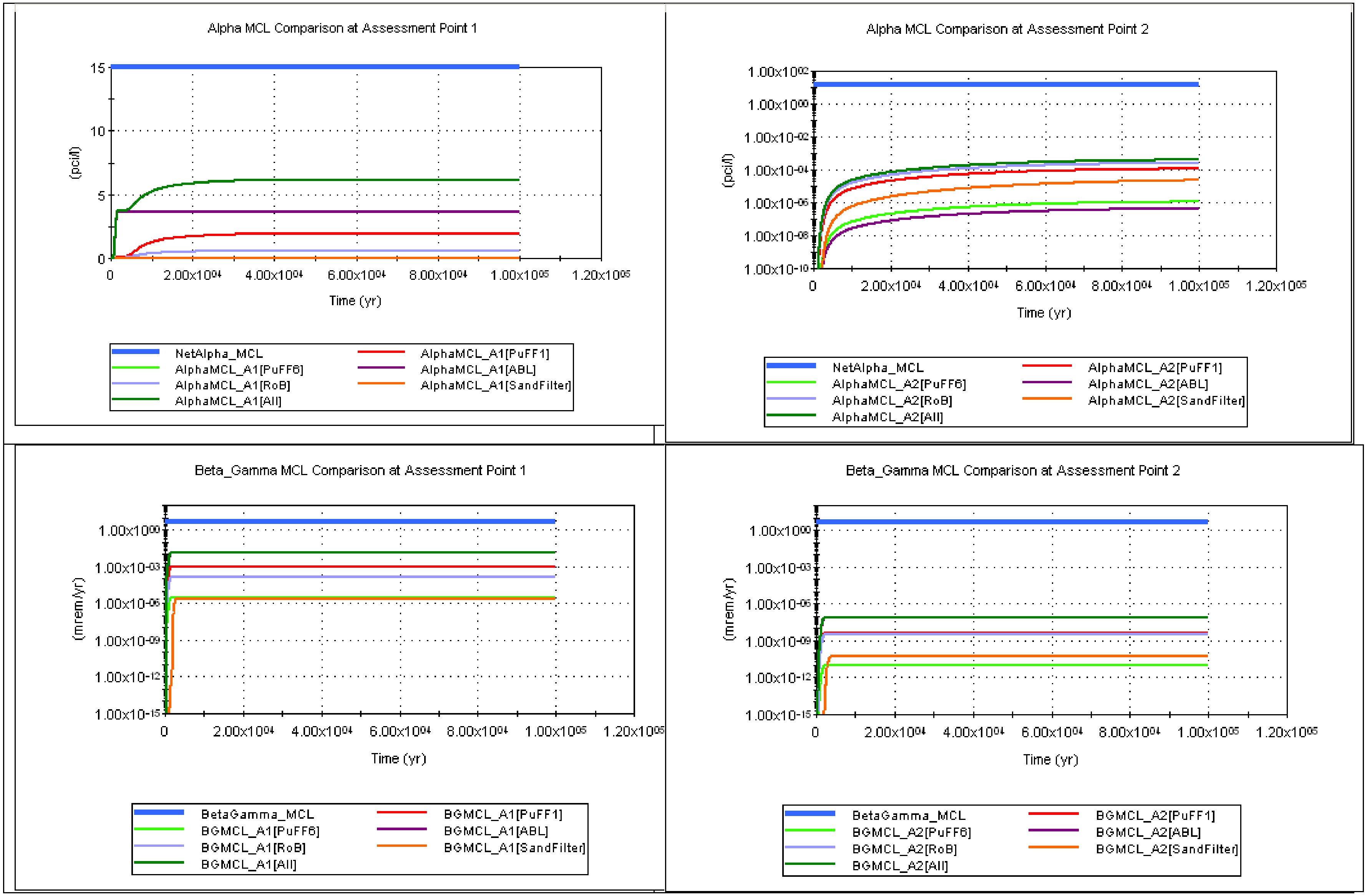
APPENDIX C REMOVE 75% OF PUFF CELLS 1-5 INVENTORY

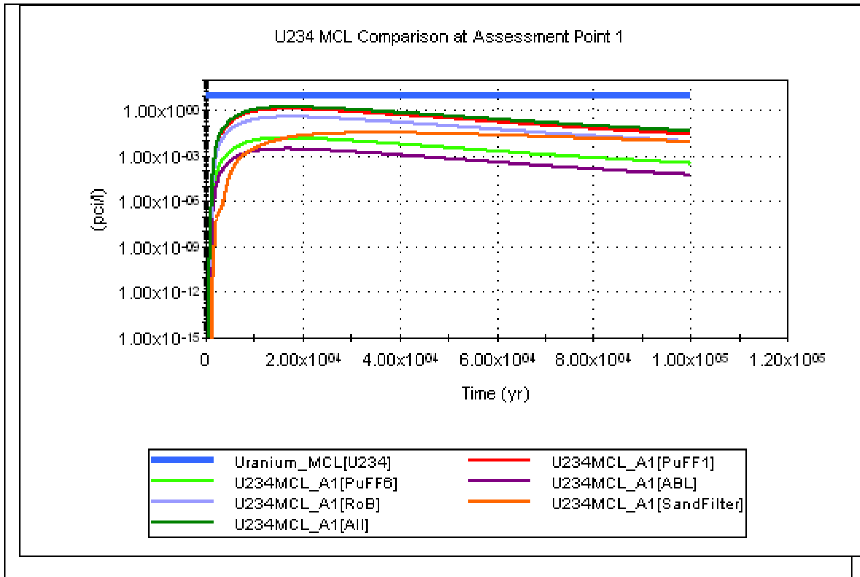


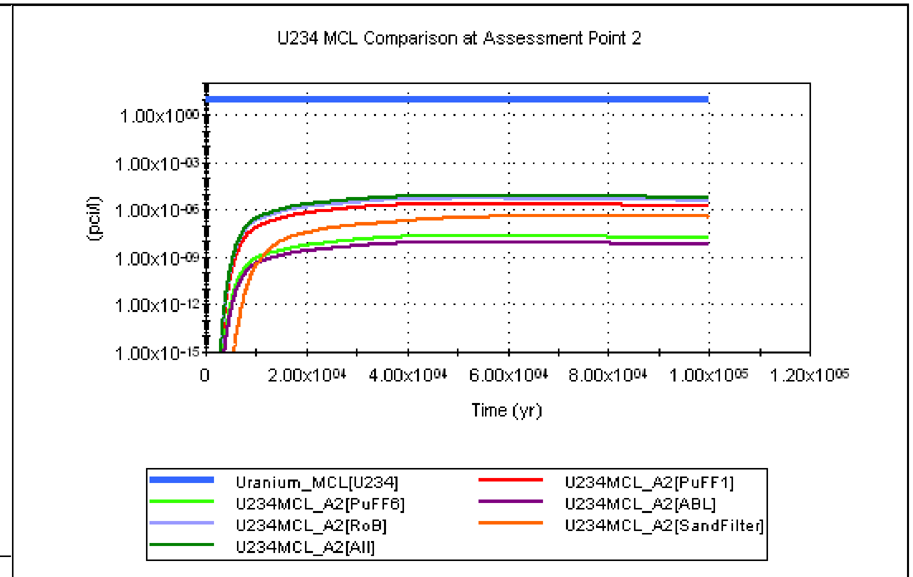
Unless otherwise noted, all plots are of mean values and are based upon the entire building.

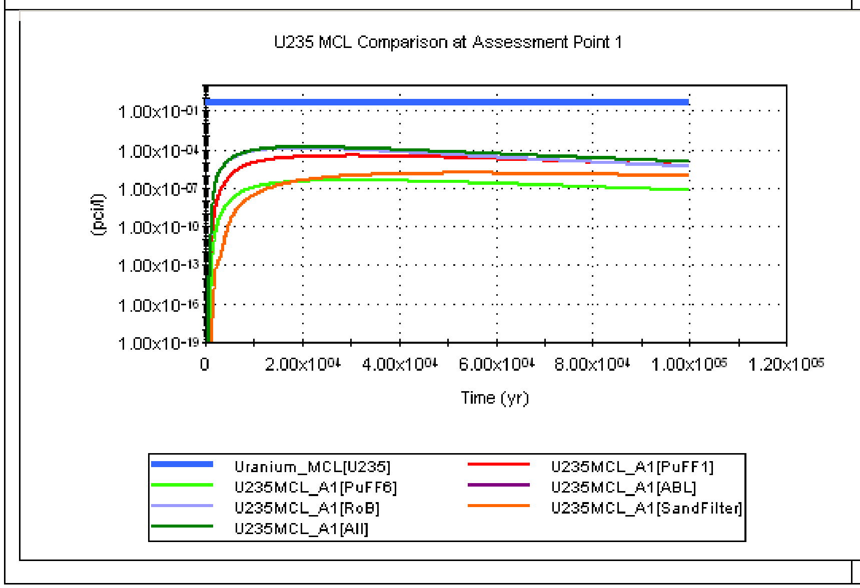


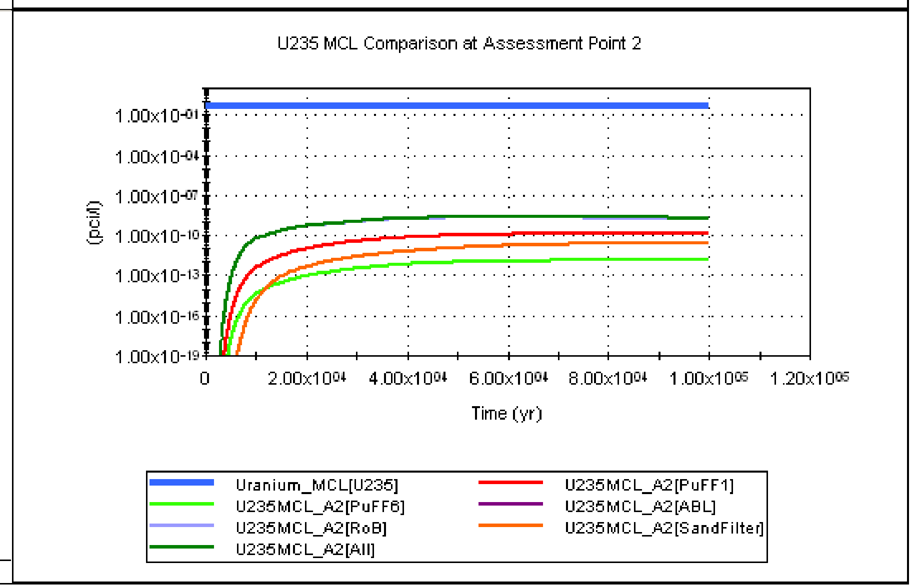


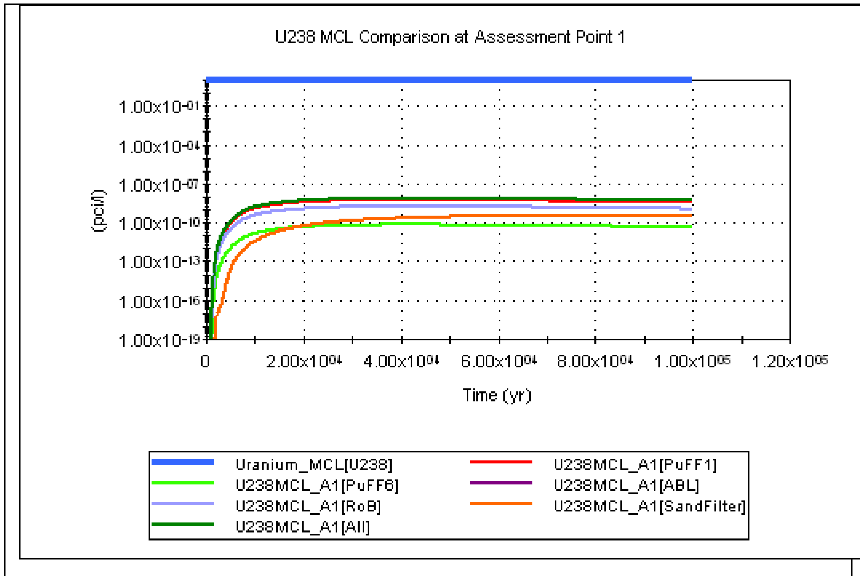

Alpha MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A1[PuFF6]
AlphaMCL_A1[RoB]
AlphaMCL_A1[All]
AlphaMCL_A1[PuFF1]
AlphaMCL_A1[ABL]
AlphaMCL_A1[SandFilter]
Alpha MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A2[PuFF6]
AlphaMCL_A2[RoB]
AlphaMCL_A2[All]
AlphaMCL_A2[PuFF1]
AlphaMCL_A2[ABL]
AlphaMCL_A2[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 1
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A1[PuFF6]
BGMCL_A1[RoB]
BGMCL_A1[All]
BGMCL_A1[PuFF1]
BGMCL_A1[ABL]
BGMCL_A1[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 2
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A2[PuFF6]
BGMCL_A2[RoB]
BGMCL_A2[All]
BGMCL_A2[PuFF1]
BGMCL_A2[ABL]
BGMCL_A2[SandFilter]

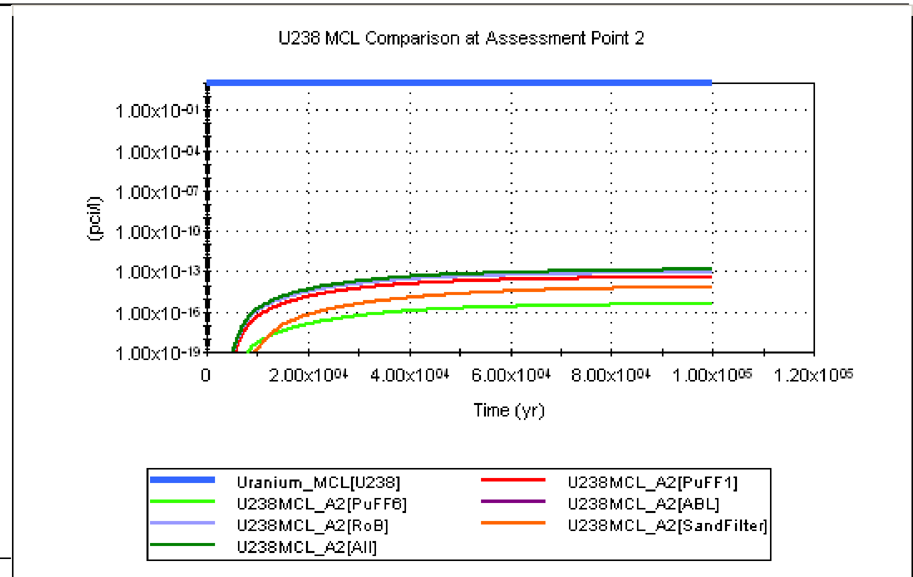

U234 MCL Comparison at Assessment Point 1
(pci/l)
1.00x10^00
1.00x10-03
1.00x10-06
1.00x10-09
1.00x10-12
1.00x10-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U234]
U234MCL_A1[PuFF6]
U234MCL_A1[RoB]
U234MCL_A1[All]
U234MCL_A1[PuFF1]
U234MCL_A1[ABL]
U234MCL_A1[SandFilter]

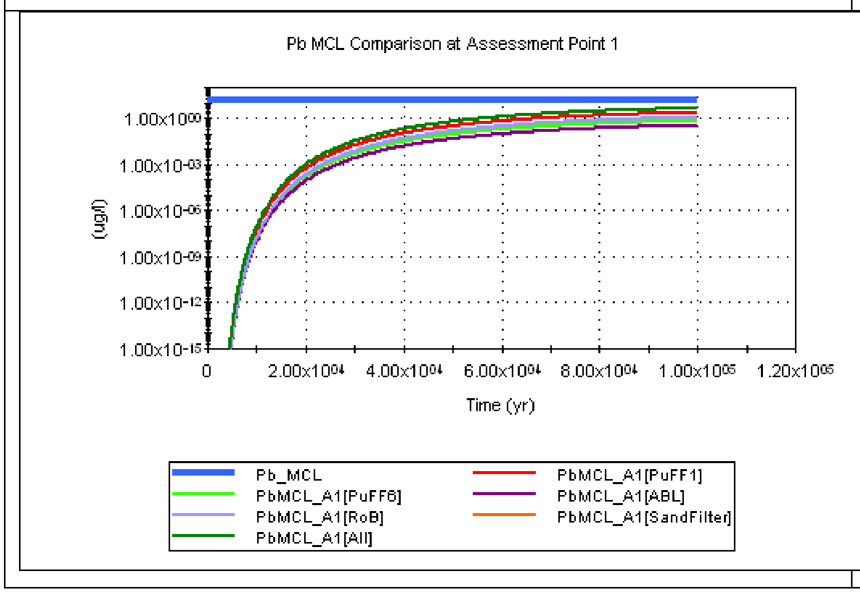

U234 MCL Comparison at Assessment Point 2
(pci/l)
1.00x10^00
1.00x10-03
1.00x10-06
1.00x10-09
1.00x10-12
1.00x10-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U234]
U234MCL_A2[PuFF6]
U234MCL_A2[RoB]
U234MCL_A2[All]
U234MCL_A2[PuFF1]
U234MCL_A2[ABL]
U234MCL_A2[SandFilter]

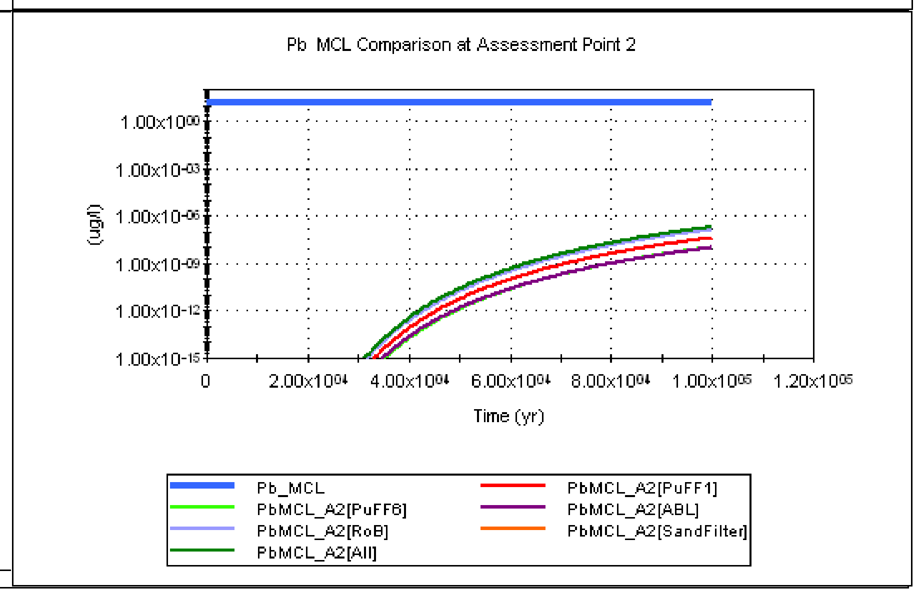

U235 MCL Comparison at Assessment Point 1
(pci/l)
1.00x10-01
1.00x10-04
1.00x10-07
1.00x10-10
1.00x10-13
1.00x10-16
1.00x10-19
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U235]
U235MCL_A1[PuFF6]
U235MCL_A1[RoB]
U235MCL_A1[All]
U235MCL_A1[PuFF1]
U235MCL_A1[ABL]
U235MCL_A1[SandFilter]

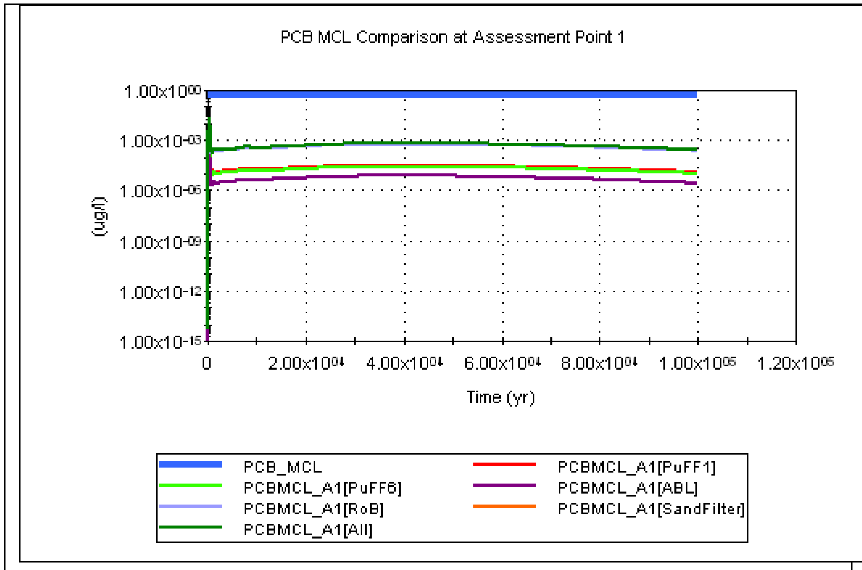

U235 MCL Comparison at Assessment Point 2
(pci/l)
1.00x10-01
1.00x10-04
1.00x10-07
1.00x10-10
1.00x10-13
1.00x10-16
1.00x10-19
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U235]
U235MCL_A2[PuFF6]
U235MCL_A2[RoB]
U235MCL_A2[All]
U235MCL_A2[PuFF1]
U235MCL_A2[ABL]
U235MCL_A2[SandFilter]

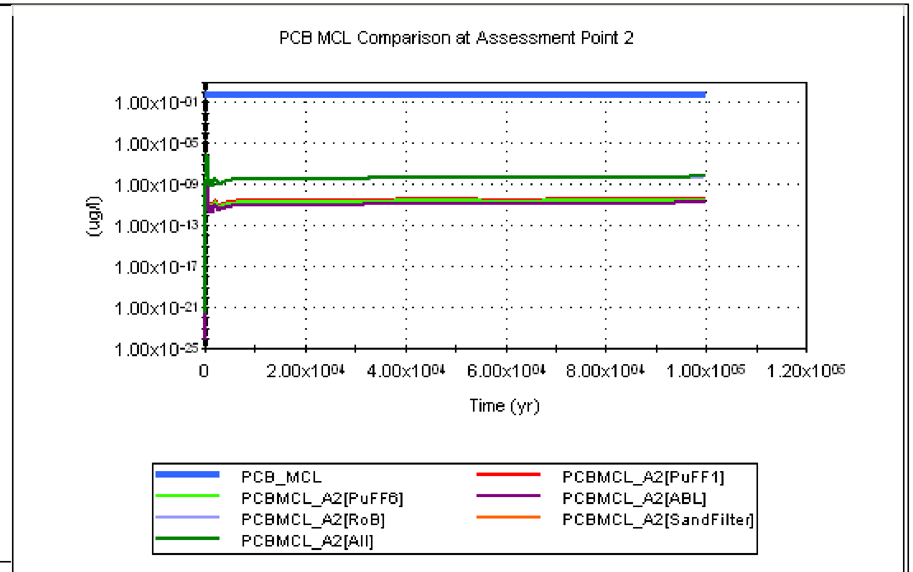

U238 MCL Comparison at Assessment Point 1
(pci/l)
1.00x10-01
1.00x10-04
1.00x10-07
1.00x10-10
1.00x10-13
1.00x10-16
1.00x10-19
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
Uranium_MCL[U238]
U238MCL_A1[PuFF6]
U238MCL_A1[RoB]
U238MCL_A1[All]
U238MCL_A1[PuFF1]
U238MCL_A1[ABL]
U238MCL_A1[SandFilter]

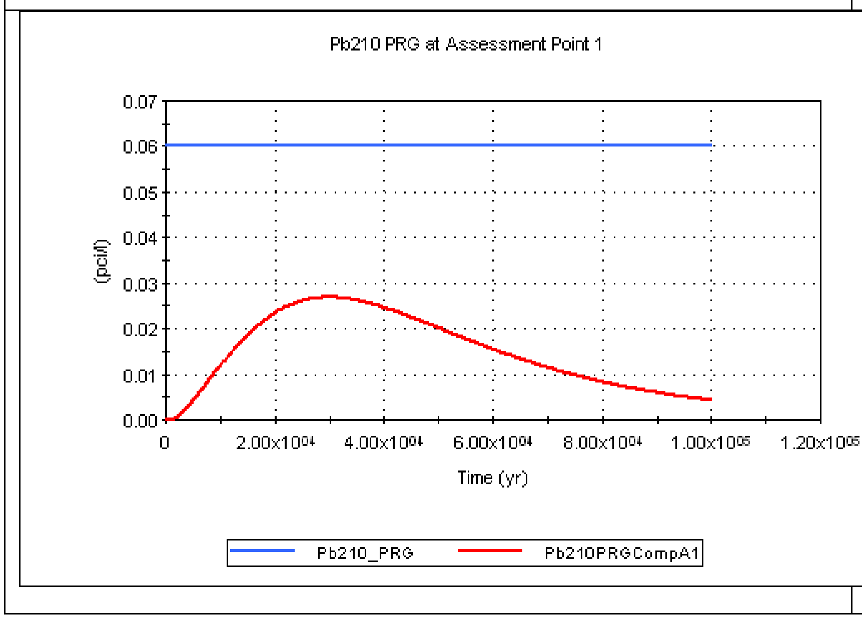

U238 MCL Comparison at Assessment Point 2
(pci/l)
1.00x10-01
1.00x10-04
1.00x10-07
1.00x10-10
1.00x10-13
1.00x10-16
1.00x10-19
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
Uranium_MCL[U238]
U238MCL_A2[PuFF6]
U238MCL_A2[RoB]
U238MCL_A2[All]
U238MCL_A2[PuFF1]
U238MCL_A2[ABL]
U238MCL_A2[SandFilter]

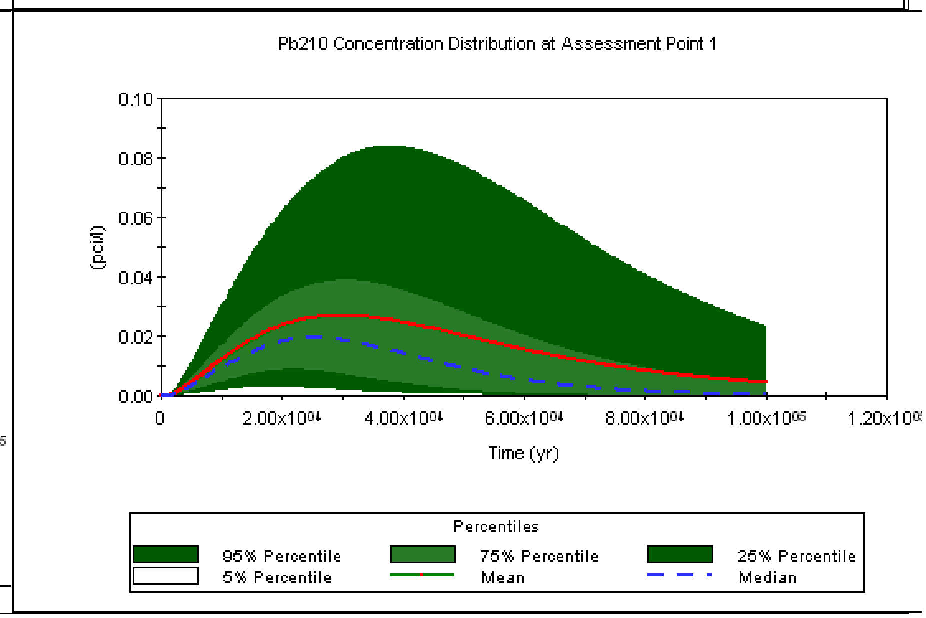

Pb MCL Comparison at Assessment Point 1
(ug/l)
1.00x1000
1.00x10-03
1.00x10-06
1.00x10-09
1.00x10-12
1.00x10-15
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
Pb_MCL
PbMCL_A1[PuFF6]
PbMCL_A1[RoB]
PbMCL_A1[All]
PbMCL_A1[PuFF1]
PbMCL_A1[ABL]
PbMCL_A1[SandFilter]

