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Modeling of Tritium Annual Flux from Concrete Rubble Buried in the Slit Trenches at the Savannah River Site (U)

by

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Modeling of Tritium Annual Flux from Concrete Rubble Buried in the Slit Trenches at the Savannah River Site

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Abstract

Some of the concrete rubble generated from the demolition and destruction of some facilities at the U.S. Department of Energy (DOE) Savannah River Site (SRS) contains tritium. The tritium-bearing rubble will be disposed in the E-Area slit trenches. In the past, it was assumed for Performance Assessment (risk) modeling that tritium leached from concrete as if the tritium existed entirely on the concrete surfaces. Although conservative (i.e., overestimates risk associated with the groundwater pathway), this assumption does not account for the slow diffusion of tritium from the inside to the outside of the concrete rubble. The objective of this modeling study was to include the diffusion process in tritium annual flux calculations for use in future Special Analyses or Performance Assessments involving the concrete rubble. Our approach was to: 1) Calculate tritium diffusion, dispersion, and advective transport within and external to particles of varying size, 2) Assume a particle size distribution of the concrete rubble based on measurements taken of an existing rubble pile, and 3) Calculate an annual fractional flux of tritium (in units of Ci/yr·Ci) from the hypothetical rubble to the underlying aquifer. Annual fractional flux values provide modelers the flexibility to vary the tritium inventory for the scenario of interest. This paper discusses the general modeling approach and presents the study results.

INTRODUCTION

A growing amount of concrete containing tritium is being generated as a result of on-going demolition and destruction activities at the SRS. To assist in determining how much radioactive low-level waste (such as the tritiated concrete) can be safely disposed, performance assessments are conducted. As a common practice in the past, these calculations assumed that all the tritium associated with buried concrete existed on the exterior concrete surfaces. Although this is a conservative assumption with respect to the groundwater pathway, it is not accurate.

The objective of this study was to more accurately model tritium release from concrete rubble. Particular attention was directed at incorporating tritium diffusion from the concrete rubble into the surrounding groundwater.

MODEL DEVELOPMENT

Modeling Approach

PC-based PORFLOW™ software Version 5.96, a product of Analytic & Computational Research, Inc. (ACRi), was used in these simulations. PORFLOW™ solves problems involving transient and steady-state fluid flow, heat and mass transport in multi-phase, variable saturation conditions, porous or fractured media flow, and dynamic changes in phases. The porous/fractured media may be anisotropic and heterogeneous. Arbitrary sources (injection or pumping wells) may be present, and chemical reactions or radioactive decay may take place in the model (ACRi, 2002). PORFLOW™ has been widely used at the SRS and in the DOE complex to address major issues related to the groundwater and radioactive waste management.

To obtain the tritium diffusion flux released from concrete waste blocks in the slit trenches, fractional fluxes for concrete blocks of a given size distribution were calculated. Individual flux of a given size was calculated by flow and transport simulations of this single block placed in the trench. A composite fractional flux was generated from these individual fluxes and the overall block size distribution. The composite calculation also included tritium radioactive decay. The composite flux is assumed to adequately represent the total actual tritium release.

Assumptions

The following major assumptions were made in the PORFLOW™ simulations:

- The Trench Disposal Unit was assumed to be adequately represented in a two-dimensional model as in the previous performance assessment calculations (McDowell-Boyer et al., 2000).

- Water infiltration at the top of the domain was 40 cm/yr.
- Longitudinal and transverse dispersivities were zero.
- Negligible tritium sorption occurred on the solids.
- Tritium diffusion flux obtained by simulations of a single concrete waste block at different sizes was additive, i.e., effects of cluster of waste blocks were not considered.
- Tritium contamination was uniformly distributed through the concrete block (Hochel and Clark, 2002).

Conceptual Model

The physical conceptual model to describe the materials, layout, and dimensions of the slit trenches is illustrated in Figure 1. Tritium diffusion was modeled for the first 25 years, during which time waste was assumed to be placed in the trenches and covered with backfill soil, no horizontal barrier (cap) was in place. Water infiltration at the top of the modeling domain was set to 40 cm/yr.

