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High-Level Waste Tanks Multi-Dimensional Contaminant Transport Model Development Enhancements for 2000

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1.0 Executive Summary

A suite of multi-dimensional computer models was developed in 1999 (Collard and Flach) to analyze the transport of residual contamination from high-level waste tanks through the subsurface to seeplines. Enhancements in 2000 to those models include the following:

1. Investigate the effect of numerical dispersion
2. Develop a solubility-limited case for U and Pu
3. Develop a plan for a database as part of the Rapid Screening Tool and start to implement that plan.

Numerical dispersion was investigated by examining the effects of refining the mesh (reducing numerical dispersion) for the aquifer model in both horizontal directions, then in the vertical direction. I-129 and Tc-99 from Tanks 17-20 were modeled and results were compared with earlier multi-dimensional modeling.

Reducing numerical dispersion was found to increase concentrations by at least a factor of 2.5, with most of the increase occurring in the horizontal directions. Collard and Flach (1999) indicated that for Tc-99 in Tank 17, the multi-dimensional model produced a dose that was about a factor of ten lower than the dose from the MEPAS model. Correcting for numerical dispersion indicates a multi-dimensional model dose lower than the MEPAS model dose by a factor of about 4. However, the MEPAS model dose was not the peak from Tank 17, but actually the dose produced at the same time when the peak dose for the entire F-Tank farm occurred. Thus, if the similar dose for the multi-

dimensional model were compared versus the MEPAS dose, that dose would be lower than the peak and the factor versus MEPAS would be even higher.

Further mesh refinements would be required to determine the full impact of numerical dispersion. Alternatively, other contaminant transport solution techniques could be adopted that reduce numerical dispersion, although they have other drawbacks.

Solubility-limited cases were established and executed for U-238 and Pu-240 from Tank 17. All residual U in Tank 17 was assumed to be U-238. Results indicated that both U-238 and Pu-240 concentrations at seepline locations were at least 10 orders of magnitude below concentration limits.

Planning for the concentration history database to be used in conjunction with the Rapid Screening Tool was extended. Computer programs were established to input information into the database. The programs incorporated extensive testing and restrictions to reduce the likelihood of erroneous information entering the database. The programs were tested on a mock database to ensure that they operated correctly.

Plans were developed to reduce the database storage requirements, while maintaining controls on the quality of the data. Further requirements for the database system were identified.

Keywords: High-Level Waste Tanks, Contaminant Transport, Seepline Analysis

2.0 Introduction

The original multi-dimensional HLW computer models (Collard and Flach, 1999) were developed to analyze the release of contaminants from tanks and their transport to the aquifer. Subsequent models were developed to analyze contaminant transport through the aquifer to seeplines. Release of contaminants from tanks was modeled on a tank-by-tank basis. Each tank model generated a contaminant flux to the aquifer, i.e. an aquifer contaminant load. Contaminant transport through the aquifer was modeled by analyzing the aquifer loads from one or more tanks, as desired, in a single multi-aquifer model. Several tank combinations were modeled in order to examine the effects of plume interaction from multiple tank sources.

All locations within the model domain that discharged to creeks were identified as seepline cells. A preliminary database was developed containing concentrations for the modeled contaminants at more than 1,000 seepline cells. Concentrations were recorded every two years of the simulation period, up to 10,000 years.

3.0 Enhancements

3.1 Numerical Dispersion

Numerical dispersion is an artifact of the modeling system. It arises from trying to reduce numerical oscillations. Numerical oscillations appear as overshoot and undershoot near the concentration front. "Overshoot describes the erroneously high values of concentration encountered upstream of the moving front. The analogous behavior on the downstream side is called undershoot. These numerical oscillations tend to be more severe as the front becomes sharper (i.e., as the advection becomes more dominant)" (Huyakorn and Pinder, 1983). To reduce the oscillations, "the use of an upstream-weighted finite element technique" (ibid) is applied. "It should be noted, however, that this upstream weighting, like all upstream-weighted finite difference techniques, curbs numerical oscillations by introducing numerical dispersion and thus leads to smearing of the concentration front" (ibid).