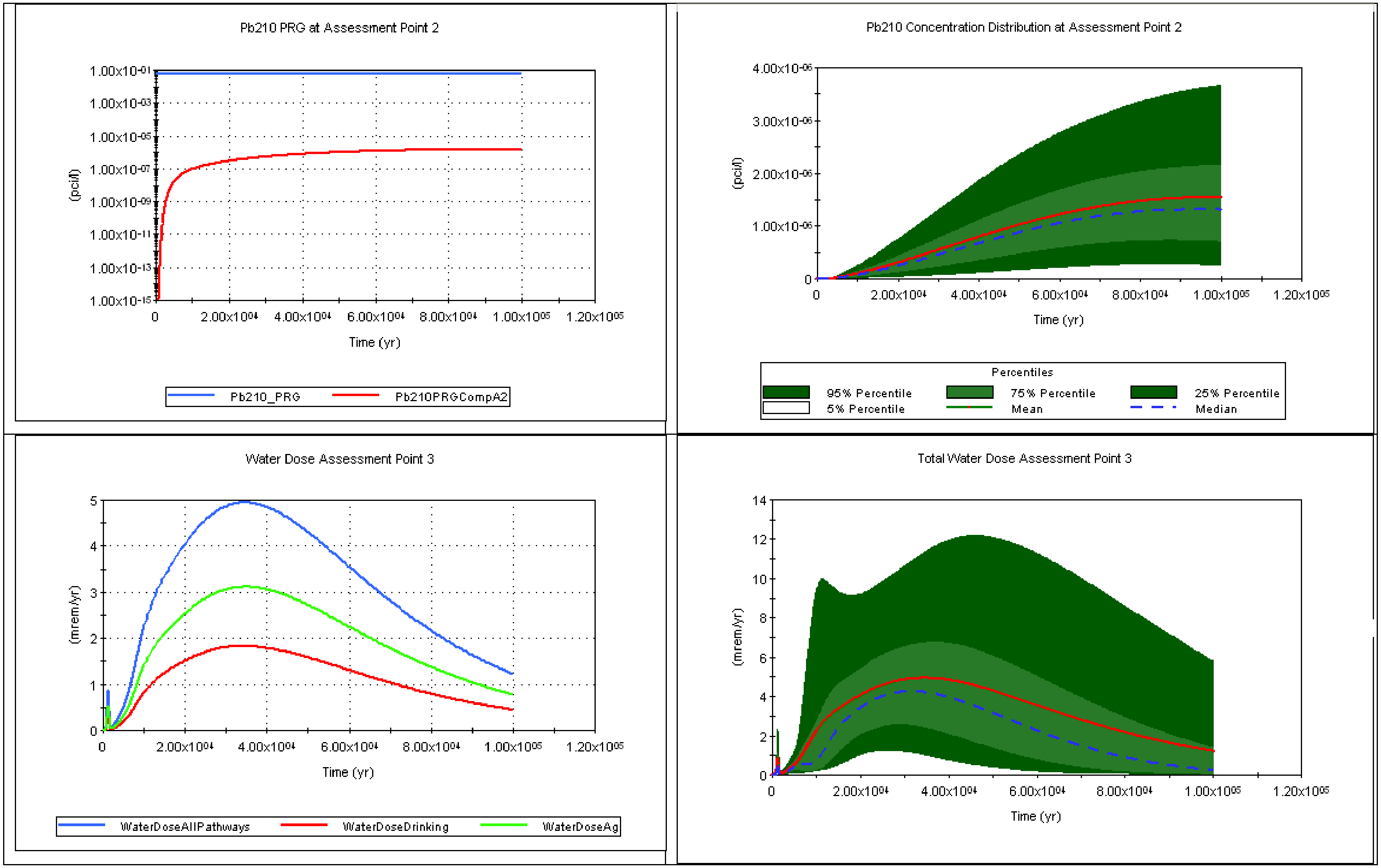

Pb MCL Comparison at Assessment Point 2
(ug/l)
1.00x1000
1.00x10-03
1.00x10-06
1.00x10-09
1.00x10-12
1.00x10-15
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
Pb_MCL
PbMCL_A2[PuFF6]
PbMCL_A2[RoB]
PbMCL_A2[All]
PbMCL_A2[PuFF1]
PbMCL_A2[ABL]
PbMCL_A2[SandFilter]


PCB MCL Comparison at Assessment Point 1
1.00x10-00
1.00x10-03
1.00x10-06
1.00x10-09
1.00x10-12
1.00x10-15
(ug/l)
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
PCB_MCL
PCBMCL_A1[PuFF6]
PCBMCL_A1[RoB]
PCBMCL_A1[All]
PCBMCL_A1[PuFF1]
PCBMCL_A1[ABL]
PCBMCL_A1[SandFilter]


PCB MCL Comparison at Assessment Point 2
1.00x10-01
1.00x10-05
1.00x10-09
1.00x10-13
1.00x10-17
1.00x10-21
1.00x10-25
(ug/l)
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
PCB_MCL
PCBMCL_A2[PuFF6]
PCBMCL_A2[RoB]
PCBMCL_A2[All]
PCBMCL_A2[PuFF1]
PCBMCL_A2[ABL]
PCBMCL_A2[SandFilter]

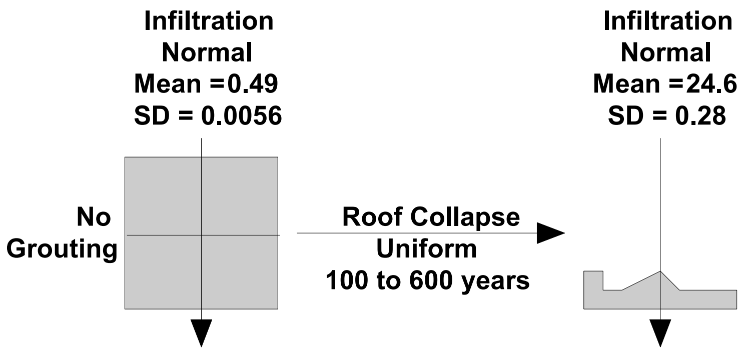

Pb210 PRG at Assessment Point 1
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
(pci/l)
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
Pb210_PRG
Pb210PRGCompA1


Pb210 Concentration Distribution at Assessment Point 1
0.10
0.08
0.06
0.04
0.02
0.00
(pci/l)
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
Time (yr)
Percentiles
95% Percentile
5% Percentile
75% Percentile
Mean
25% Percentile
Median

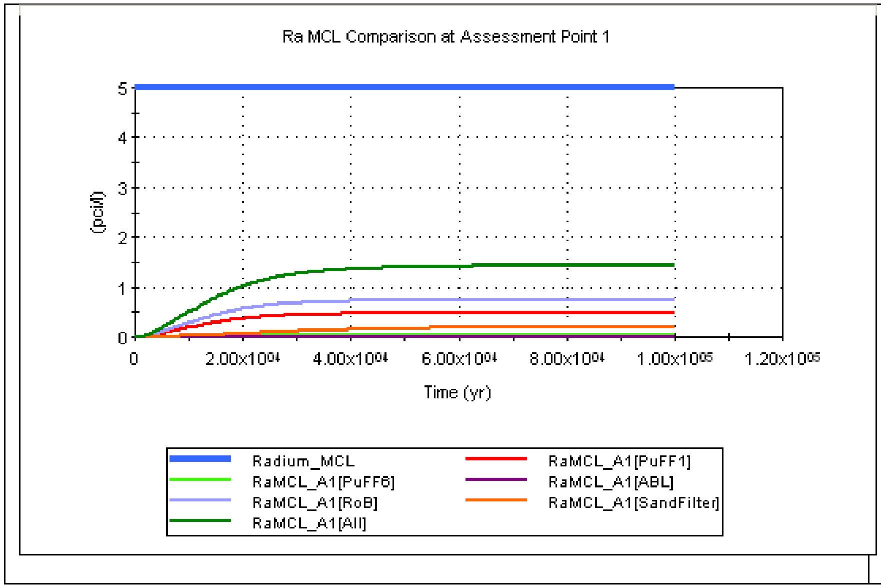


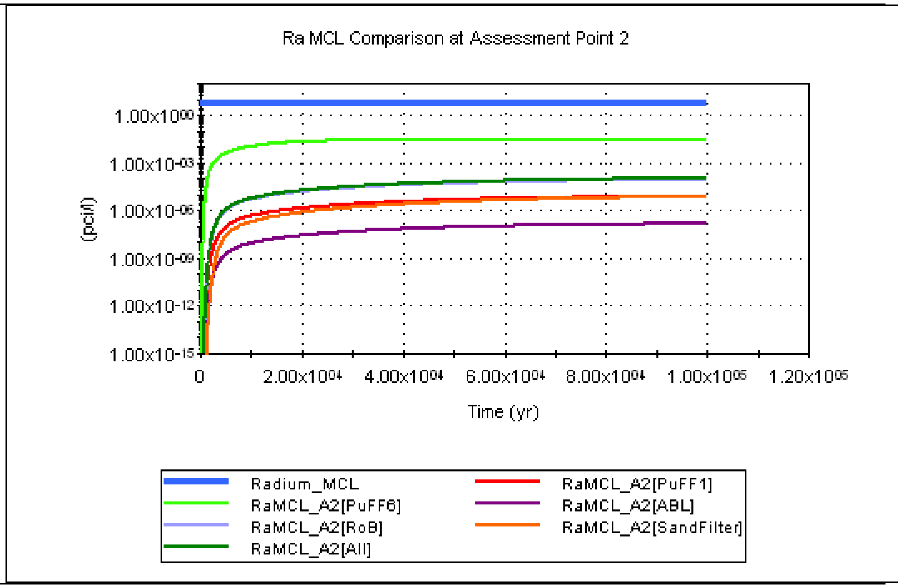
DOE Order 435.1 dose limit is 25 mrem/yr at 100 m from facility boundary (i.e. Assessment Point 3).

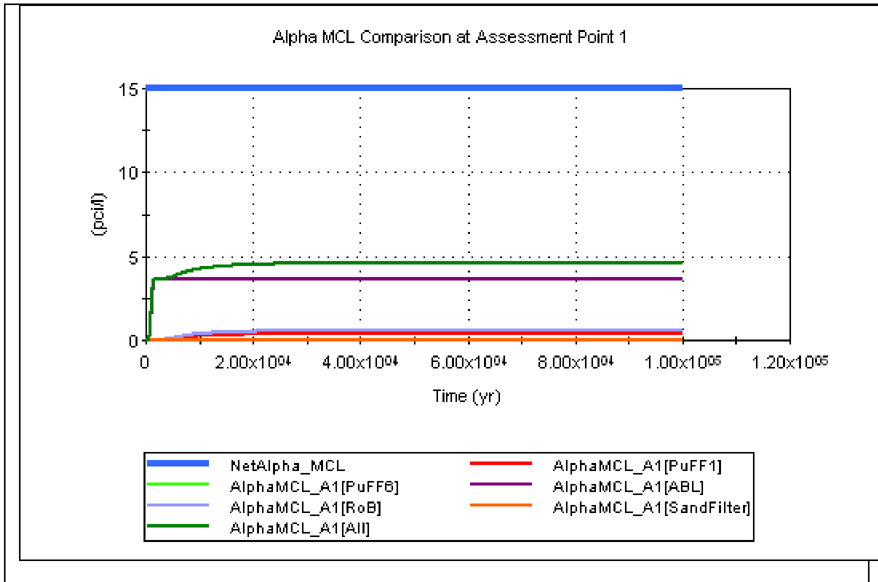
APPENDIX D REMOVE 95% OF PUFF CELLS 1-5 INVENTORY

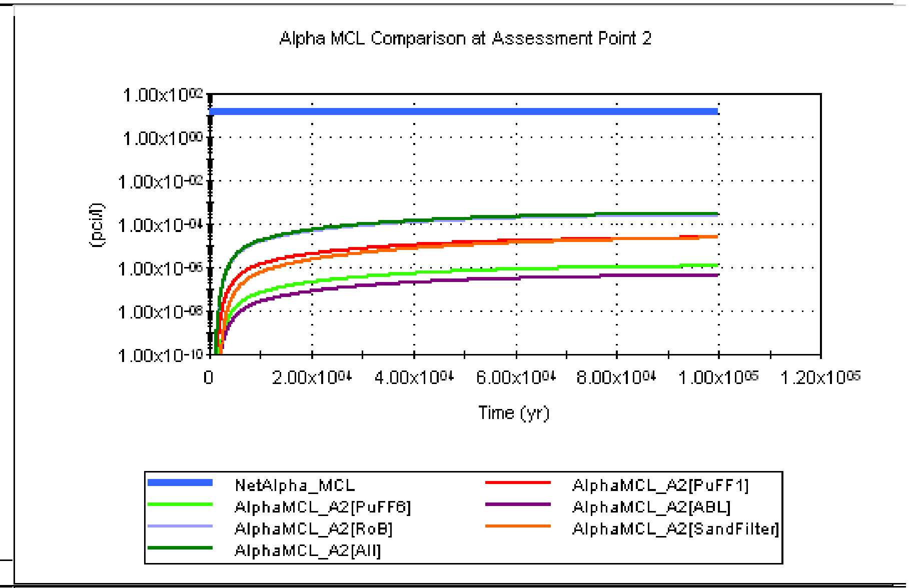


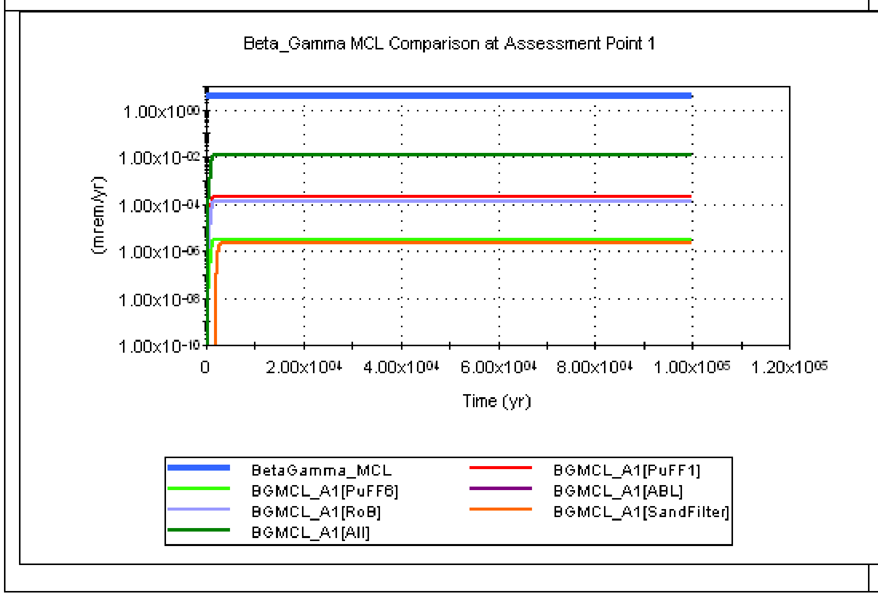
Unless otherwise noted, all plots are of mean values and are based upon the entire building.

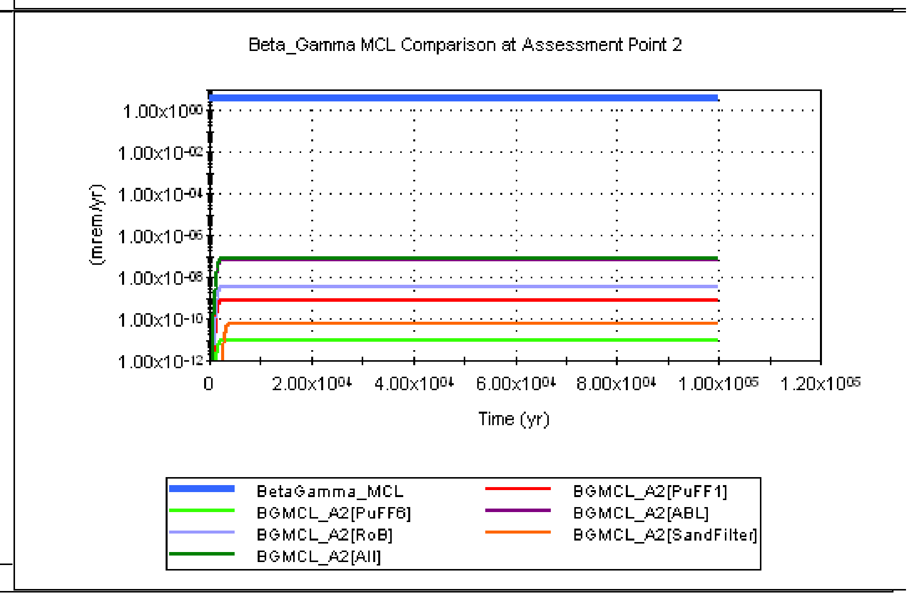


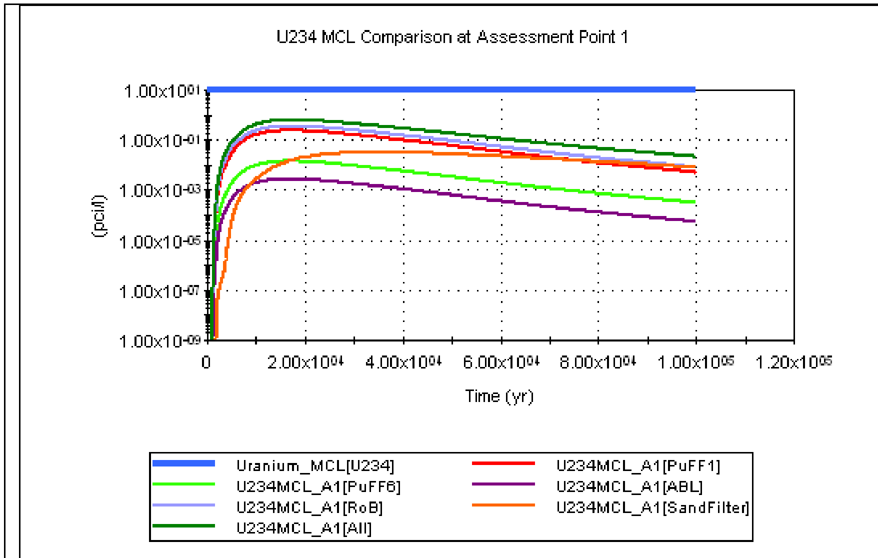


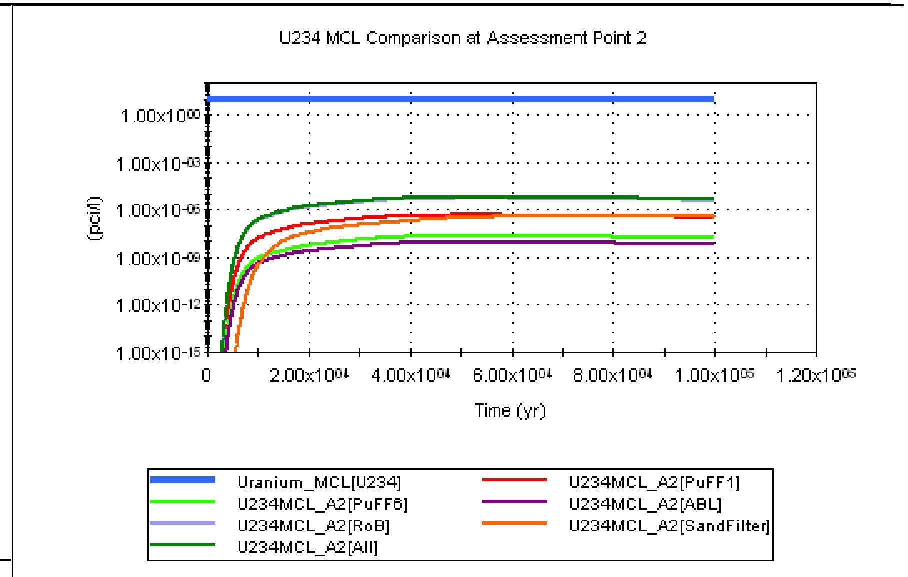

Alpha MCL Comparison at Assessment Point 1
15
10
5
0
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
NetAlpha_MCL
AlphaMCL_A1[PuFF6]
AlphaMCL_A1[RoB]
AlphaMCL_A1[All]
AlphaMCL_A1[PuFF1]
AlphaMCL_A1[ABL]
AlphaMCL_A1[SandFilter]

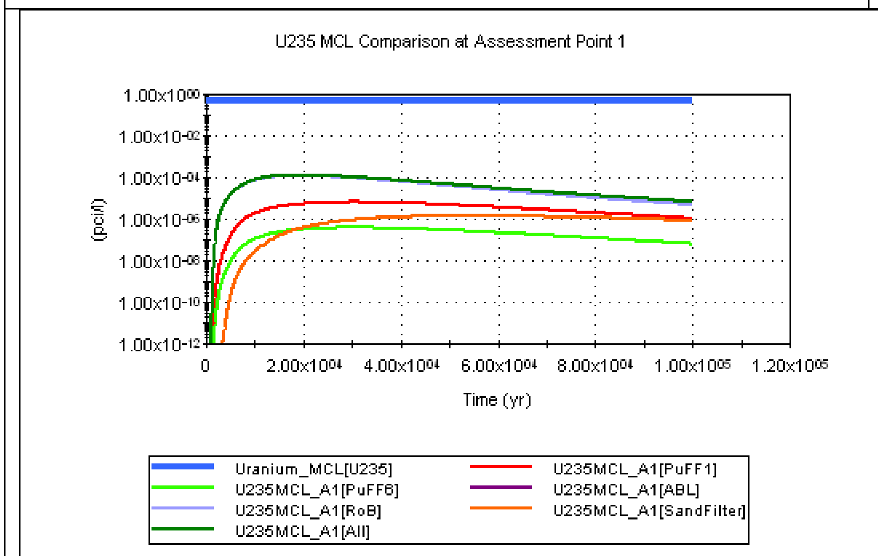

Alpha MCL Comparison at Assessment Point 2
1.00x10^02
1.00x10^00
1.00x10^-02
1.00x10^-04
1.00x10^-06
1.00x10^-08
1.00x10^-10
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
NetAlpha_MCL
AlphaMCL_A2[PuFF6]
AlphaMCL_A2[RoB]
AlphaMCL_A2[All]
AlphaMCL_A2[PuFF1]
AlphaMCL_A2[ABL]
AlphaMCL_A2[SandFilter]

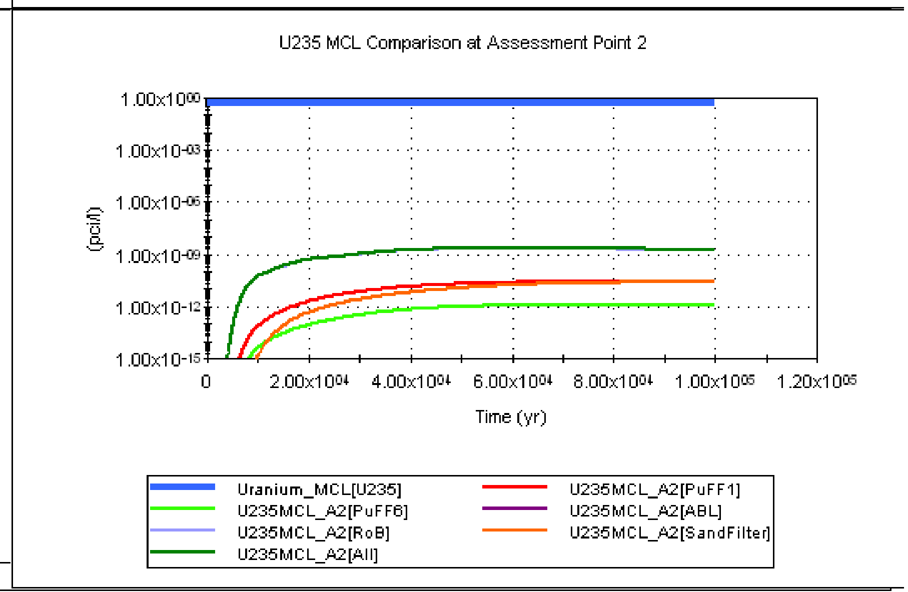

Beta_Gamma MCL Comparison at Assessment Point 1
1.00x10^00
1.00x10^-02
1.00x10^-04
1.00x10^-06
1.00x10^-08
1.00x10^-10
(mrem/yr)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
BetaGamma_MCL
BGMCL_A1[PuFF6]
BGMCL_A1[RoB]
BGMCL_A1[All]
BGMCL_A1[PuFF1]
BGMCL_A1[ABL]
BGMCL_A1[SandFilter]

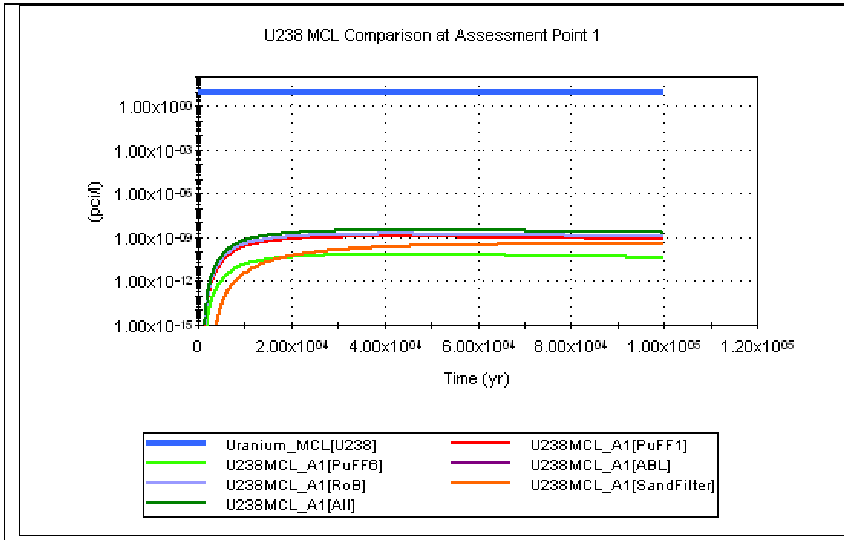

Beta_Gamma MCL Comparison at Assessment Point 2
1.00x10^00
1.00x10^-02
1.00x10^-04
1.00x10^-06
1.00x10^-08
1.00x10^-10
1.00x10^-12
(mrem/yr)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
BetaGamma_MCL
BGMCL_A2[PuFF6]
BGMCL_A2[RoB]
BGMCL_A2[All]
BGMCL_A2[PuFF1]
BGMCL_A2[ABL]
BGMCL_A2[SandFilter]

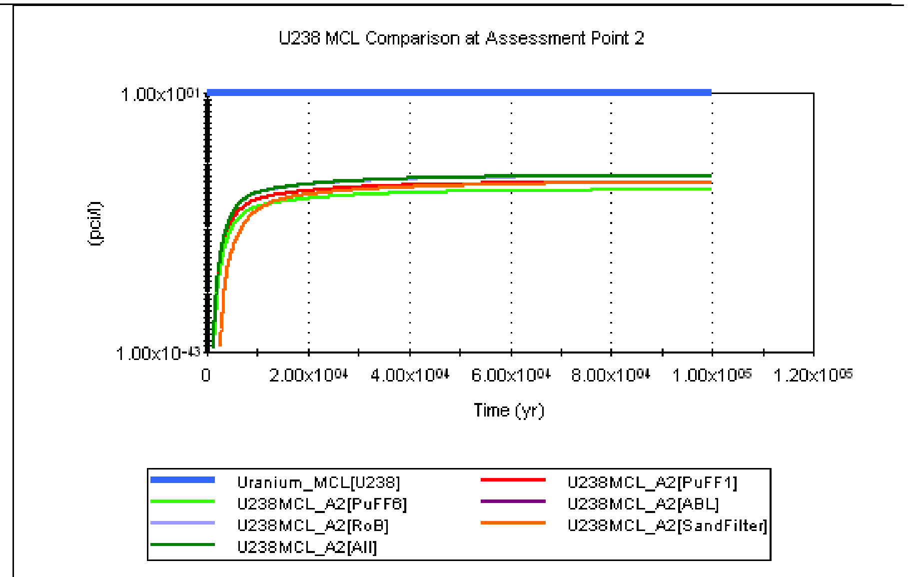

U234 MCL Comparison at Assessment Point 1
(pci/l)
1.00x10^01
1.00x10^-01
1.00x10^-03
1.00x10^-05
1.00x10^-07
1.00x10^-09
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U234]
U234MCL_A1[PuFF6]
U234MCL_A1[RoB]
U234MCL_A1[All]
U234MCL_A1[PuFF1]
U234MCL_A1[ABL]
U234MCL_A1[SandFilter]

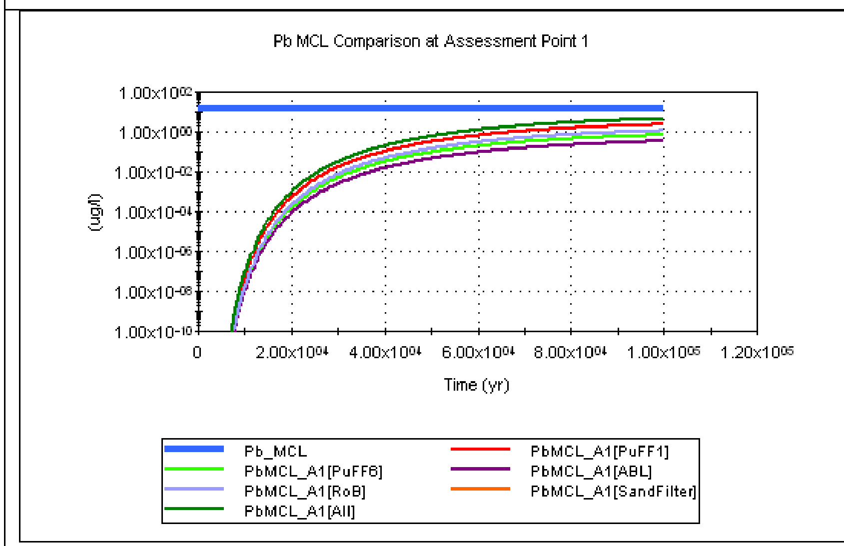

U234 MCL Comparison at Assessment Point 2
(pci/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U234]
U234MCL_A2[PuFF6]
U234MCL_A2[RoB]
U234MCL_A2[All]
U234MCL_A2[PuFF1]
U234MCL_A2[ABL]
U234MCL_A2[SandFilter]