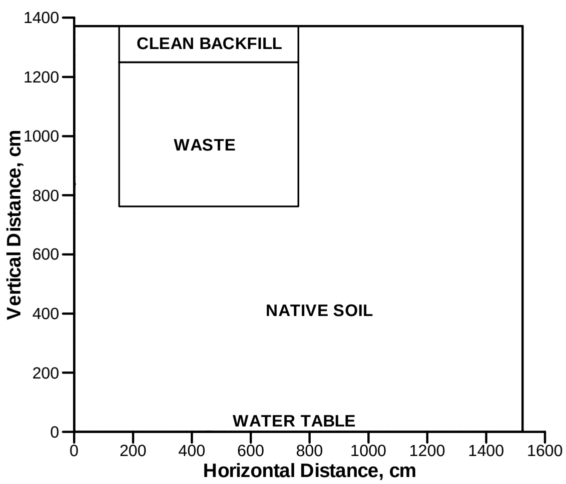


Figure 1. Conceptual model

The modeling grid used for the simulations is displayed in Figure 2. In order to provide numerical stability the meshes had a gradual transition from wider grids to narrower grids near the boundaries and where there are changes in material properties. The dark bands represent the narrow grids where the hypothetical concrete waste existed. A blowup of Figure 2, containing a 2cm x 1cm concrete block, is presented in Figure 3.

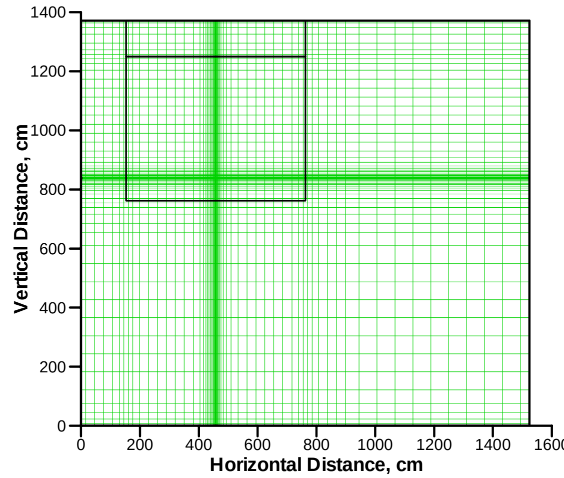


Figure 2. Modeling grid

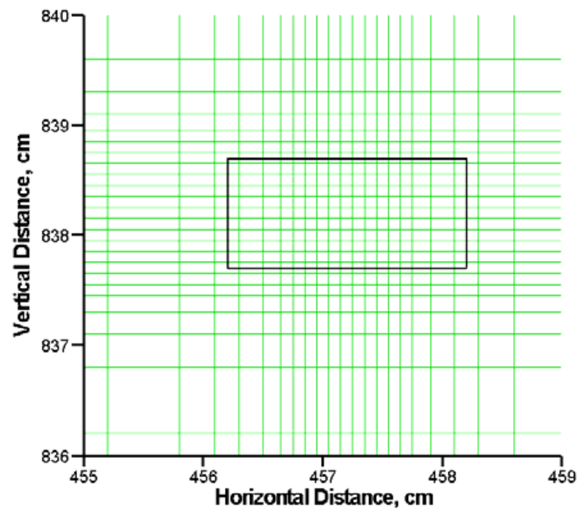


Figure 3. 2cm x 1cm concrete waste block

The material properties used in the PORFLOW™ simulations are listed in Table 1.

