SRNL-TR-2009-00052, Rev 1

Key Words:
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Performance Assessment

Retention:
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Saltstone Disposition Facility Stochastic Transport and Fate Model Benchmarking

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1.0 Introduction

The GoldSim fate and transport model [Taylor, 2009] is used to assess the sensitivity of the dose to a member of the pubic for various parameters which affect the transport of contaminants. The preferred method for assessing the sensitivities is with a Monte Carlo type analysis. This type of analysis requires many realizations, or runs, to generate sufficient statistics so that sensitivities can be determined. Running a full-fledged multi-dimensional model (in this case, Porflow) would create excessive run times. A less detailed model with fast run-times which gives sufficiently similar results is desired.

The less detailed model chosen for these sensitivity analyses is the Saltstone Disposal Facility modeled in the Goldsim environment. Goldsim is a 1-dimesional, “coarsely” noded modeling environment. A comparison of the two models is necessary to assure that the results from the Goldsim model are sufficiently similar to the Porflow results. The Porflow results are used as the baseline for comparison since the Porflow model is a multi-dimensional flow and transport model which is used to determine compliance with regulatory guidelines. The Goldsim model, with its coarse noding and 1-dimension, is therefore benchmarked against the Porflow model.

The results of the benchmarking effort show that the two models are remarkably similar before any benchmarking derived parameters are applied to the Goldsim model. The shapes of the concentration curves are quite similar, with the major differences being in magnitudes. The timing of events, such as contaminant breakthough at various spots of interest is usually very close. This report will describe the process through which the benchmarking of the two models was achieved.

One final point is that the benchmarking process is extremely important in the understanding of the system behavior. Two independent contaminant transport models have been used to solve the same problem. When these two models give divergent results it is necessary to fully understand what is going on in both models and to assess which is the “expected” system response. Some system responses are not as expected, but if both models predict the same type of behavior, it might be an indication that the previous understanding of the system was lacking. A technical review procedure will typically specify that one way to validate results is to perform an independent analysis. This is what the benchmarking procedure does.

This report describes the benchmarking of the SDF Base Case, sometimes referred to as Case A, and a fast flowpath case, Case C.

2.0 Methodology

The basic tenet of the benchmarking process is that the Porflow results are the "baseline". The Goldsim model results should attempt to emulate those results without violating any physical laws. Although every attempt was made to make the two models as similar as possible, because of the different solution formulations of the two codes, there are expected to be a number of differences between the two models. This section is a discussion of the methodology employed to minimize the differences in the solution of the two models.

2.1 General comments

The data used to predict the behavior of the saltstone grout show that it will survive intact during the performance period and for a considerable time after that. Therefore, the releases from the future disposal cells are quite small. One must decide if it is necessary to match data, which although they have a finite computational value, are meaningless in the real world. For example, obviously concentrations of less than 10-23 mol/L are meaningless as that would imply fractional atoms. Neither code does statistical thermodynamics so any meaningful number must be above the continuum. For radioactive half-lives to have any meaning a statistically valid sample must exist.

These are all theoretical arguments. If one were to move into the real world one must think of how the contaminants can be measured. If a detection limit is nanograms/liter (or nanomoles/liter) one will see that during most of the simulation the concentrations of most of the contaminants are well below that value.

Perhaps the most important lesson learned during the benchmarking process was the importance of the vaults' walls. Because the assumption of saltstone durability obviated the assumption that the majority of the contaminant release would flow downward from the saltstone through the vault bottoms, the benchmarking made it starkly clear that the driver for the dose was release from the vaults' walls. The implication of this will be discussed in the following sections.

The benchmarking of two cases showed that even thought the vault walls were important, based on the case run, their importance, and the transport mechanism, could substantially change, particularly for Future Disposal Cells (FDCs). Case C is dominated by Vault 1 and Vault 4 due to their initial wall inventory. The FDCs had relatively little loss of contaminants because none was in the wall and the preferred flow path was around the grout.

2.1.1 Where Benchmarking Was Performed

Benchmarking was performed at two model locations: the interface between the unsaturated and saturated zones, and at the 100 m boundary sectors.

2.1.1.1 Unsaturated-Saturated Zones interface

The first step in benchmarking was done at the unsaturated-saturated zones (UZ-SZ) interface. In terms of the Porflow model, this was the logical place to begin. The Porflow analyses use two models, one for the saturated zone (3-dimensional), and one for the unsaturated zone (2-dimensional). These models are run independently with the interface between the models being the contaminant mass flux. The mass flux being transferred between the models, and the one to which the benchmarking is applied, is the total mass flux leaving the unsaturated zone's computational domain.

The Goldsim model is integrated in that the saturated and unsaturated zones are directly coupled. For ease of comparison the next to last (cell 9) mixing cell of the unsaturated zone is used. This is because the cell which connects the outlet of the unsaturated zone to the saturated zone has its flow divided up among the cells of the waste footprint. There is essentially no difference in the mass flux leaving the ninth and tenth cells, so the ninth was chosen so that summing all the flowpaths in the tenth cell would not be necessary. This provided a sufficiently good result, especially if one considers that the primary point of interest is the 100 m boundary.

The data comparison between the two models is rather straightforward for this benchmarking point. Both models provide data that is essentially the same. Both are providing a total mass flux leaving their respective boundaries. For Porflow it is the sum of mass fluxes leaving all four faces, with the bottom plane being by far the most important. The Goldsim model, by definition, provides the total mass leaving through the single pathway connecting the ninth and tenth cell. There might be a small difference in the models' representation in what is crossing their respective boundaries at any point in time due to the multi-dimensionality of Porflow, but the size of the time steps should obviate any of those differences.

The challenge during benchmarking was getting the mass fluxes to match at the boundary. The following discussion regarding wall release is an example of why running the two complementary models leads to a better system understanding. If only the GoldSim model were run, the phenomenon would have been missed completely. If only the PorFlow model were run, it is possible that this nuance of system behavior would have been overlooked. The following became apparent once both models were thoroughly examined following preliminary benchmarking.

The wall release is rather complicated. Figure 1 shows the PorFlow material zones. During the course of the base case simulation the wall concrete fails hydraulically while the floor stays intact. That means that the flow from the wall will be diverted by the floor into a region of backfill and then into sandy soil. The flow field also carries the contaminants under the vault. This becomes important for radionuclides such as ^{237}Np. In a time lapse one can see the ^{237}Np progressing under the vault in the sandy soil (K_d = 0.6 ml/g) and being drawn into the clean, bottom side of the floor (K_d = 3000 ml/g). There are many complicated, interrelated phenomena which can't be explicitly captured in a 1-D model. The initial GoldSim model had the wall cells flowing directly into the top cell of the UZ. Once this phenomenon was recognized a series of mixing cells were added to simulate both the vault floor and adjacent backfill.

Case A and Case C provide for different wall behavior. Case A represents and "intact" system, with the waste being in contact with the vault walls. This allows for diffusion between the waste and the walls. Case C is a circumferential crack which isolates the waste from the walls. The waste release is primarily the result of the initial inventory in the walls.

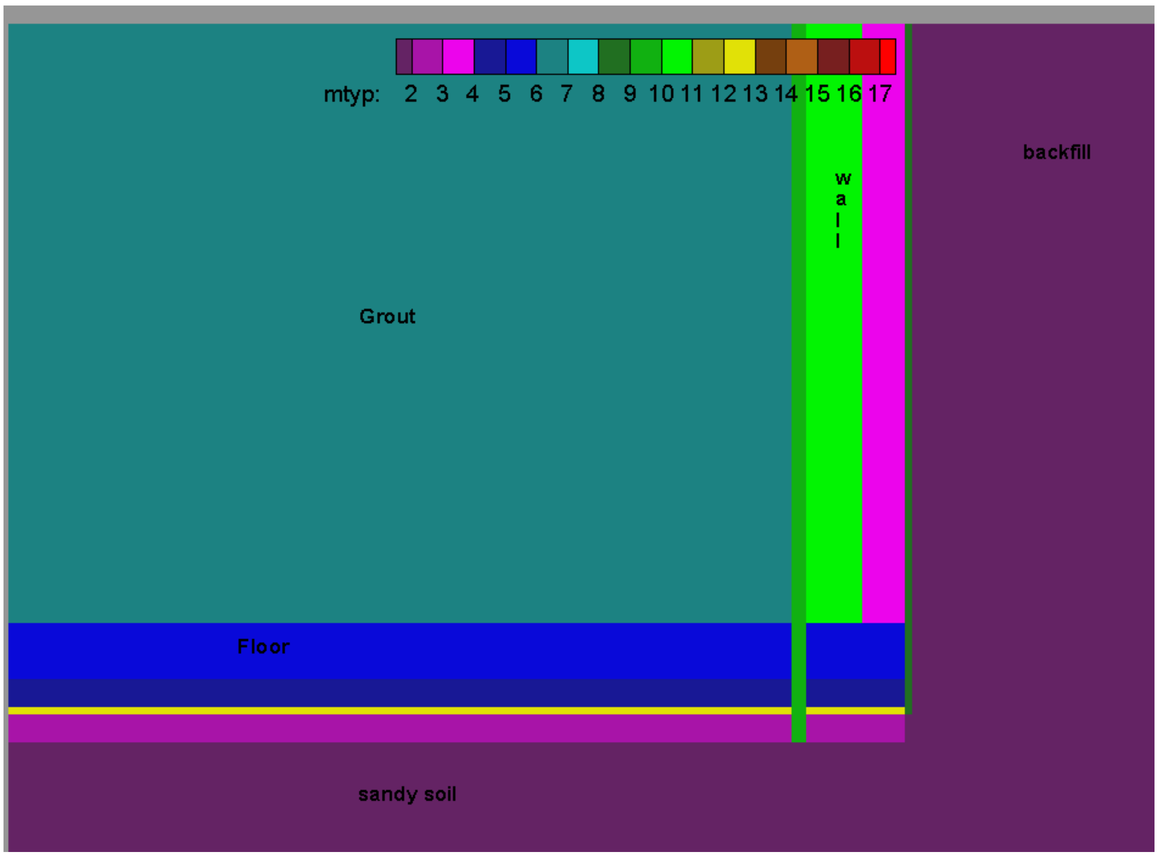

Figure 1 Porflow Material Zones

2.1.1.2 100 m Compliance Boundary Benchmarking

The benchmarking at the 100 m boundary had several complications the UZ-SZ benchmarking did not. Figure 2 shows the sectors, labeled A-K, used in the Porflow model. Logic was set up so that the code would choose the highest value for any computational node within a sector for a given time step. In addition, the figure shows a plan view; there are actually three aquifers modeled in Porflow. The logic selects the highest value from any aquifer within a sector. The location within a sector, when seen as a vertical stack, can move in time in any of the three dimensions. The movement does not appear to be great, but it still presented some challenges.

Because an exact match between the two models was not expected, several decisions were made about how to benchmark at the 100 m boundary. Goldsim uses a well-mixed computational cell assumption meaning that average values for a mixing cell are what one would expect. Therefore, rather than trying to benchmark to different locations within a sector, the value reported by Porflow was treated as the cell-averaged value. The plume function, which is the first step in the benchmarking process, was calculated assuming that the values reported from Porflow were the values from the center of a location. The plume function has an offset from the centerline of a plume so the distance from the streamlines to the center of the sectors was the value used in the function. The arrows in Figure 2 indicate the center of the Porflow sectors.

