**United States Department of Energy**

**Savannah River Site**

# Streamtube Fate and Transport Modeling of the Source Term for the Old Radioactive Waste Burial Ground Savannah River Site, Aiken, South Carolina (U)

**WSRC-RP-99-4215**

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**Prepared by:**
**Westinghouse Savannah River Company**
**Savannah River Site**
**Aiken, SC 29808**

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**Title:** **Streamtube Fate and Transport Modeling of the Source Term for the Old Radioactive Waste Burial Ground, Savannah River Site, Aiken, South Carolina (U)**

**Author:**

______________________________ ____________

**Kevin Brewer, Ph.D.** **Date**
**Fate and Transport Analysis Group**
**Site Geotechnical Services Department**
**Project, Engineering, and Construction Department**

**Technical Reviewer:**

______________________________ ____________

**Jeff Thibault** **Date**
**Site Characterization Group**
**Site Geotechnical Services Department**
**Project, Engineering, and Construction Department**

**Approval:**

______________________________ ____________

**Elizabeth Topp** **Date**
**Manager, Fate and Transport Analysis Group**
**Site Geotechnical Services Department**
**Project, Engineering, and Construction Department**

## Executive Summary

The modeling described in this report is an extension of previous fate and transport modeling for the Old Radioactive Waste Burial Ground (ORWBG) Corrective Measures Study/Feasibility Study (CMS/FS). The purpose of this and the previous modeling is to provide quantitative input to the screening of remedial alternatives for the CMS/FS for this site. This new modeling was undertaken to help address concerns about some of the assumptions used in the previous modeling, specifically: (1) that the remedial alternative effectiveness was being underpredicted due to the way the vadose zone transport was modeled, and (2) that the allowing of leaching of constituents before the current cover system was in place would reduce the potential future effectiveness of some remedial alternatives.

The current modeling considers the main fate and transport processes as depicted in Figure ES-1. These processes are infiltration of water through the waste, leaching of constituents from the waste form into the vadose zone, fate and transport of constituents as they migrate through the vadose zone, fate and transport of the constituents through the saturated zone, and finally discharge of constituents at the seep line. A "streamtube" approach was used to account for variable distribution of constituents of interest (COIs) in the ORWBG and for flowpaths that vary depending on location in the ORWBG. Rather than performing a single one-dimensional analysis with the entire ORWBG as the source, the modeling involved performing numerous one-dimensional analyses with elements of the ORWBG as independent sources. Summation of the individual streamtube results provides a total picture of the fate and transport from the entire ORWBG.

There are five remedial alternatives modeled: (a) native soil cover without a biological/human barrier, (b) native soil cover with a biological/human barrier, (c) a Resource, Conservation and Recovery Act (RCRA) quality synthetic cap without a biological/human barrier, (d) a RCRA quality clay cap without a biological/human barrier, and (e) a RCRA quality clay cap with a biological/human barrier. The basic differences amongst these alternatives are with the effectiveness of reducing infiltration (with the RCRA clay cap being the most effective), and with the expected life of the reduced infiltration. The expected life of the non-barrier alternatives is assumed to be 100 years (30 years for the RCRA synthetic cap), corresponding to the expected time-frame of institutional controls at the ORWBG. The expected life of the alternatives with the (biological/human) barrier is greater than 1000 years. Specific engineering details of each of these options can be found in the ORWBG CMS/FS. For all alternative scenarios, the infiltration

for the period between 1974 and 1995 assumes no reduction, with the soil cover beginning in 1995. The RCRA caps are assumed to be installed in 2000, except for the “trigger” scenarios discussed below, where the RCRA caps are assumed to be installed in 2024.

Four groups of modeled scenarios were considered: modeling of the five remedial alternatives using a constant infiltration rate through the vadose zone (as previous modeled), modeling of those same five remedial alternatives allowing a variable infiltration rate through the vadose zone, modeling of four remedial alternatives (the RCRA synthetic cap was not modeled) assuming that any leaching of the source COIs would not occur until the Soil Cover was placed (though decay was allowed), and finally, modeling of RCRA Clay Cap alternatives with the placement of the cap dependant on a “trigger” level of contamination of selective constituents. The “trigger” scenario group also assumed delayed infiltration until the Soil Cover was placed.

The “trigger” modeling scenarios were originally designed around a “trigger” of 0.5 pCi/ml for carbon-14, technetium-99, iodine-129, or tritium detected at a distance of 1/3 the total saturated flow distance. However, the results showed that the “trigger” occurred much sooner for tritium than the other three constituents, and that the resulting RCRA Cap installation time-frame would be the same as that already modeling in other scenarios (i.e. installation around year 2000). Thus, the tritium “trigger” was ignored and an installation of the RCRA Cap at 50 years (year 2024) was assumed based on the “trigger” times for the other three constituents. (The minimum “trigger” times for carbon-14 was 126 years; for technetium-99, 54 years; and for iodine-129, 101 years.)