The contaminant transport equation consists of both an advection term and a dispersion term that causes the problem. For upstream weighting, as applied in PORFLOW (ACRi, 1998), "the solution of the advection term is only accurate to the first order and as a result, it can lead to significant numerical dispersion when applied to advection-dominated problems, since the truncation error resulting from the advection solution is of the same order and could overwhelm the second-derivative physical dispersion term" (Zheng and Wang, 1998). "The numerical solution adds a purely

numerical dispersion to the real phenomenon of hydrodynamic dispersion and this increases the total dispersion of the solute in the medium erroneously" (de Marsily, 1986).

If numerical dispersion smears contamination from a concentration front across an interface with a small neighboring cell, then little accuracy is lost. As the size of the interface with the neighboring cell increases, the accuracy decreases. Thus, in this study, numerical dispersion was investigated by refining the mesh (creating smaller cells) and comparing the results to those of the original mesh. A full investigation of numerical dispersion would require continued refinements of the mesh size until no substantial differences between successive meshes could be detected, but such an investigation is beyond the scope of this work effort.

The investigation used two refined meshes. The first new mesh consisted of cells that were half the original size in both the X and Y horizontal directions. The second new mesh consisted of cells that were half the original size in the Z, or vertical direction. Two meshes were generated because halving the mesh size in all three directions would have created a mesh with a very high number of cells requiring excessive computer run times.

Both I-129 and Tc-99, as in the original models, were analyzed using each new mesh. The analyses were conducted for the 4-pack consisting of Tanks 17-20 in the F-farm. Results from these analyses serve as an indicator of the expected results from all analyses.

Peak concentrations at seeplines in both the old and new models are presented in Tables 3.1.1 to 3.1.4 for comparison. The tables include the ratios of the new-to-old results and differences in time when the peaks occurred.

Table 3.1.1. Comparison of Tc-99 Seepline Concentrations from Horizontally-Refined Model with Seepline Concentrations from Original Multi-Dimensional Model

Seepline Location[1]		Original Model		Horizontally-Refined Model		Comparison	
X	**Y**	**Peak Conc.**	**Time**	**Peak Conc.**	**Time**	**New Conc./ Old Conc.**	**New Time- Old Time**
3100	8200	2.59	6337	4.99	6327	1.93	-10
3100	8400	2.20	6342	4.01	6339	1.82	-3
3300	8600	1.70	6337	2.13	6329	1.25	-8
3100	8000	1.70	6319	5.07	6277	2.98	-42
2900	8400	1.68	6345	4.01	6339	2.39	-6
3300	8200	1.66	6325	3.95	6319	2.38	-6
3100	8600	1.65	6347	2.80	6331	1.70	-16
3300	8400	1.61	6331	3.04	6329	1.89	-2
2900	8600	1.46	6355	2.00	6347	1.37	-8
2500	8400	1.44	6355	1.26	6367	0.88	12

[1]Seepline locations with 10 highest concentrations in original model presented

Table 3.1.2. Comparison of I-129 Seepline Concentrations from Horizontally-Refined Model with Seepline Concentrations from Original Multi-Dimensional Model

Seepline Location[1]		Original Model		Horizontally-Refined Model		Comparison	
X	**Y**	**Peak Conc.**	**Time**	**Peak Conc.**	**Time**	**New Conc./ Old Conc.**	**New Time- Old Time**
3100	8200	7.48E+04	1355	1.44E+05	1349	1.93	-6

3100	8400	6.36E+04	1361	1.16E+05	1361	1.82	0
3300	8600	4.91E+04	1353	6.15E+04	1349	1.25	-4
3100	8000	4.91E+04	1339	1.46E+05	1351	2.98	12
2900	8400	4.85E+04	1361	1.16E+05	1361	2.39	0
3300	8200	4.78E+04	1343	1.14E+05	1341	2.38	-2
3100	8600	4.77E+04	1363	8.07E+04	1351	1.69	-12
3300	8400	4.64E+04	1347	8.78E+04	1349	1.89	2
2900	8600	4.20E+04	1371	5.79E+04	1363	1.38	-8
2500	8400	4.16E+04	1373	3.64E+04	1375	0.87	2

[1]Seepline locations with 10 highest concentrations in original model presented

Table 3.1.3. Comparison of Tc-99 Seepline Concentrations from Vertically-Refined Model with Seepline Concentrations from Original Multi-Dimensional Model