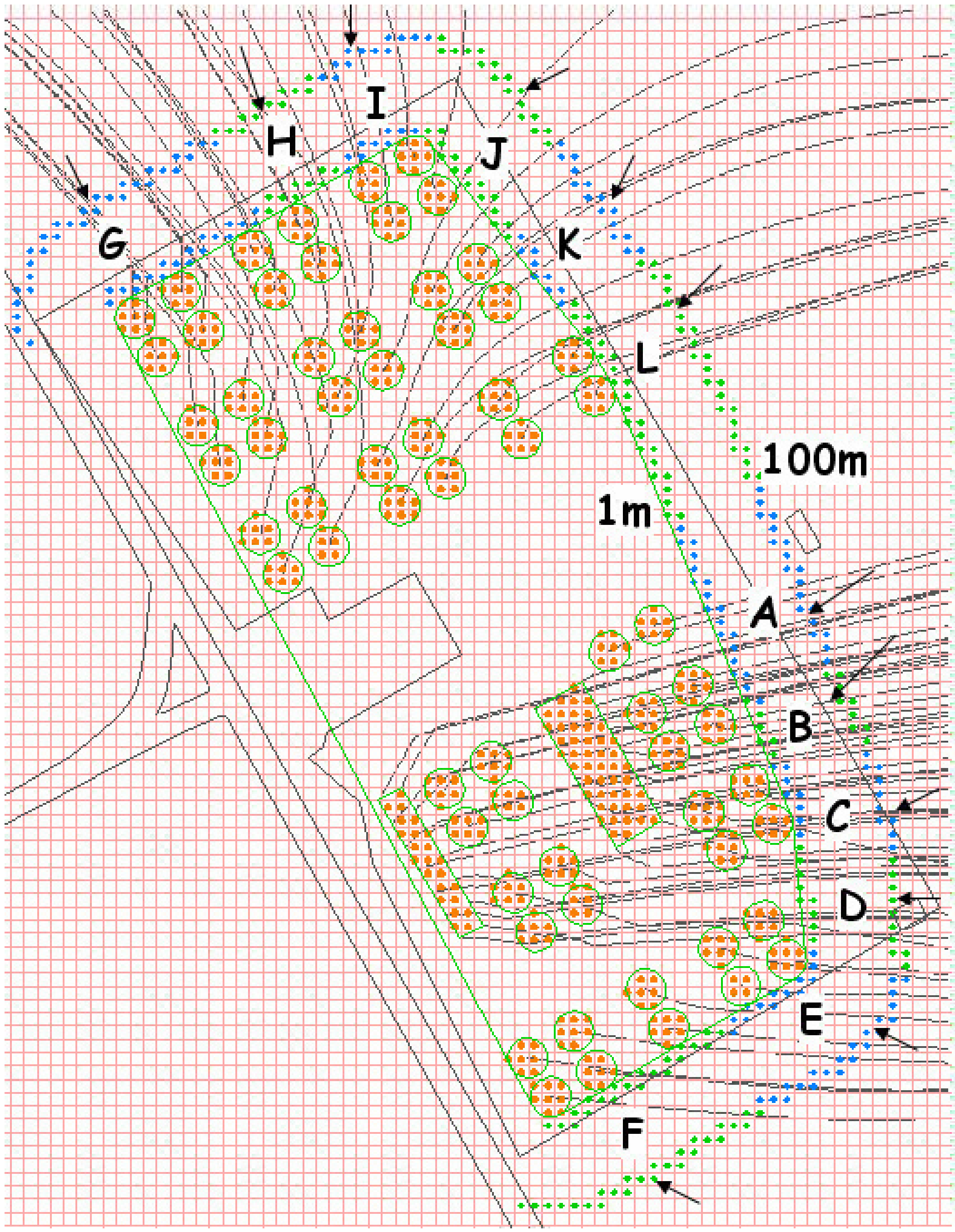

Figure 2 Porflow Sectors

Figure 2 does not tell the whole story. It shows the streamlines from each disposal cell defined by each disposal cell's plume maximum concentration. It also shows the results in a plan view so that one cannot readily tell what is happening in the z-direction. Figure 3 shows the concentrations in all three aquifers. The dilute plume heading to the north is the result of contaminant transfer in the lowest aquifer emanating from Vault 4. Some small fractional release of the contaminants goes straight down in the lowest aquifer which in the SDF has a flow almost perpendicular to the higher two aquifers. Vault 1 demonstrates similar behavior. Although not anticipated, because of the logic Porflow used to select its concentrations, this became an important phenomenon.

This phenomenon would most likely not have been recognized were it not for the benchmarking. Based strictly on the streamlines, the results from Porflow seemed reasonable. During the benchmarking it became apparent that there had to be an additional contributor to the northern sectors than those defined solely by the streamlines. This observation caused a detailed investigation in what might be causing the mismatch between the two models. The investigation led to this understanding. While this did not appreciably affect the manner in which the Porflow results were treated in terms of compliance, it did lead to a better understanding of the system behavior.

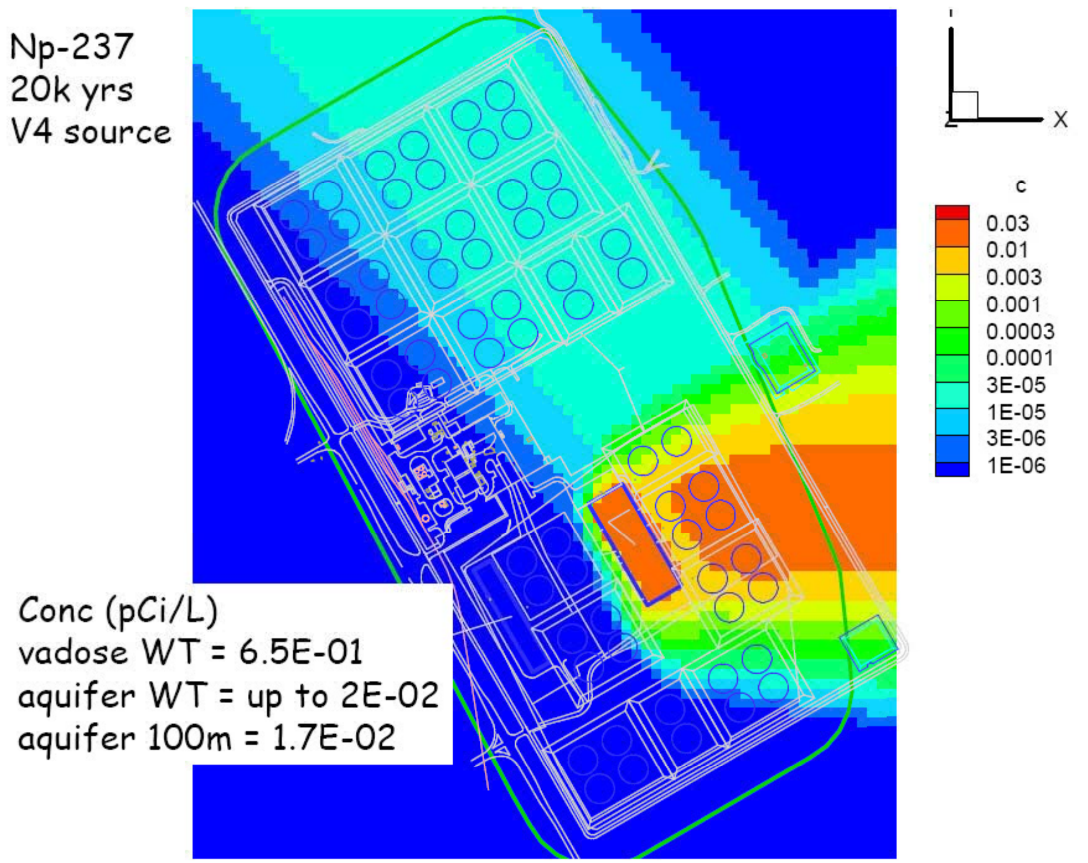

Figure 3 Vault4 contaminant distribution

The previous discussion alluded to the fact the system behavior at the 100 m facility boundary is an integrated behavior. Many vaults contribute to each of the sectors; thus, it is important while benchmarking is to ensure the sector concentrations are aligned. Porflow does not supply information as to which disposal cells contribute to which sector. That must be inferred from the various cells' streamlines. Later in this report when the benchmarking results are discussed there will be only one section on the compliance boundary benchmarking with discussions on how those benchmarks were obtained. Individual vaults will be discussed for the UZ benchmarking.

2.1.2 What was benchmarked

Before benchmarking began, the Porflow results were run through the SDF dose calculator in order to determine which radionuclides were most important to dose. Again, because of the assumption that the saltstone stays relatively intact throughout the compliance period, the only radionuclides which contributed substantially to the dose were the mobile ones, ^{99}Tc, ^{226}Ra, ^{237}Np, and ^{129}I. These are mobile during diffusive transport from the saltstone to the vault wall to the soil. Once in the soil these radionuclides are highly mobile during the advective phase of the transport. This is the reason that these three are seen as major contributors at the compliance boundary.

2.1.3 ^{99}Tc benchmarking challenges

^{99}Tc provided a number of challenges for benchmarking. Since it was presumed that ^{99}Tc would be a significant contributor to the SDF peak dose, it was decided at the beginning of the SDF PA analysis development that the ^{99}Tc contaminant released would be treated differently that the other radionuclides. A detailed discussion of the ^{99}Tc contaminant release treatment can be found in [Flach et al, 2009]. Briefly, in the Porflow analysis it was decided to treat the transition from reducing to oxidizing conditions in the saltstone and vault walls as occurring in individual columns of computational cells rather than an entire region as with the other radionuclides. The sawtooth pattern of Figure 4 shows this behavior. As a column of cells goes from reducing to oxidizing, the ^{99}Tc is flushed from the column giving a temporary increase in magnitude. This behavior in the simulation is obviously an artifact of the modeling paradigm. In nature, one would expect a more continuous behavior rather than the jagged behavior exhibited by the model. Therefore, it was judged unnecessary to attempt to match this artificial behavior from the Porflow model with the Goldsim model.

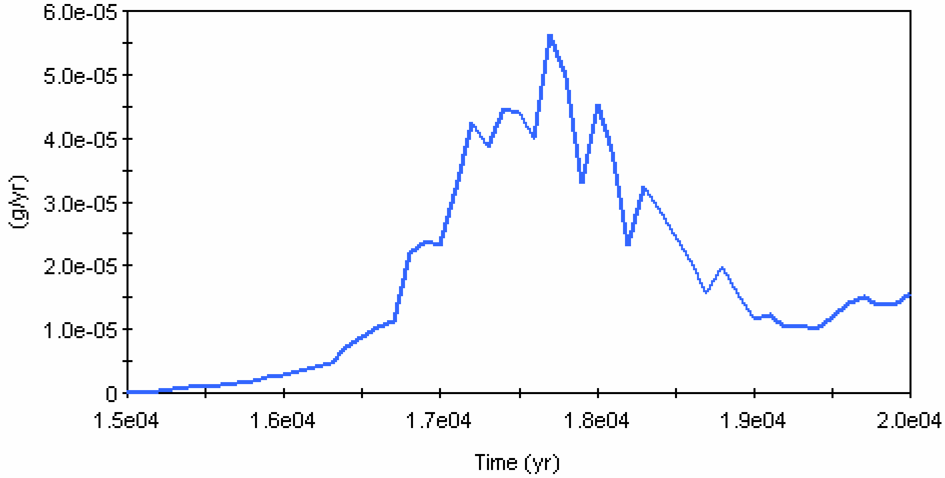

Figure 4 ^{99}Tc UZ-SZ mass flux

The benchmarking is further complicated by the fact that an effective distribution coefficient was used for ^{99}Tc in the Porflow analysis. This turned out to have minimal impact on the benchmarking because an effective distribution coefficient was employed to mimic the average behavior of the Porflow release.

2.1.4 ^{226}Ra Benchmarking Challenges

The benchmarking of ^{226}Ra was different from the other three radionuclides in that it is a daughter product. Not only must one assess its behavior, but also its parents. The modeled parents which contribute to ^{226}Ra are ^{242m}Am, ^{246}Cm, ^{242}Pu, ^{238}Pu, ^{238}U, ^{234}U, and ^{230}Th.