With the amount of data generated during each modeling run and the ability of the computer to generate very precise numbers, it can be tempting to consider slight changes in either concentration or mass/activity values as important. However, due to the limitations and assumptions of the computer models, the these modeling results should only be used to compare remedial alternatives at an order-of-magnitude level, with any differences between scenarios of less than a factor of 10 considered insignificant. Additionally, although the computer code outputs concentration (and mass) values at very low levels (i.e., 1.0E-45, etc.), any concentration (or mass) value less than approximately 1.0E-5 should be considered as equivalent to zero.

A complete presentation of the results for all scenarios and COIs is given in the formal model documentation. Not all presentation methods are provided with each COI/element in this summary, as that would require an excessive number of plots and maps (more than 1,000 for each scenario modeled). To make this summary manageable, the following discussion and presentation of modeling results will focus on cadmium, mercury, and tritium, as these three constituents demonstrate the main three characteristic (i.e., bounding) responses.

Analysis of all the scenarios in each grouping has resulted in the identification of four groups of COIs: (1) relatively immobile persistent constituents (carbon-14, plutonium-239, uranium-238, neptunium-237, uranium-235, lead, and mercury), (2) relatively immobile, short-lived constituents (plutonium-238, cesium-137, strontium-90, and cobalt-60), (3) mobile short-lived constituents (tritium), and (4) mobile persistent constituents (technitium-99, iodine-129, cadmium, and VOCs). Of these four groups, the mobile persistent constituents appear to be the most important to evaluating remedial alternatives, with cadmium demonstrating the most impact (with respect to ultimate mass movement past the seeps) by different remedial alternatives. A summary of the observed responses of each COI is given in Table ES-1. Computed cumulative mass (activity) fluxes for into the vadose zone, into the saturated zone, and out of the system, are given for select constituents in Tables ES-2 through ES-6.

The results of this modeling indicate that although computed water table concentrations are slightly different for some COIs, the use of a variable vadose zone infiltration rate vs. a constant vadose zone infiltration rate has no impact on assessment of remedial alternatives, as shown by the examples in Figure ES-2. Further, the use of the delayed leaching assumption only effectively impacted tritium fate and transport as seen in Figures ES-3 and ES-4, but with no significant impact to the comparison of remedial alternatives. The results for the “trigger” scenarios indicate that delayed installation of a RCRA Clay Cap does not significantly affect water table or seep concentrations, except for tritium (see Figure ES-5 and Tables ES-3 and ES-6). In particular, it is important to note that there is no significant difference in total mass flux to the water table or to the seep for cadmium or mercury between the RCRA clay cap (with barrier) installed in year 2000 versus year 2024 (see Tables ES-4 and ES-5).

The overall conclusion from this modeling exercise is that, for the most part, the majority of COIs are relatively unaffected by the remedial alternatives. Although some COIs show a reduction in mass/activity entering the saturated zone with a RCRA Clay Cap compared to the Soil Cover, except for cadmium and mercury, there is no significant reduction in mass/activity leaving the system (i.e., seeping from the saturated zone), as seen by the examples shown in Figures ES-6 through ES-8. For cadmium and mercury, significant effects of remedial alternatives on water table and seep concentrations do not appear for over 100 years and 500 years, respectively. There appears to be some benefit in reducing transport of mass/activity to the vadose and saturated zones by using some sort of system to maintain cover/cap integrity – whether for the existing Soil Cover system, or a RCRA Clay Cap.