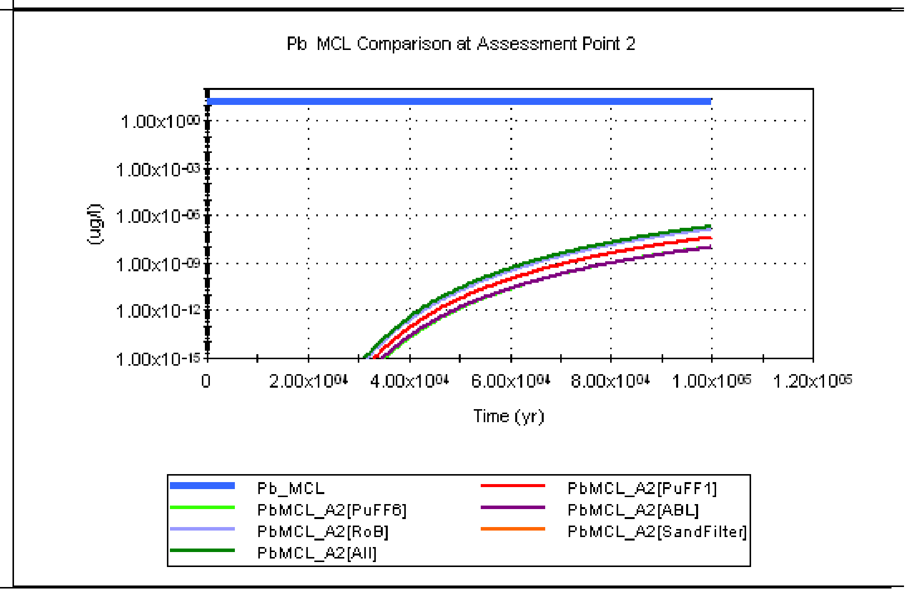

U235 MCL Comparison at Assessment Point 1
(pci/l)
1.00x10^00
1.00x10^-02
1.00x10^-04
1.00x10^-06
1.00x10^-08
1.00x10^-10
1.00x10^-12
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U235]
U235MCL_A1[PuFF6]
U235MCL_A1[RoB]
U235MCL_A1[All]
U235MCL_A1[PuFF1]
U235MCL_A1[ABL]
U235MCL_A1[SandFilter]

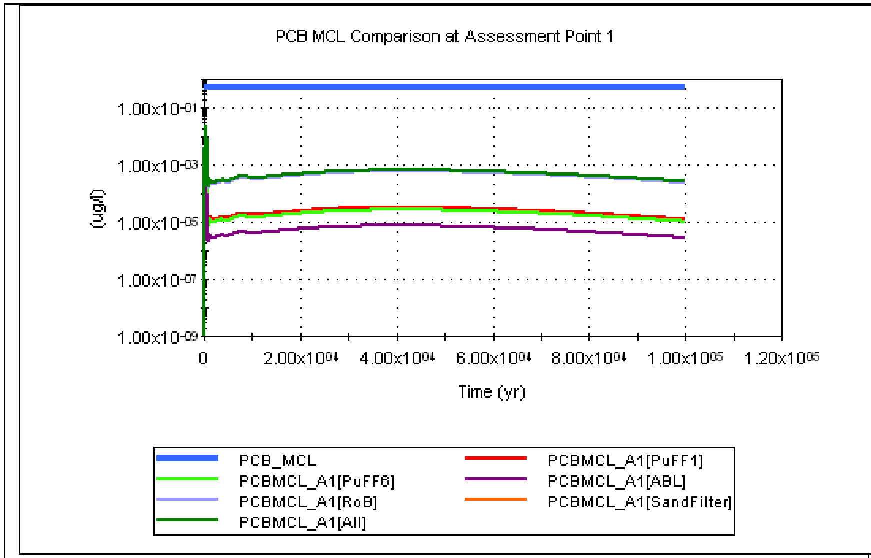

U235 MCL Comparison at Assessment Point 2
(pci/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U235]
U235MCL_A2[PuFF6]
U235MCL_A2[RoB]
U235MCL_A2[All]
U235MCL_A2[PuFF1]
U235MCL_A2[ABL]
U235MCL_A2[SandFilter]

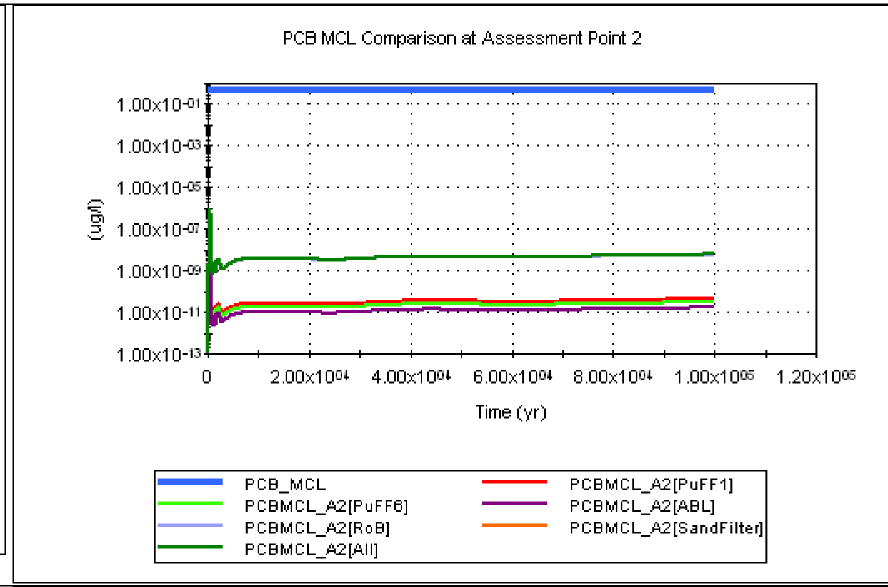

U238 MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
Uranium_MCL[U238]
U238MCL_A1[PuFF6]
U238MCL_A1[RoB]
U238MCL_A1[All]
U238MCL_A1[PuFF1]
U238MCL_A1[ABL]
U238MCL_A1[SandFilter]

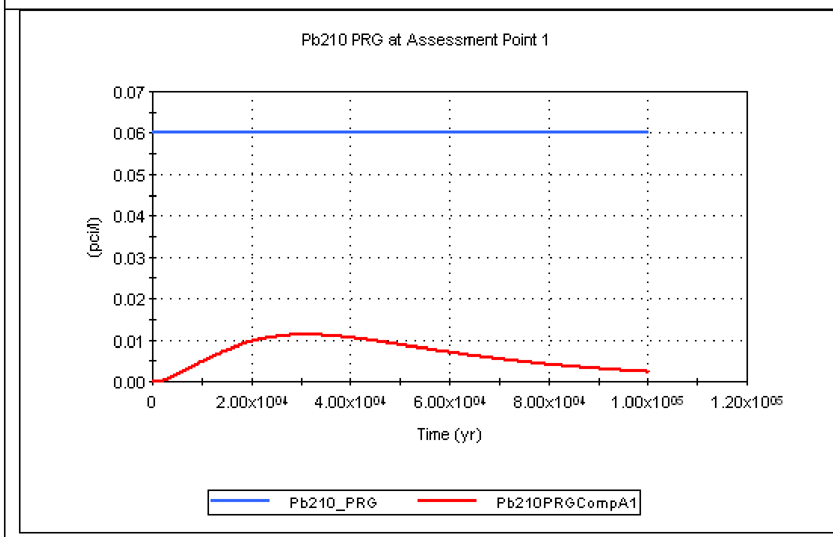

U238 MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
Uranium_MCL[U238]
U238MCL_A2[PuFF6]
U238MCL_A2[RoB]
U238MCL_A2[All]
U238MCL_A2[PuFF1]
U238MCL_A2[ABL]
U238MCL_A2[SandFilter]

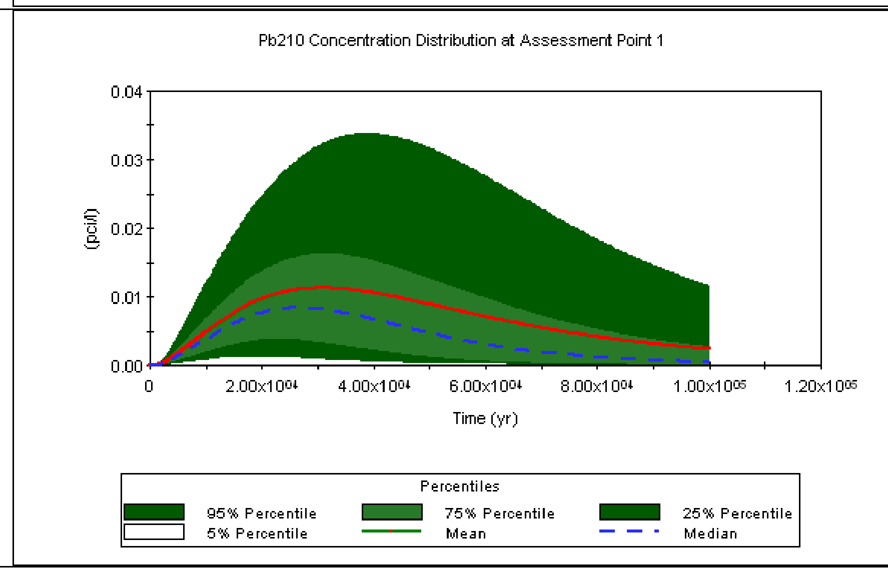

Pb MCL Comparison at Assessment Point 1
(ug/l)
Time (yr)
Pb_MCL
PbMCL_A1[PuFF6]
PbMCL_A1[RoB]
PbMCL_A1[All]
PbMCL_A1[PuFF1]
PbMCL_A1[ABL]
PbMCL_A1[SandFilter]

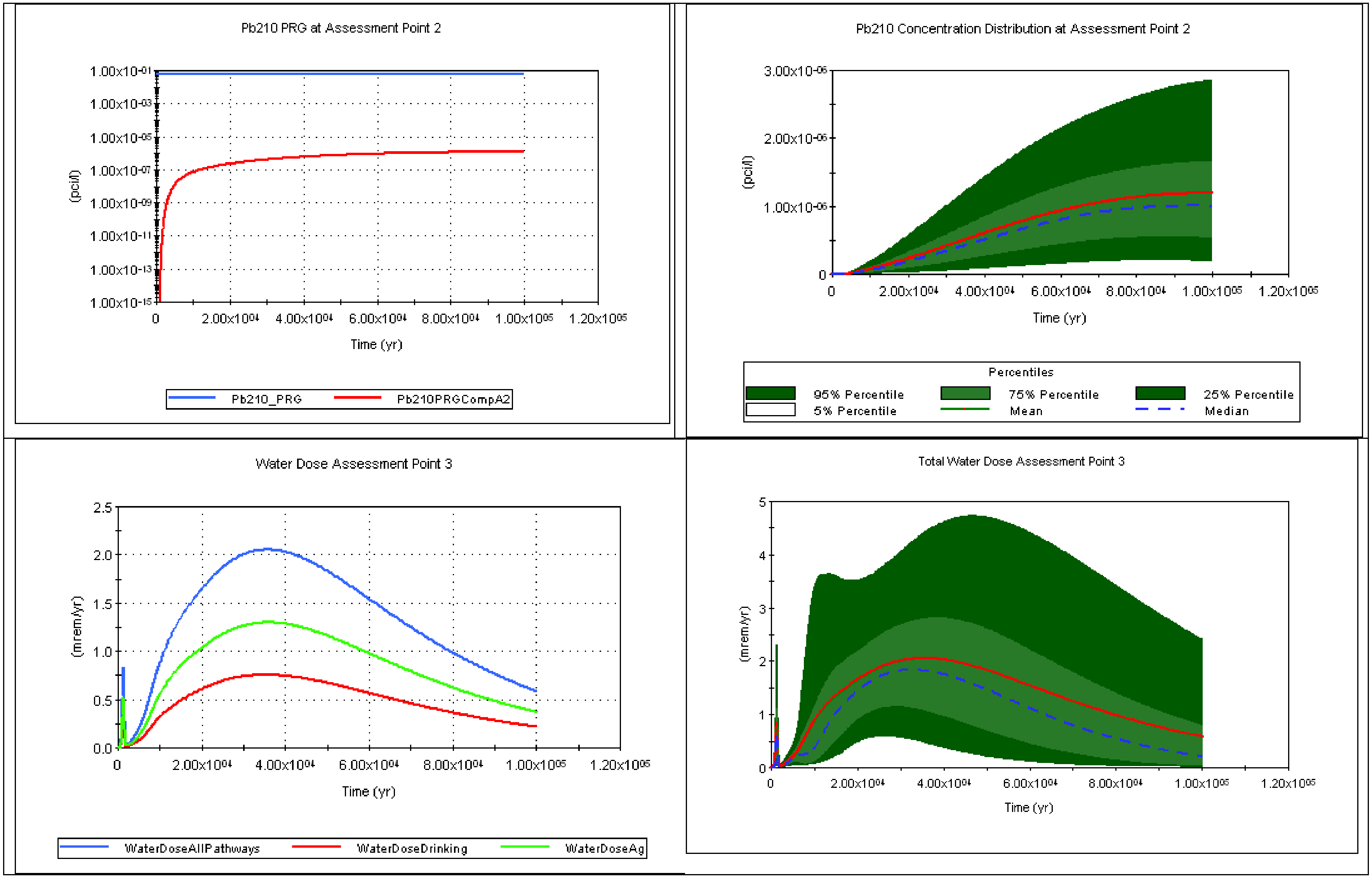

Pb MCL Comparison at Assessment Point 2
(ug/l)
Time (yr)
Pb_MCL
PbMCL_A2[PuFF6]
PbMCL_A2[RoB]
PbMCL_A2[All]
PbMCL_A2[PuFF1]
PbMCL_A2[ABL]
PbMCL_A2[SandFilter]


PCB MCL Comparison at Assessment Point 1
1.00x10-01
1.00x10-03
1.00x10-05
1.00x10-07
1.00x10-09
(ug/l)
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
PCB_MCL
PCBMCL_A1[PuFF6]
PCBMCL_A1[RoB]
PCBMCL_A1[All]
PCBMCL_A1[PuFF1]
PCBMCL_A1[ABL]
PCBMCL_A1[SandFilter]


PCB MCL Comparison at Assessment Point 2
1.00x10-01
1.00x10-03
1.00x10-05
1.00x10-07
1.00x10-09
1.00x10-11
1.00x10-13
(ug/l)
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
PCB_MCL
PCBMCL_A2[PuFF6]
PCBMCL_A2[RoB]
PCBMCL_A2[All]
PCBMCL_A2[PuFF1]
PCBMCL_A2[ABL]
PCBMCL_A2[SandFilter]

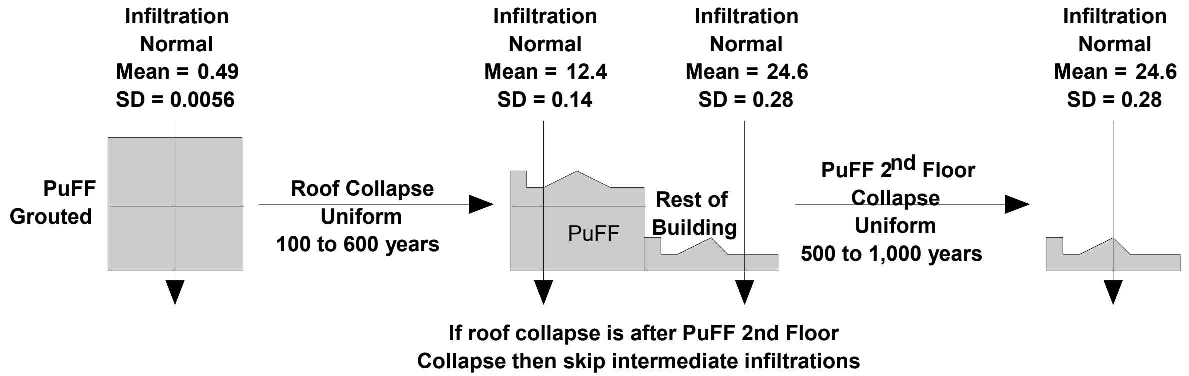

Pb210 PRG at Assessment Point 1
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
(pci/l)
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
Pb210_PRG
Pb210PRGCompA1


Pb210 Concentration Distribution at Assessment Point 1
0.04
0.03
0.02
0.01
0.00
(pci/l)
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
Percentiles
95% Percentile
5% Percentile
75% Percentile
Mean
25% Percentile
Median

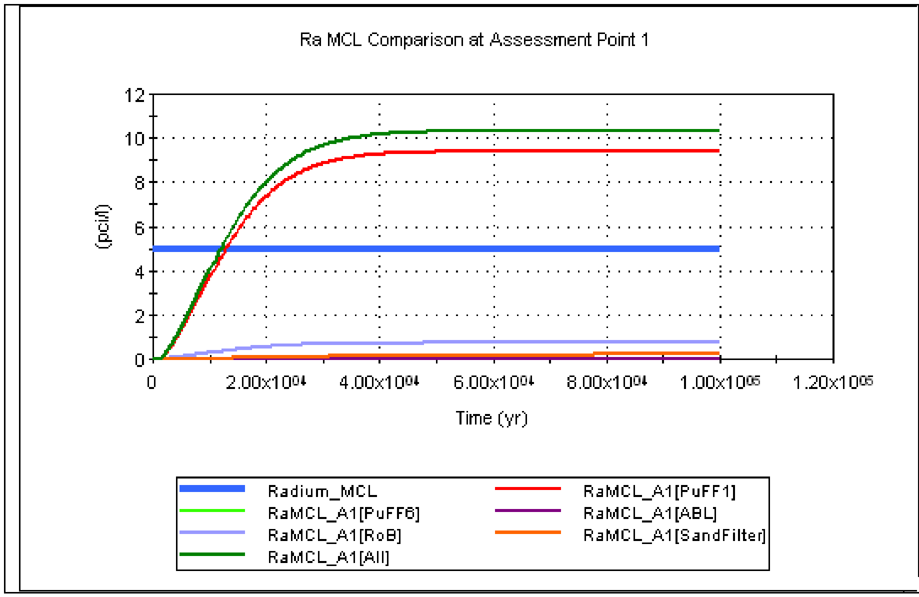


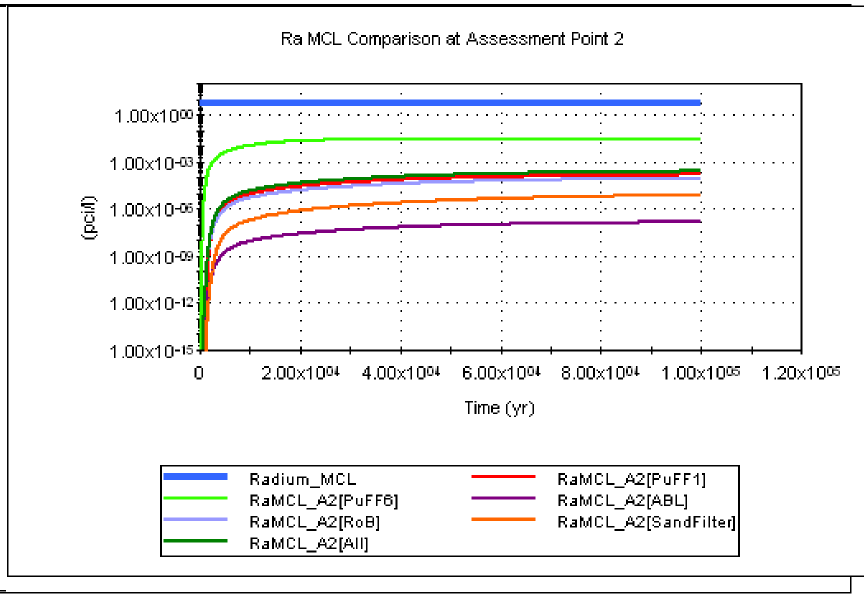
DOE Order 435.1 dose limit is 25 mrem/yr at 100 m from facility boundary (i.e. Assessment Point 3).

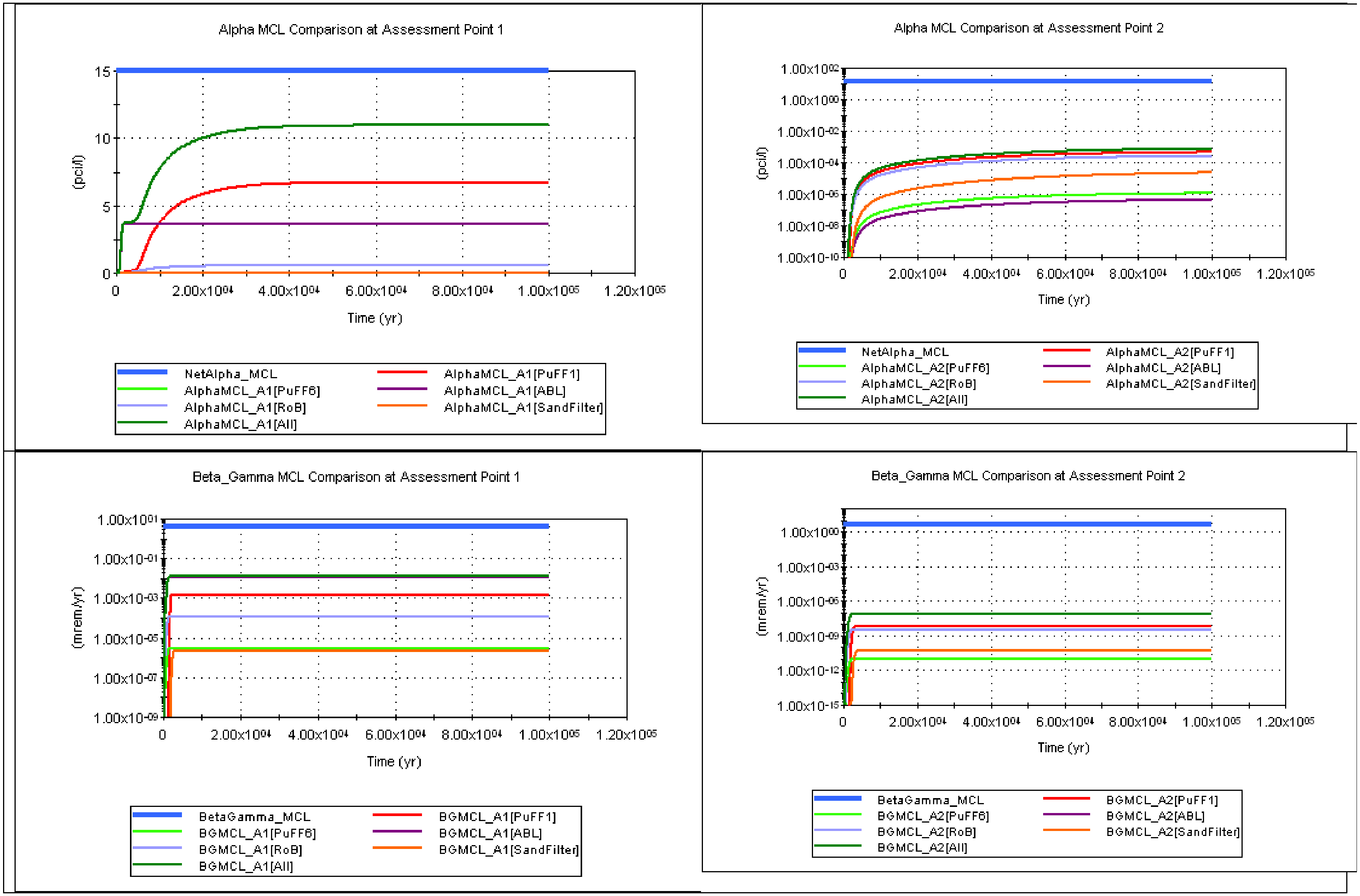
APPENDIX E GROUT PUFF CELLS 1-5



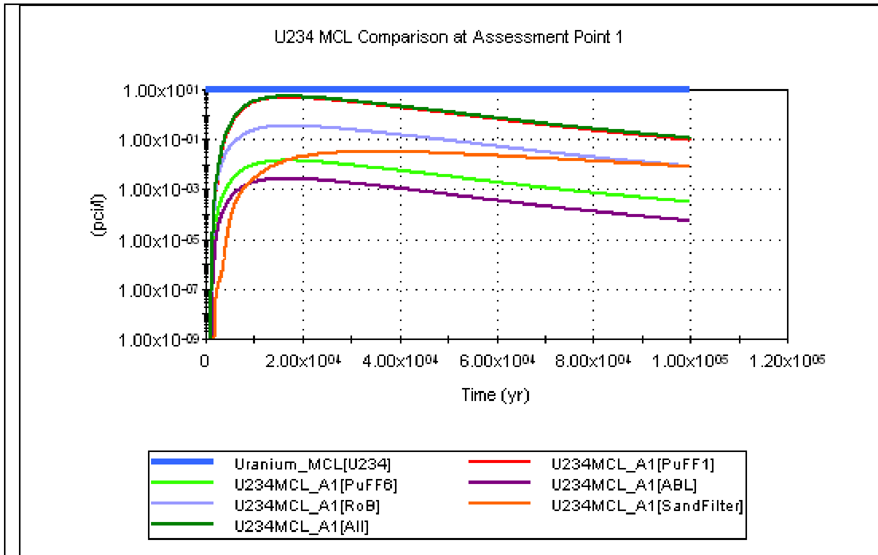
Unless otherwise noted, all plots are of mean values and are based upon the entire building.