Simulations of each parent alone were made to determine the contribution of each parent to the total ^{226}Ra in the system. At the beginning of the simulation 99.9% of the ^{226}Ra was from ^{230Th}. At 10, 000 years 84.1% was from ^{230Th}, 15.4% from ^{234}U and 0.5% from ^{238}U. The other parents contributed much lower fractions. For the three parents with substantial contributions, the vast majority of their initial inventory (90%+) is in Vault 4. Therefore, the benchmarking effort for ^{226}Ra focused on Vault 4.

2.1.5 General tweaking comments

The benchmarking process was fairly straightforward. The UZ benchmarking was primarily done by working with a few parameters which affected the contaminant behavior in the vault based on the UZ-SZ mass flux. The SZ benchmarking was accomplished by adjusting the plume parameters and the contribution of the various vaults to the sectors.

Vault 2 (the FDCs) fell into good agreement once the wall behavior was defined. Vault 1 behaved similarly. Vault 4, which one would have expected to behave similarly to Vault 1 was the most problematic of the three. Part of its difficulty may stem from it being so close to the 100 meter boundary. There was little transport time in the aquifer to "smooth" out its behavior. The Vault 4 wall treatment was also different in the Porflow analysis, and this contributed to the difficulty.

A brief discussion of the mixing cell in the SZ from which the contaminant concentrations are selected for dose calculations is warranted. The SDF Goldsim model as originally envisioned and implemented has an SZ whose total path length is equivalent to the longest path length from a disposal cell to the compliance boundary along a streamline. It was thought that the timing of the contaminant peaks from different disposal cells would correspond to different mixing cells based on the travel. This may be true if one were to perform analyses with short time steps. However, with the time steps chosen and used in the benchmarking being 100 years, the travel time within the SZ can be accomplished in essentially one time step. The K_d formulation serves to retard the transport and that retardation becomes lost in the SZ of the Goldsim model because of the time step size. Therefore, the concentrations from the last mixing cell in the SZ were used for all disposal cells.

2.2 FDC (Vault2) benchmarking

2.2.1 Case A

Little was necessary to achieve an acceptable benchmarking for an FDC in the unsaturated zone. Except for ^{99}Tc, with all the physical parameters in both models the same, the timing and magnitude of the ^{237}Np and ^{129}I releases were consistent.

2.2.1.1 What was tweaked

To obtain a reasonable benchmarking of the ^{99}Tc it was necessary to adjust its distribution coefficient. For all the reasons mentioned in Section 2.1.3, the ^{99}Tc distribution coefficient was increased in the reducing region and reduced in the oxidizing region.

2.2.1.2 Results

Note that in all the results sections Porflow data is shown by the red curve and Goldsim data by the blue curve.

All three benchmarks show a good comparison. Of particular interest is the time after the vault wall transitions from reducing to oxidizing. Table 1 shows the Porflow derived drinking water dose just before the transition from reducing to oxidizing conditions in the sector which gives the highest dose. Given that these three radionuclides are the major contributors to dose, their contribution to a yearly dose is quite small. Therefore, efforts were made to make a reasonable agreement after the transitions. Figure 5, Figure 6, and Figure 7 all show a good agreement at the UZ-SZ interface. One must remember that both models use only one FDC in order to calculate the flux to the saturated zone.

Table 1 Porflow Drinking water Dose

Radionuclide	Drinking water Dose (mrem/yr)
^{129}I	0.06
^{237}Np	6e-8
^{99}Tc	8e-6
^{226}Ra	0.04

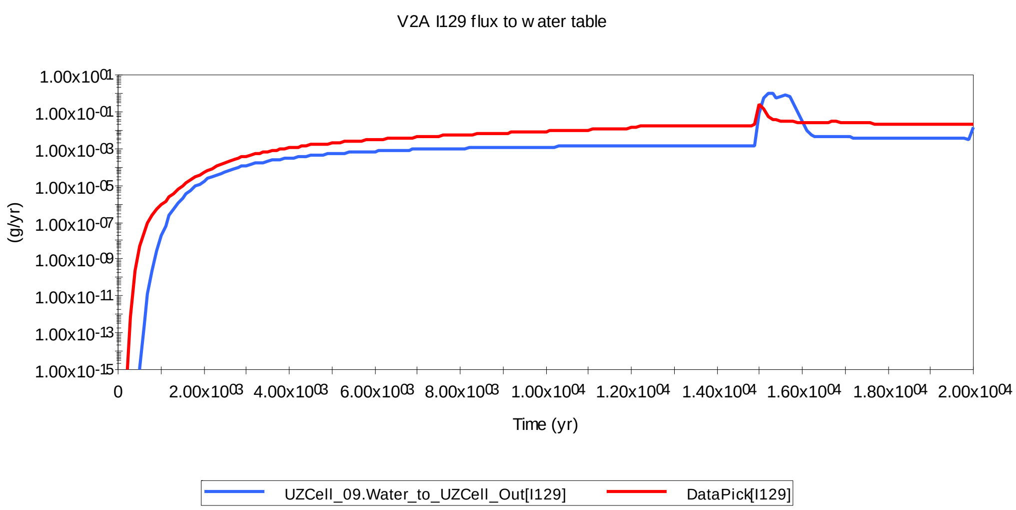

Figure 5 FDC ^{129}I Comparison Case A

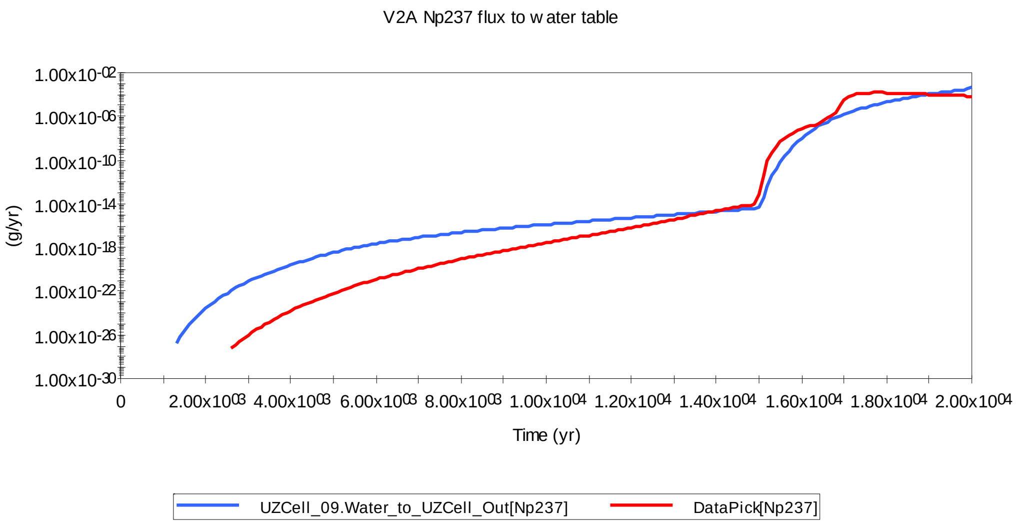

Figure 6 FDC ^{237}Np Comparison Case A

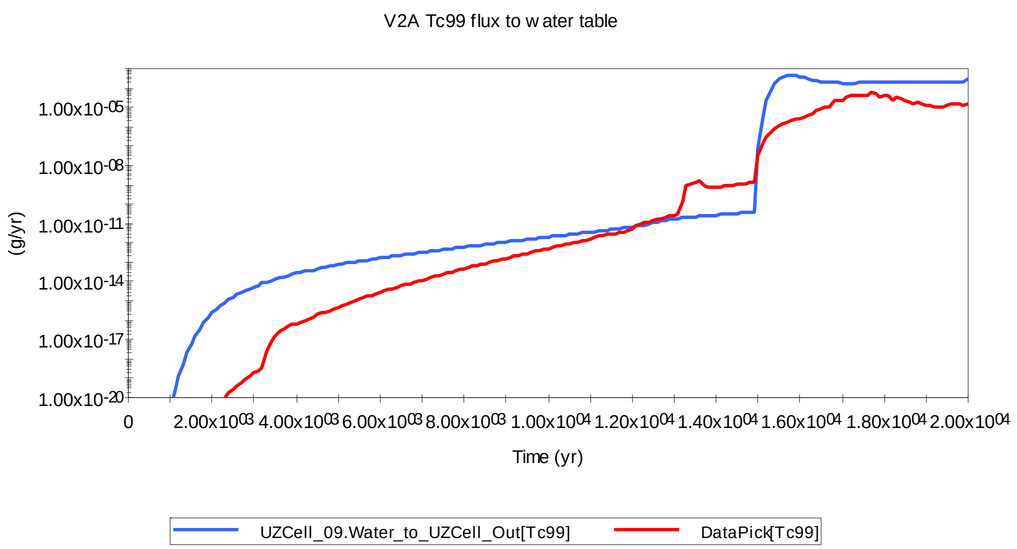

Figure 7 FDC ^{99}Tc Comparison Case A

2.2.2 Case C

The FDCs are different from the other two vaults in that there is no initial waste loading in the walls. The waste release is from the grout to the crack, which extends through the base mat.

2.2.2.1 What was tweaked

The waste release from the grout to the crack flow is by diffusion. The model uses a direct transfer pathway to move the waste from the grout to the unsaturated zone. A CaseCBypassDiffBMFactor was used to adjust the transfer rate and is radionuclide specifc.

2.2.2.2 Results

The results matched quite well. It should be noted that this is a fairly simple configuration in terms of waste release. There is only one flow path of significance, and it remains fairly constant in flow.