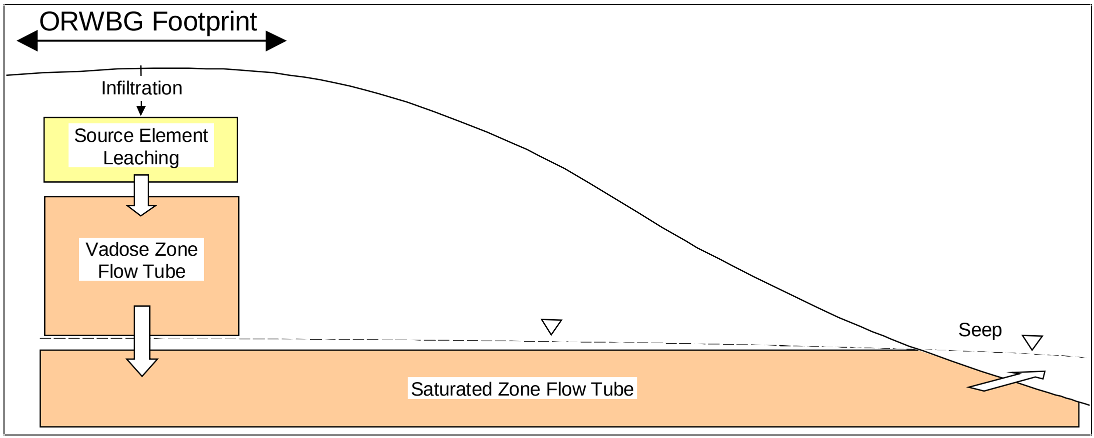
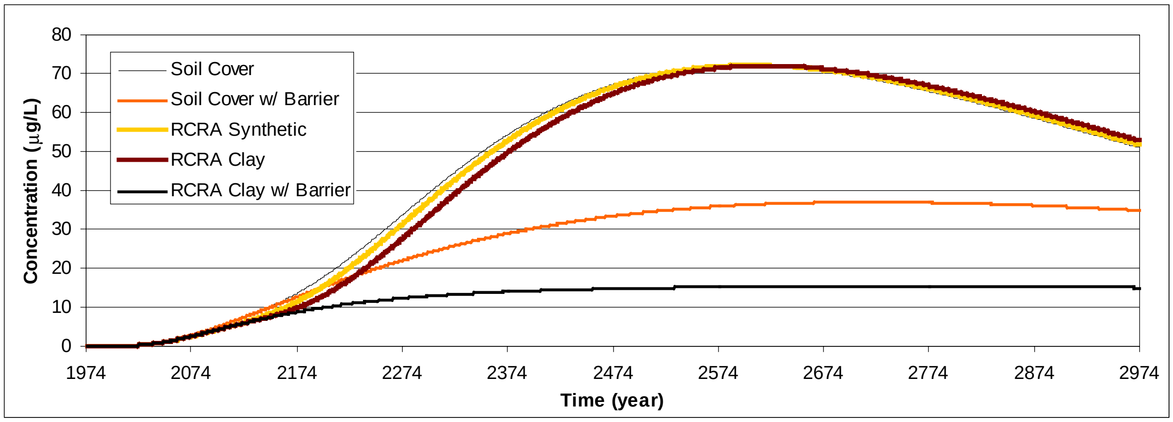
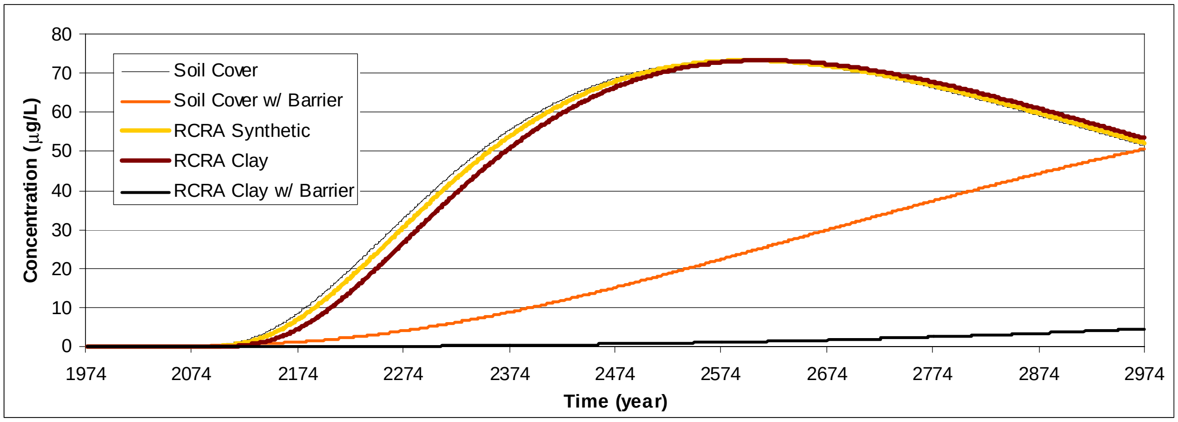