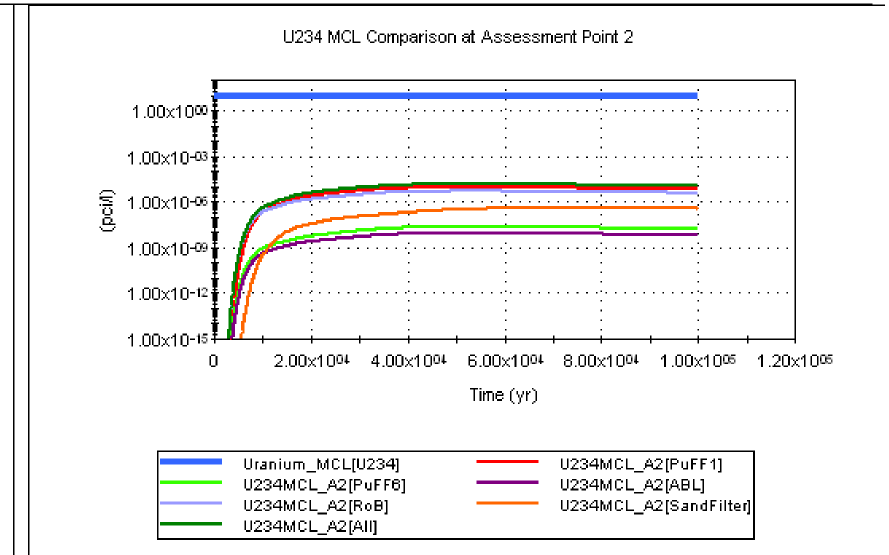


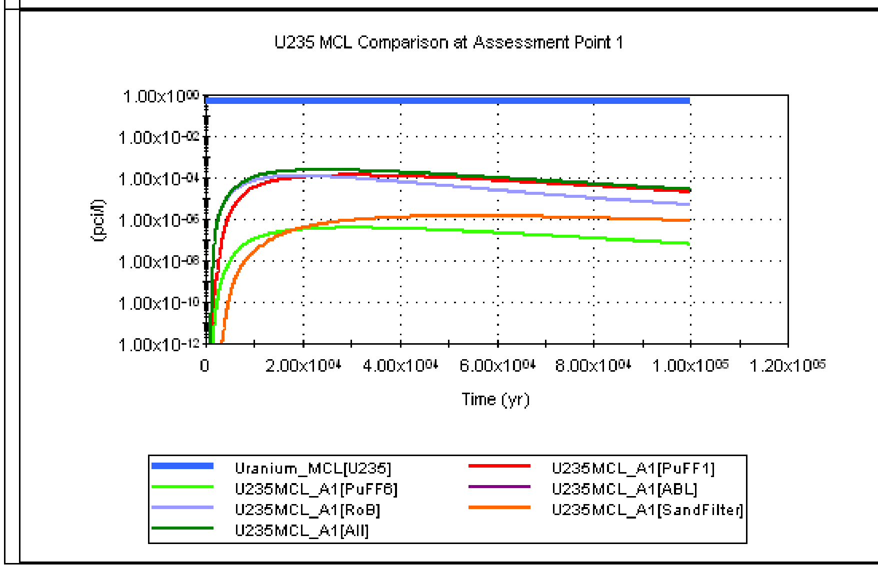


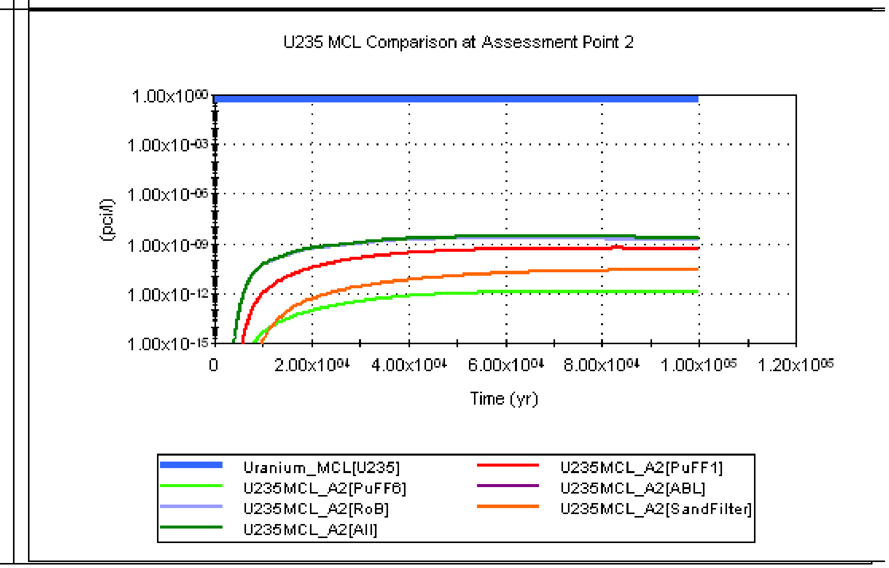


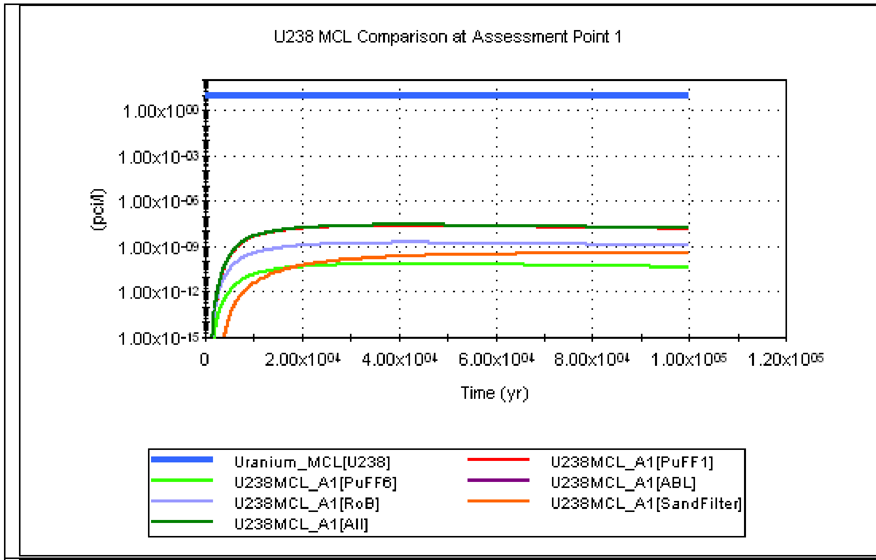
Alpha MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A1[PuFF6]
AlphaMCL_A1[RoB]
AlphaMCL_A1[All]
AlphaMCL_A1[PuFF1]
AlphaMCL_A1[ABL]
AlphaMCL_A1[SandFilter]
Alpha MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A2[PuFF6]
AlphaMCL_A2[RoB]
AlphaMCL_A2[All]
AlphaMCL_A2[PuFF1]
AlphaMCL_A2[ABL]
AlphaMCL_A2[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 1
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A1[PuFF6]
BGMCL_A1[RoB]
BGMCL_A1[All]
BGMCL_A1[PuFF1]
BGMCL_A1[ABL]
BGMCL_A1[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 2
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A2[PuFF6]
BGMCL_A2[RoB]
BGMCL_A2[All]
BGMCL_A2[PuFF1]
BGMCL_A2[ABL]
BGMCL_A2[SandFilter]

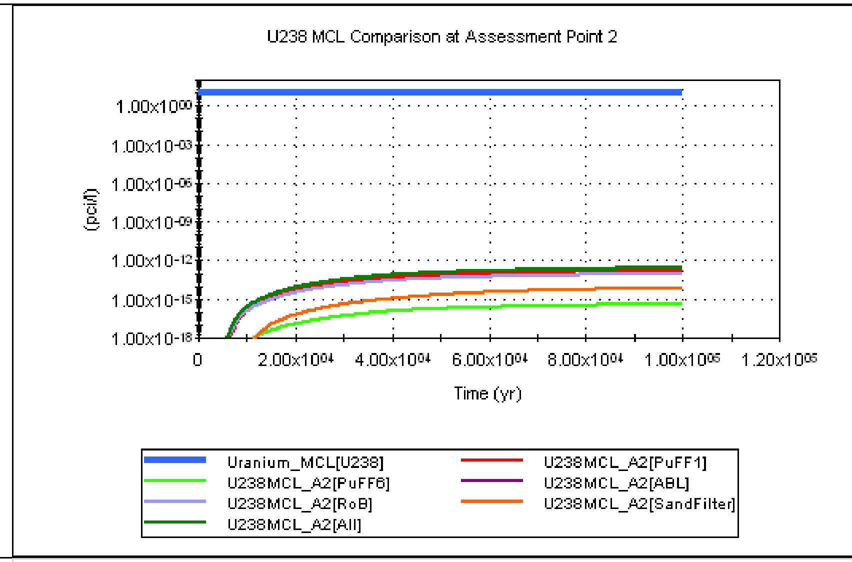

U234 MCL Comparison at Assessment Point 1
(pci/l)
1.00x10^01
1.00x10^-01
1.00x10^-03
1.00x10^-05
1.00x10^-07
1.00x10^-09
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U234]
U234MCL_A1[PuFF6]
U234MCL_A1[RoB]
U234MCL_A1[All]
U234MCL_A1[PuFF1]
U234MCL_A1[ABL]
U234MCL_A1[SandFilter]

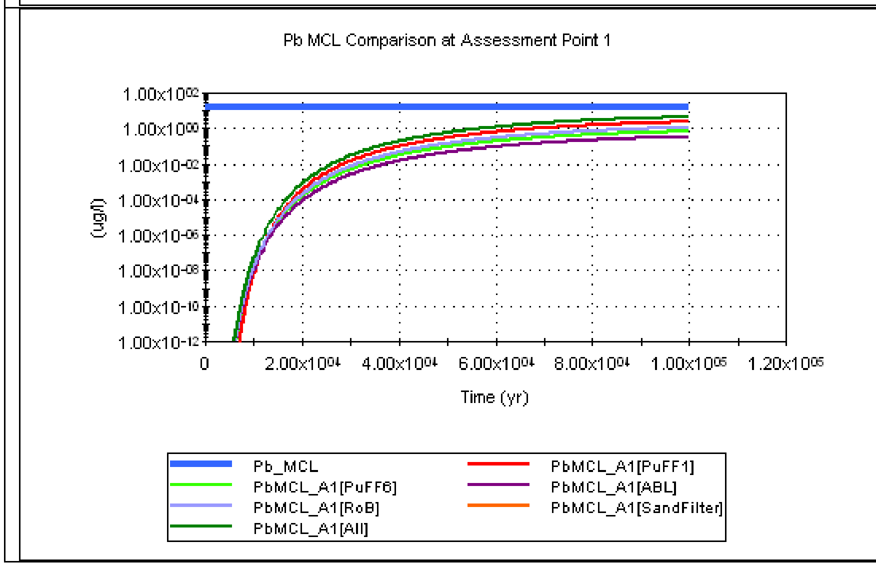

U234 MCL Comparison at Assessment Point 2
(pci/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U234]
U234MCL_A2[PuFF6]
U234MCL_A2[RoB]
U234MCL_A2[All]
U234MCL_A2[PuFF1]
U234MCL_A2[ABL]
U234MCL_A2[SandFilter]

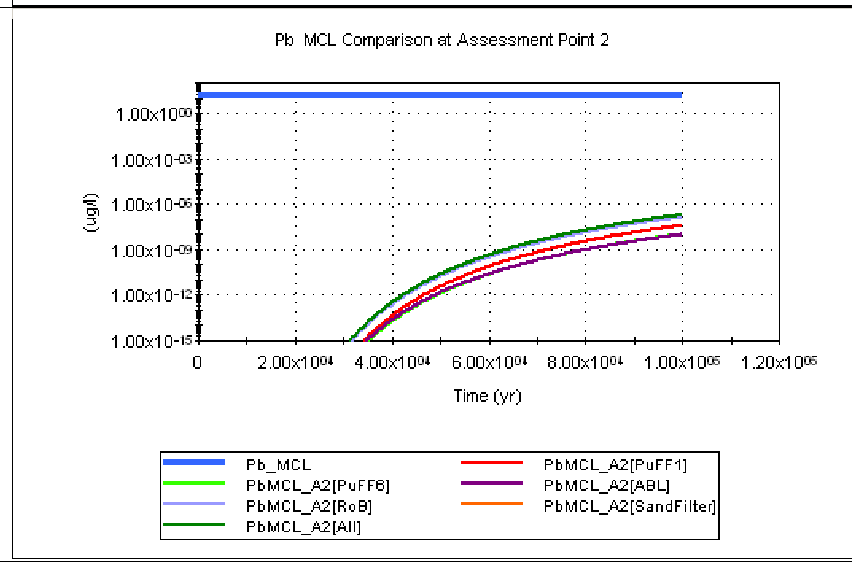

U235 MCL Comparison at Assessment Point 1
(pci/l)
1.00x10^00
1.00x10^-02
1.00x10^-04
1.00x10^-06
1.00x10^-08
1.00x10^-10
1.00x10^-12
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U235]
U235MCL_A1[PuFF6]
U235MCL_A1[RoB]
U235MCL_A1[All]
U235MCL_A1[PuFF1]
U235MCL_A1[ABL]
U235MCL_A1[SandFilter]

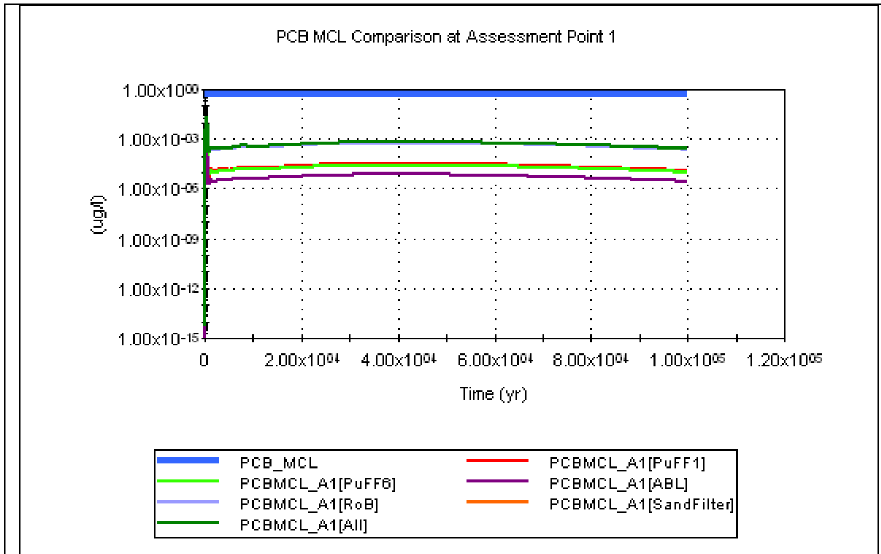

U235 MCL Comparison at Assessment Point 2
(pci/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U235]
U235MCL_A2[PuFF6]
U235MCL_A2[RoB]
U235MCL_A2[All]
U235MCL_A2[PuFF1]
U235MCL_A2[ABL]
U235MCL_A2[SandFilter]

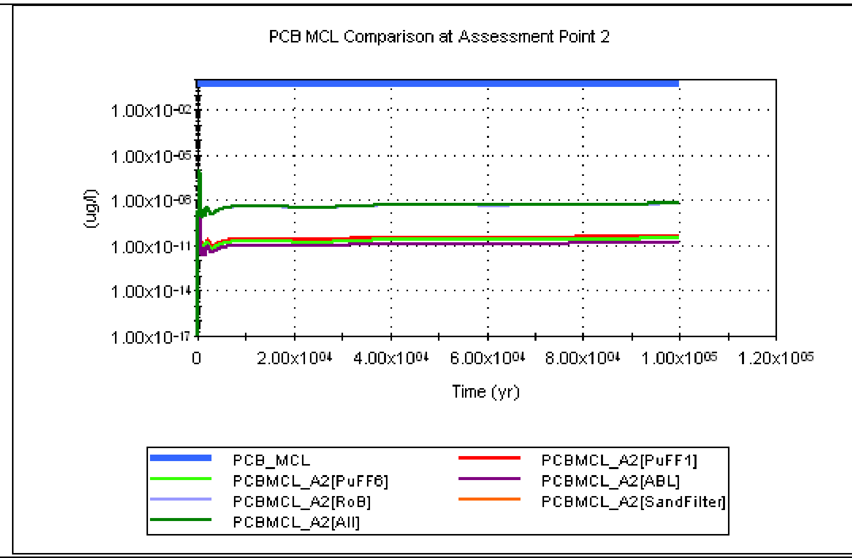

U238 MCL Comparison at Assessment Point 1
(pci/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U238]
U238MCL_A1[PuFF6]
U238MCL_A1[RoB]
U238MCL_A1[All]
U238MCL_A1[PuFF1]
U238MCL_A1[ABL]
U238MCL_A1[SandFilter]

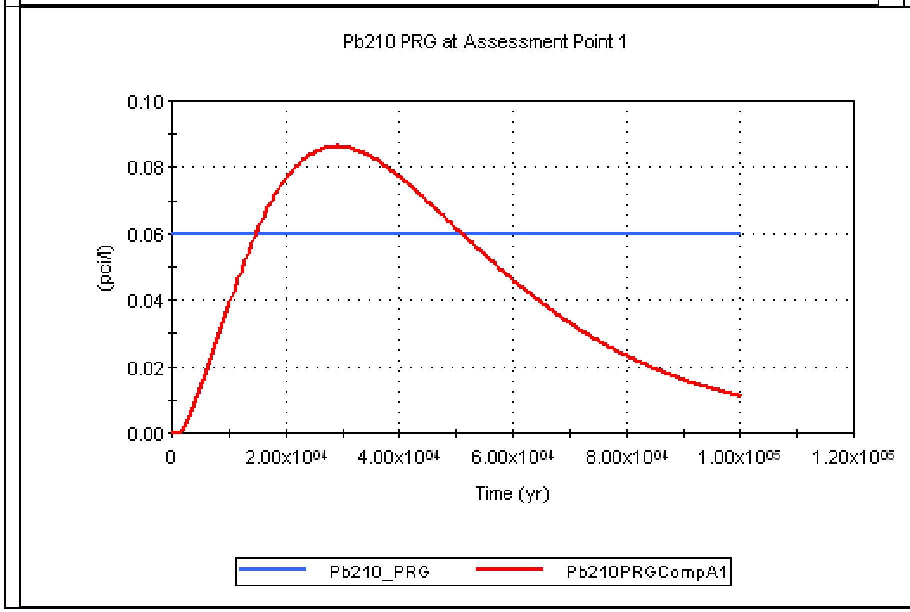

U238 MCL Comparison at Assessment Point 2
(pci/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
1.00x10^-18
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U238]
U238MCL_A2[PuFF6]
U238MCL_A2[RoB]
U238MCL_A2[All]
U238MCL_A2[PuFF1]
U238MCL_A2[ABL]
U238MCL_A2[SandFilter]

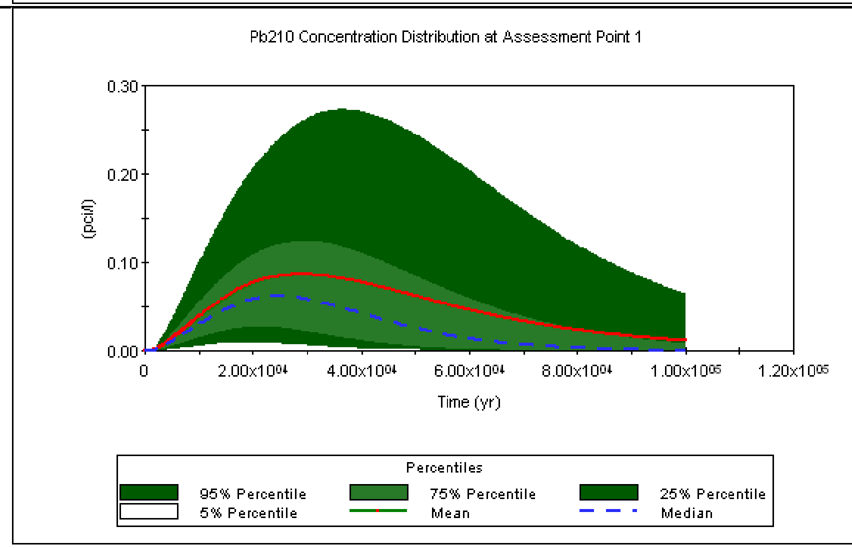

Pb MCL Comparison at Assessment Point 1
(ug/l)
1.00x10^02
1.00x10^00
1.00x10^-02
1.00x10^-04
1.00x10^-06
1.00x10^-08
1.00x10^-10
1.00x10^-12
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Pb_MCL
PbMCL_A1[PuFF6]
PbMCL_A1[RoB]
PbMCL_A1[All]
PbMCL_A1[PuFF1]
PbMCL_A1[ABL]
PbMCL_A1[SandFilter]

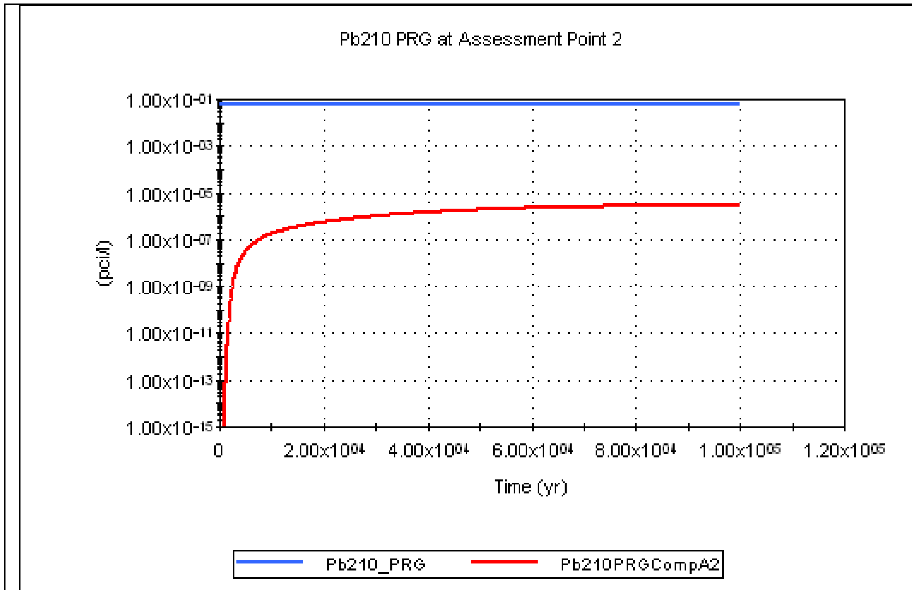

Pb MCL Comparison at Assessment Point 2
(ug/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Pb_MCL
PbMCL_A2[PuFF6]
PbMCL_A2[RoB]
PbMCL_A2[All]
PbMCL_A2[PuFF1]
PbMCL_A2[ABL]
PbMCL_A2[SandFilter]

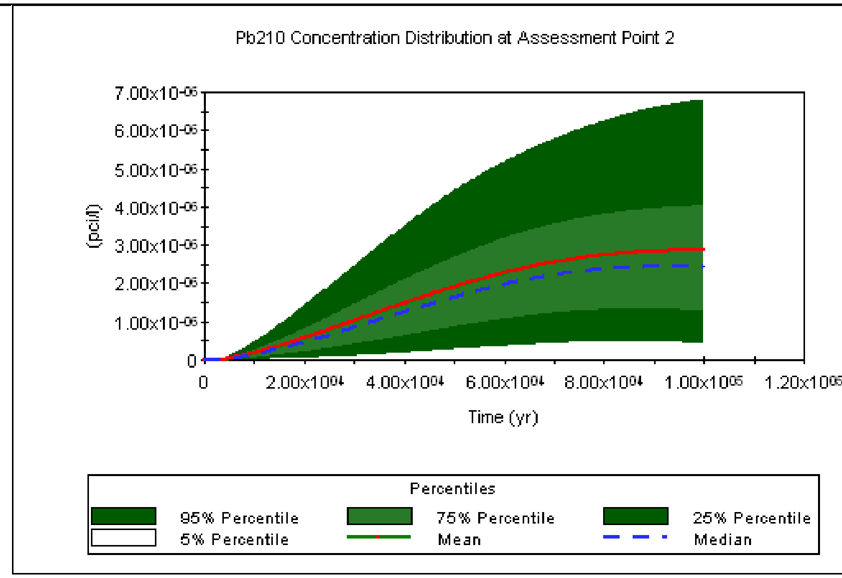

PCB MCL Comparison at Assessment Point 1
(ug/l)
Time (yr)
PCB_MCL
PCBMCL_A1[PuFF6]
PCBMCL_A1[RoB]
PCBMCL_A1[All]
PCBMCL_A1[PuFF1]
PCBMCL_A1[ABL]
PCBMCL_A1[SandFilter]

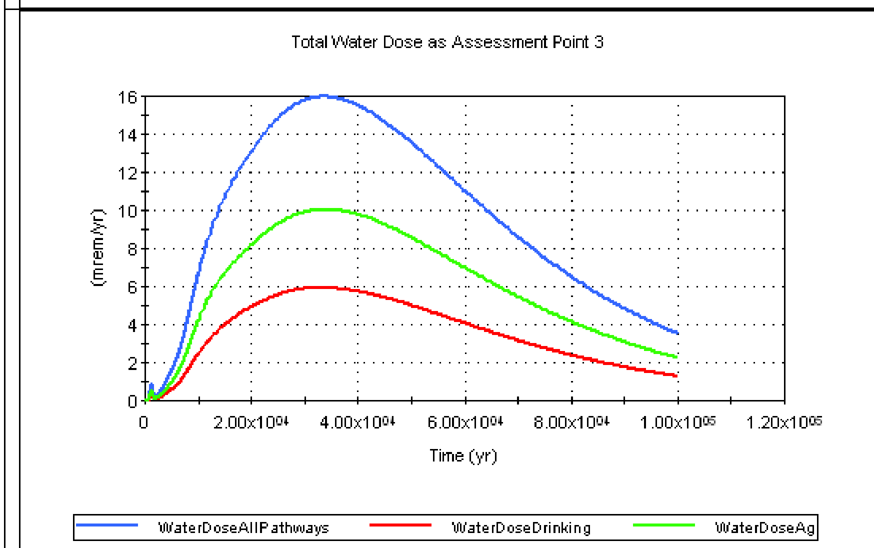

PCB MCL Comparison at Assessment Point 2
(ug/l)
Time (yr)
PCB_MCL
PCBMCL_A2[PuFF6]
PCBMCL_A2[RoB]
PCBMCL_A2[All]
PCBMCL_A2[PuFF1]
PCBMCL_A2[ABL]
PCBMCL_A2[SandFilter]

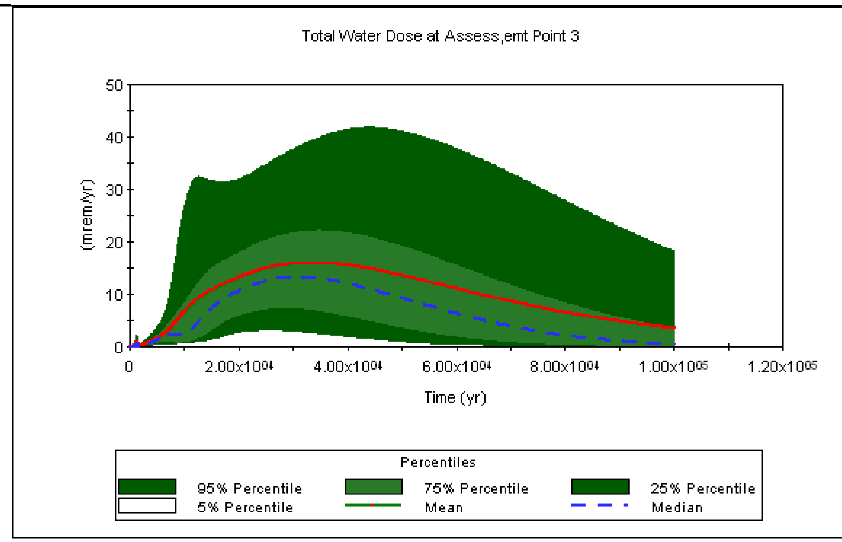

Pb210 PRG at Assessment Point 1
(pci/l)
Time (yr)
Pb210_PRG
Pb210PRGCompA1


Pb210 Concentration Distribution at Assessment Point 1
(pci/l)
Time (yr)
Percentiles
95% Percentile
5% Percentile
75% Percentile
Mean
25% Percentile
Median



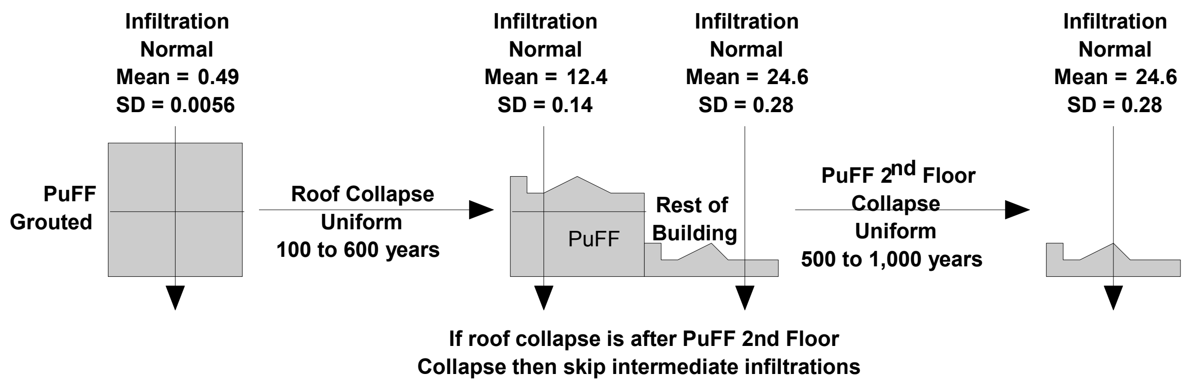




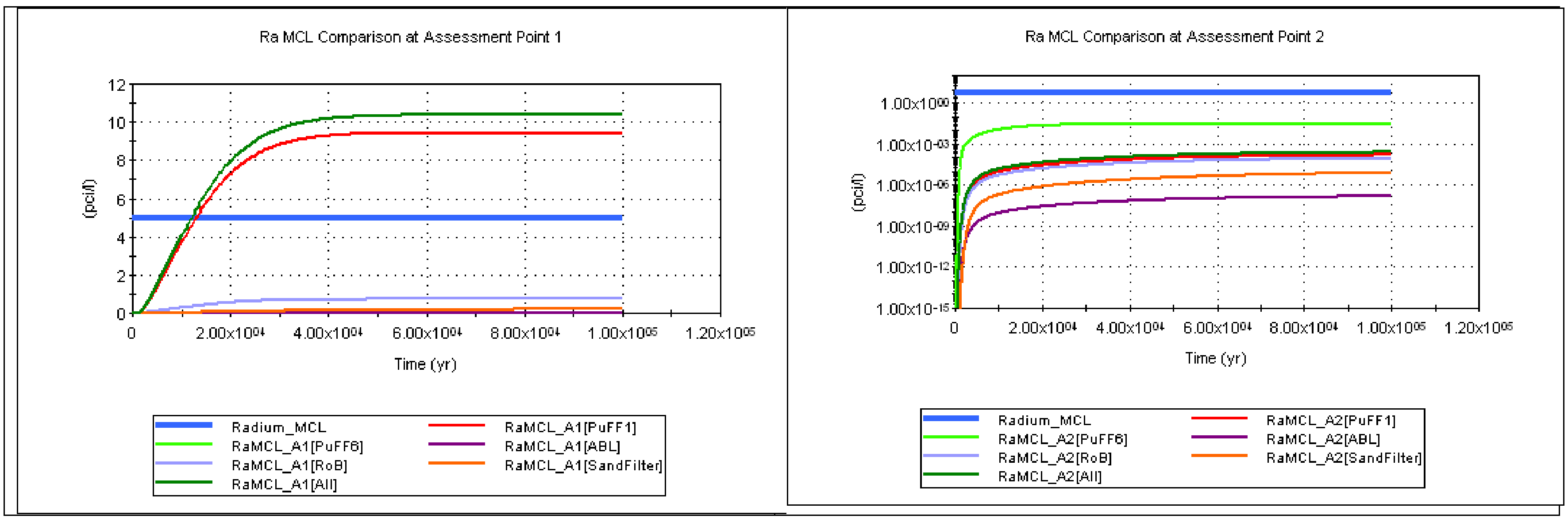


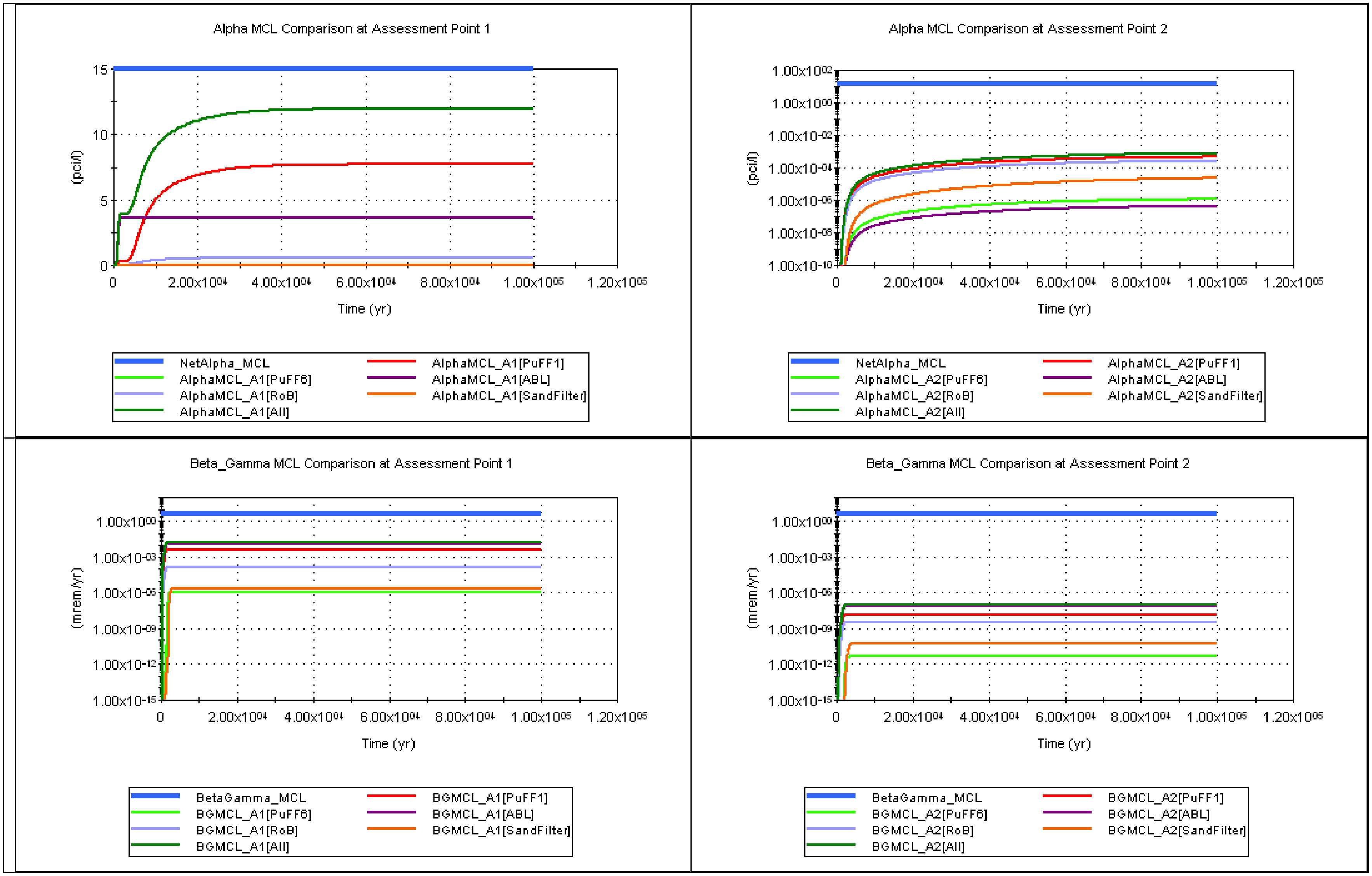
DOE Order 435.1 dose limit is 25 mrem/yr at 100 m from facility boundary (i.e. Assessment Point 3).