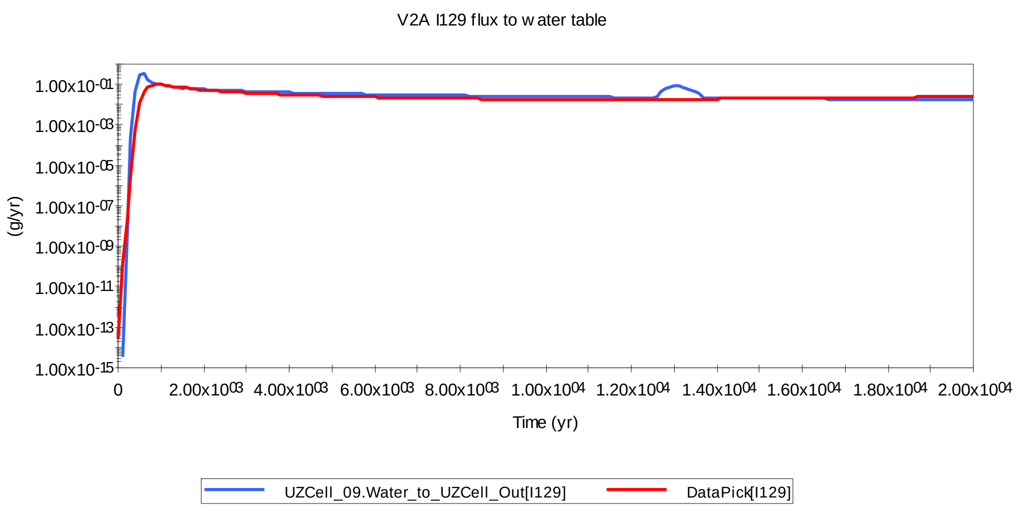

Figure 8 FDC ^{129}I Comparison Case C

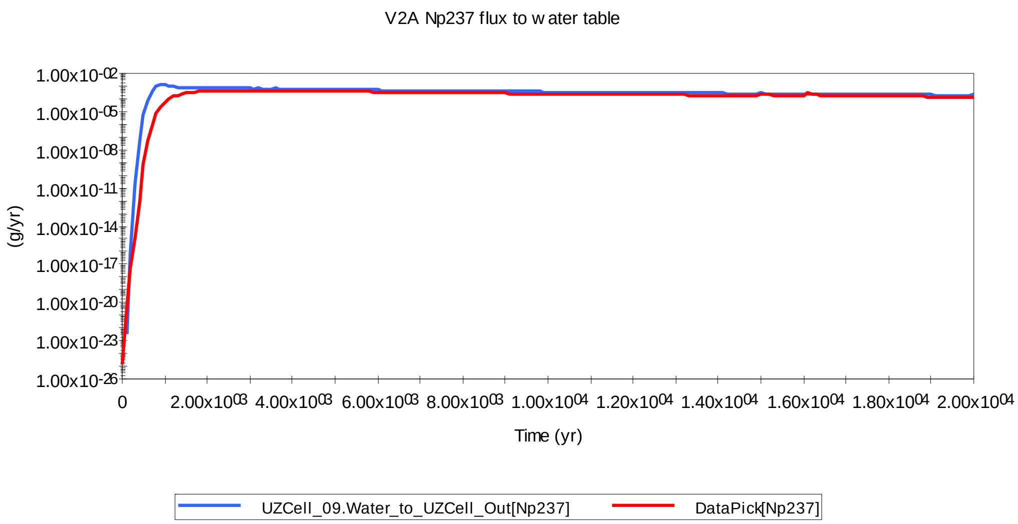

Figure 9 FDC ^{237}Np Comparison Case C

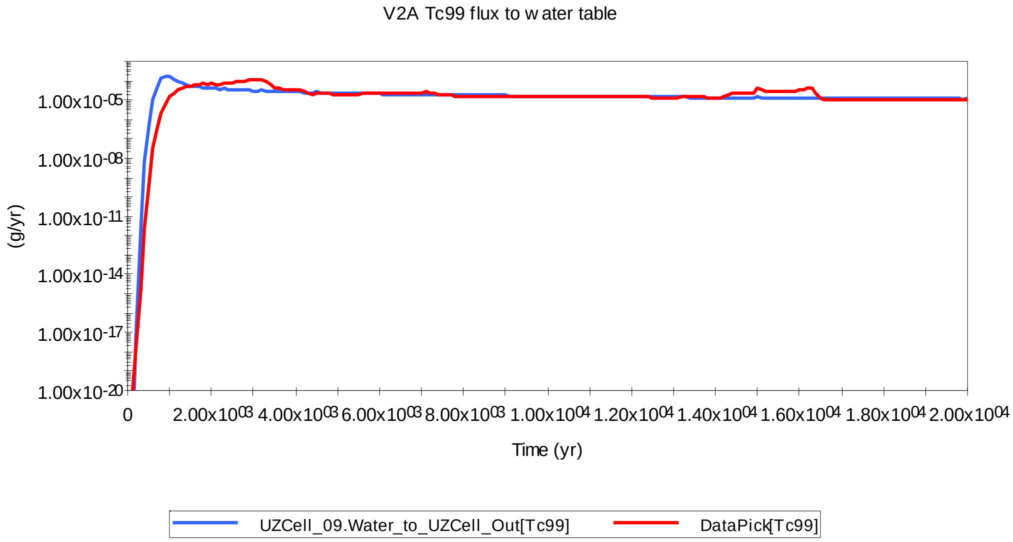

Figure 10 FDC ^{99}Tc Comparison Case C

2.3 Vault 1 Benchmarking

2.3.1 Case A

The Vault1 benchmarking followed the FDC benchmarking. With the common parameters of the two being set during the FDC benchmarking, the Vault 1 benchmarking turned out to be the easiest of the three.

2.3.1.1 What was tweaked

Only one parameter exclusive to Vault 1 was adjusted to achieve the benchmarking results shown in Section 2.3.1.2, with that being the initial wall inventory of contaminants. The PorFlow analysis assumed the total vault inventory was evenly distributed throughout the saltstone and the vault walls. The Goldsim model wall inventory was adjusted to reflect agreement between the two models at the UZ-SZ interface.

2.3.1.2 Results

The Vault 1 results show quite good agreement. The ^{129}I (Figure 11) might have been made better during the middle portion of the transient by adjusting the diffusion term, thereby providing more inventory to the wall to be removed. However, as noted above, the dose contribution is less than 0.1 mrem/yr, so the adjustment was not warranted. The small bumps on the ^{99}Tc (Figure 13) curve are due to the reducing-oxidizing transition in the wall cells and are not reflected in the GoldSim model.

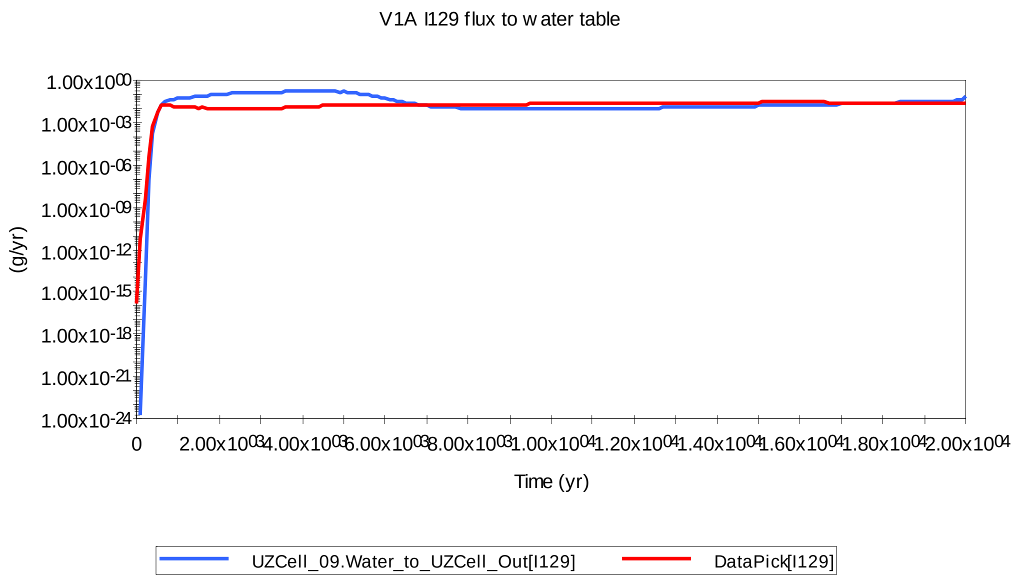

Figure 11 Vault1 ^{129}I Comparison Case A

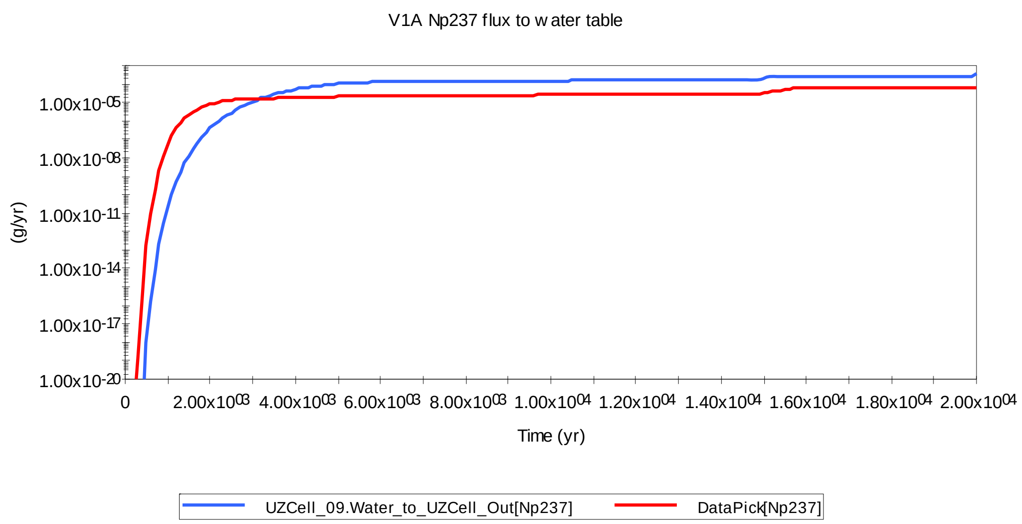

Figure 12 Vault1 ^{237}Np Comparison Case A

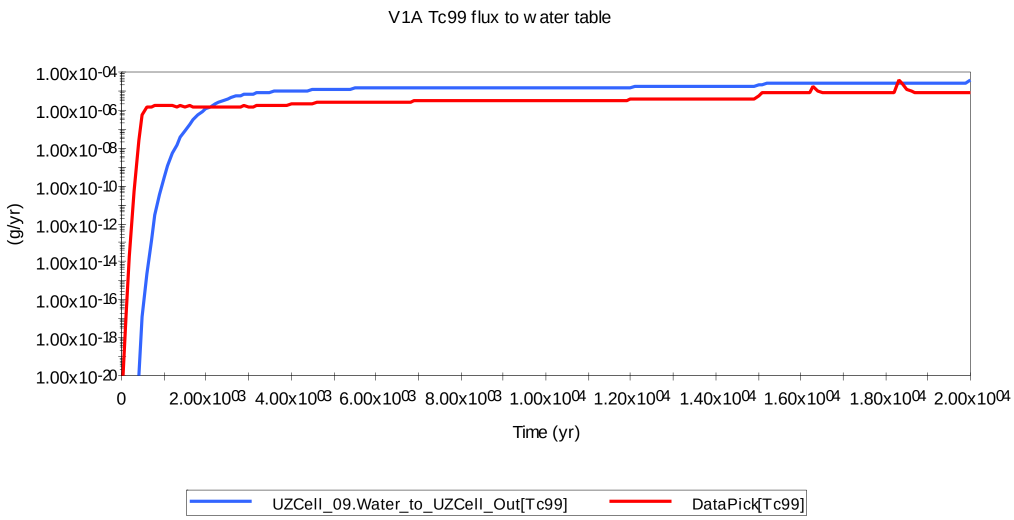

Figure 13 Vault1 ^{99}Tc Comparison Case A

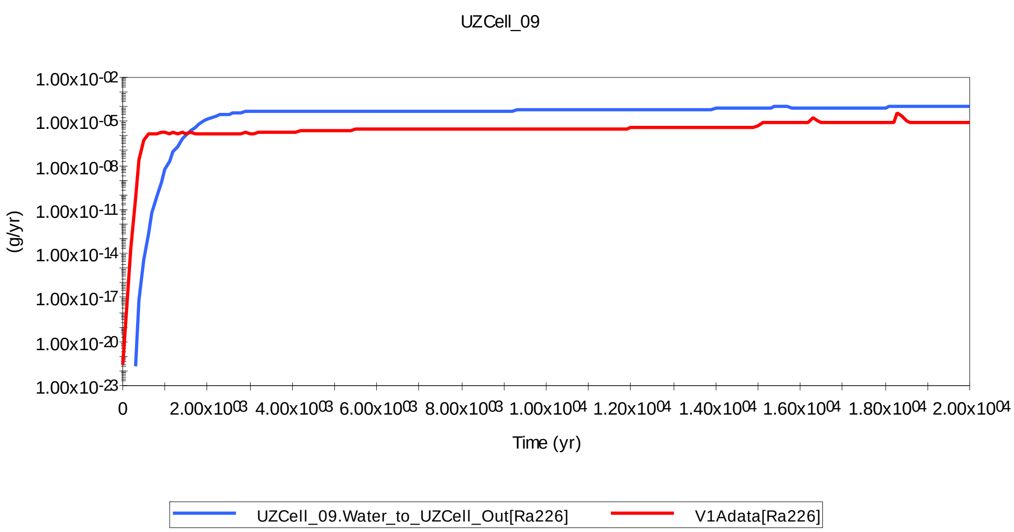

Figure 14 Vault 1 ^{226}Ra comparison Case A

2.3.2 Case C

The calibration from the FDCs to Vault 1 was not as simple for Case C as for Case A. Rather than having the waste released from the grout to the crack as with the FDCs, the waste release is a function of the initial wall inventory. The grout is isolated from the vault wall at the beginning of the analysis period. Adjusting the initial inventory allowed the GoldSim model's results to match PorFlow's.