Seepline Location[1]		**Original Model**		**Vertically-Refined Model**		**Comparison**	
X	**Y**	**Peak Conc.**	**Time**	**Peak Conc.**	**Time**	**New Conc./ Old Conc.**	**New Time-Old Time**
3100	8200	2.59	6337	3.10	6327	1.20	-10
3100	8400	2.20	6342	2.77	6333	1.26	-9
3300	8600	1.70	6337	2.08	6327	1.22	-10
3100	8000	1.70	6319	1.40	6313	0.82	-6
2900	8400	1.68	6345	2.20	6335	1.31	-10
3300	8200	1.66	6325	1.38	6315	0.83	-10
3100	8600	1.65	6347	2.10	6337	1.27	-10
3300	8400	1.61	6331	1.83	6321	1.14	-10
2900	8600	1.46	6355	1.92	6343	1.32	-12
2500	8400	1.44	6355	1.80	6345	1.25	-10

[1]Seepline locations with 10 highest concentrations in original model presented

Table 3.1.4. Comparison of I-129 Seepline Concentrations from Vertically-Refined Model with Seepline Concentrations from Original Multi-Dimensional Model

Seepline Location[1]		**Original Model**		**Vertically-Refined Model**		**Comparison**	
X	**Y**	**Peak Conc.**	**Time**	**Peak Conc.**	**Time**	**New Conc./ Old Conc.**	**New Time-Old Time**
3100	8200	7.48E+04	1355	8.93E+04	1349	1.19	-6
3100	8400	6.36E+04	1361	8.00E+04	1357	1.26	-4
3300	8600	4.91E+04	1353	6.00E+04	1349	1.22	-4
3100	8000	4.91E+04	1339	4.03E+04	1331	0.82	-8
2900	8400	4.85E+04	1361	6.35E+04	1359	1.31	-2

3300	8200	4.78E+04	1343	3.99E+04	1335	0.84	-8
3100	8600	4.77E+04	1363	6.06E+04	1361	1.27	-2
3300	8400	4.64E+04	1347	5.27E+04	1341	1.14	-6
2900	8600	4.20E+04	1371	5.54E+04	1369	1.32	-2
2500	8400	4.16E+04	1373	5.18E+04	1371	1.24	-2

[1]Seepline locations with 10 highest concentrations in original model presented

Table 3.1.1 shows that the new Tc-99 concentrations for a horizontally-refined mesh are about twice those for the original multi-dimensional mesh. Table 3.1.2 shows that the ratio of new-to-old I-129 concentrations for a horizontally-refined mesh are essentially identical to those for Tc-99. The times when the peaks occurred did not vary substantially between the original and the refined-mesh models. The last entry in the first two tables indicates a lower peak concentration for the refined mesh than for the original mesh. This occurs because the refined mesh tends to narrow the width of the contaminant plume. With the same amount of mass, locations within the heart of the plume receive more contamination, while locations outside receive less contamination.

Table 3.1.3 shows that the new Tc-99 concentrations for a vertically-refined mesh are about twenty-five percent higher than those for the original mesh. Table 3.1.4 shows similar behavior for I-129. The times when the peaks occur for the vertically-refined mesh are very close to those for the original mesh. Two entries each in Table 3.1.3 and Table 3.1.4 have new-to-old ratios below unity that indicate locations where the peak concentration for the vertically-refined mesh is less than that for the original mesh.

The total effects of numerical dispersion are a combination of the horizontal and vertical numerical dispersions. These results do not show the full effects of numerical dispersion, but they do show that reducing numerical dispersion at least increases the highest peak concentrations by a factor of about 2.5 when comparing seepline concentrations versus earlier multi-dimensional models.

Significant numerical dispersion indicates that an even more refined mesh is needed to produce more accurate results. Refinements of the mesh can continue until results become much less sensitive to the size of the cells. A second approach is to employ a different transport solution method that produces less numerical dispersion.

In the first approach, the ultimate mesh may contain so many cells that solution of the transport equations requires an impractical amount of time when all the contaminants of interest are considered for all the tanks. The computer time is increased due to the finer mesh and the need for smaller time steps when using a finer mesh. For example, the wall-clock runtime increased from 6 hours to 38 hours for Tc-99 in the horizontally-refined mesh. Alternatively, a solution with a highly-refined mesh may be used to establish a factor to account for numerical dispersion. Other contaminants could be analyzed with the coarser model, then the results could be multiplied by the numerical dispersion factor. Before adopting such a method, several contaminants would need to be analyzed with both the coarse and the highly-refined meshes to ensure that the numerical dispersion factor was consistent for different contaminants.