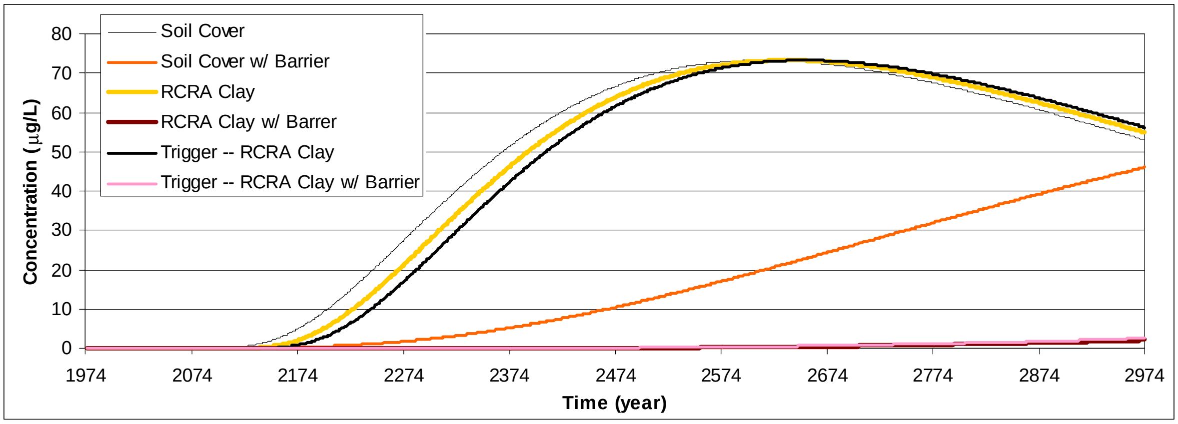

**Figure ES-1. Conceptual Model of the Hydrologic Processes**




a) Constant Infiltration Modeling Results

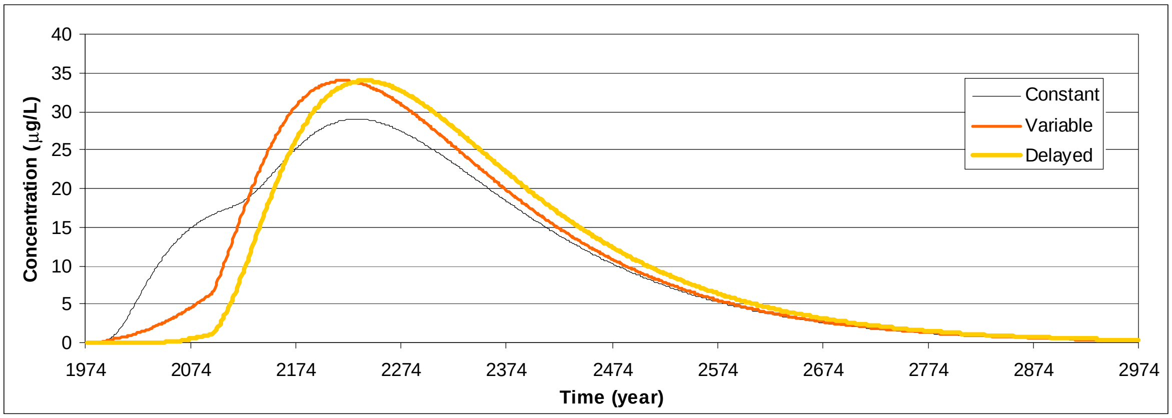



b) Variable Infiltration Modeling Results

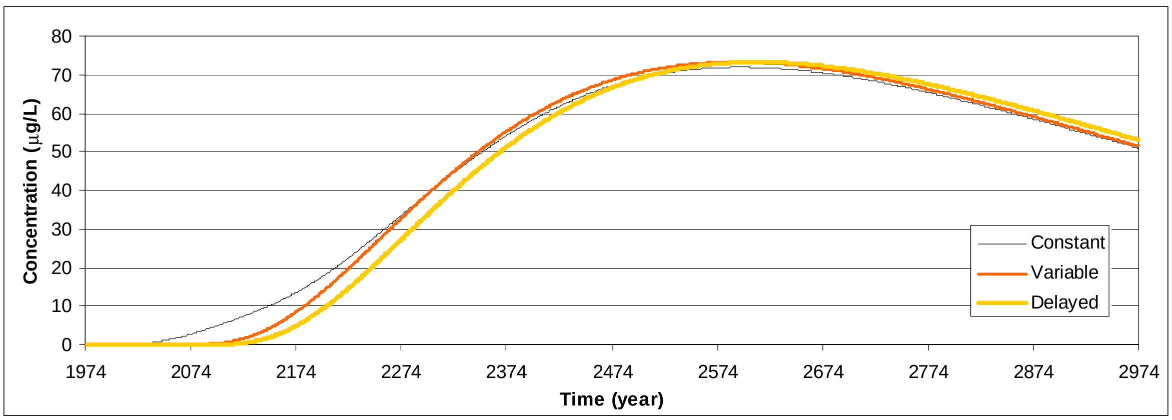



c) Delayed Infiltration Modeling Results

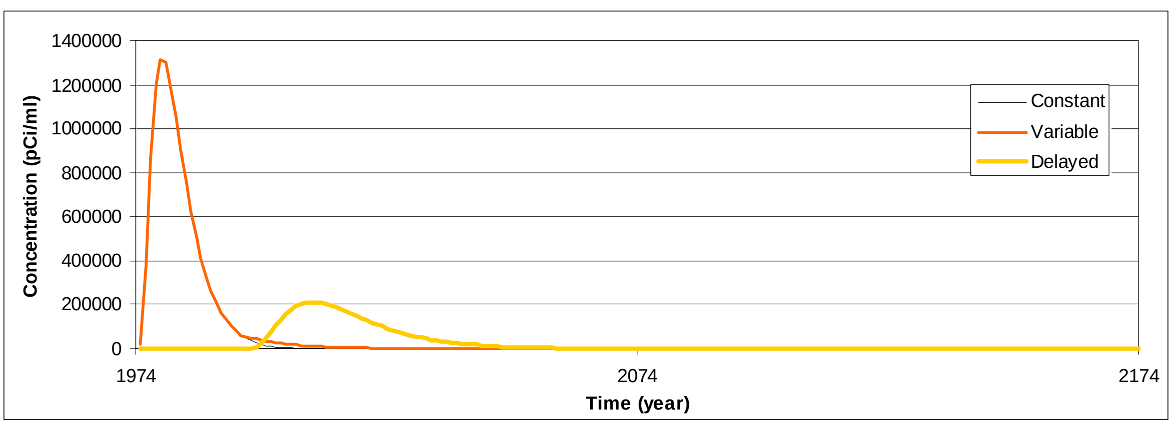