2.3.2.1 What was tweaked

The initial vault wall inventory was adjusted to match the PorFlow release of contaminants. This was the only parameter adjusted.

2.3.2.2 Results

Figure 15 through Figure 18 show the comparisons of the flux at the water table.

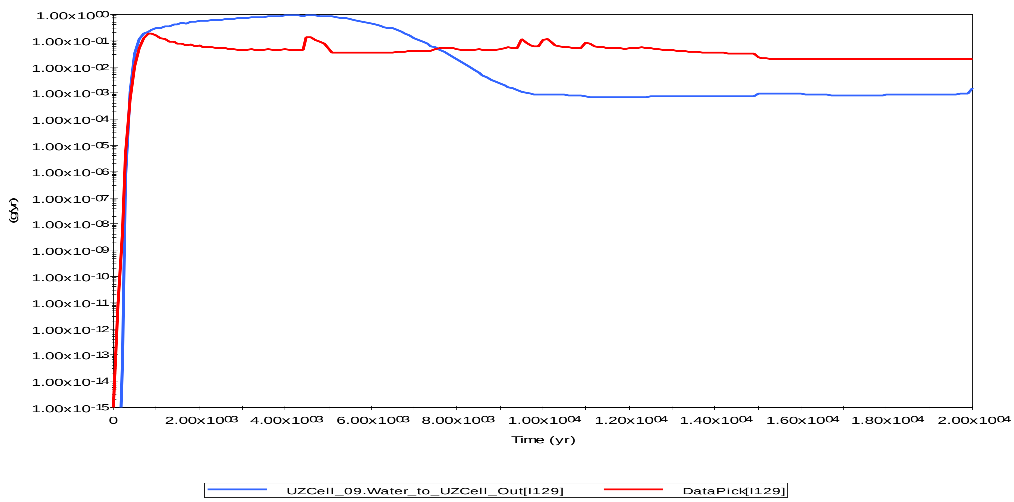

Figure 15 Vault 1 ^{129}I comparison Case C

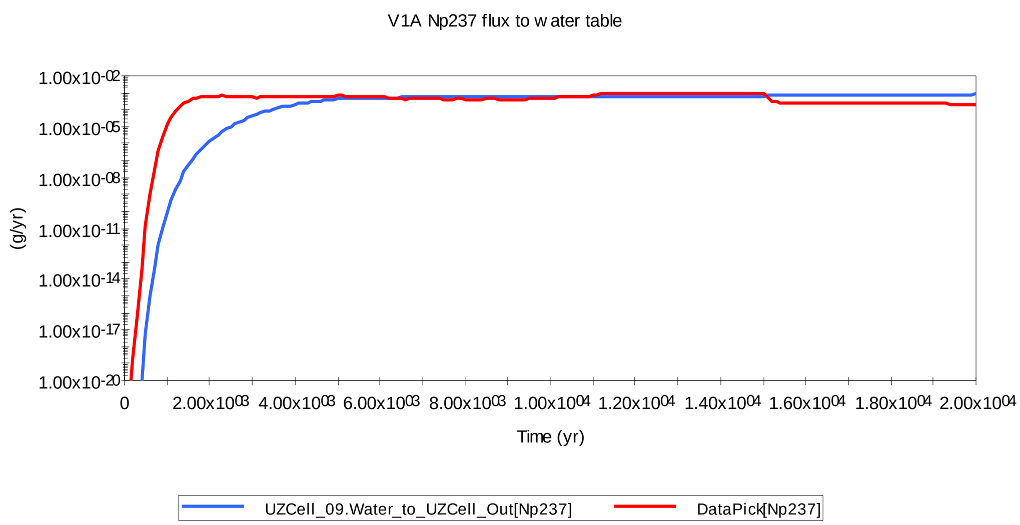

Figure 16 Vault 1 ^{237}Np comparison Case C

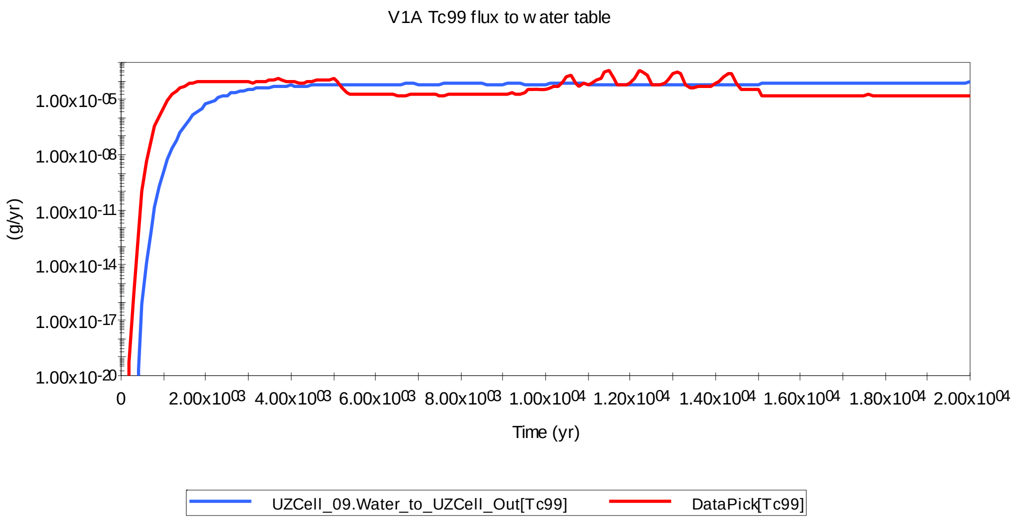

Figure 17 Vault 1 ^{99}Tc compaison Case C

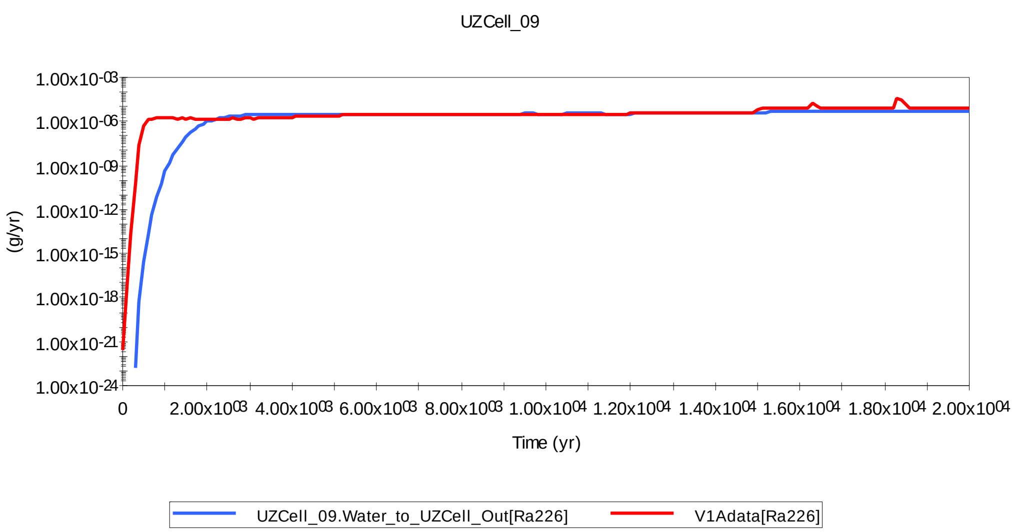

Figure 18 Vault 1 ^{226}Ra comparison Case C

2.4 Vault 4 Benchmarking

2.4.1 Case A

Vault 4 was the most difficult to benchmark. The Vault 4 transition from reducing to oxidizing occurred much earlier than the other two vaults, as can be seen by the large gradient around 9000 years in Figure 21 (versus about 15,000 years for the FDCs and Vault 1). The benchmarking did not result in complete agreement between the two models, but the contaminant release trends are basically the same for the two models.

2.4.1.1 What was tweaked

The Vault 4 wall inventories were adjusted for the species of interest. The diffusion coefficient of ^{129}I was adjusted upward. The flow in the grout was adjusted upward and the flow in the wall was adjusted downward. The initial wall contaminant inventory was adjusted. This proved to be the most important parameter. Diffusion into the wall was adjusted during the transient.

2.4.1.2 Results

Figure 20 and Figure 21 show that during the final quarter of the transient the wall inventories are being depleted. This has implications for the other two vaults in that if the transients are to be run for longer periods of time, their results would probably be similar. The peak flux occurs in the Goldsim model before this time period so that a sensitivity of the peak dose can be assessed.