Table 1. Model input values for materials

	Density (g/cm^3)	Porosit y	Diffusion Coefficient (cm^2/yr)
Waste	2.65	0.38	158
Clean backfill	2.65	0.51	158
Native soil	2.65	0.42	158
Concrete	2.65	0.20	158

In each simulation, a concrete waste block of a given size was first placed into the fine mesh region of the waste trench. A steady-state flow field was generated by running the flow simulation for 3000 years. For illustration, Figure 4 shows the flow field obtained in the simulation of a 2cm x 1cm concrete block. The steady-state flow field was then used in the subsequent transport simulation. In each transport simulation, an initial inventory of 1 Ci of tritium was assumed for each waste block. Once the annual fractional tritium release rate was calculated for each of the waste block sizes, a composite flux could be determined for a hypothetical concrete rubble pile buried in the E-area slit trench. This was done by summing the annual fluxes estimated for each block size after they had been weighted to reflect the block size distributions observed in an actual concrete rubble pile.

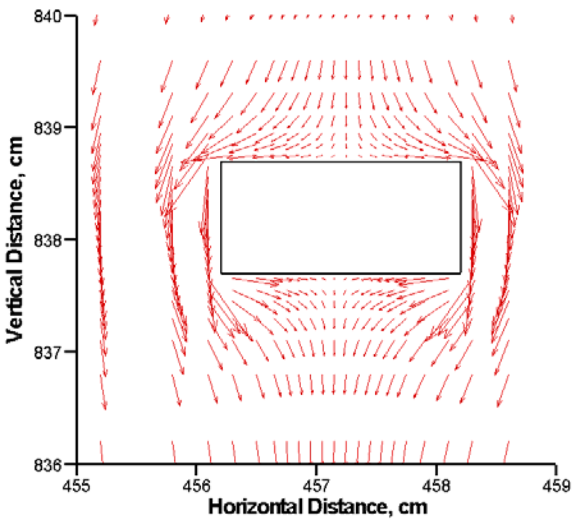


Figure 4. Flow simulation of 2cm x 1cm concrete block

ESTIMATION OF CONCRETE RUBBLE SIZE DISTRIBUTION

The particle size distribution was measured for an existing concrete rubble pile. This concrete rubble was generated during the demolition of a large concrete saddle and did not contain tritium. A 10ft x 20ft section of the concrete rubble pile was selected as a representative study area. A smaller 3ft x 3ft subsection of the larger study area was selected as representative of the smaller fraction of rubble mixed with soil. It was estimated that the 3ft x 3ft subsection represented approximately one fifth of the total amount of smaller rubble and soil within the larger 10ft x 20ft study area. For size estimation, large blocks of concrete were measured in three dimensions in order to determine the approximate volume of each. Small concrete pieces were weighed and sieved. Concrete density was used in order to calculate the percent by volume of each fraction.

Two estimated particle size distributions were developed based on these studies. The first distribution was based on the particle size distribution of the concrete rubble in the entire 10ft x 20ft study area (using the 3ft x 3ft area to estimate the smaller rubble distributed over the entire area). This particle size distribution is considered to be the "Best-Estimate" block size distribution and accounts for both the large and smaller concrete blocks. The second distribution was based only on the particle size distribution of concrete in the 3ft x 3ft study area. The smaller study area is considered a conservative estimate based only on the size distribution of the smaller concrete rubble generated during demolition. The two distributions are given in Tables 2 and 3.

Table 2. Best-estimate particle size distribution of concrete in the 10ft x 20ft study area

Fraction	Length (cm)	Width (cm)	Vol %
1	0.4	0.2	3.48
2	1.2	0.6	0.04
3	2	1	0.11
4	16	8	1.95
5	60	30	94.42
	Total		100

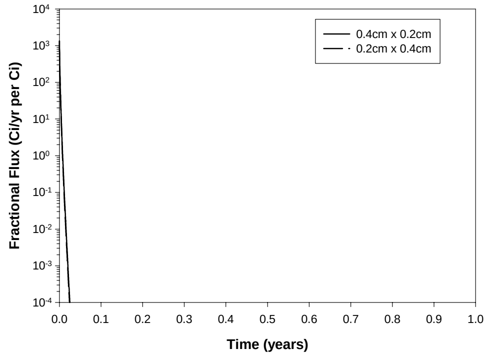
Table 3. Small block particle size distribution within the 3ft x 3ft study area