**Figure ES-2. Concentration in Saturated Zone below ORWBG vs. Time for Mercury: Sum of All Elements**




a) Cadmium: Sum of All Elements

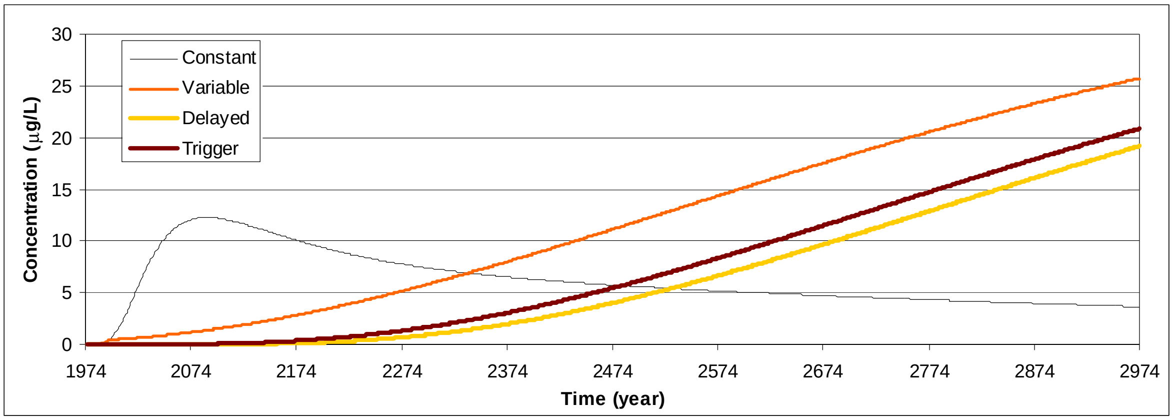



b) Mercury: Sum of All Elements

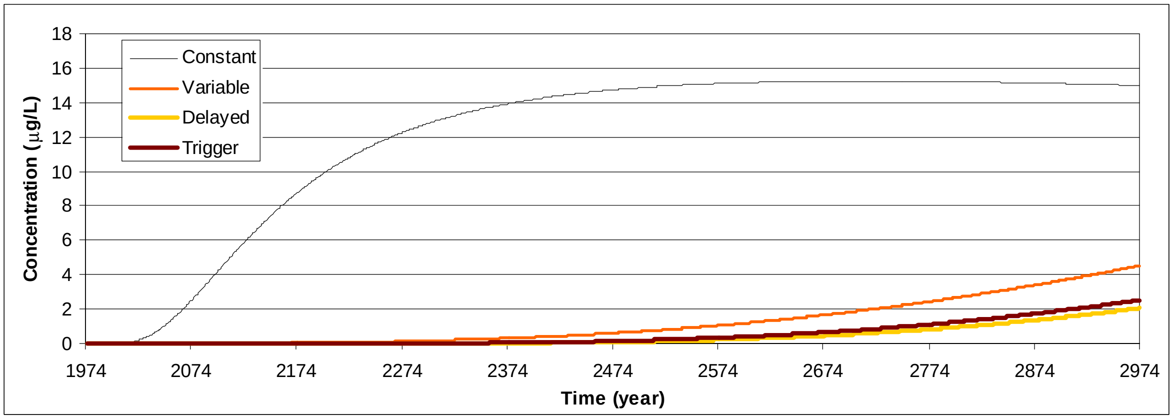



c) Tritium: Sum of All Elements (note time axis scale difference)