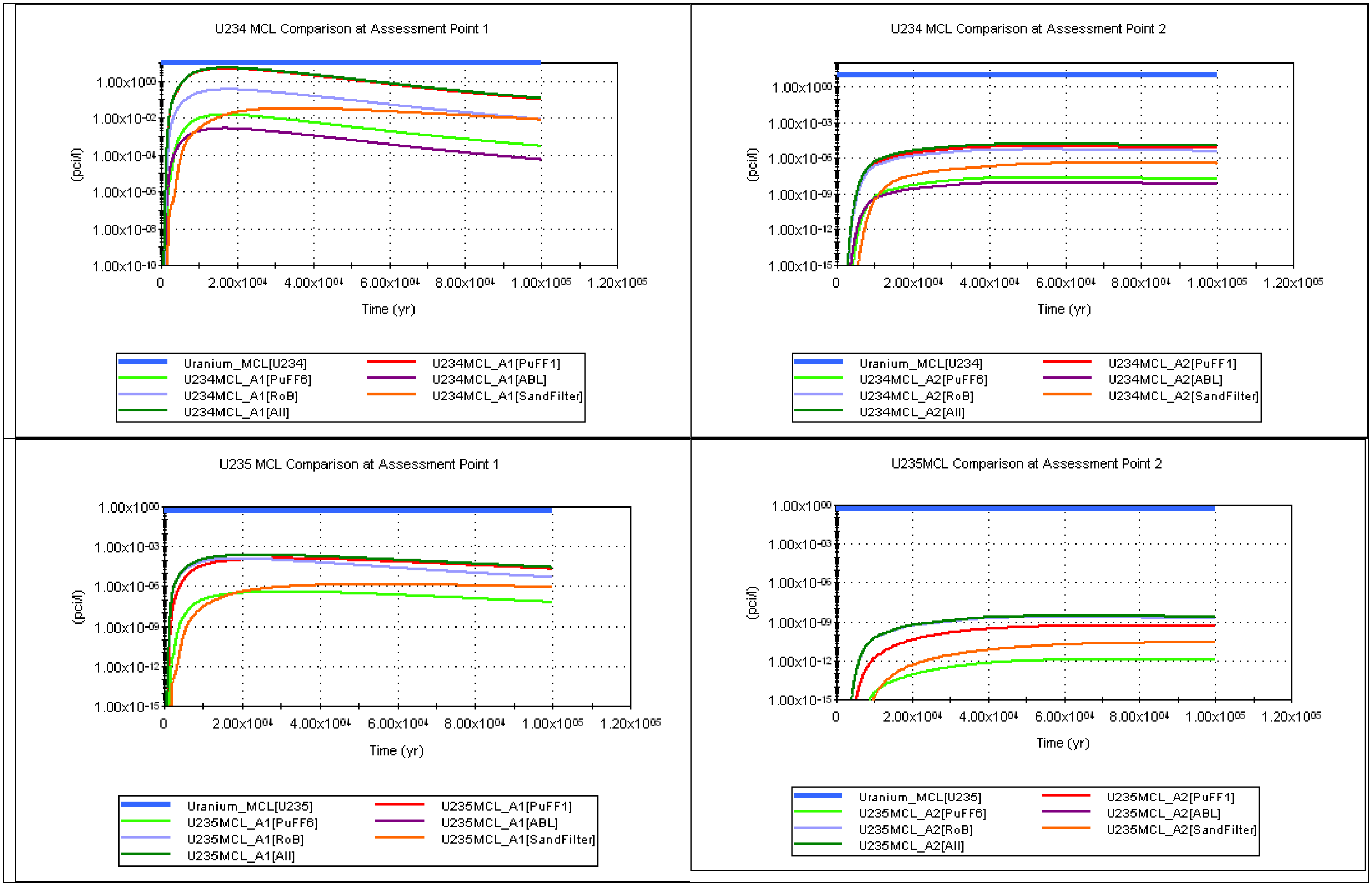
APPENDIX F GROUT PUFF CELLS 6-9

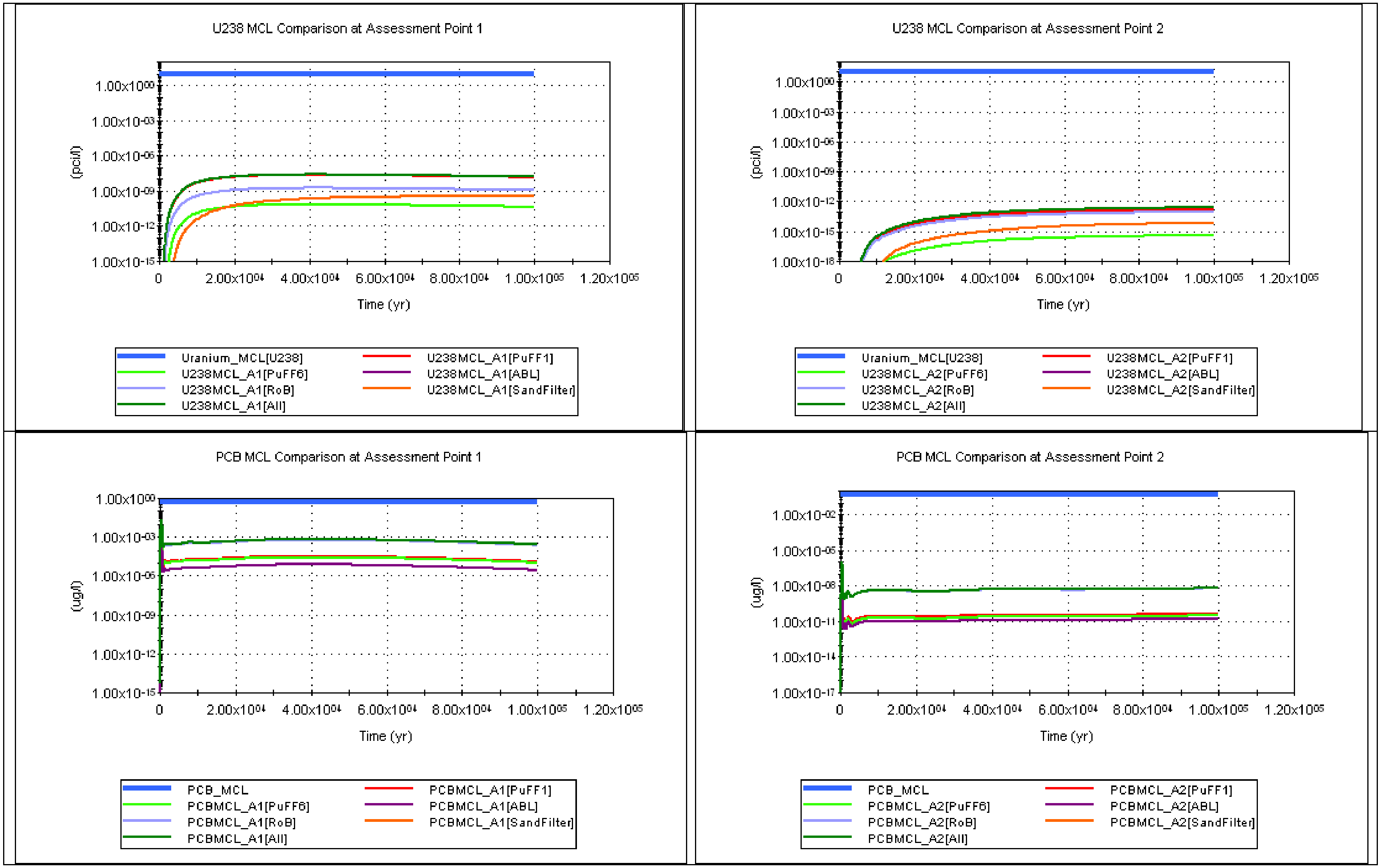


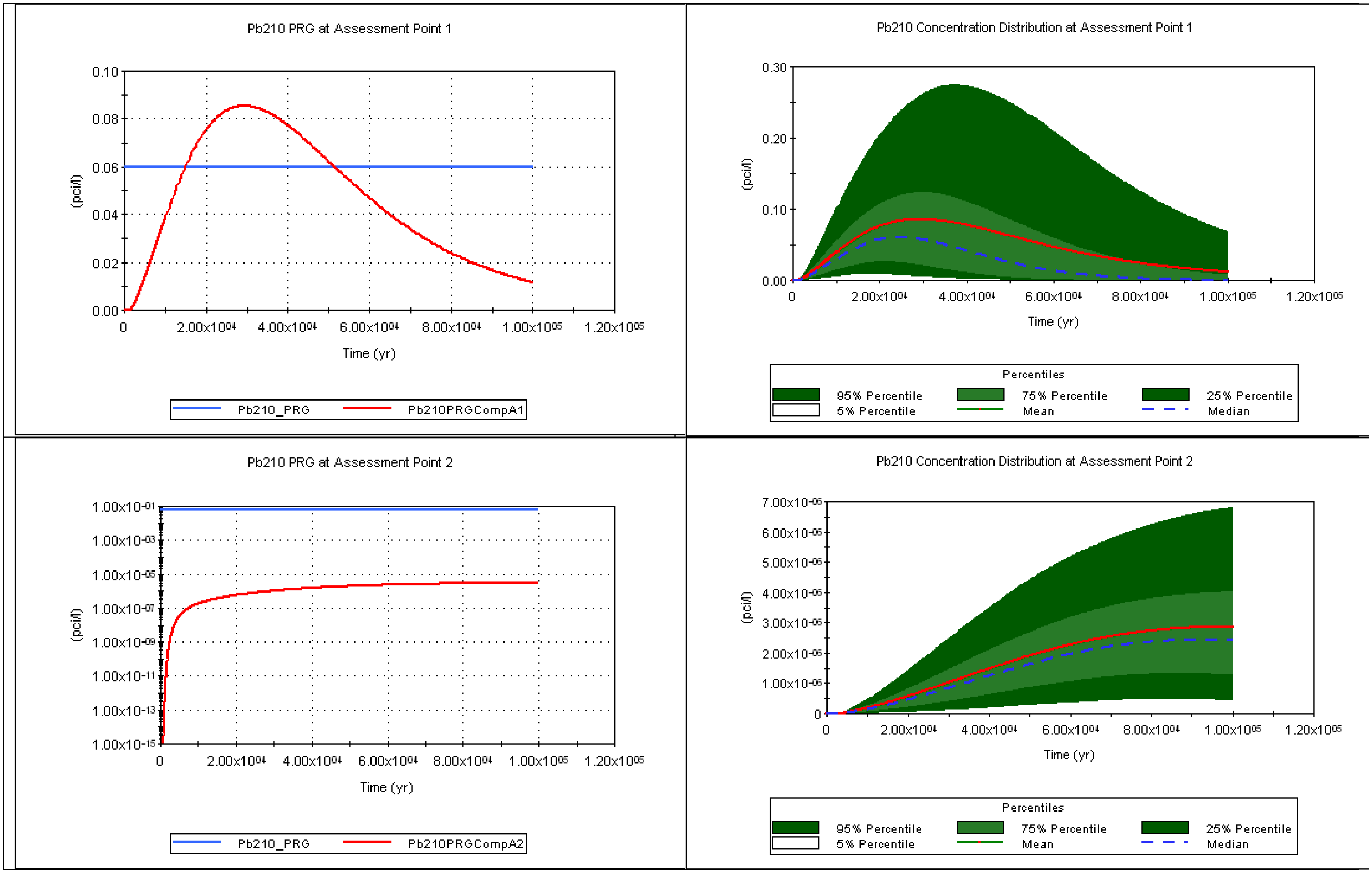
Unless otherwise noted, all plots are of mean values and are based upon the entire building.

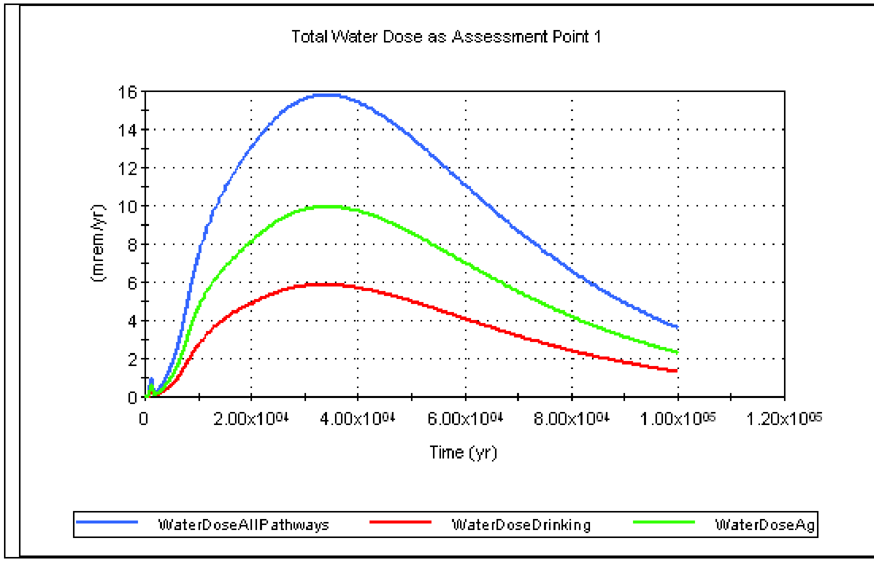


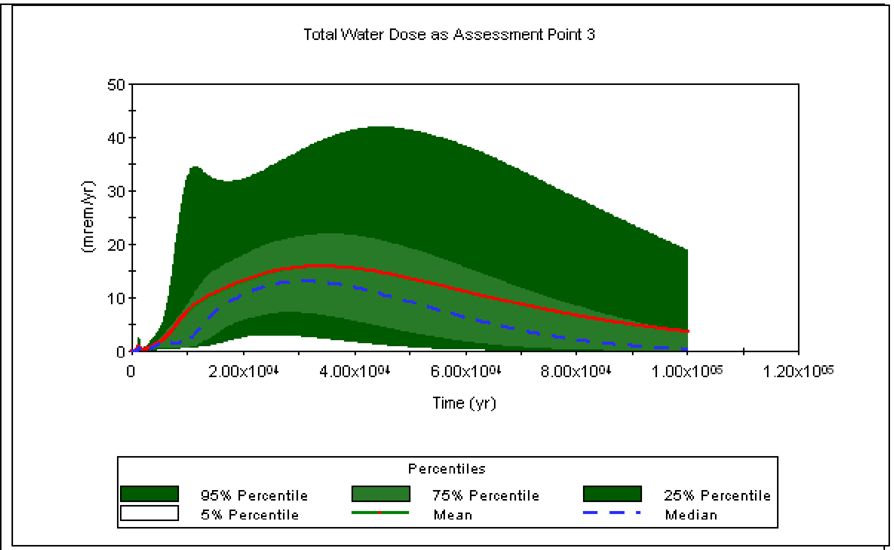

Alpha MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A1[PuFF6]
AlphaMCL_A1[RoB]
AlphaMCL_A1[All]
AlphaMCL_A1[PuFF1]
AlphaMCL_A1[ABL]
AlphaMCL_A1[SandFilter]
Alpha MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A2[PuFF6]
AlphaMCL_A2[RoB]
AlphaMCL_A2[All]
AlphaMCL_A2[PuFF1]
AlphaMCL_A2[ABL]
AlphaMCL_A2[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 1
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A1[PuFF6]
BGMCL_A1[RoB]
BGMCL_A1[All]
BGMCL_A1[PuFF1]
BGMCL_A1[ABL]
BGMCL_A1[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 2
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A2[PuFF6]
BGMCL_A2[RoB]
BGMCL_A2[All]
BGMCL_A2[PuFF1]
BGMCL_A2[ABL]
BGMCL_A2[SandFilter]


U234 MCL Comparison at Assessment Point 1
1.00x10^00
1.00x10^-02
1.00x10^-04
1.00x10^-06
1.00x10^-08
1.00x10^-10
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U234]
U234MCL_A1[PuFF1]
U234MCL_A1[PuFF6]
U234MCL_A1[ABL]
U234MCL_A1[RoB]
U234MCL_A1[SandFilter]
U234MCL_A1[All]
U234 MCL Comparison at Assessment Point 2
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U234]
U234MCL_A2[PuFF1]
U234MCL_A2[PuFF6]
U234MCL_A2[ABL]
U234MCL_A2[RoB]
U234MCL_A2[SandFilter]
U234MCL_A2[All]
U235 MCL Comparison at Assessment Point 1
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U235]
U235MCL_A1[PuFF1]
U235MCL_A1[PuFF6]
U235MCL_A1[ABL]
U235MCL_A1[RoB]
U235MCL_A1[SandFilter]
U235MCL_A1[All]
U235MCL Comparison at Assessment Point 2
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U235]
U235MCL_A2[PuFF1]
U235MCL_A2[PuFF6]
U235MCL_A2[ABL]
U235MCL_A2[RoB]
U235MCL_A2[SandFilter]
U235MCL_A2[All]


U238 MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
Uranium_MCL[U238]
U238MCL_A1[PuFF6]
U238MCL_A1[RoB]
U238MCL_A1[All]
U238MCL_A1[PuFF1]
U238MCL_A1[ABL]
U238MCL_A1[SandFilter]
U238 MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
Uranium_MCL[U238]
U238MCL_A2[PuFF6]
U238MCL_A2[RoB]
U238MCL_A2[All]
U238MCL_A2[PuFF1]
U238MCL_A2[ABL]
U238MCL_A2[SandFilter]
PCB MCL Comparison at Assessment Point 1
(ug/l)
Time (yr)
PCB_MCL
PCBMCL_A1[PuFF6]
PCBMCL_A1[RoB]
PCBMCL_A1[All]
PCBMCL_A1[PuFF1]
PCBMCL_A1[ABL]
PCBMCL_A1[SandFilter]
PCB MCL Comparison at Assessment Point 2
(ug/l)
Time (yr)
PCB_MCL
PCBMCL_A2[PuFF6]
PCBMCL_A2[RoB]
PCBMCL_A2[All]
PCBMCL_A2[PuFF1]
PCBMCL_A2[ABL]
PCBMCL_A2[SandFilter]

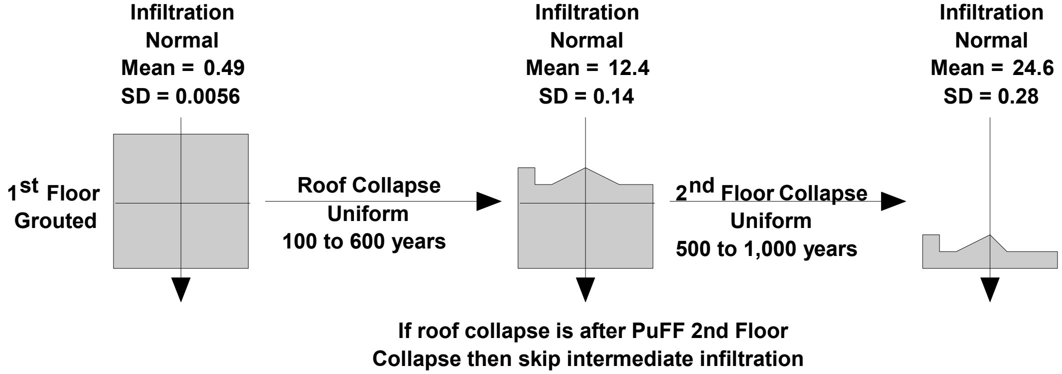

Pb210 PRG at Assessment Point 1
(pci/l)
Time (yr)
Pb210_PRG
Pb210PRGCompA1
Pb210 Concentration Distribution at Assessment Point 1
(pci/l)
Time (yr)
Percentiles
95% Percentile
75% Percentile
25% Percentile
5% Percentile
Mean
Median
Pb210 PRG at Assessment Point 2
(pci/l)
Time (yr)
Pb210_PRG
Pb210PRGCompA2
Pb210 Concentration Distribution at Assessment Point 2
(pci/l)
Time (yr)
Percentiles
95% Percentile
75% Percentile
25% Percentile
5% Percentile
Mean
Median



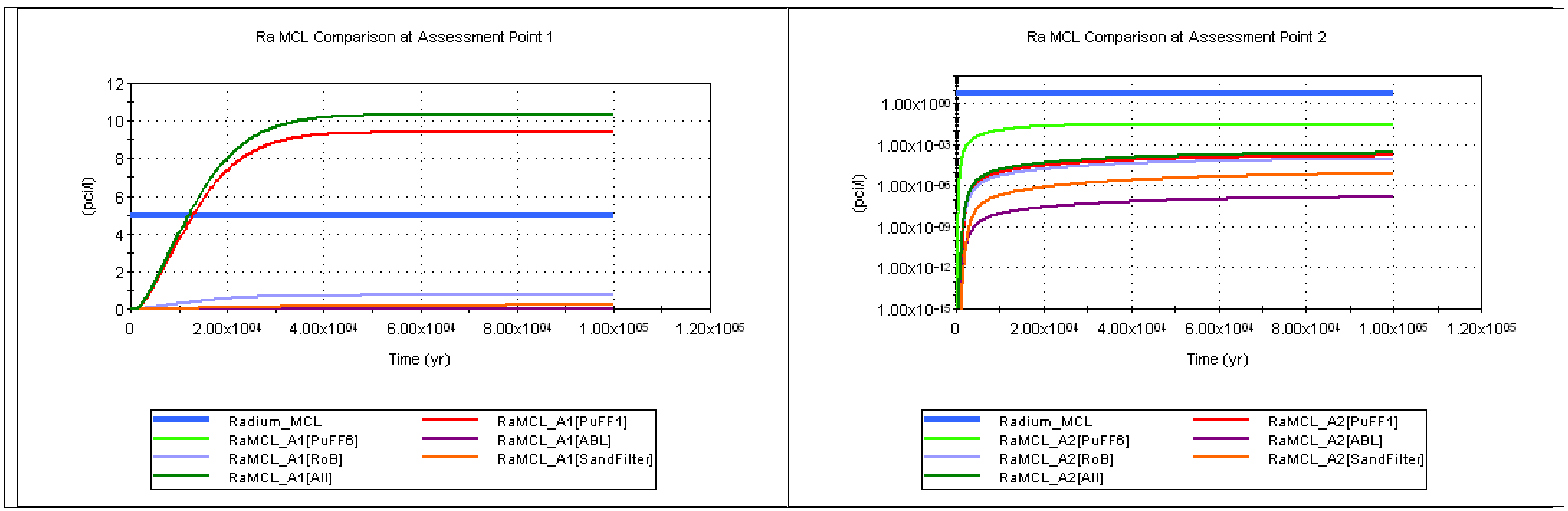


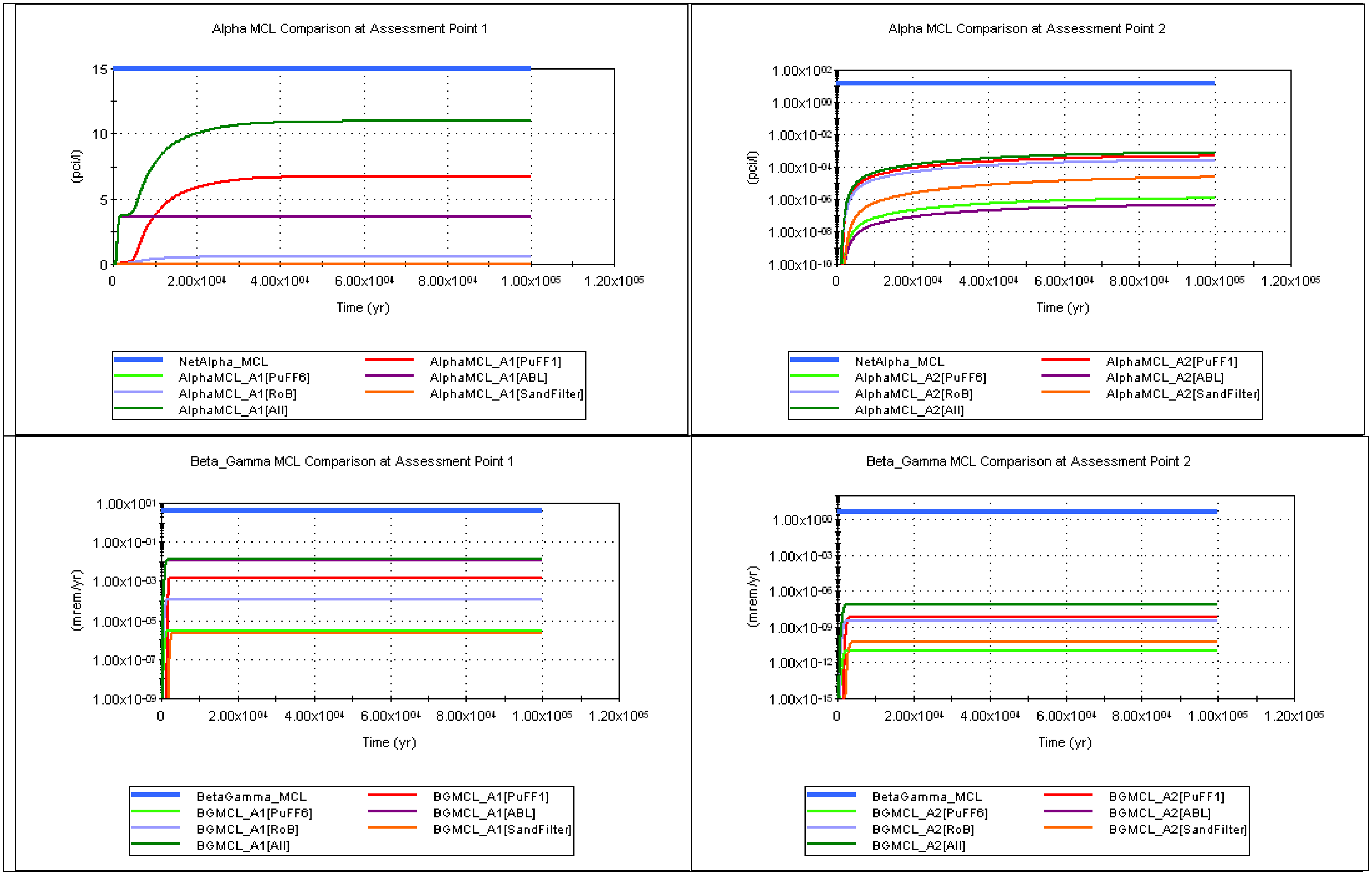
DOE Order 435.1 dose limit is 25 mrem/yr at 100 m from facility boundary (i.e. Assessment Point 3).