The second approach would be to employ a solution method such as the Discrete Parcel Random Walk (DPRW) (de Marsily, 1986) or a total-variation-diminishing (TVD) method (Zheng and Wang, 1998). These methods may reduce the amount of numerical dispersion, but they can introduce other problems as discussed below.

The random walk solution involves placing many particles in cells to represent the mass of contaminant present. The concentration can then be calculated by dividing the mass of contaminant by the volume of water in the cell. However, the concentration is not used in transport calculations, so numerical dispersion is eliminated.

The particles are placed in the cells, then they are displaced by the velocity of the flow and by a random selection of dispersion. Thus the random walk represents Brownian motion which is known to be responsible for molecular diffusion. "The DPRW method is, however, unstable when the number of particles is increased: the solution oscillates and must be smoothed. Therefore it is not very accurate" (de Marsily, 1986).

Another promising solution method is the third-order total-variation-diminishing (TVD) scheme for solving the advection term. TVD refers to the property "that the sum of concentration differences between adjacent nodes diminishes over successive transport steps, a necessary condition if the transport solution is to remain largely free of spurious oscillations. The TVD methods are essentially higher-order finite-difference (or finite-volume) methods, and as such, they belong to the Eulerian family of solution techniques and are inherently mass conservative. Because a higher order method usually minimizes numerical dispersion at the expense of introducing spurious oscillations, TVD schemes are typically implemented with numerical procedures (termed flux limiters) to suppress or eliminate spurious oscillations while preserving the sharp concentration fronts. Compared to the standard finite-difference method with either upstream or central-in-space weighting, TVD schemes are generally much more accurate in solving advection-dominated problems, albeit with a greater computational burden" (Zheng and Wang, 1998).

The TVD scheme can be utilized either by modifying PORFLOW or by adopting another program. Another section of Westinghouse recently purchased the MT3DMS program authored by Zheng and Wang (1998). An interface program that converts FACT information to the MT3DMS format (similar to the program that converts FACT output to the PORFLOW, ACRi, 1998, format) would be required before using MT3DMS. MT3DMS also offers a dual porosity model that could more accurately represent contaminant movement in the subsurface.

3.2 Solubility-Limited Case

In cementitious environments U and Pu are solubility limited. Thus, in a grout-filled tank, the release of U and Pu will be controlled by their solubility limits. For such cases, the actual inventory, rather than a nominal unit curie inventory must be modeled. Models for Tank 17 were developed using actual inventories (DOE, 1997). Because an inventory for U-238 was not specified in the report, all the U listed as a chemical constituent was assumed to be U-238. Peak results are presented in Table 3.2.1 and Table 3.2.2 for U-238 and Pu-240, respectively.

Table 3.2.1. Seepline Concentrations for Solubility-Limited U-238

X[1]	Y	Peak Conc. (pCi/L)	Time (years)
3100	8000	6.59E-10	10000
3300	8200	4.79E-10	10000
3300	8000	4.74E-10	10000
2900	8200	4.10E-10	10000
2900	8000	3.81E-10	10000
3100	8200	3.68E-10	10000
3500	8200	3.40E-10	10000
3300	8400	3.38E-10	10000
3500	8400	2.92E-10	10000
3500	8600	2.75E-10	10000

[1]Seepline locations with 10 highest concentrations presented

Table 3.2.2. Seepline Concentrations for Solubility-Limited Pu-240

X[1]	Y	Peak Conc. (pCi/L)	Time (years)
5300	7800	1.77E-13	10000
5300	8000	1.58E-13	10000
5100	8000	8.26E-14	10000
5300	8200	7.24E-14	10000
5100	8200	4.88E-14	10000
5100	7800	3.91E-14	10000
5100	8600	5.37E-14	10000
5100	8800	4.15E-14	10000
4900	8800	2.38E-14	10000
5100	7600	2.10E-14	10000

[1]Seepline locations with 10 highest concentrations presented

Results for U-238 show a maximum peak of 6.6E-10 pCi/L with the tenth highest peak falling to about 2.8E-10 pCi/L. The concentration limit for U-238 from the Performance Assessment (McDowell-Boyer, et. al, 2000) was 6.7 pCi/L. U-238 from Tank 17 is 10 orders of magnitude below the Performance Assessment concentration limit.