Fraction	Length (cm)	Width (cm)	Vol %
1	0.4	0.2	19.28
2	1.2	0.6	4.02
3	2	1	12.37
4	16	8	64.33
5	60	30	0.0
	Total		100

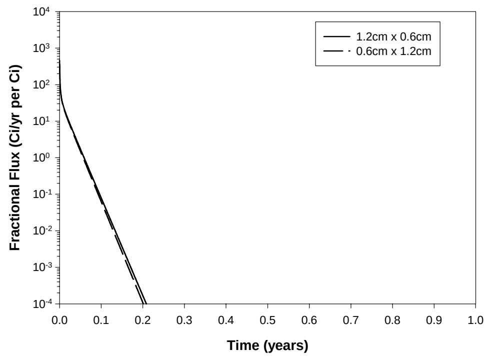
RESULTS

The fractional annual tritium fluxes from the five modeled block sized are presented in Figure 5. In these simulations an initial tritium inventory of 1Ci was assumed. The results show that the block position (e.g., 0.4cm x 0.2cm vs. 0.2cm x 0.4cm) has negligible effect on the tritium flux. As block size increased, the duration increased before the entire 1Ci tritium inventory had diffused out of the blocks and had traveled by dispersion and advection through the vadose zone into the underlying aquifer. For the three smallest block sizes (i.e., 0.4cm x 0.2cm, 1.2cm x 0.6cm, and 2cm x 1cm), the entire tritium inventory depleted within one year. The two larger blocks required several years to deplete the tritium inventory.

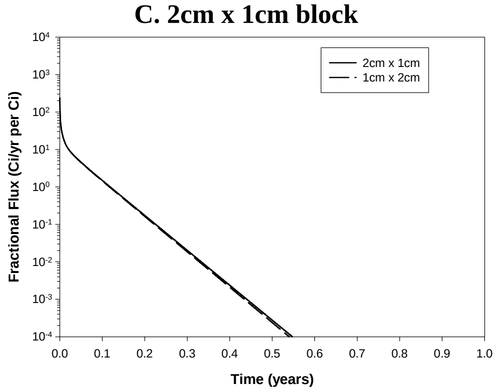
A. 0.4cm x 0.2cm block



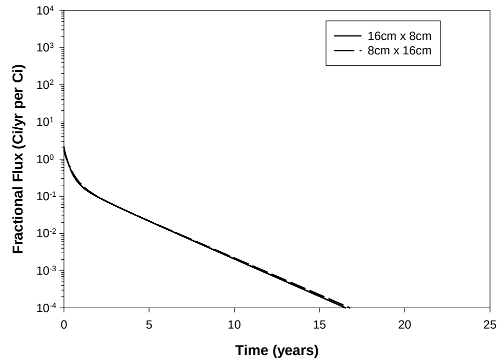
B. 1.2cm x 0.6cm block



C. 2cm x 1cm block



D. 16cm x 8cm block



E. 60cm x 30cm

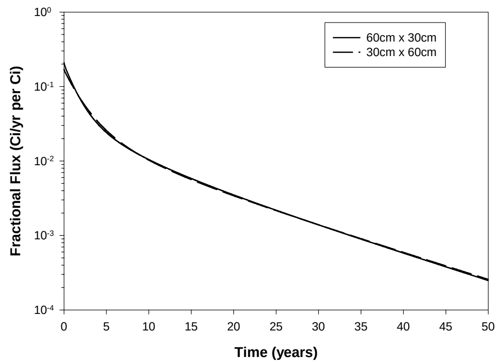


Figure 5. Fractional flux of tritium

The composite fractional flux of tritium for the best-estimate and the smaller (conservative) block size distributions are presented in Figure 6. The smaller block size distribution reflects an arbitrary conservative estimate in which the largest block size (i.e., the 60cm x 30cm blocks) was excluded from the transport calculation. The results differ substantially, in that the best-estimate scenario containing the largest class of blocks produced a much slower annual flux.