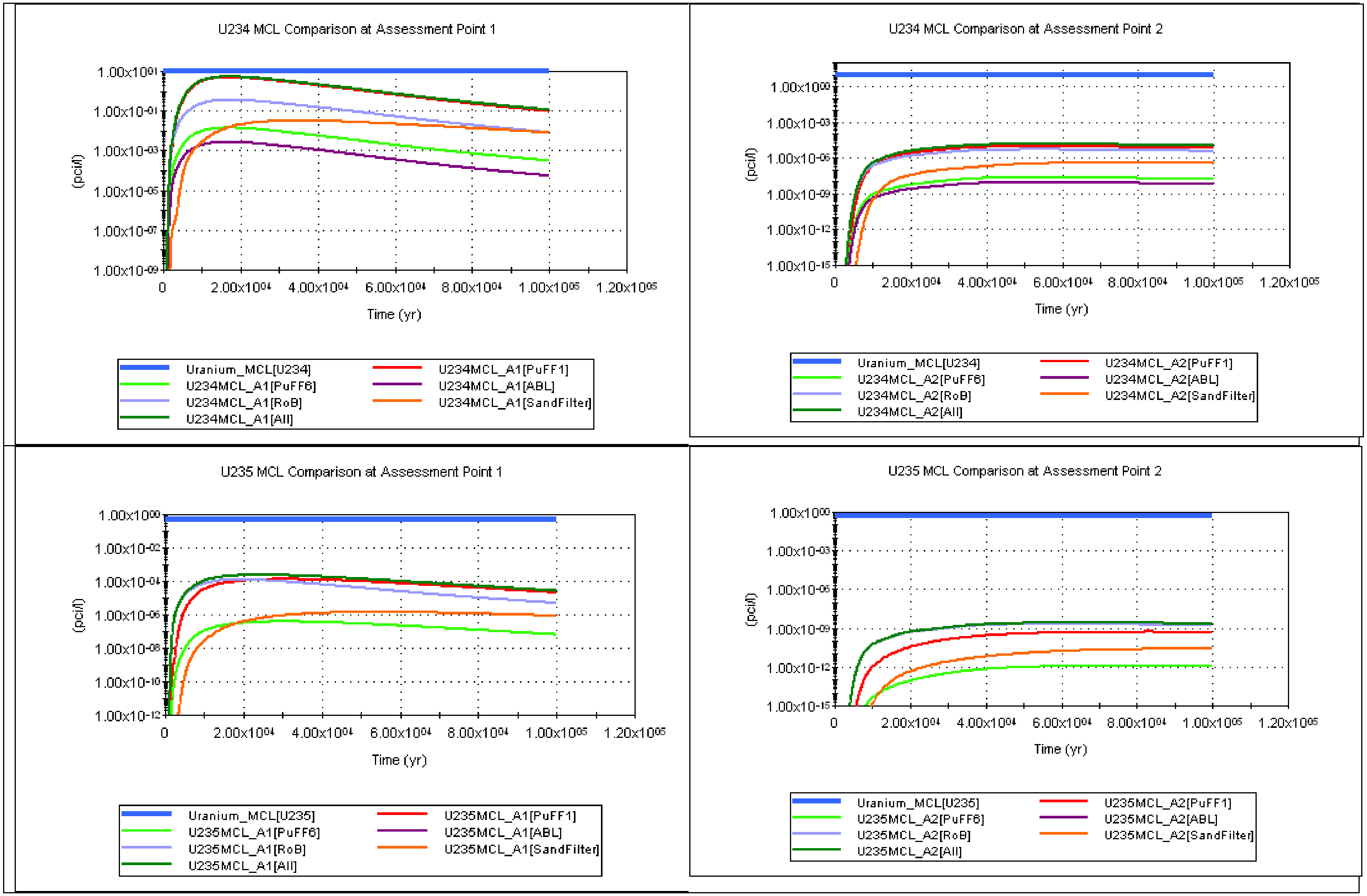
APPENDIX G GROUT ENTIRE FIRST FLOOR

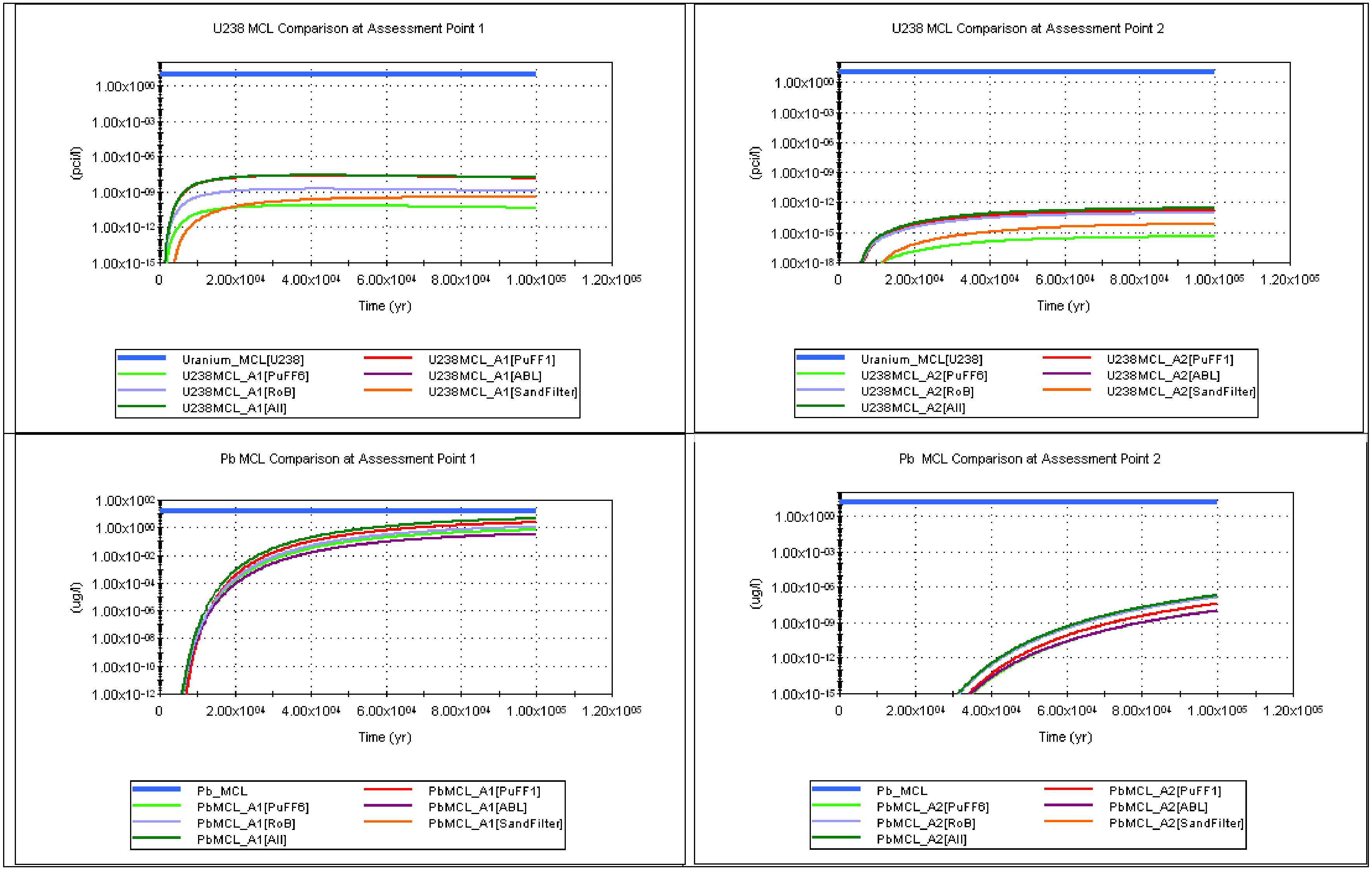


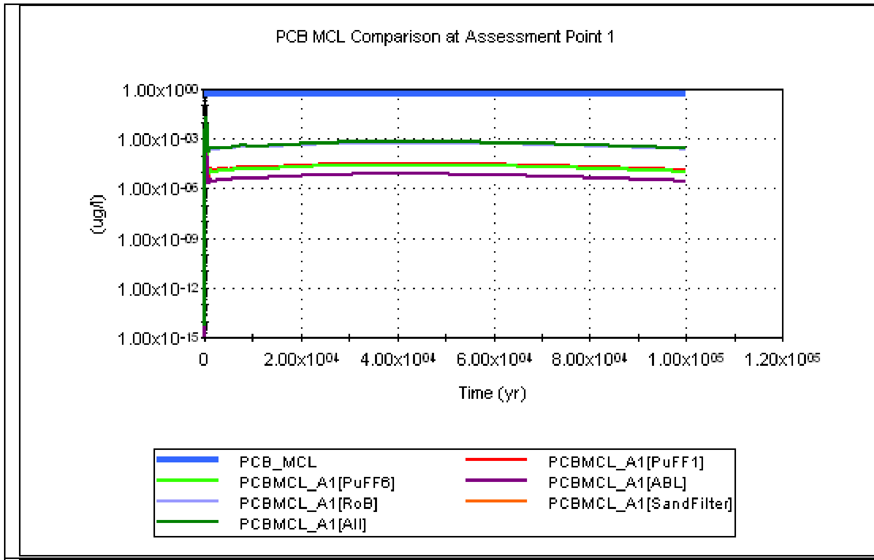
Unless otherwise noted, all plots are of mean values and are based upon the entire building.

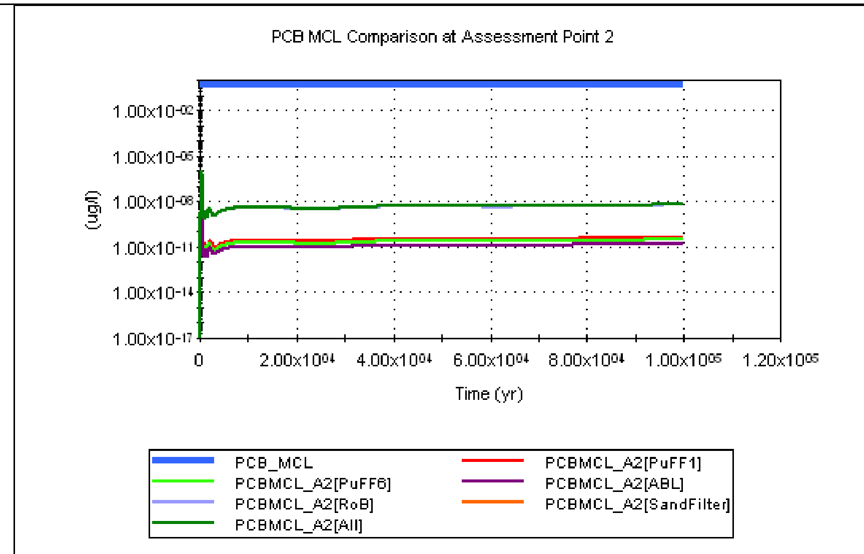


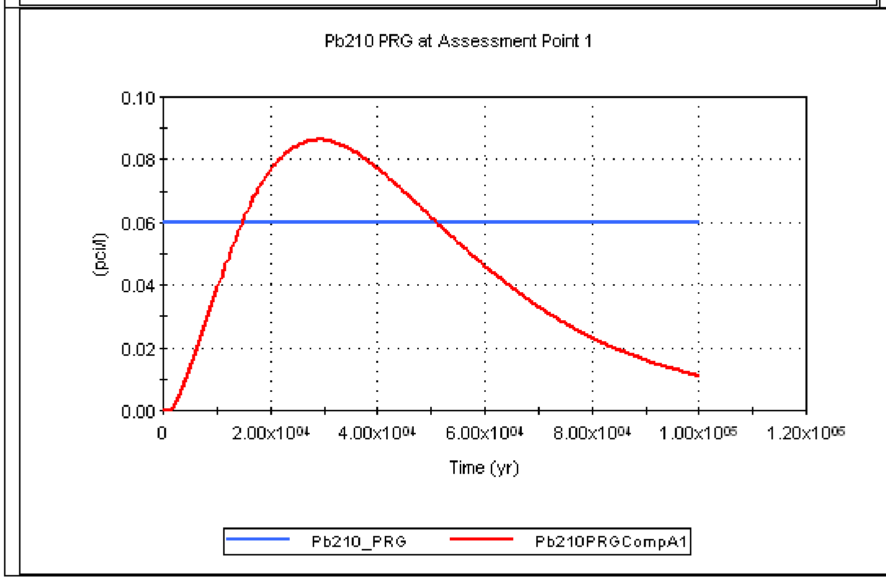

Alpha MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A1[PuFF6]
AlphaMCL_A1[RoB]
AlphaMCL_A1[All]
AlphaMCL_A1[PuFF1]
AlphaMCL_A1[ABL]
AlphaMCL_A1[SandFilter]
Alpha MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A2[PuFF6]
AlphaMCL_A2[RoB]
AlphaMCL_A2[All]
AlphaMCL_A2[PuFF1]
AlphaMCL_A2[ABL]
AlphaMCL_A2[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 1
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A1[PuFF6]
BGMCL_A1[RoB]
BGMCL_A1[All]
BGMCL_A1[PuFF1]
BGMCL_A1[ABL]
BGMCL_A1[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 2
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A2[PuFF6]
BGMCL_A2[RoB]
BGMCL_A2[All]
BGMCL_A2[PuFF1]
BGMCL_A2[ABL]
BGMCL_A2[SandFilter]

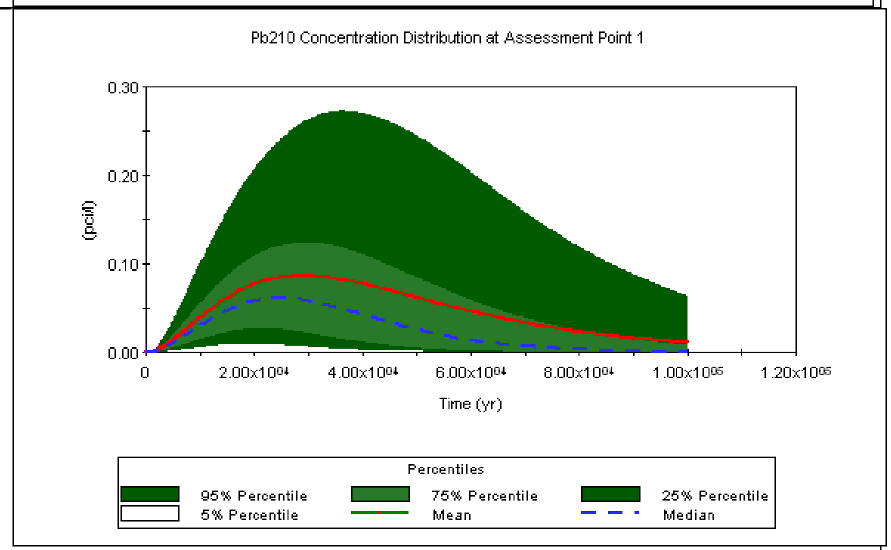

U234 MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
Uranium_MCL[U234]
U234MCL_A1[PuFF6]
U234MCL_A1[RoB]
U234MCL_A1[All]
U234MCL_A1[PuFF1]
U234MCL_A1[ABL]
U234MCL_A1[SandFilter]
U234 MCL Comparison at Assessment Point 2
Uranium_MCL[U234]
U234MCL_A2[PuFF6]
U234MCL_A2[RoB]
U234MCL_A2[All]
U234MCL_A2[PuFF1]
U234MCL_A2[ABL]
U234MCL_A2[SandFilter]
U235 MCL Comparison at Assessment Point 1
Uranium_MCL[U235]
U235MCL_A1[PuFF6]
U235MCL_A1[RoB]
U235MCL_A1[All]
U235MCL_A1[PuFF1]
U235MCL_A1[ABL]
U235MCL_A1[SandFilter]
U235 MCL Comparison at Assessment Point 2
Uranium_MCL[U235]
U235MCL_A2[PuFF6]
U235MCL_A2[RoB]
U235MCL_A2[All]
U235MCL_A2[PuFF1]
U235MCL_A2[ABL]
U235MCL_A2[SandFilter]

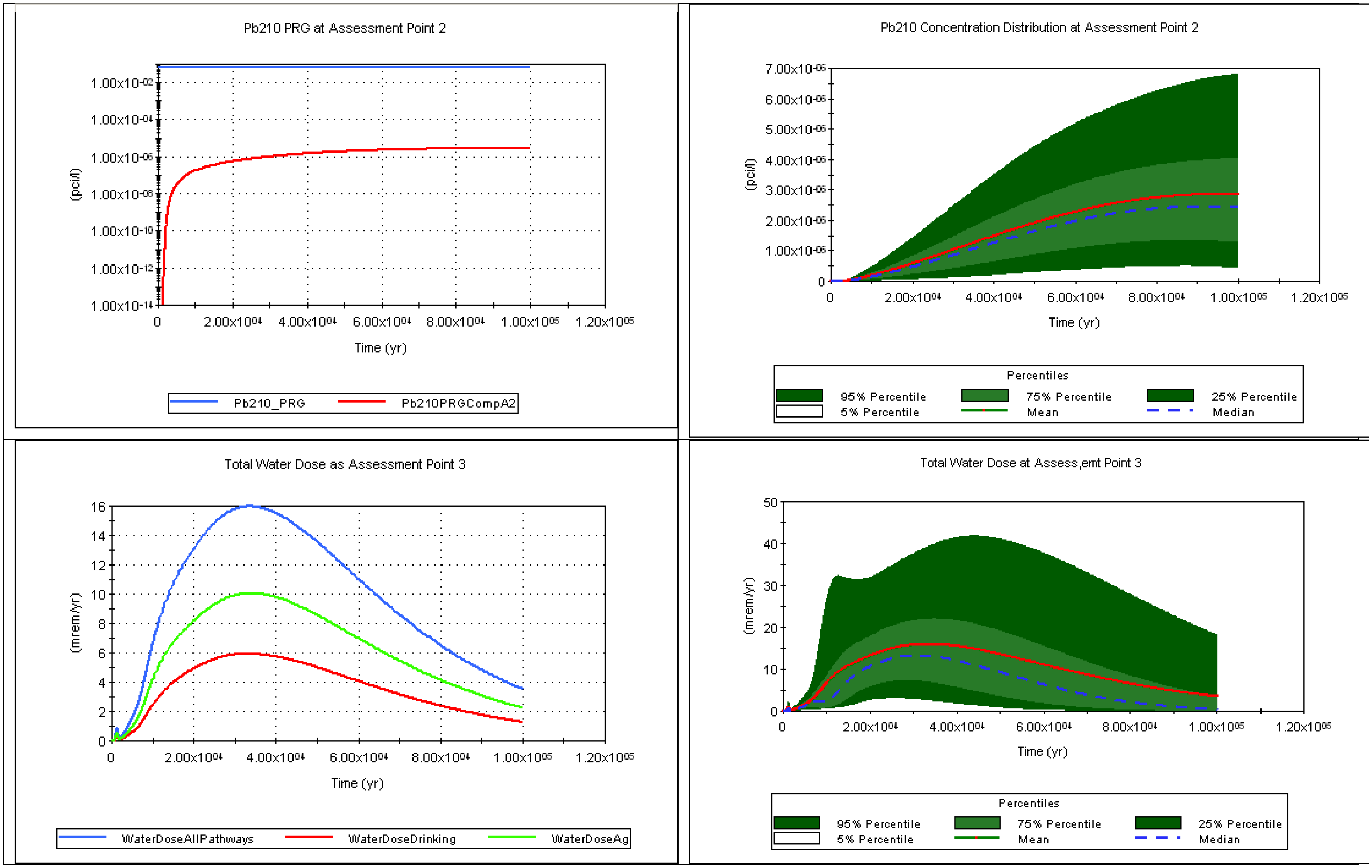

U238 MCL Comparison at Assessment Point 1
(pci/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U238]
U238MCL_A1[PuFF6]
U238MCL_A1[RoB]
U238MCL_A1[All]
U238MCL_A1[PuFF1]
U238MCL_A1[ABL]
U238MCL_A1[SandFilter]
U238 MCL Comparison at Assessment Point 2
(pci/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
1.00x10^-18
Time (yr)
Uranium_MCL[U238]
U238MCL_A2[PuFF6]
U238MCL_A2[RoB]
U238MCL_A2[All]
U238MCL_A2[PuFF1]
U238MCL_A2[ABL]
U238MCL_A2[SandFilter]
Pb MCL Comparison at Assessment Point 1
(ug/l)
1.00x10^02
1.00x10^00
1.00x10^-02
1.00x10^-04
1.00x10^-06
1.00x10^-08
1.00x10^-10
1.00x10^-12
Time (yr)
Pb_MCL
PbMCL_A1[PuFF6]
PbMCL_A1[RoB]
PbMCL_A1[All]
PbMCL_A1[PuFF1]
PbMCL_A1[ABL]
PbMCL_A1[SandFilter]
Pb MCL Comparison at Assessment Point 2
(ug/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
Time (yr)
Pb_MCL
PbMCL_A2[PuFF6]
PbMCL_A2[RoB]
PbMCL_A2[All]
PbMCL_A2[PuFF1]
PbMCL_A2[ABL]
PbMCL_A2[SandFilter]


PCB MCL Comparison at Assessment Point 1
(ug/l)
1.00x10⁰⁰
1.00x10-03
1.00x10-06
1.00x10-09
1.00x10-12
1.00x10-15
0
2.00x10⁰⁴
4.00x10⁰⁴
6.00x10⁰⁴
8.00x10⁰⁴
1.00x10⁰⁵
1.20x10⁰⁵
Time (yr)
PCB_MCL
PCBMCL_A1[PuFF6]
PCBMCL_A1[RoB]
PCBMCL_A1[All]
PCBMCL_A1[PuFF1]
PCBMCL_A1[ABL]
PCBMCL_A1[SandFilter]


PCB MCL Comparison at Assessment Point 2
(ug/l)
1.00x10-02
1.00x10-05
1.00x10-08
1.00x10-11
1.00x10-14
1.00x10-17
0
2.00x10⁰⁴
4.00x10⁰⁴
6.00x10⁰⁴
8.00x10⁰⁴
1.00x10⁰⁵
1.20x10⁰⁵
Time (yr)
PCB_MCL
PCBMCL_A2[PuFF6]
PCBMCL_A2[RoB]
PCBMCL_A2[All]
PCBMCL_A2[PuFF1]
PCBMCL_A2[ABL]
PCBMCL_A2[SandFilter]

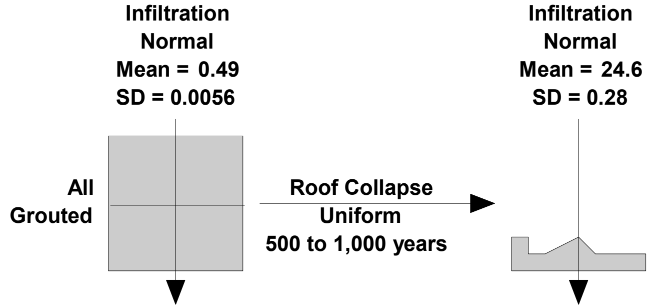

Pb210 PRG at Assessment Point 1
(pci/l)
0.10
0.08
0.06
0.04
0.02
0.00
0
2.00x10⁰⁴
4.00x10⁰⁴
6.00x10⁰⁴
8.00x10⁰⁴
1.00x10⁰⁵
1.20x10⁰⁵
Time (yr)
Pb210_PRG
Pb210PRGCompA1


Pb210 Concentration Distribution at Assessment Point 1
(pci/l)
0.30
0.20
0.10
0.00
0
2.00x10⁰⁴
4.00x10⁰⁴
6.00x10⁰⁴
8.00x10⁰⁴
1.00x10⁰⁵
1.20x10⁰⁵
Time (yr)
Percentiles
95% Percentile
5% Percentile
75% Percentile
Mean
25% Percentile
Median



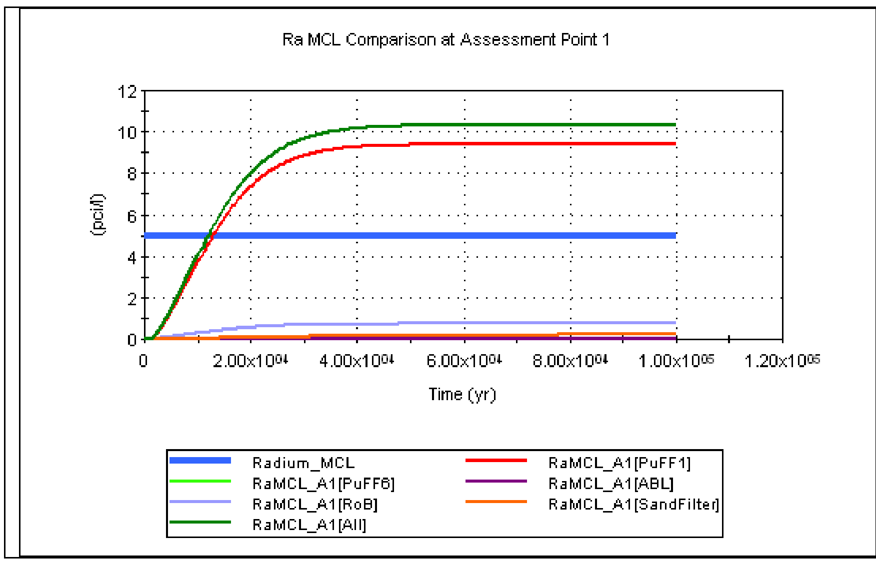
DOE Order 435.1 dose limit is 25 mrem/yr at 100 m from facility boundary (i.e. Assessment Point 3).