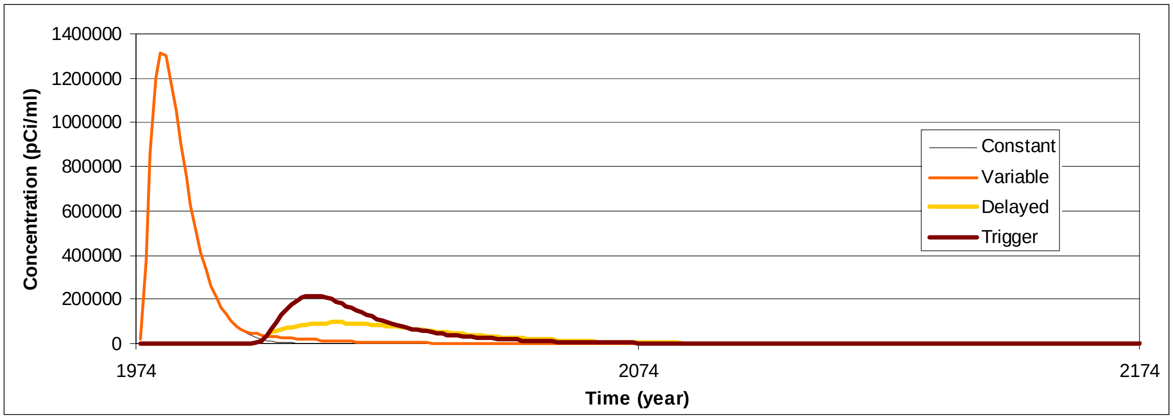
**Figure ES-3. Concentration in Saturated Zone below ORWBG vs. Time: Various Model Results for Soil Cover (no barrier)**