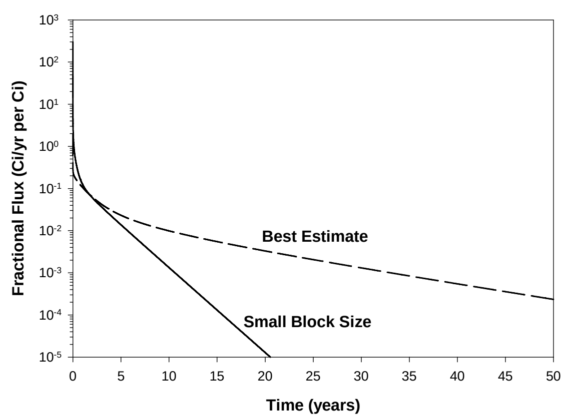


Figure 6. Composite fractional flux of tritium for the best-estimate block size distribution and the small block size distribution

Figures 7 and 8 were created from the same data used to create Figure 6, but were expressed in terms of cumulative radioactivity lost due to transport (diffusion and advection) and decay. For the best-estimate scenario (Figure 7), ~90% of the tritium either decayed or was transported from the concrete rubble after 20 years. Of this 90% tritium loss, about 50% was due to transport, whereas the remaining 40% was due to decay. The loss due to transport was important during the initial 10 years. Afterwards, the two processes were equally important for controlling tritium concentrations. In the scenario consisting of a small block size distribution (Figure 8), 98% of the tritium was lost after only 2.2 years, and not surprisingly, transport was the most important process controlling tritium concentrations in the system.

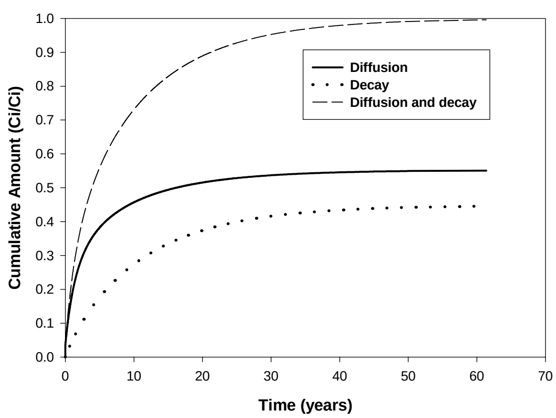


Figure 7. Cumulative loss of tritium from concrete blocks with the best-estimate size distribution

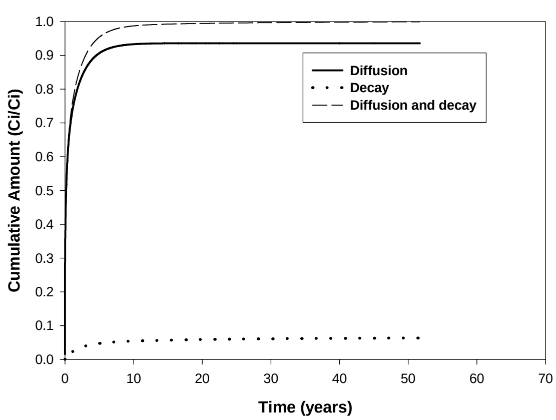


Figure 8. Composite loss of tritium from concrete blocks with a small block size distribution

CONCLUSIONS

Simulations showed that for the best-estimate of concrete block size distribution ~90% of the tritium either decayed or was transported out of the concrete rubble within 20 years. Of this 90% tritium loss, about 50% was due to transport, whereas the remaining 40% was due to decay. Loss due to transport was more important during the initial 10 years. Afterwards, the two processes were equally important for controlling tritium concentrations.

This paper provides a first approximation quantifying tritium diffusion from concrete particles into groundwater. Additional work needs to be directed at quantifying the block size distribution of tritium-containing concrete rubble, the influence of inter-block interactions of diffusion process, and uneven distribution of tritium within concrete rubble blocks.

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