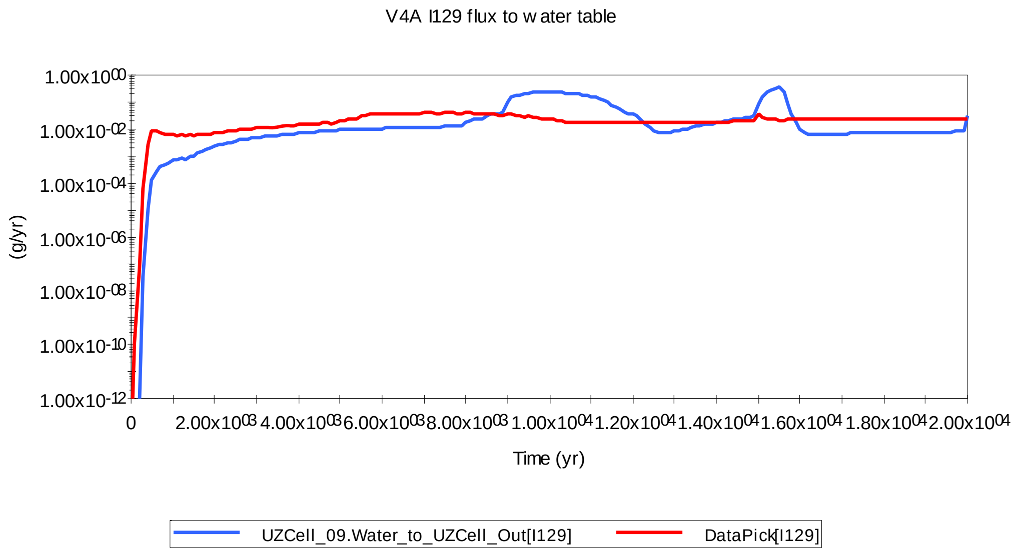

Figure 19 Vault 4 ^{129}I Comparison Case A

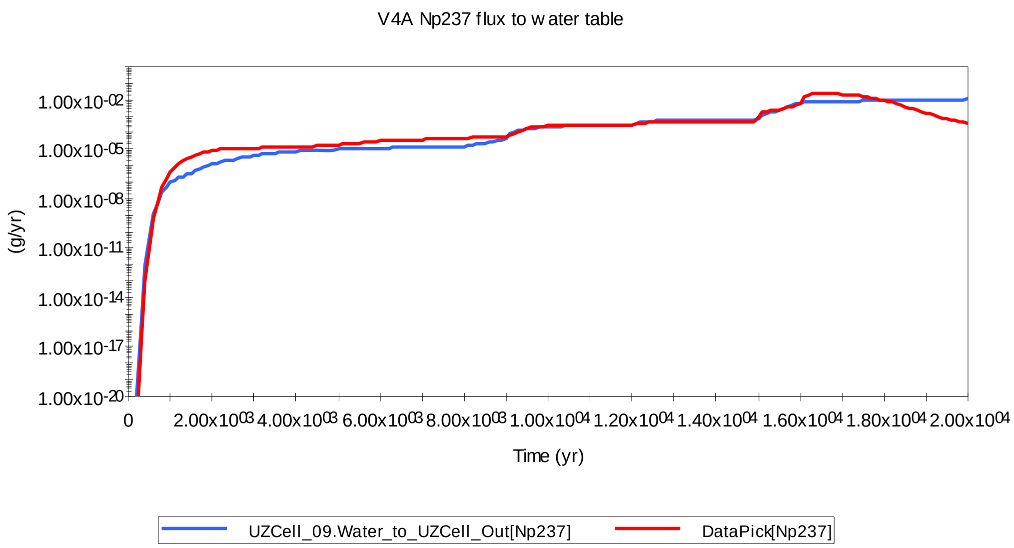

Figure 20 Vault 4 ^{237}Np Comparison Case A

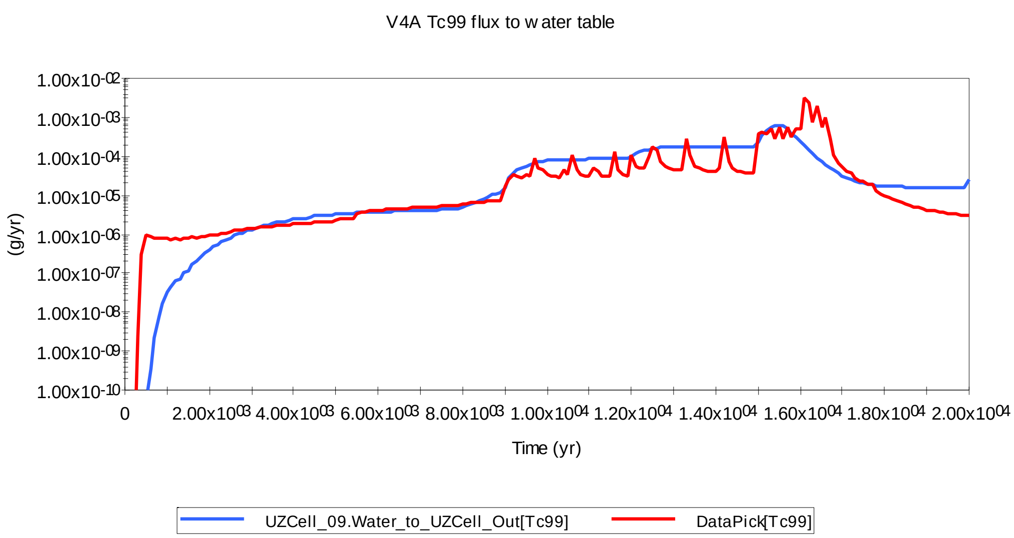

Figure 21 Vault 4 ^{99}Tc Comparison Case A

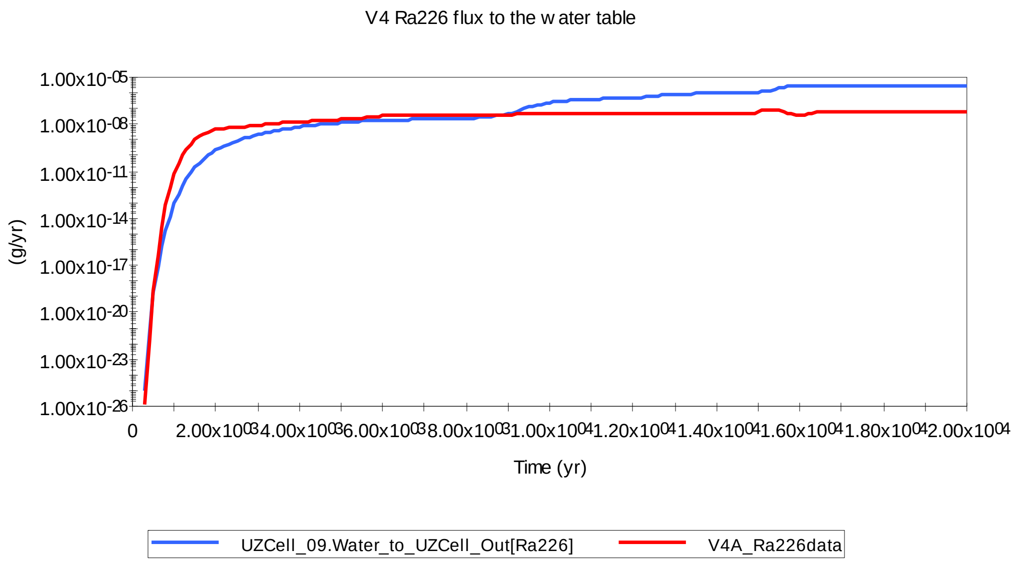

Figure 22 Vault 4 ^{226}Ra Comparison Case A

2.4.2 Case C

A balancing act was required between the early (<5,000 years) and later concentrations. It was decided to match the later behavior as that is when the doses associated with Vault 4 begin to rise substantially.

2.4.2.1 What was tweaked

As with Vault 1, the important parameter was the initial wall loading.

2.4.2.2 Results

The results show that the GoldSim underpredicts the early concentrations and then does a good job at later times.

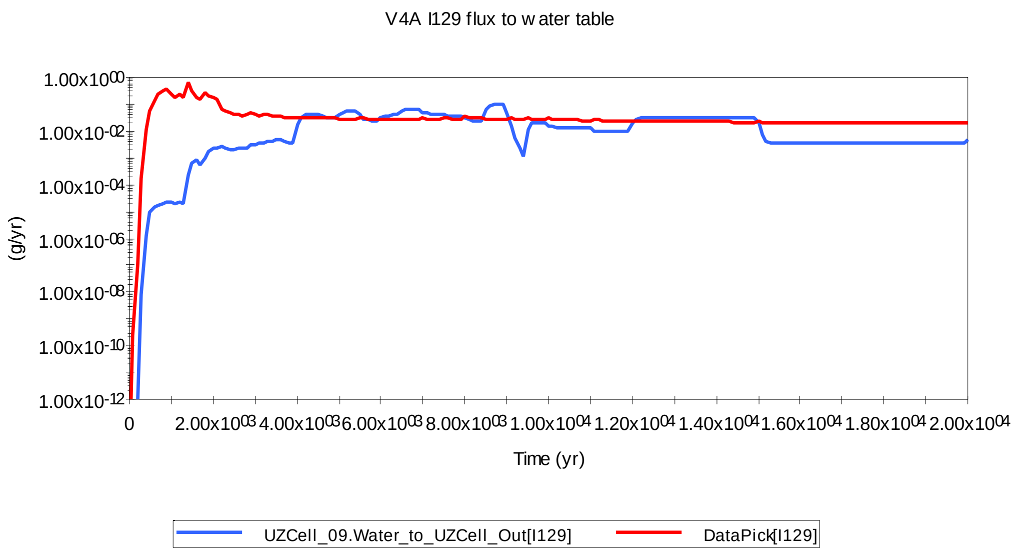

Figure 23 Vault 4 ^{129}I comparison Case C

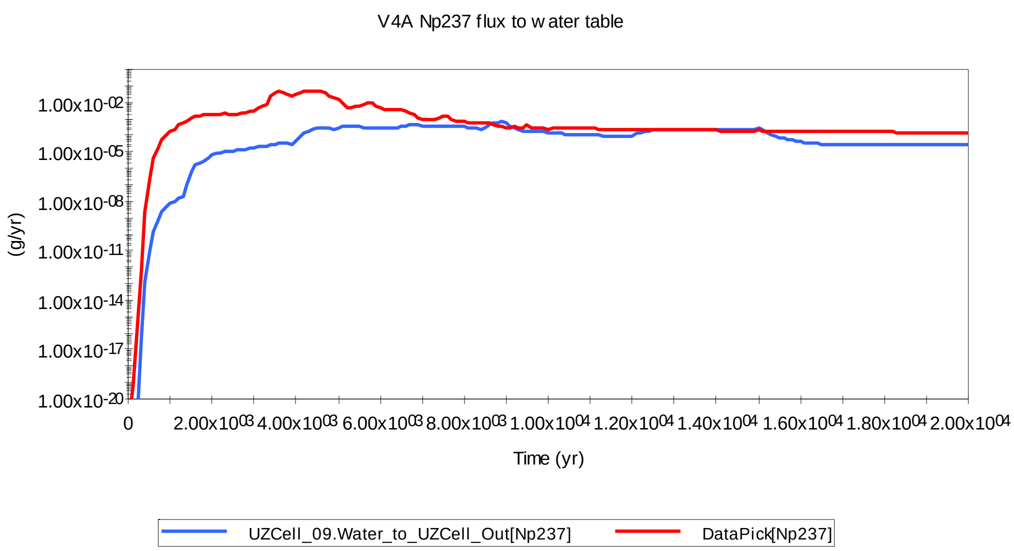

Figure 24 Vault 4 ^{237}Np comparison Case C

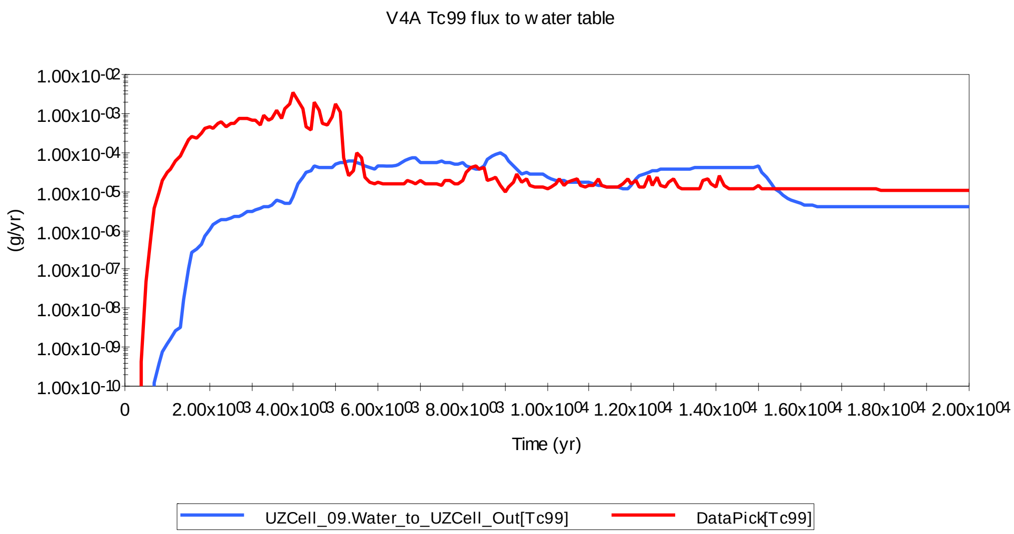

Figure 25 Vault 4 ^{99}Tc comparison Case C

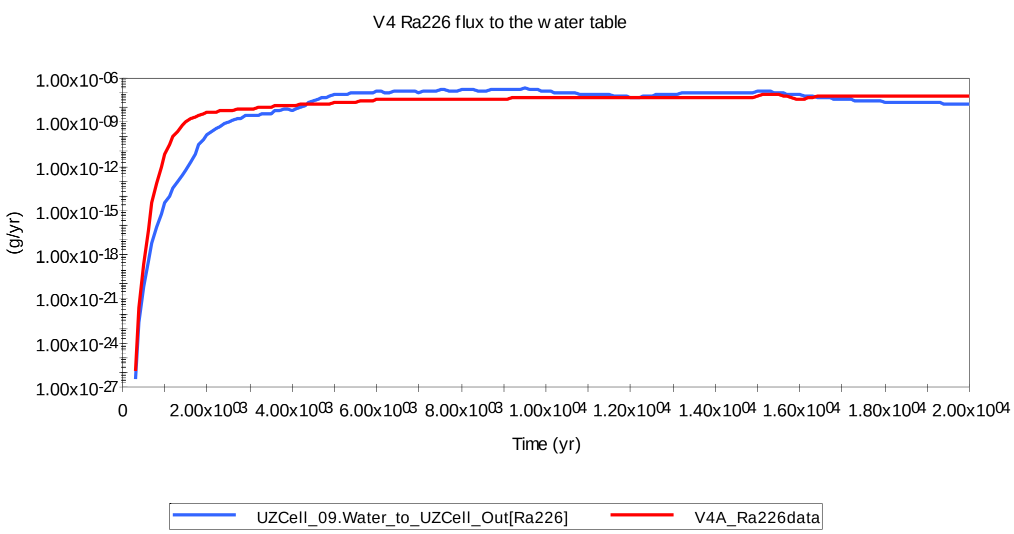

Figure 26 Vault 4 ^{226}Ra comparison Case C

2.5 Saturated Zone Benchmarking Case A

The SZ benchmarking is complicated by the fact that the points of interest are affected by multiple sources. Fortunately, the arrivals of the peaks could generally be ascribed to a source, or multiple sources, because of the time step length and the travel distance. This allowed for a relatively simple benchmarking of the SZ flow rate. Once this was established the rest of the benchmarking proceeded.