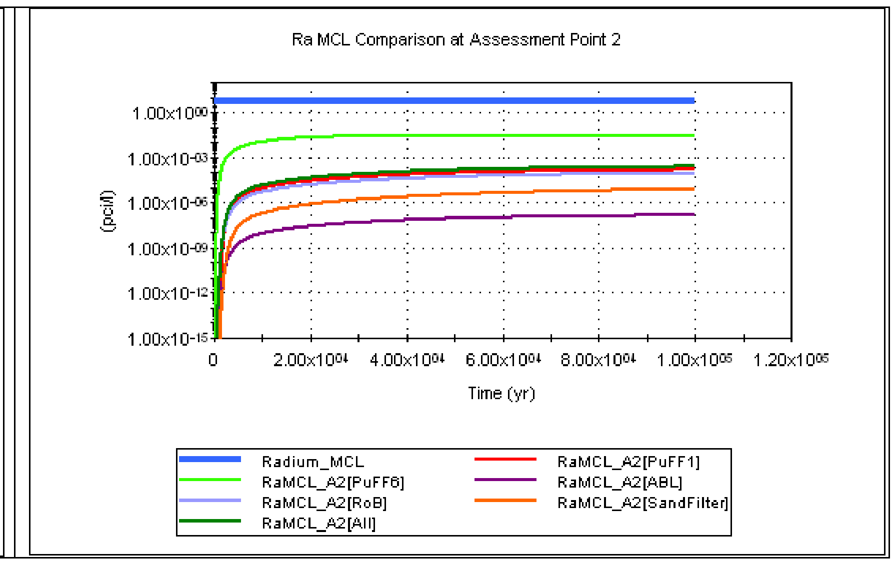
APPENDIX H GROUT ENTIRE BUILDING

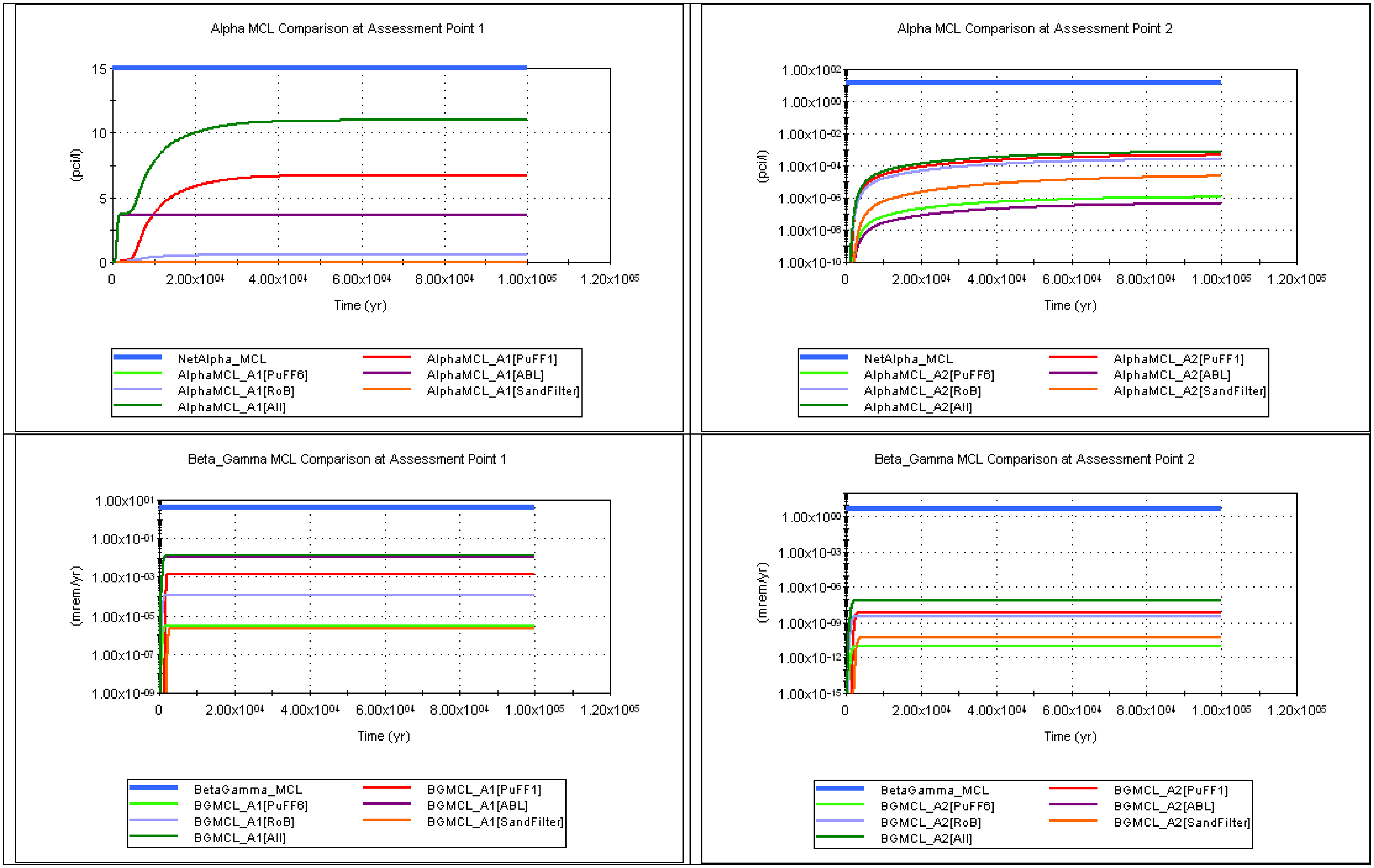


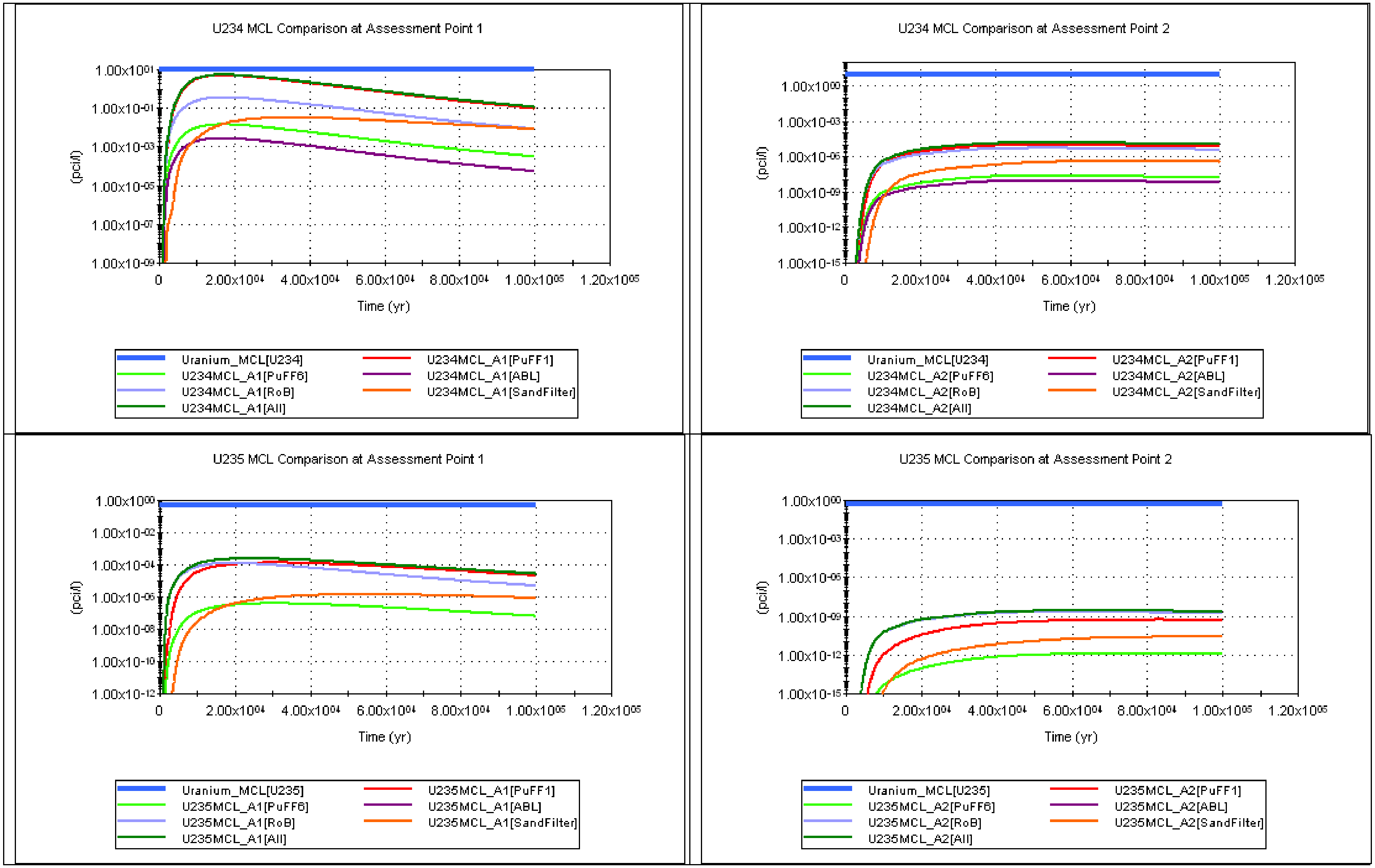
This Building Condition & Infiltration Conceptual Model also applies to the Sand Filter (Building 294-2F)

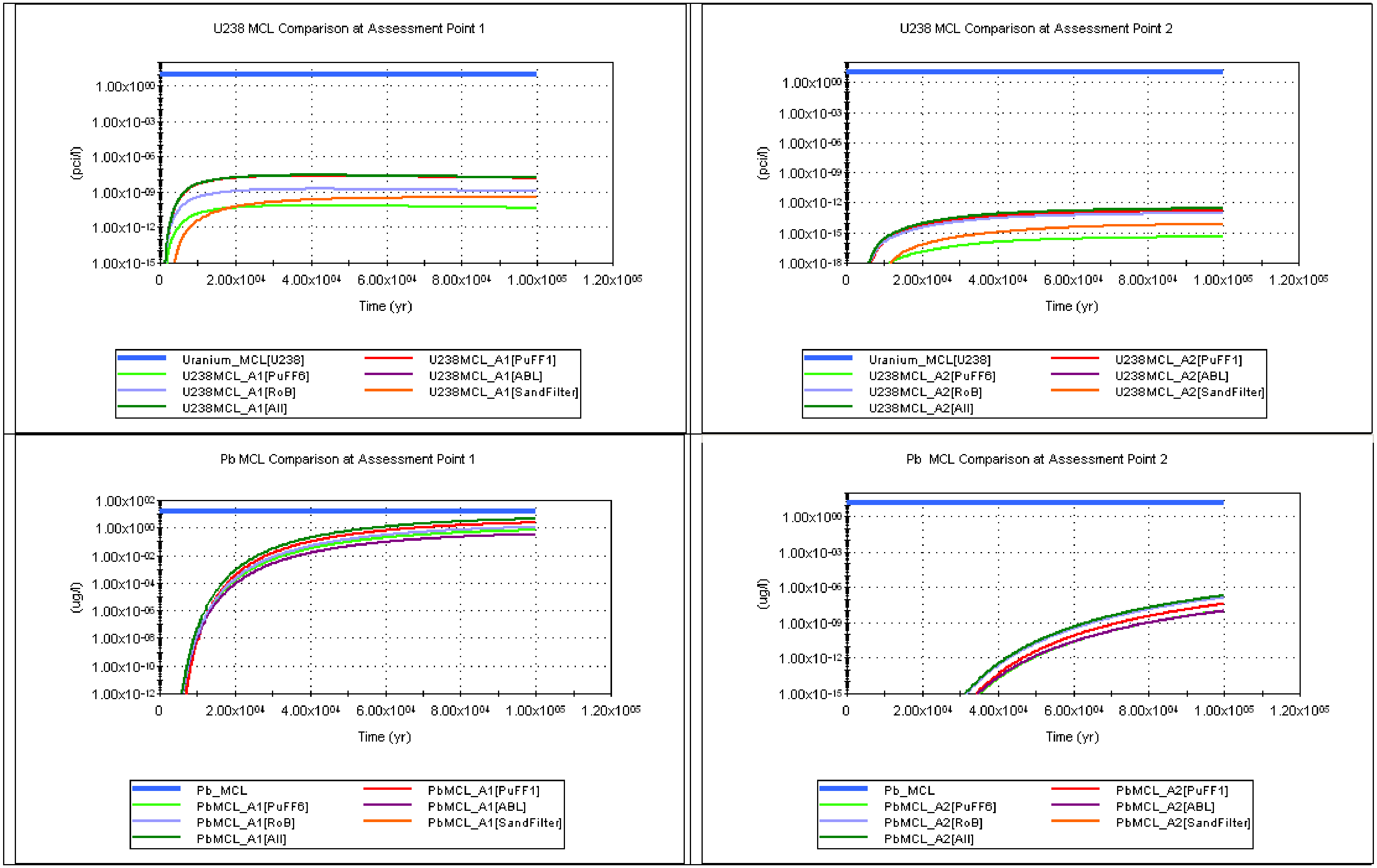
Unless otherwise noted, all plots are of mean values and are based upon the entire building.



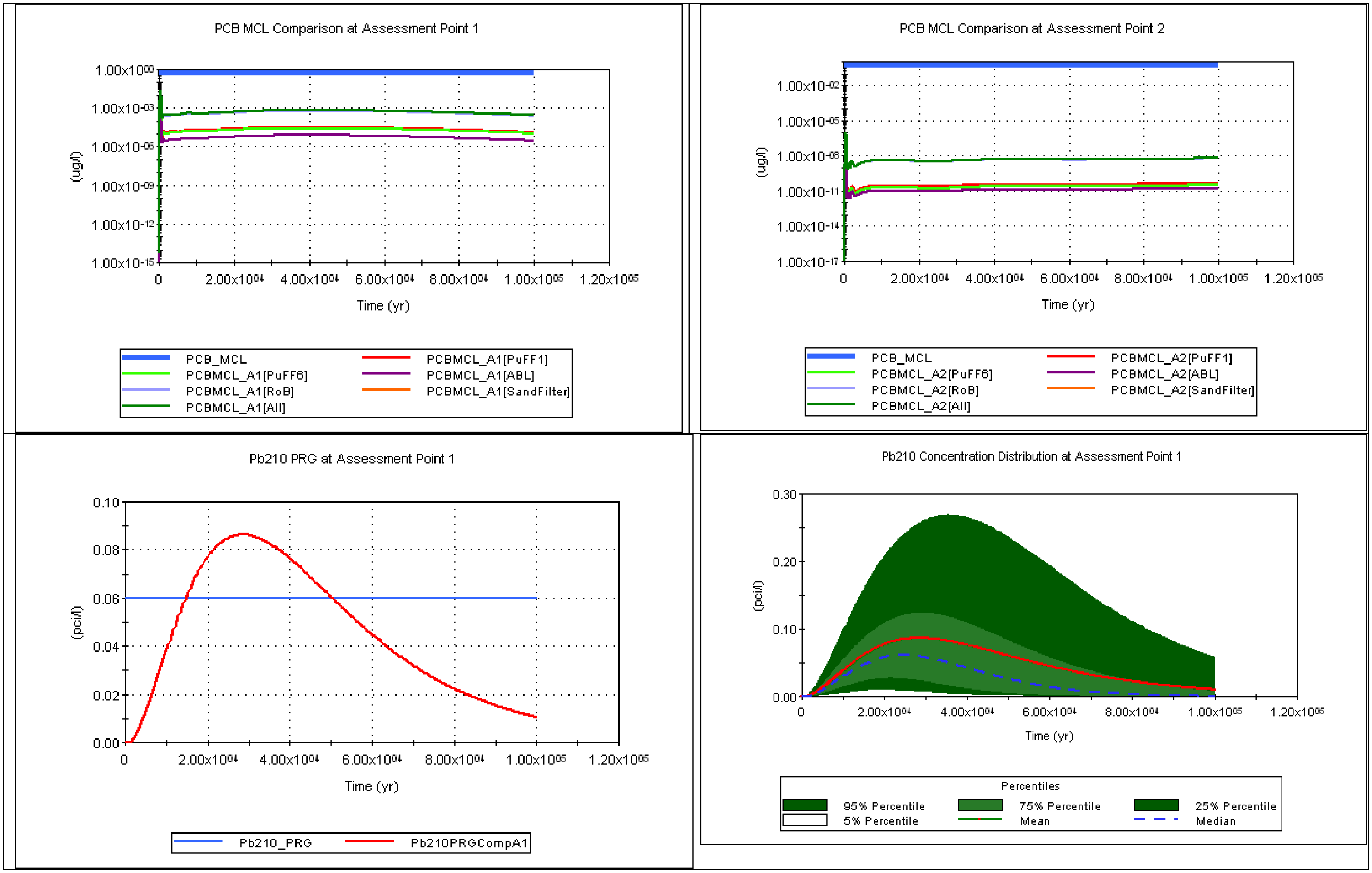


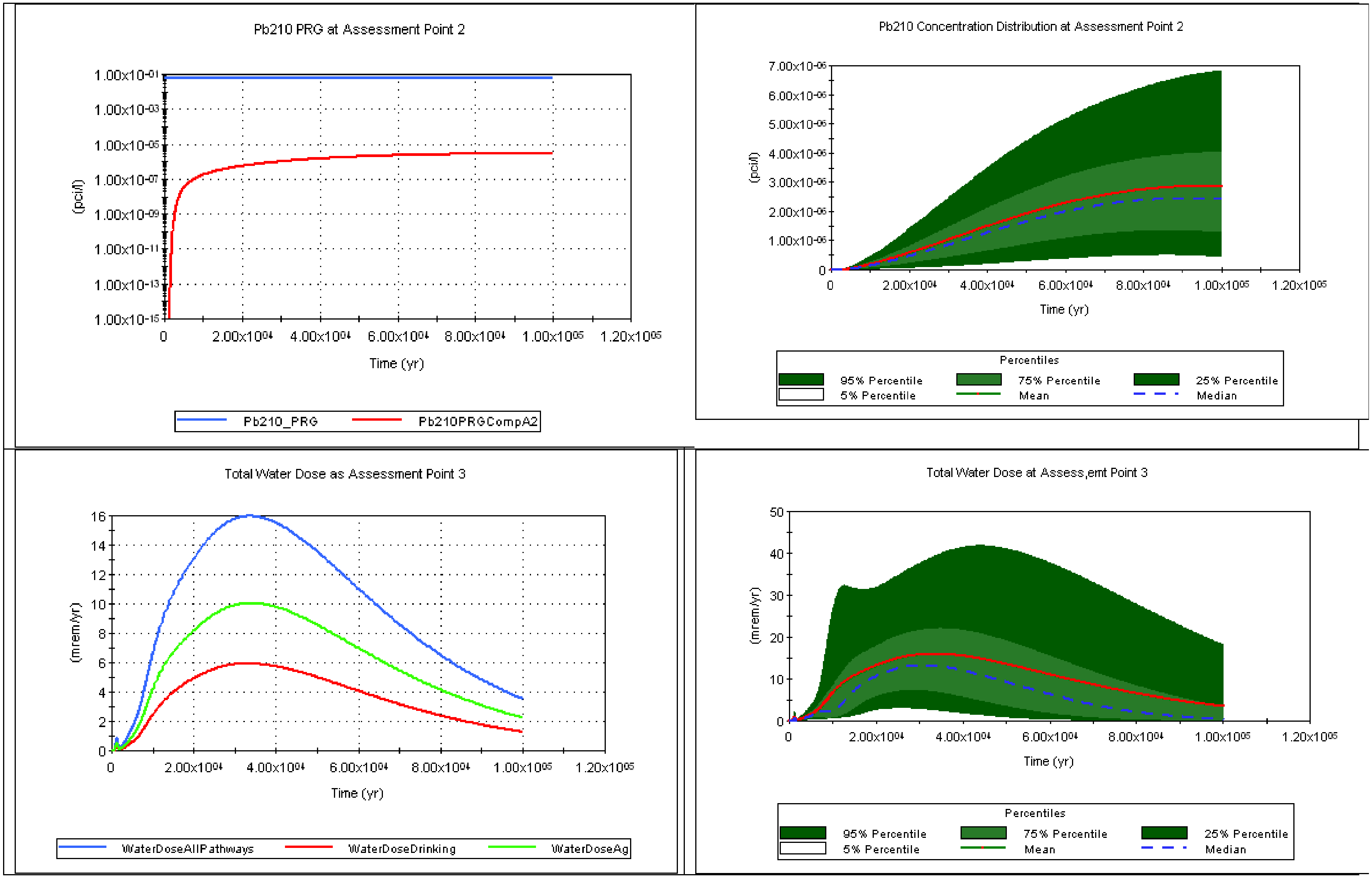

Alpha MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A1[PuFF6]
AlphaMCL_A1[RoB]
AlphaMCL_A1[All]
AlphaMCL_A1[PuFF1]
AlphaMCL_A1[ABL]
AlphaMCL_A1[SandFilter]
Alpha MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A2[PuFF6]
AlphaMCL_A2[RoB]
AlphaMCL_A2[All]
AlphaMCL_A2[PuFF1]
AlphaMCL_A2[ABL]
AlphaMCL_A2[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 1
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A1[PuFF6]
BGMCL_A1[RoB]
BGMCL_A1[All]
BGMCL_A1[PuFF1]
BGMCL_A1[ABL]
BGMCL_A1[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 2
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A2[PuFF6]
BGMCL_A2[RoB]
BGMCL_A2[All]
BGMCL_A2[PuFF1]
BGMCL_A2[ABL]
BGMCL_A2[SandFilter]


U234 MCL Comparison at Assessment Point 1
1.00x10^01
1.00x10^-01
1.00x10^-03
1.00x10^-05
1.00x10^-07
1.00x10^-09
(pci/l)
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Uranium_MCL[U234]
U234MCL_A1[PuFF6]
U234MCL_A1[RoB]
U234MCL_A1[All]
U234MCL_A1[PuFF1]
U234MCL_A1[ABL]
U234MCL_A1[SandFilter]
U234 MCL Comparison at Assessment Point 2
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
(pci/l)
Time (yr)
Uranium_MCL[U234]
U234MCL_A2[PuFF6]
U234MCL_A2[RoB]
U234MCL_A2[All]
U234MCL_A2[PuFF1]
U234MCL_A2[ABL]
U234MCL_A2[SandFilter]
U235 MCL Comparison at Assessment Point 1
1.00x10^00
1.00x10^-02
1.00x10^-04
1.00x10^-06
1.00x10^-08
1.00x10^-10
1.00x10^-12
(pci/l)
Time (yr)
Uranium_MCL[U235]
U235MCL_A1[PuFF6]
U235MCL_A1[RoB]
U235MCL_A1[All]
U235MCL_A1[PuFF1]
U235MCL_A1[ABL]
U235MCL_A1[SandFilter]
U235 MCL Comparison at Assessment Point 2
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
(pci/l)
Time (yr)
Uranium_MCL[U235]
U235MCL_A2[PuFF6]
U235MCL_A2[RoB]
U235MCL_A2[All]
U235MCL_A2[PuFF1]
U235MCL_A2[ABL]
U235MCL_A2[SandFilter]



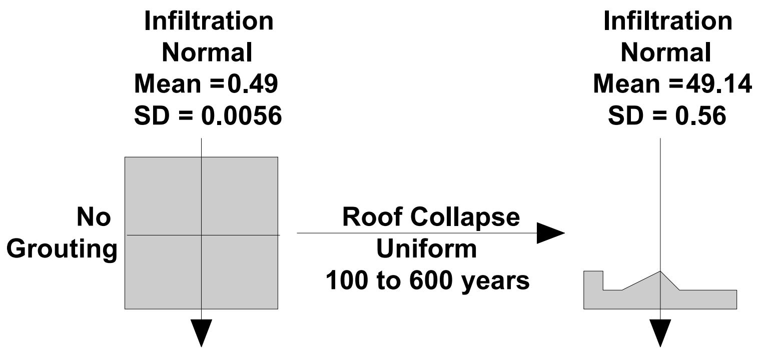
U238 MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
Uranium_MCL[U238]
U238MCL_A1[PuFF6]
U238MCL_A1[RoB]
U238MCL_A1[All]
U238MCL_A1[PuFF1]
U238MCL_A1[ABL]
U238MCL_A1[SandFilter]
U238 MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
Uranium_MCL[U238]
U238MCL_A2[PuFF6]
U238MCL_A2[RoB]
U238MCL_A2[All]
U238MCL_A2[PuFF1]
U238MCL_A2[ABL]
U238MCL_A2[SandFilter]
Pb MCL Comparison at Assessment Point 1
(ug/l)
Time (yr)
Pb_MCL
PbMCL_A1[PuFF6]
PbMCL_A1[RoB]
PbMCL_A1[All]
PbMCL_A1[PuFF1]
PbMCL_A1[ABL]
PbMCL_A1[SandFilter]
Pb MCL Comparison at Assessment Point 2
(ug/l)
Time (yr)
Pb_MCL
PbMCL_A2[PuFF6]
PbMCL_A2[RoB]
PbMCL_A2[All]
PbMCL_A2[PuFF1]
PbMCL_A2[ABL]
PbMCL_A2[SandFilter]


PCB MCL Comparison at Assessment Point 1
1.00x10-00
1.00x10-03
1.00x10-06
1.00x10-09
1.00x10-12
1.00x10-15
(ug/l)
0
2.00x1004
4.00x1004
6.00x1004
8.00x1004
1.00x1005
1.20x1005
Time (yr)
PCB_MCL
PCBMCL_A1[PuFF6]
PCBMCL_A1[RoB]
PCBMCL_A1[All]
PCBMCL_A1[PuFF1]
PCBMCL_A1[ABL]
PCBMCL_A1[SandFilter]
PCB MCL Comparison at Assessment Point 2
1.00x10-02
1.00x10-05
1.00x10-08
1.00x10-11
1.00x10-14
1.00x10-17
(ug/l)
Time (yr)
PCB_MCL
PCBMCL_A2[PuFF6]
PCBMCL_A2[RoB]
PCBMCL_A2[All]
PCBMCL_A2[PuFF1]
PCBMCL_A2[ABL]
PCBMCL_A2[SandFilter]
Pb210 PRG at Assessment Point 1
0.10
0.08
0.06
0.04
0.02
0.00
(pci/l)
Time (yr)
Pb210_PRG
Pb210PRGCompA1
Pb210 Concentration Distribution at Assessment Point 1
0.30
0.20
0.10
0.00
(pci/l)
Time (yr)
Percentiles
95% Percentile
5% Percentile
75% Percentile
Mean
25% Percentile
Median

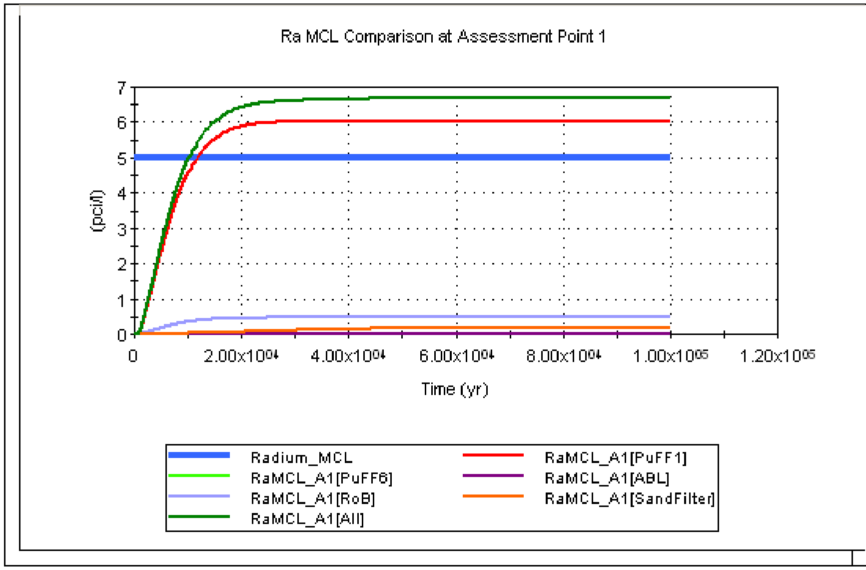


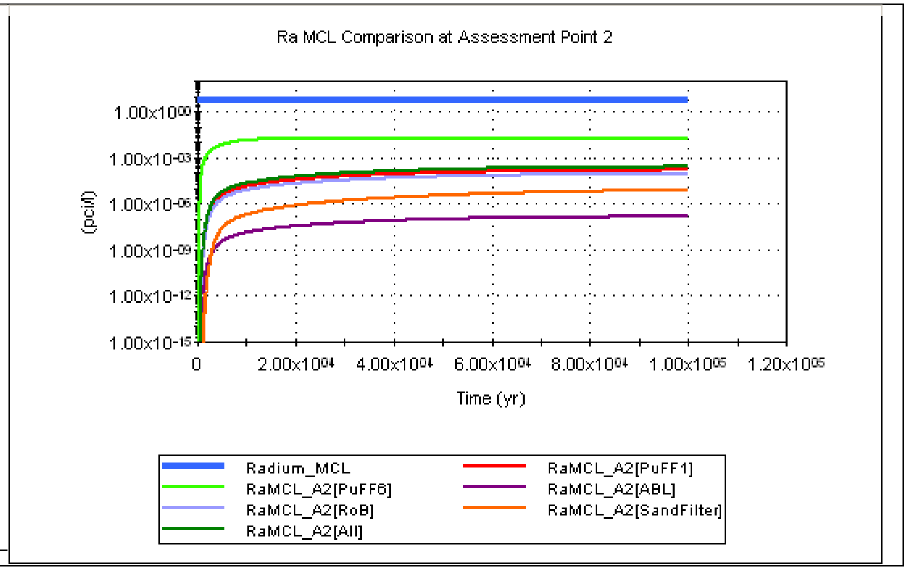
DOE Order 435.1 dose limit is 25 mrem/yr at 100 m from facility boundary (i.e. Assessment Point 3).