Results for Pu-240 show a maximum peak of 1.8E-13 pCi/L with the tenth highest peak falling to about 2.1E-14 pCi/L. The concentration limit for Pu-240 from the Performance Assessment (McDowell-Boyer, et. al, 2000) was 8.1 pCi/L. Pu-240 from Tank 17 is 13 orders of magnitude below the Performance Assessment concentration limit.

Figure 1 shows the Pu-240 concentration history for the seepline locations that exhibited the 10 highest concentrations. Figure 2 shows the U-238 concentration history for the seepline locations that exhibited the 10 highest concentrations.

3.3 Database Plan as part of the Rapid Screening Tool and Start of Implementation

The Rapid Screening Tool uses an expedited approach to determine peak concentrations when the only changes involve nuclide inventories in tanks. Other components of the model may change, but are typically assumed to be constants. For example, the rate of recharge and the elevation of the water table likely vary on a daily basis, but these changes are ignored in light of the larger uncertainties in trying to predict conditions and effects over a 10,000-year time frame.

The algorithm for the Rapid Screening Tool is shown in Figure 3. One curie of a specific nuclide is input as the inventory of a tank, e.g., Tank A. That model is run and the concentration at each seepline location is recorded as its unit response. The final response at each seepline location for Tank A is the unit response multiplied by the final inventory of Tank A. The same steps are followed for Tank B and any other tanks.

At a specific seepline location, the concentration created by the final inventory of a specific nuclide in Tank A is calculated by dividing the curies of that nuclide at that seepline location by the volume of water at that seepline location. The same calculation is performed for the final inventory in Tank B. The total concentration at that seepline location is calculated by summing the curies from Tank A and Tank B, then dividing by the volume of water.

However, the total concentration can be calculated by summing the concentration from Tank A with the concentration from Tank B. This total concentration is equivalent, because the identical water molecules are used to calculate the concentrations for Tank A (assuming Tank B does not exist), Tank B (assuming Tank A does not exist), and the total concentration.

The Rapid Screening Tool uses rapid, spreadsheet-like calculations to predict the responses for any tank inventory combination. Thus, if expected clean-up levels are not attained in a single tank, an assessment can be made to help determine the best course of action. For example, more cleaning of that tank can be conducted or other tanks could be cleaned more thoroughly. Alternatively, if a specific nuclide resists cleaning and its residuals are higher than expected in several tanks, then reanalysis of all tanks can be rapidly conducted. Specific contaminants can be targeted for more aggressive cleaning and the total effects of such a campaign, if effective, can be rapidly determined.

While this method is simple in concept, it can be database intensive. For example, if 1,000 seepline locations are identified and results for 20 contaminants are stored for every 2 years of a 10,000-year simulation period, then 100 million concentrations must be stored for each tank. With 51 tanks, the total storage required is about 5 billion concentrations or 10 gigabytes of storage for the lowest level of numerical precision.

A more economical plan is to store a minimal set of concentrations that sufficiently simulates the concentration history curve at each seepline location. Because the concentration history curves generally exhibit gradual slope changes, 25 points typically are expected to suffice, but in some cases 50 points may be required. This approach reduces the storage from 5,000 records to 50 for each concentration history curve. However, each record is twice as large because the time must be recorded with the concentration. Thus the overall size of the database is reduced by a factor of 50 and possibly 100, producing a storage requirement of 200 megabytes that is large, but manageable.