2.5.1 What was tweaked

Because the SZ cell size is relatively arbitrary, it represents an "average" SZ thickness times area, a factor was applied to all regions to account for the "dilution" shown by PorFlow.

Two parameters adjusted after the flowrate was set were a plume factor and the contribution of Vault 1 and Vault 4 to unexpected regions. The plume factor was adjusted only for Region J. This is where a flow divide occurs and this region was more affected than Region I. A factor was added to donor fractions of Vault 1 and Vault 4's mass to the cells normal to their main flow path. (See discussion in Section 2.1.1.2)

2.5.2 Results

The location of the results' sectors can be found in Figure 2. Again, although there are differences between the two models' results, the release trends are similar. Therefore, one can perform sensitivity and uncertainty analyses on the PorFlow concentrations using the GoldSim model. The dotted lines are GoldSim and the solid lines are PorFlow.

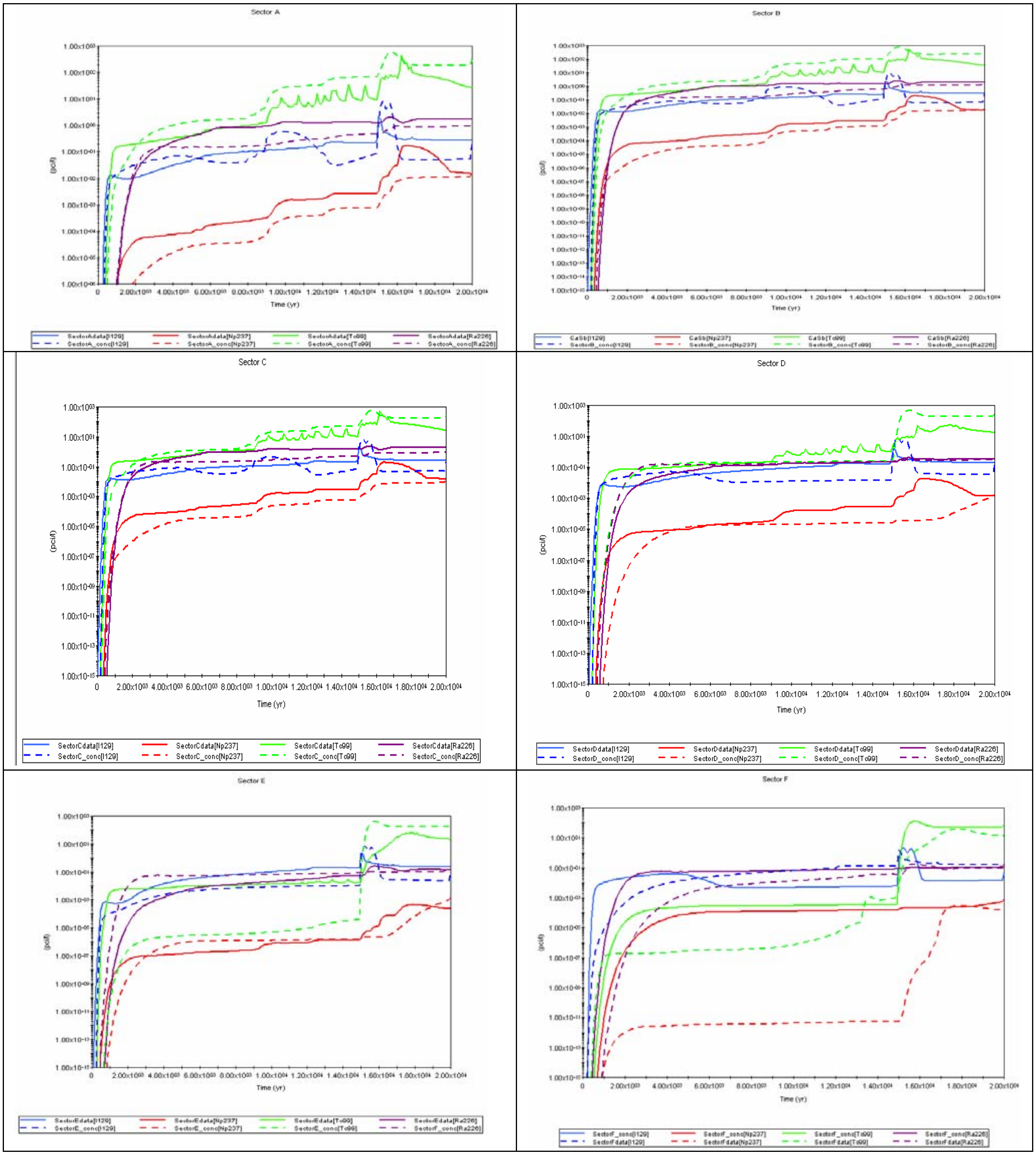

Figure 27 South Sectors Compliance Boundary Comparisons Case A

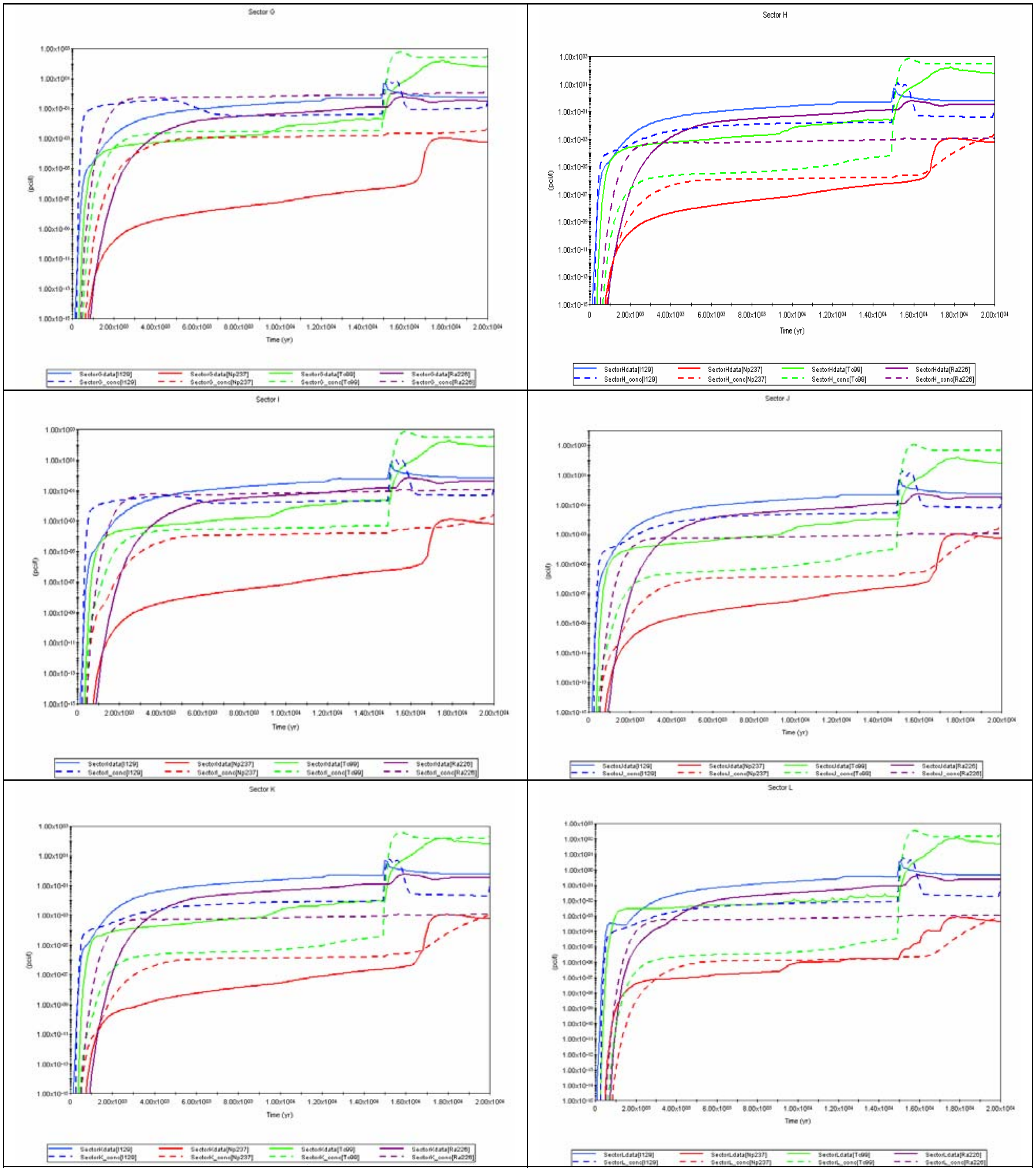

Figure 28 North Sectors Compliance Boundary Comparisons Case A

2.6 Saturated Zone Benchmarking Case C

The Case C benchmarking had all the same challenges as did Case A. In addition, Case C showed a sensitivity to the fraction of Vault 1 applied to the sectors.

2.6.1 What was tweaked

In addition to the tweaks discussed in Section 2.5.1 the fraction of Vault 1 applied to the sectors. This was determined to be necessary through inference and is the reason Vault 4 factors were not changed. If one were to look at the ratios of radionuclides in a sector (before applying a new benchmarking fraction to Vault 1) one would see that some radionuclides were showing lower concentrations than the PorFlow while others were matching pretty well. It turned out that Vault 1 had a similar ratio of radionuclides so if one were to increase the addition of Vault 1 inventory into a sector it would increase those radionuclides which needed increasing while not affecting (as much) those which did not. Although the reason for the addition of more Vault 1 inventory is definitively nailed down, I believe it is due to the driving force of the crack forcing more of the contamination into the lower aquifers. Remember that the PorFlow results are the maximum value for any aquifer within a sector.

2.6.2 Results

The comparison also shows that Vault 1 seems to affect the sectors without a strong Vault 4 interaction. The PorFlow results show a smoother behavior for all the sectors except those directly in front of Vault 4. This smoother behavior is indicative of Vault 1 behavior.