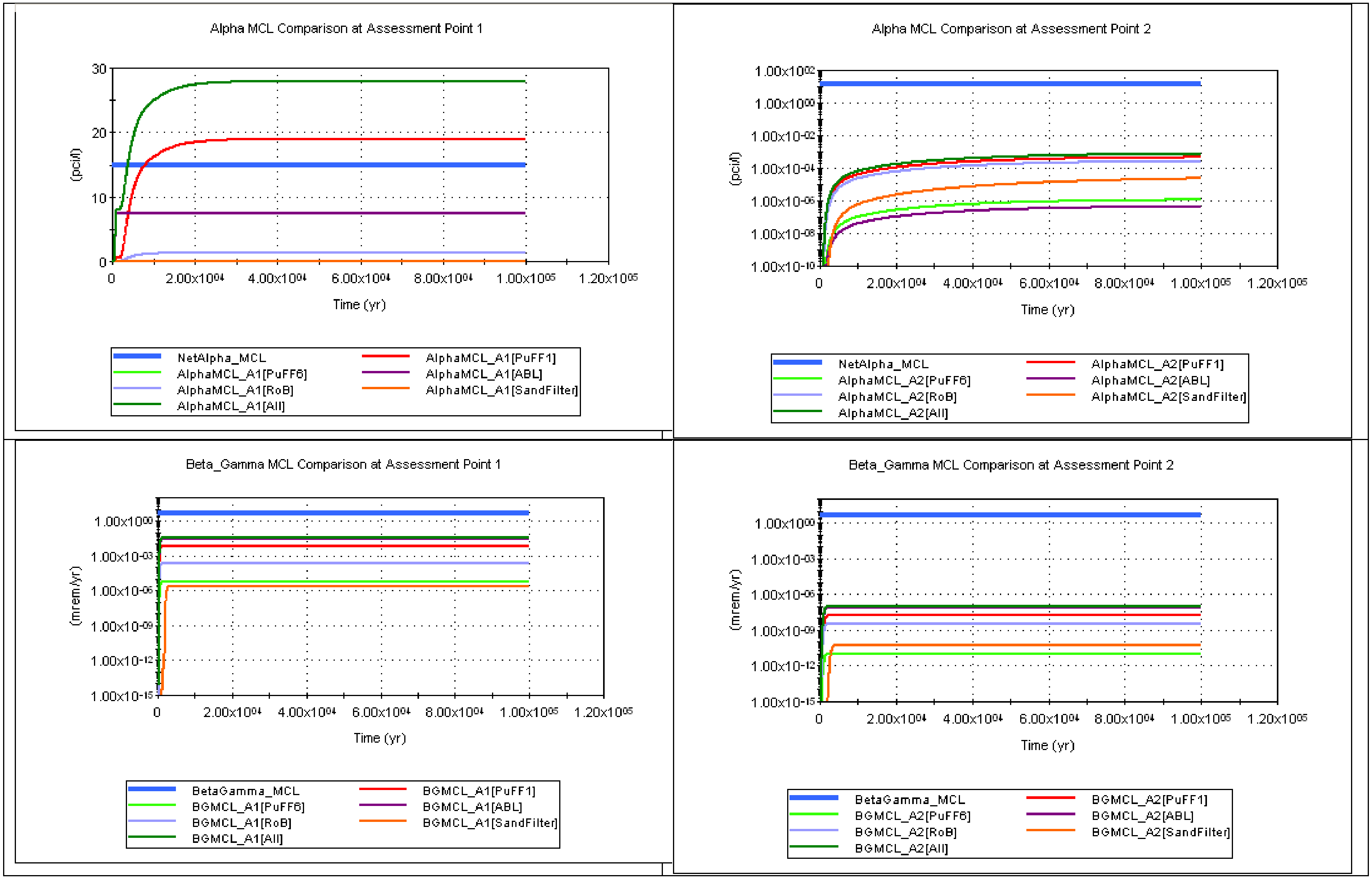
APPENDIX I INFILTRATION SET TO PRECIPITATION

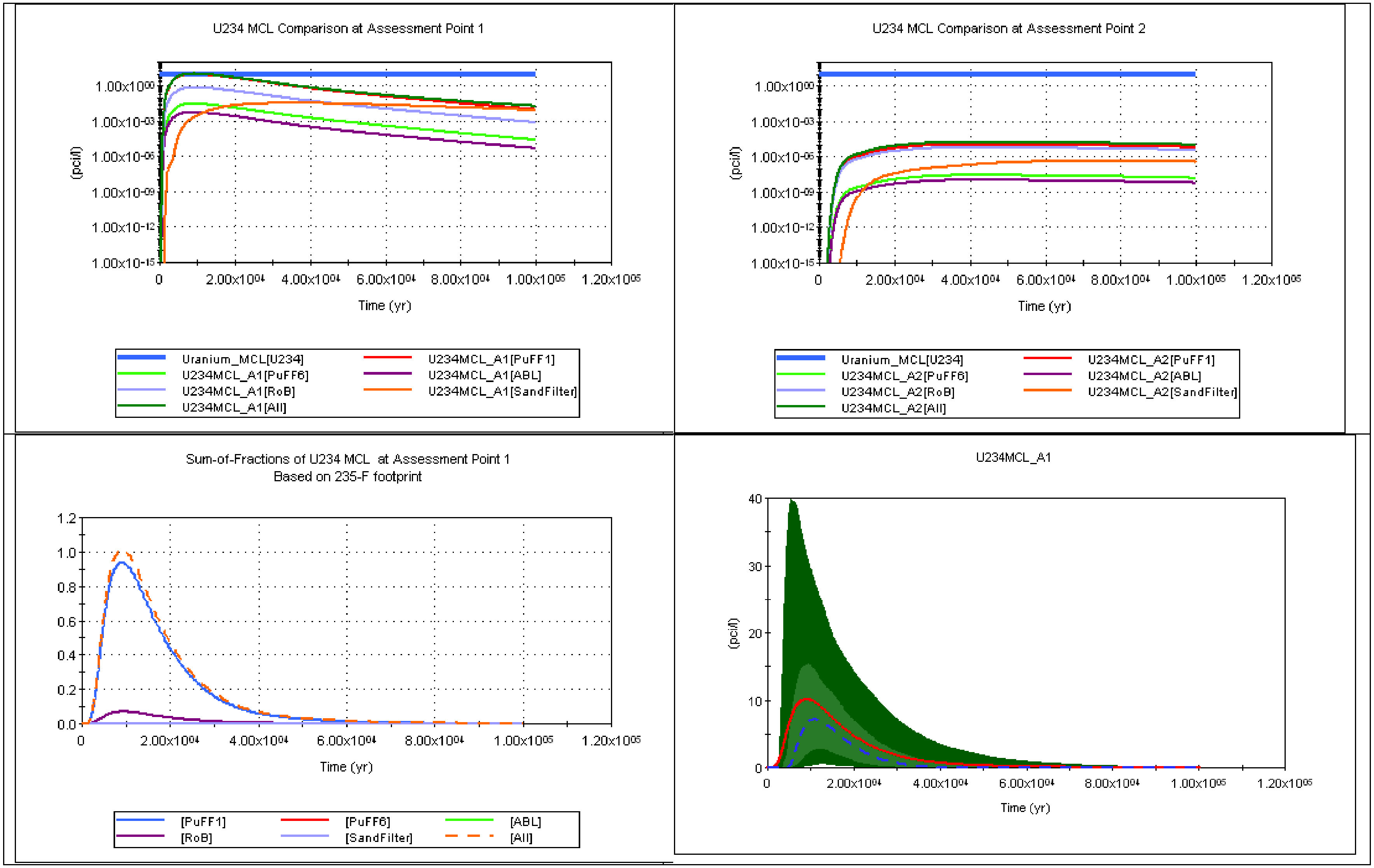


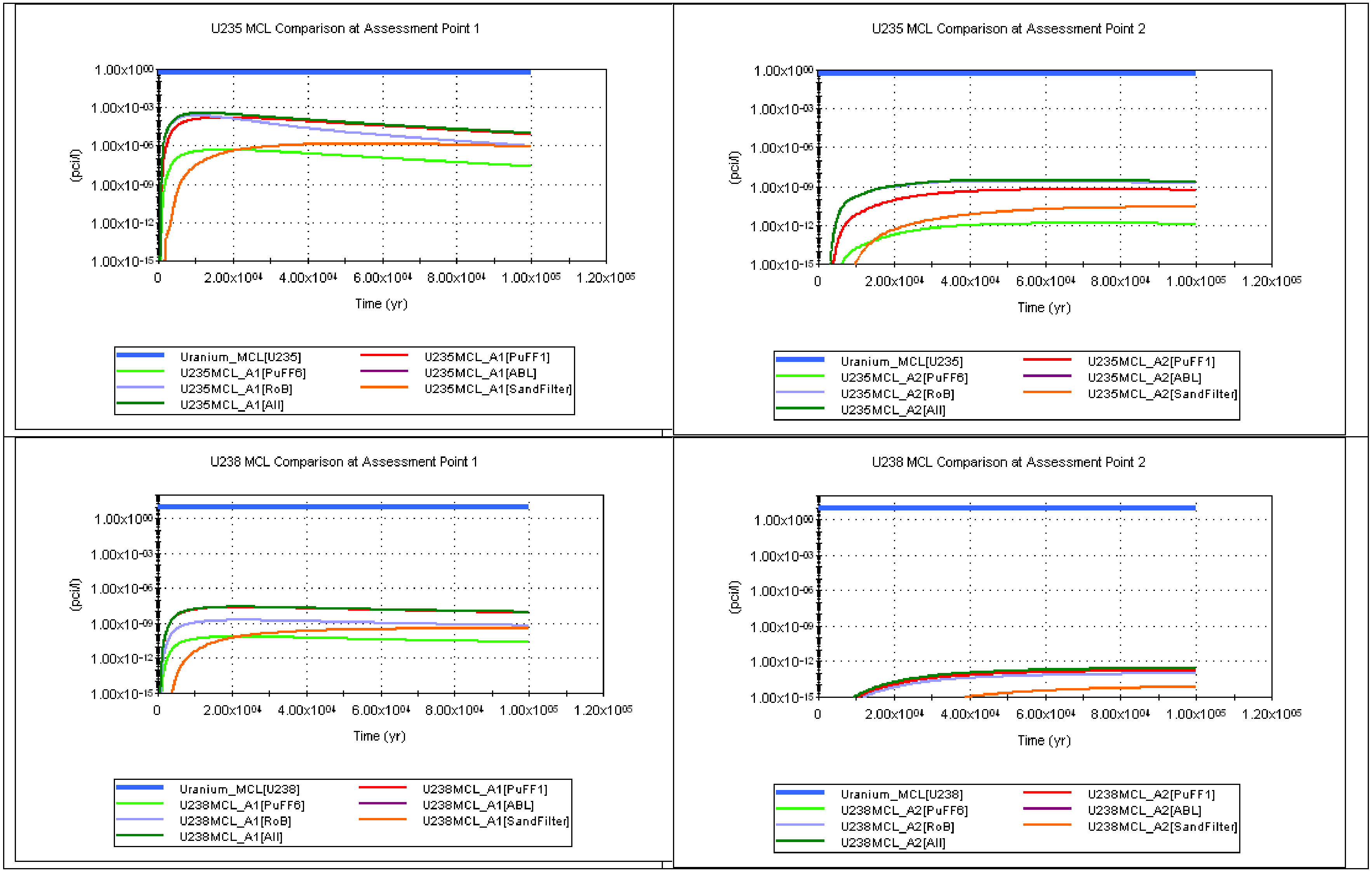
Unless otherwise noted, all plots are of mean values and are based upon the entire building.

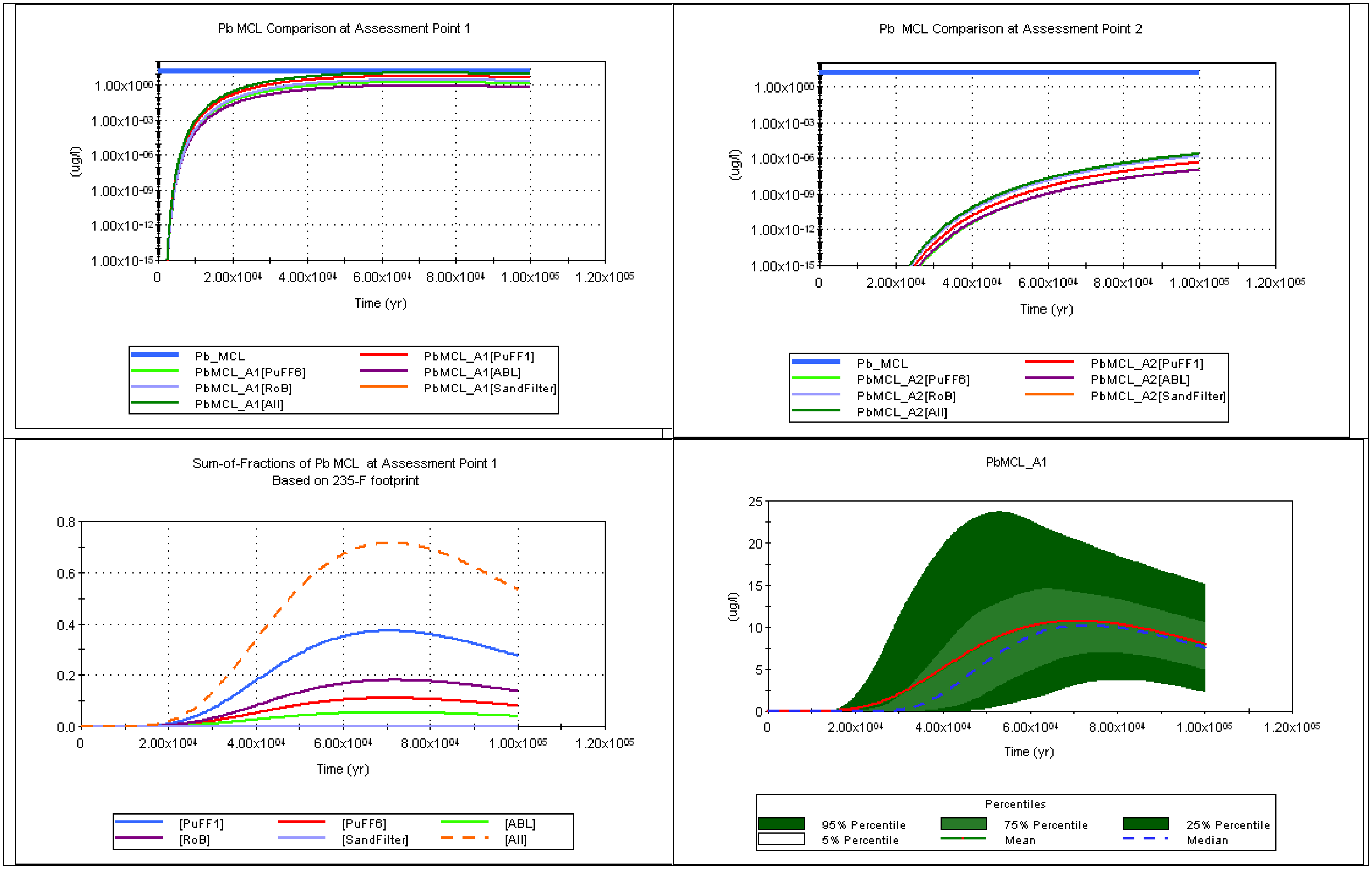


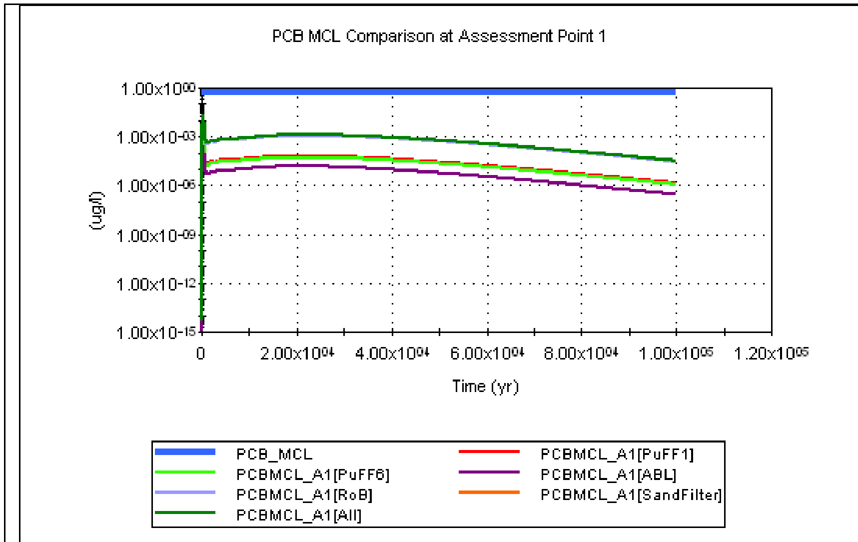


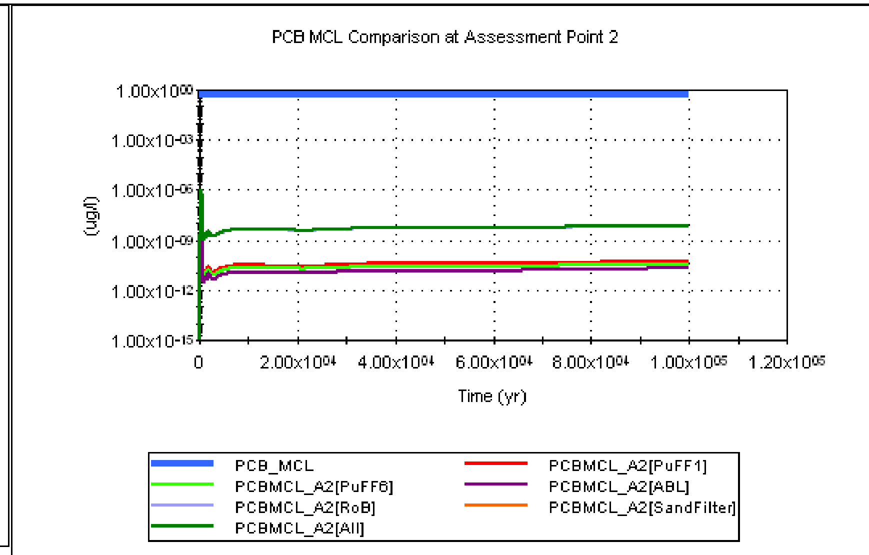

Alpha MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A1[PuFF6]
AlphaMCL_A1[RoB]
AlphaMCL_A1[All]
AlphaMCL_A1[PuFF1]
AlphaMCL_A1[ABL]
AlphaMCL_A1[SandFilter]
Alpha MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
NetAlpha_MCL
AlphaMCL_A2[PuFF6]
AlphaMCL_A2[RoB]
AlphaMCL_A2[All]
AlphaMCL_A2[PuFF1]
AlphaMCL_A2[ABL]
AlphaMCL_A2[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 1
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A1[PuFF6]
BGMCL_A1[RoB]
BGMCL_A1[All]
BGMCL_A1[PuFF1]
BGMCL_A1[ABL]
BGMCL_A1[SandFilter]
Beta_Gamma MCL Comparison at Assessment Point 2
(mrem/yr)
Time (yr)
BetaGamma_MCL
BGMCL_A2[PuFF6]
BGMCL_A2[RoB]
BGMCL_A2[All]
BGMCL_A2[PuFF1]
BGMCL_A2[ABL]
BGMCL_A2[SandFilter]

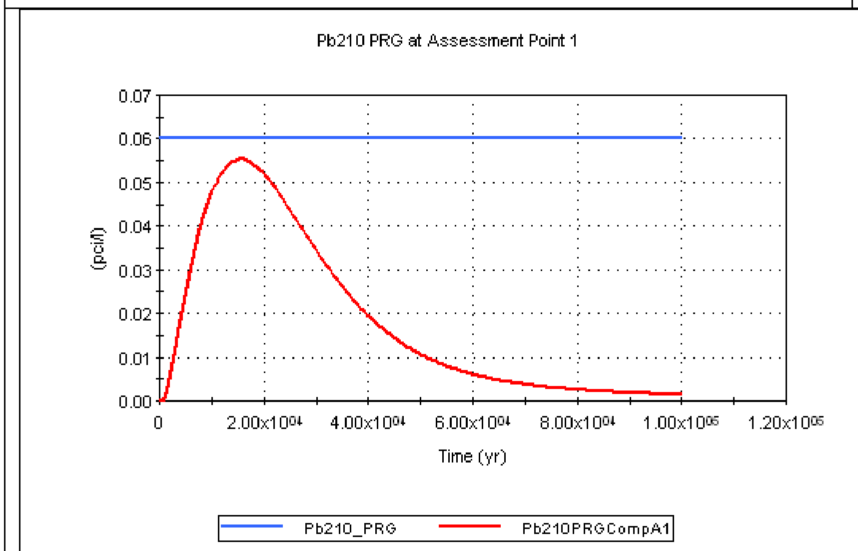

U234 MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
Uranium_MCL[U234]
U234MCL_A1[PuFF6]
U234MCL_A1[RoB]
U234MCL_A1[All]
U234MCL_A1[PuFF1]
U234MCL_A1[ABL]
U234MCL_A1[SandFilter]
U234 MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
Uranium_MCL[U234]
U234MCL_A2[PuFF6]
U234MCL_A2[RoB]
U234MCL_A2[All]
U234MCL_A2[PuFF1]
U234MCL_A2[ABL]
U234MCL_A2[SandFilter]
Sum-of-Fractions of U234 MCL at Assessment Point 1
Based on 235-F footprint
Time (yr)
[PuFF1]
[PuFF6]
[ABL]
[RoB]
[SandFilter]
[All]
U234MCL_A1
(pci/l)
Time (yr)

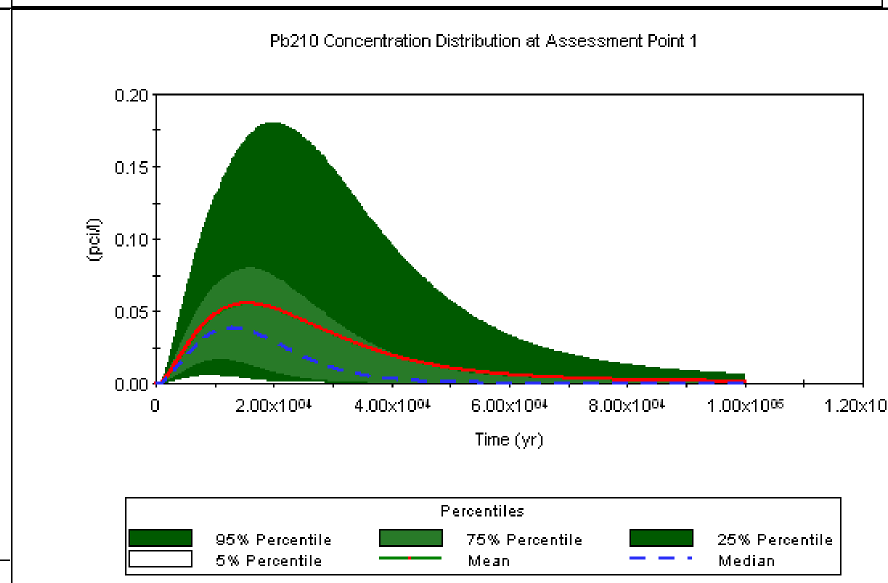

U235 MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
Uranium_MCL[U235]
U235MCL_A1[PuFF6]
U235MCL_A1[RoB]
U235MCL_A1[All]
U235MCL_A1[PuFF1]
U235MCL_A1[ABL]
U235MCL_A1[SandFilter]
U235 MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
Uranium_MCL[U235]
U235MCL_A2[PuFF6]
U235MCL_A2[RoB]
U235MCL_A2[All]
U235MCL_A2[PuFF1]
U235MCL_A2[ABL]
U235MCL_A2[SandFilter]
U238 MCL Comparison at Assessment Point 1
(pci/l)
Time (yr)
Uranium_MCL[U238]
U238MCL_A1[PuFF6]
U238MCL_A1[RoB]
U238MCL_A1[All]
U238MCL_A1[PuFF1]
U238MCL_A1[ABL]
U238MCL_A1[SandFilter]
U238 MCL Comparison at Assessment Point 2
(pci/l)
Time (yr)
Uranium_MCL[U238]
U238MCL_A2[PuFF6]
U238MCL_A2[RoB]
U238MCL_A2[All]
U238MCL_A2[PuFF1]
U238MCL_A2[ABL]
U238MCL_A2[SandFilter]

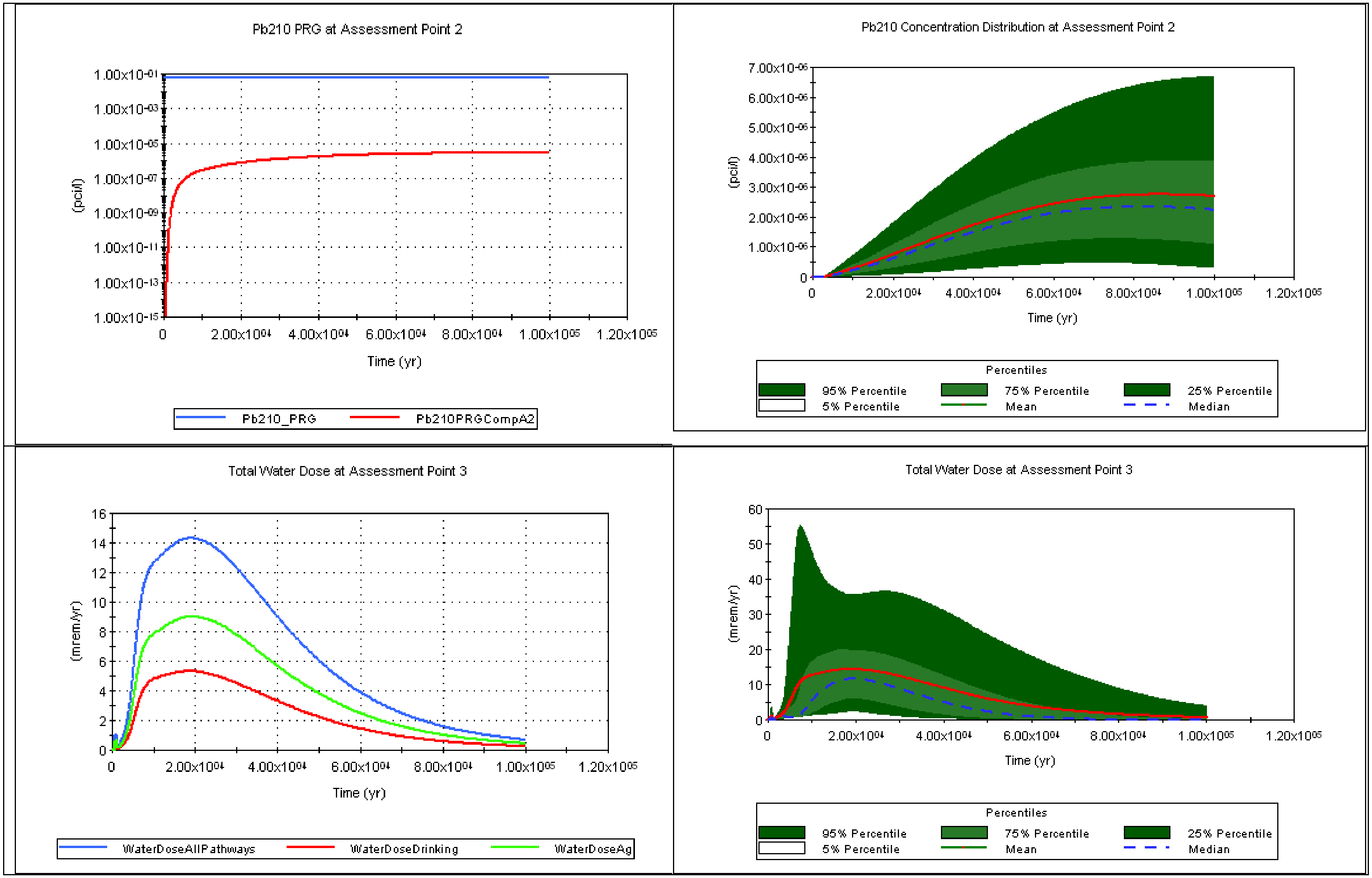

Pb MCL Comparison at Assessment Point 1
(ug/l)
Time (yr)
Pb_MCL
PbMCL_A1[PuFF6]
PbMCL_A1[RoB]
PbMCL_A1[All]
PbMCL_A1[PuFF1]
PbMCL_A1[ABL]
PbMCL_A1[SandFilter]
Pb MCL Comparison at Assessment Point 2
(ug/l)
Time (yr)
Pb_MCL
PbMCL_A2[PuFF6]
PbMCL_A2[RoB]
PbMCL_A2[All]
PbMCL_A2[PuFF1]
PbMCL_A2[ABL]
PbMCL_A2[SandFilter]
Sum-of-Fractions of Pb MCL at Assessment Point 1
Based on 235-F footprint
Time (yr)
[PuFF1]
[RoB]
[PuFF6]
[SandFilter]
[ABL]
[All]
PbMCL_A1
(ug/l)
Time (yr)
Percentiles
95% Percentile
5% Percentile
75% Percentile
Mean
25% Percentile
Median


PCB MCL Comparison at Assessment Point 1
(ug/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
PCB_MCL
PCBMCL_A1[PuFF6]
PCBMCL_A1[RoB]
PCBMCL_A1[All]
PCBMCL_A1[PuFF1]
PCBMCL_A1[ABL]
PCBMCL_A1[SandFilter]


PCB MCL Comparison at Assessment Point 2
(ug/l)
1.00x10^00
1.00x10^-03
1.00x10^-06
1.00x10^-09
1.00x10^-12
1.00x10^-15
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
PCB_MCL
PCBMCL_A2[PuFF6]
PCBMCL_A2[RoB]
PCBMCL_A2[All]
PCBMCL_A2[PuFF1]
PCBMCL_A2[ABL]
PCBMCL_A2[SandFilter]


Pb210 PRG at Assessment Point 1
(pci/l)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Pb210_PRG
Pb210PRGCompA1


Pb210 Concentration Distribution at Assessment Point 1
(pci/l)
0.20
0.15
0.10
0.05
0.00
0
2.00x10^04
4.00x10^04
6.00x10^04
8.00x10^04
1.00x10^05
1.20x10^05
Time (yr)
Percentiles
95% Percentile
75% Percentile
25% Percentile
5% Percentile
Mean
Median



DOE Order 435.1 dose limit is 25 mrem/yr at 100 m from facility boundary (i.e. Assessment Point 3).

APPENDIX J SENSITIVITY ANALYSIS PARAMETER DENOUEMENT

From the GoldSim User's Guide:

Coefficient of determination: This coefficient varies between 0 and 1, and represents the fraction of the total variance in the result that can be explained based on a linear (regression) relationship to the input variables (i.e., Result = aX + bY + cZ + …). The closer this value is to 1, the better that the relationship between the result and the variables can be explained with a linear model.

Correlation Coefficient: Rank (Spearman) or value (Pearson) correlation coefficients range between -1 and 1, and express the extent to which there is a linear relationship between the selected result and an input variable.

SRC (Standardized Regression Coefficient): Standardized regression coefficients range between -1 and 1 and provide a normalized measure of the linear relationship between variables and the result. They are the regression coefficients found when all of the variables (and the result) are transformed and expressed in terms of the number of standard deviations away from their mean. GoldSim's formulation is based on Iman et al (1985).

Partial Correlation Coefficient: Partial correlation coefficients vary between -1 and 1, and reflect the extent to which there is a linear relationship between the selected result and an input variable, after removing the effects of any linear relationships between the other input variables and both the result and the input variable in question. For systems where some of the input variables may be correlated, the partial correlation coefficients represent the "unique" contribution of each input to the result. GoldSim's formulation is based on Iman et al (1985).

Importance Measure: This measure varies between 0 and 1, and represents the fraction of the result's variance that is explained by the variable. This measure is useful in identifying nonlinear, non-monotonic relationships between an input variable and the result (which conventional correlation coefficients may not reveal). The importance measure is a normalized version of a measure discussed in Saltelli and Tarantola (2002).