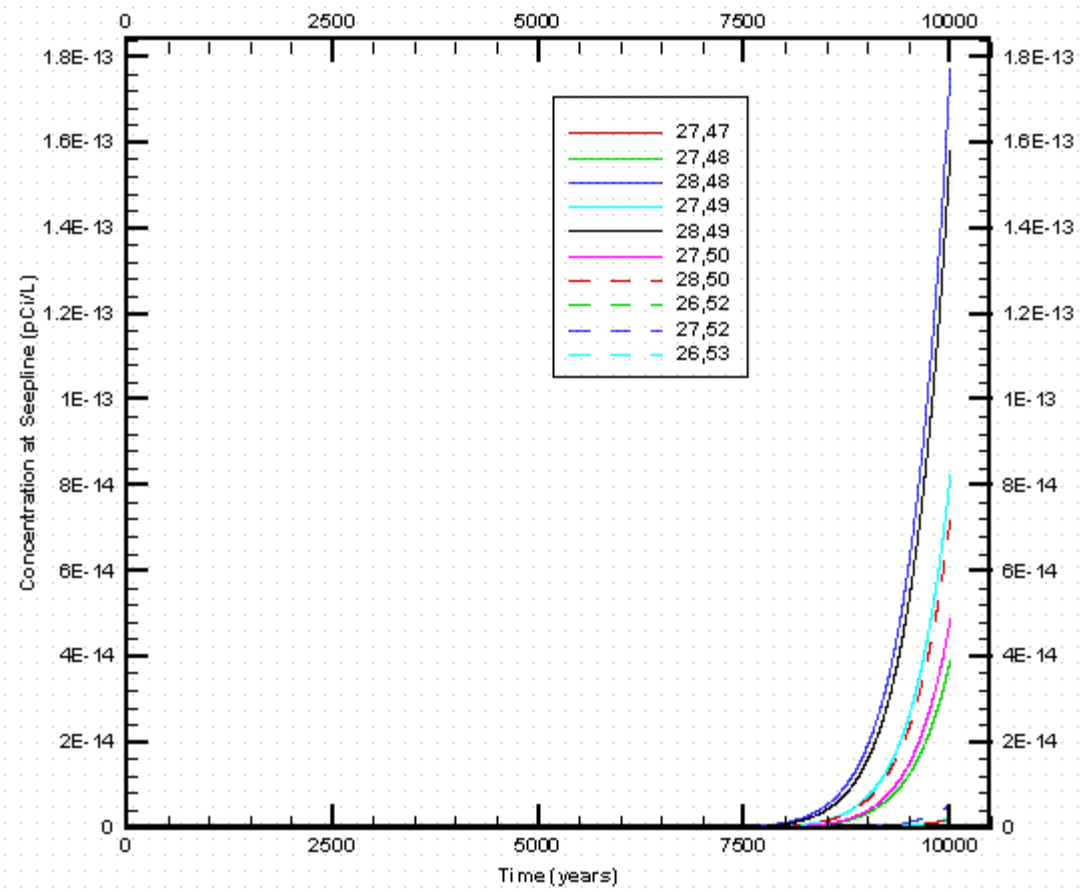

Figure 1. Pu-240 Concentrations at Seeplines – Top 10 for 3.3 Ci in Tank 17

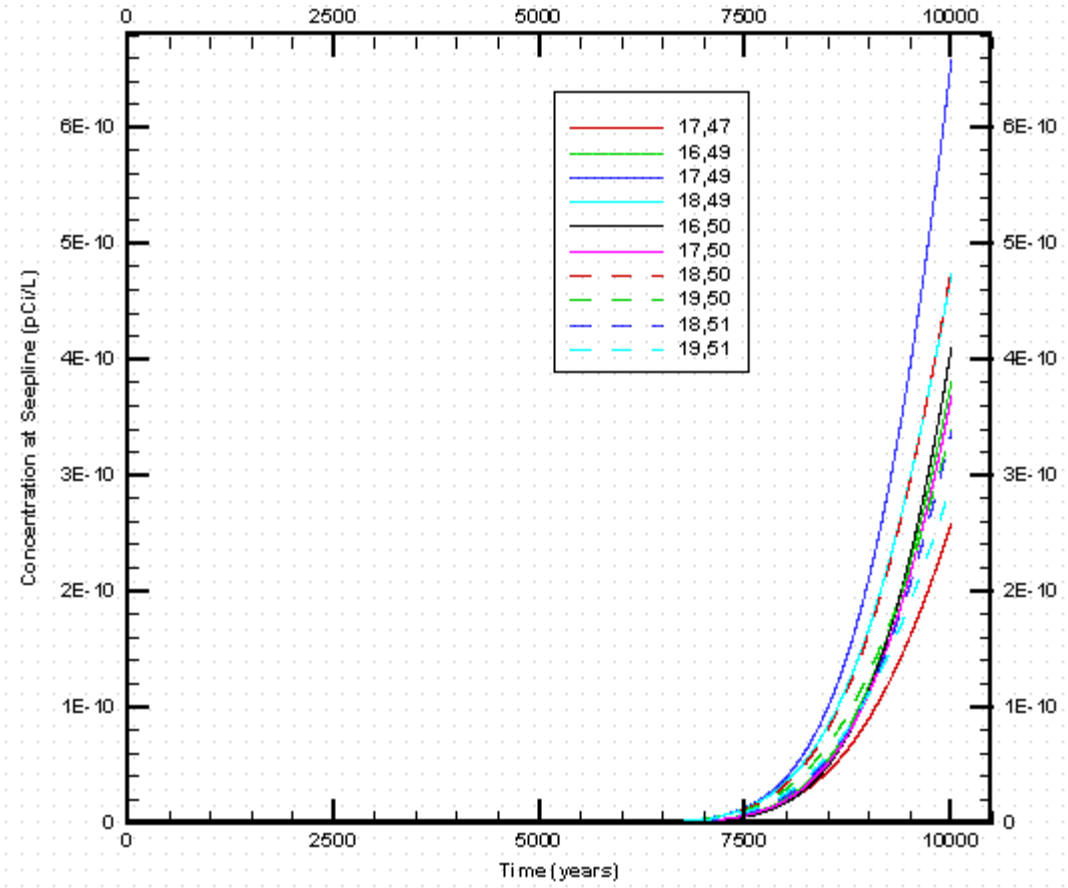

Figure 2. U-238 Concentrations at Seeplines – Top 10 for 0.188 Ci in Tank 17

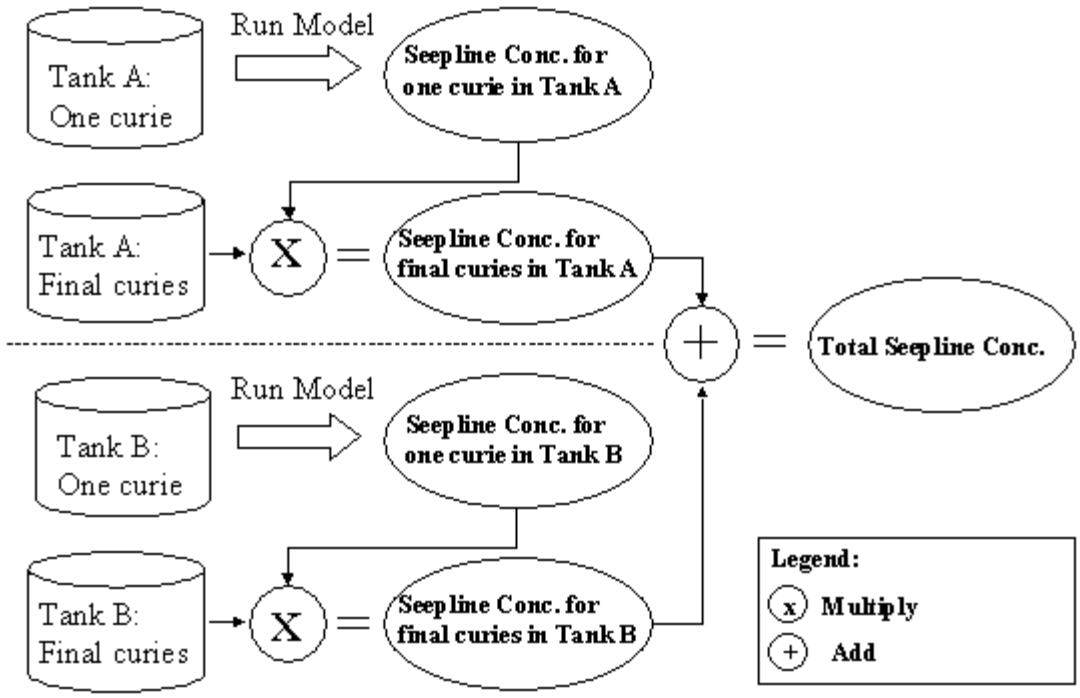

Figure 3. Algorithm for Rapid Screening Tool

The database is designed as a series of files. The hierarchy of the files is as follows:

Directory for F-Area Tank Farm (repeated for H-Area Tank Farm)

- Identifying Tag for each Nuclide
- Identifying Tag for each Computer Run
- Identifying Tag for and order that each Seepline Location was written to Database
- Subdirectory for a Specific Nuclide (repeated for each nuclide)
    - Order that each Tank was written to Database (identifying tag is tank number)
    - Concentration History Database

The directory level of files identifies the tank farm. Separate models were established for each tank farm, hence separating results by tank farm was a logical choice.