a) Cadmium: Sum of All Elements

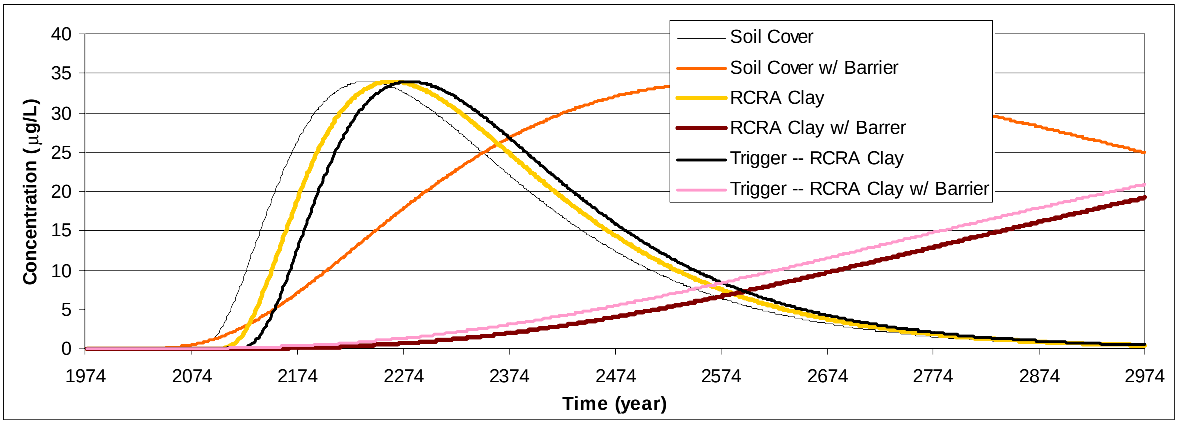



b) Mercury: Sum of All Elements

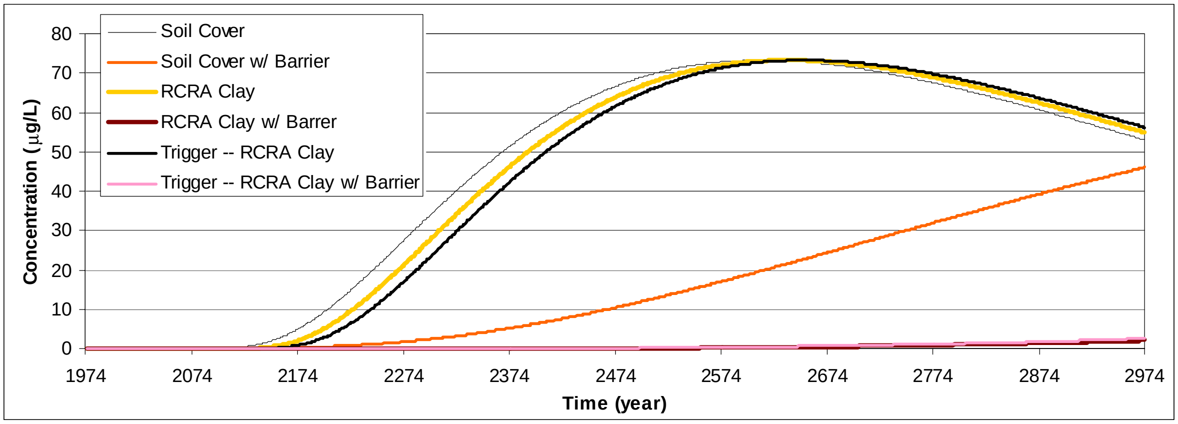



c) Tritium: Sum of All Elements (note time axis scale difference)

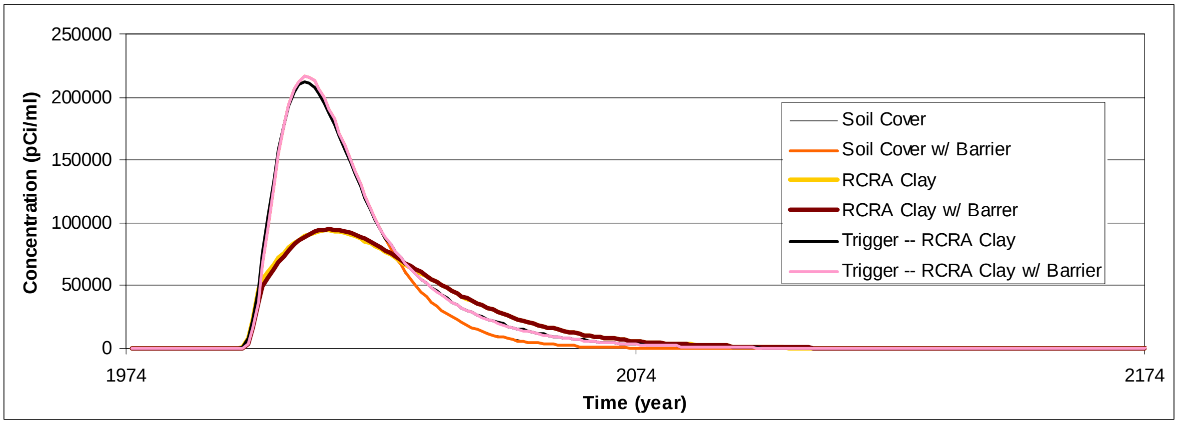
**Figure ES-4. Concentration in Saturated Zone below ORWBG vs. Time: Various Model Results for RCRA Clay Cap with Barrier**