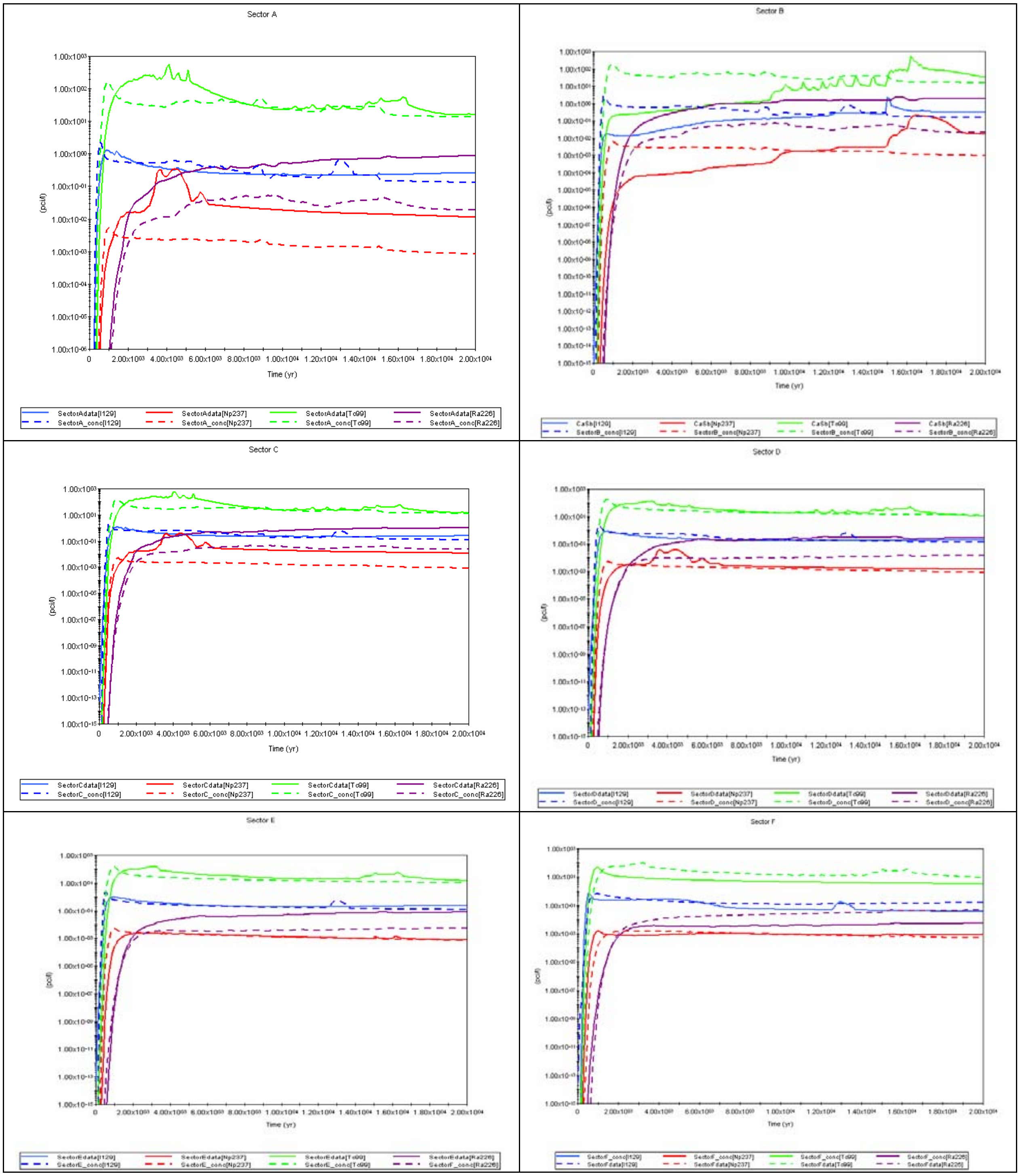

Figure 29 South Sectors Compliance Boundary Comparisons Case C

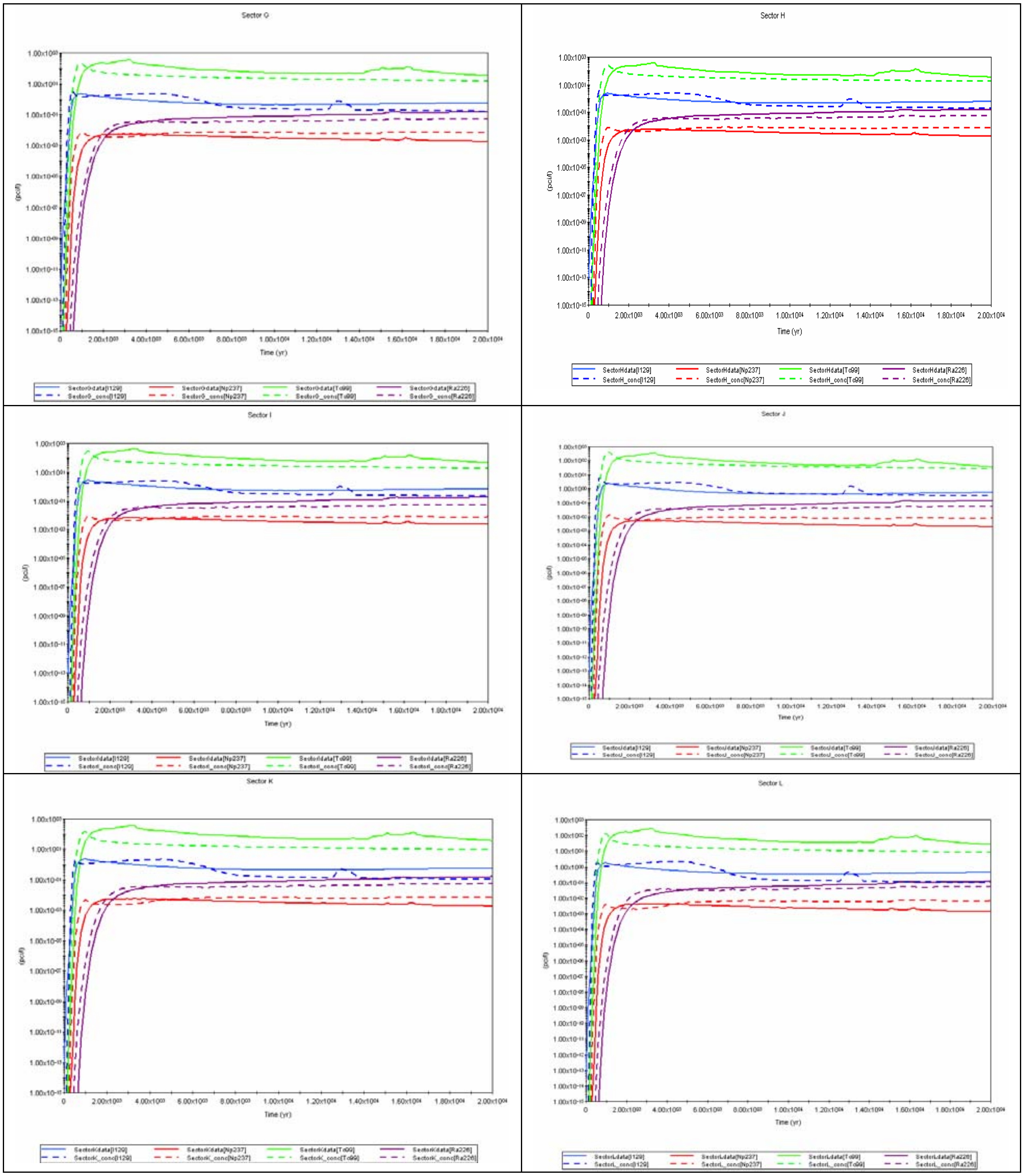

Figure 30 North Sectors Compliance Boundary Comparisons Case C

3.0 Doses

Figure 31 shows a comparison of the doses between the GoldSim transport and dose model ("Transport Model") and the GoldSim dose model which uses PorFlow generated concentrations for Case A. the trends are all similar, timings of peaks are similar, magnitude of the peaks are similar, and the sectors of the peaks are similar.

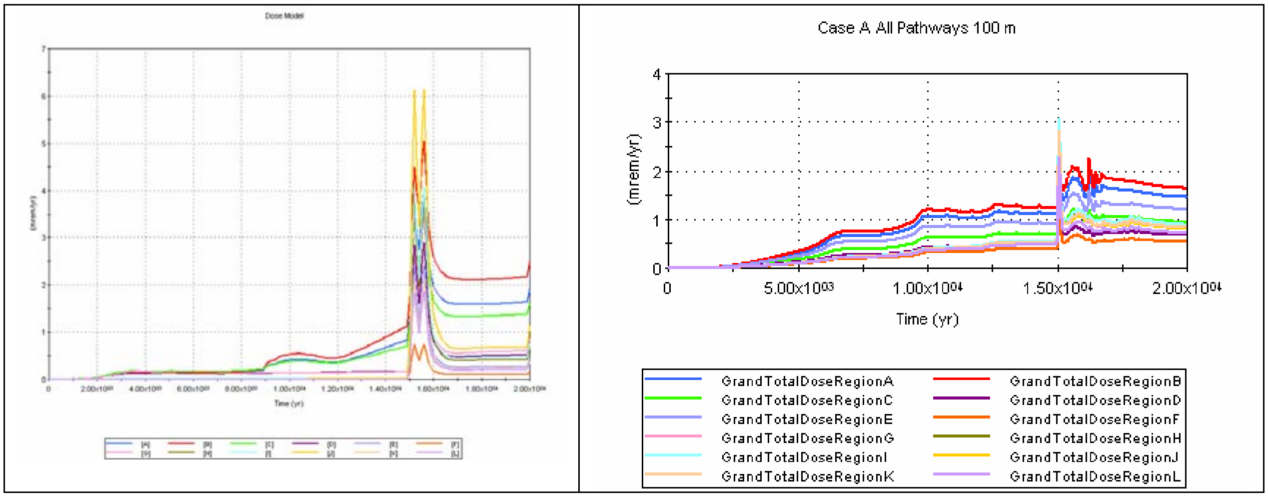

Figure 31 Dose Comparison Case A

Figure 32 shows the results for Case C. While the trends are similar early in time (<17,000 years), later in time they diverge. The reason for the divergence is that the PorFlow runs were made only for those radionuclides which were considered "key radionuclides" based on Case A. The increase in dose in the GoldSim transport model is due to the arrival of several plutonium isotopes. As these isotopes did not show up at the 100 m boundary in either model for Case A, they were not considered key radionuclides and were not run for Case C.

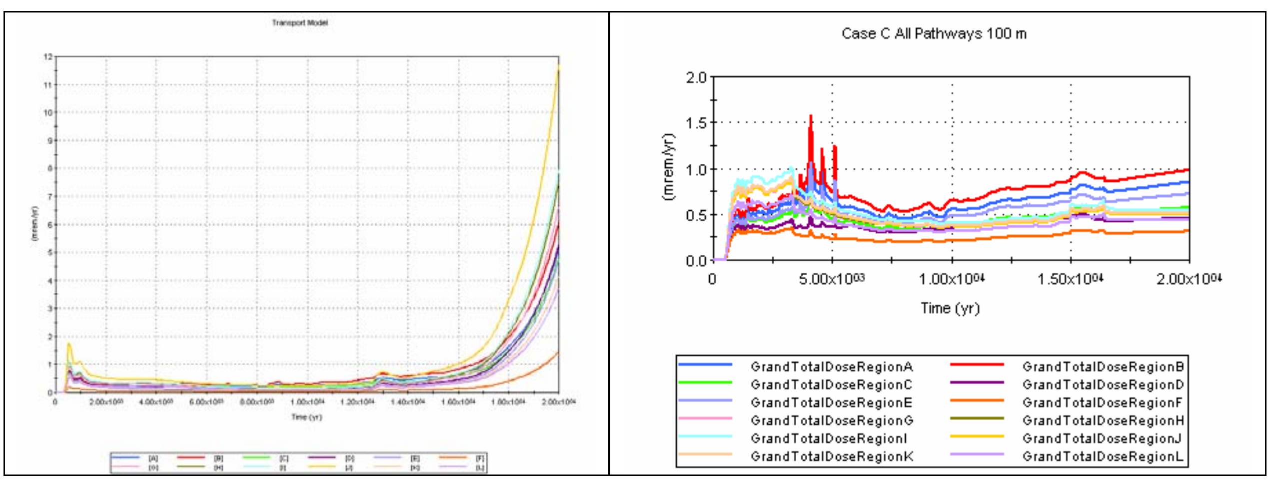

Figure 32 Dose Comparison Case C

4.0 References

Taylor, G. A., *Saltstone Disposition Facility Stochastic Transport and Fate Model Description*, SRNL-TR-2009-00050 Rev. 0, March, 2009.

Flach, G. P., Jordan, J., M, Whiteside, T., *Numerical Flow and Transport Simulations Supporting the Saltstone Disposal Facility Performance Assessment*, SRNL-STI-2009-00115, Rev. 0, March, 2009.