Each record stored in the database includes information that identifies the nuclide, computer run, tank, and seepline location. Tag files within the tank farm directory contain short, numerical identifiers for nuclides, descriptions of computer runs, and seepline locations. The tag files help reduce overall storage requirements, while serving to preserve data integrity.

The tag file for the seepline location also indicates the order that each seepline location curve was written to the file. This order is not allowed to change, so that data is consistent. The programs do not allow a user to change only one seepline location curve, but requires all seepline location curves for a single computer run to be added or replaced at the same time.

The database files containing the concentration time histories consist of binary records to reduce storage requirements. Those files are directly (rather than sequentially) retrievable to avoid needing to read the entire database every time a report is desired. The database files are in each nuclide subdirectory. Accompanying the database files are the tank order files indicating the order in which the tanks were written to the specific nuclide database.

3.3.1 Data Reduction

After each PORFLOW (ACRi, 1998) run, information must be extracted and reduced to the 50 points or less that describe the concentration history curve. An algorithm has been developed and coded to reduce the raw data to the 50 points that describe the curve.

In the first pass, the algorithm selects and stores the peak concentration. In the second pass, the algorithm selects and stores all local maxima and minima where the slope passes through zero. In the third pass, the algorithm selects and stores concentrations along the upslopes and downslopes where the slope rapidly changes. The user controls the slope variation selection process by providing a tolerance. In the fourth and final pass, the algorithm reduces time gaps by selecting filler points to obtain a total of 50 points.

3.3.2 Data Integrity

As described above, the 50 data points must be combined with an identifying tag to help insure data integrity. The program has been written and tested to input the 50 points into the database. In addition to the identifying tag, other safeguards, such as forcing all seepline location information to be written or rewritten in a single computer run, were built into the program to help prevent the introduction of erroneous information into the database.

3.3.3 Remaining Database and Rapid Screening Tool Work Efforts

A database with projected tank inventories is needed to allow calculation of final responses from individual tanks and total responses from all tanks. Auxiliary programs may be required to help populate that database. Many PORFLOW runs are required to populate the concentration history database.

It may be possible to reduce the size of the database by eliminating some seepline locations. If the concentration at Seepline A is always less than the concentration at Seepline B, then there is no need to preserve information for Seepline A. If this relationship of concentrations can be demonstrated for each tank modeled independently, then it will be true for all combinations of tanks. Thus, one must essentially first build the full database, then reduce it after examining the concentration relationships between each set of two seepline locations.

Programs are required to select information from the concentration history database and the tank inventory database and to produce reports. The programs must process information from both databases to calculate the final response at each seepline location. The programs must allow the user to input proposed tank inventories to help determine the effect of different levels of cleanup.

A post-data-reduction algorithm must be developed to determine how well the 50 points can back-predict the original curve. Expectations are that there will be less than a 1 percent error in the back-predictions.

4.0 Summary and Conclusions

Numerical dispersion was investigated and was found to be reducing peak concentrations by at least a factor of 2.5. Further modeling refinements can be made, but computational limitations probably mean that the full extent of numerical dispersion can never be determined. Alternative contaminant-transport solution schemes can be adopted, although they will require either upgrading PORFLOW (ACRi, 1998) or using another computer program, such as MT3DMS (Zheng and Wang, 1998).

Solubility-limited models were established for U-238 and Pu-240 and were executed. As expected, seepline concentrations were well below concentration limits. Extension of this model to other tanks and other solubility-limited nuclides can be readily accomplished as the need arises.

Development of the Rapid Screening Tool was advanced. Files and file system layouts and relationships were established. An algorithm was developed and separately programmed to reduce concentration history curves, or any continuous curve, to a series of not more than 50 points. The algorithm examines and captures peaks and significant slope changes. A computer program was developed and tested to populate the concentration database. Other needs to complete the Rapid Screening Tool were identified.

The development of the Rapid Screening Tool has been independent of actual modeling results. However, before starting to populate the concentration database, final decisions on models must be established. Changes to the underlying models would require completely repopulating the concentration history database. Hence, all parties must be satisfied with the underlying models before proceeding. One decision involves how to handle numerical dispersion. Other decisions involve inspecting the models with their assumptions and material properties to determine if they are fully acceptable.

5.0 References

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