a) Cadmium: Sum of All Elements

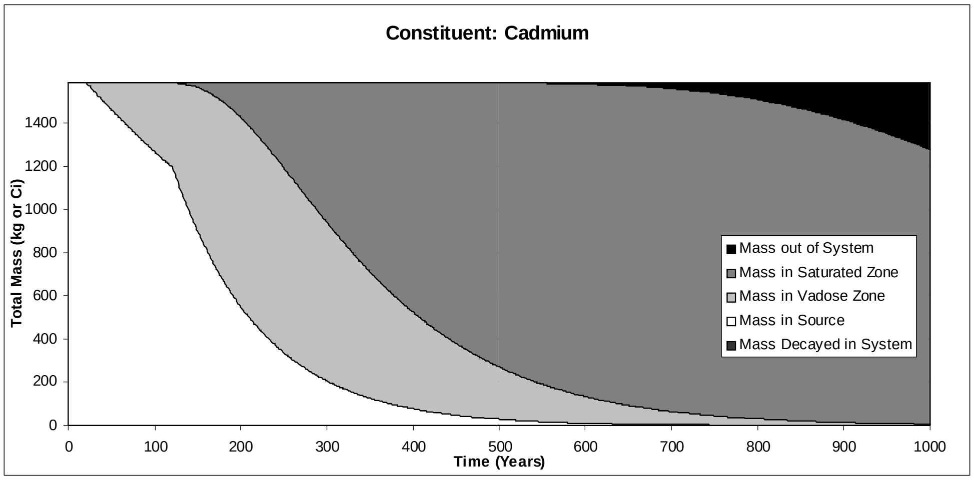



b) Mercury: Sum of All Elements

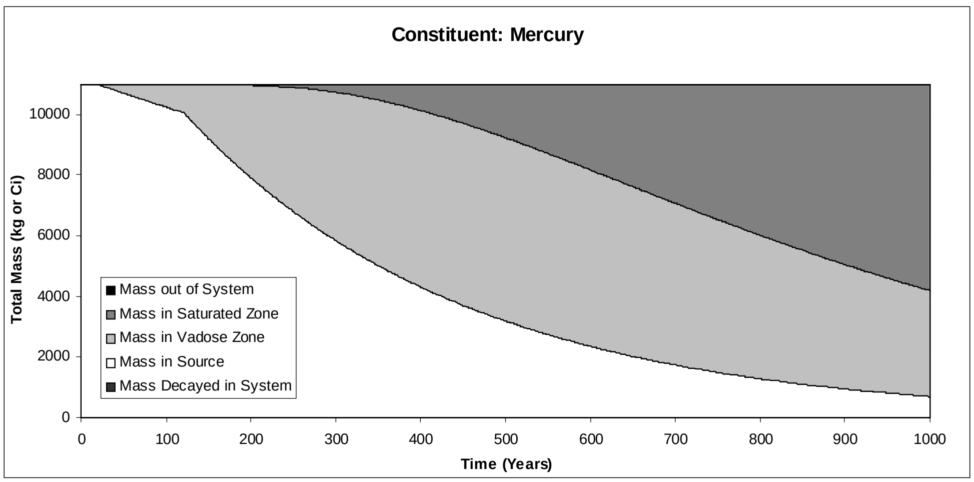



c) Tritium: Sum of All Elements (note time axis scale difference)

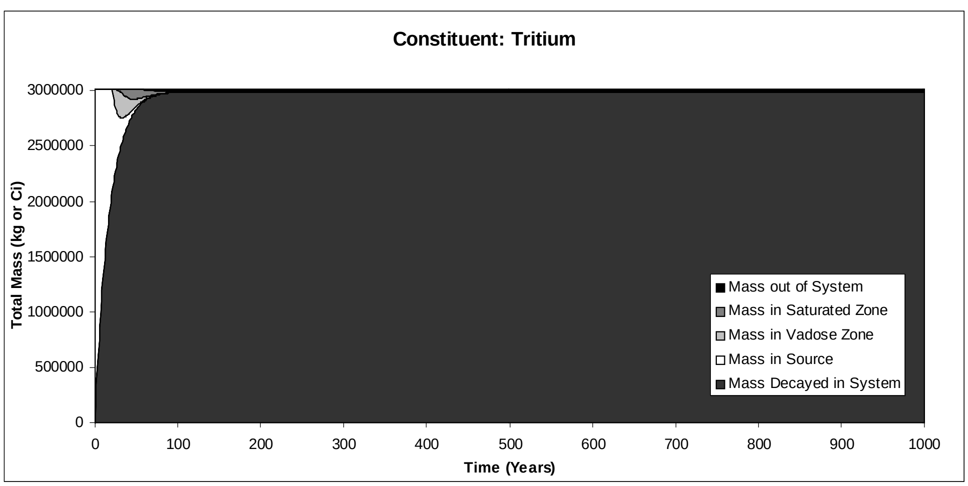
**Figure ES-5. Concentration in Saturated Zone below ORWBG vs. Time: Delayed Leaching Model Results (including "Trigger") for all Remedial Alternatives**




a) Cadmium: Delayed Leaching Model Results

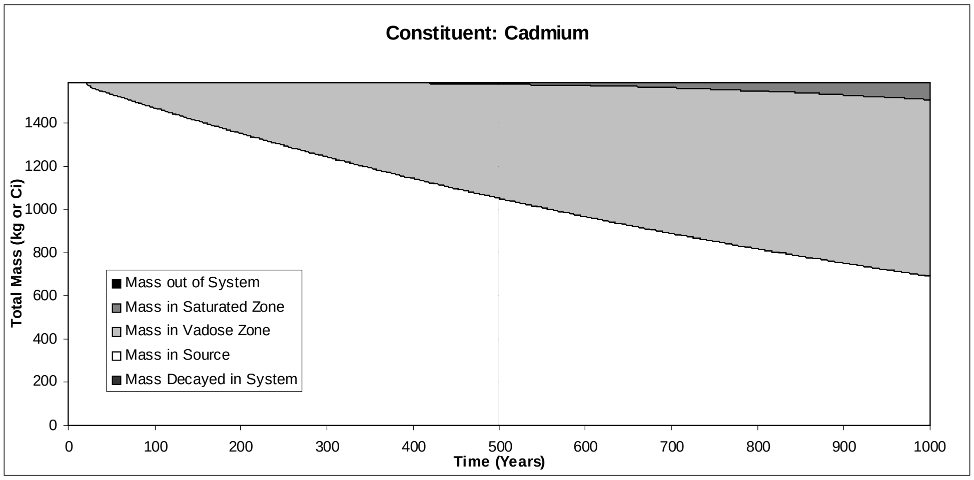



b) Mercury: Delayed Leaching Model Results

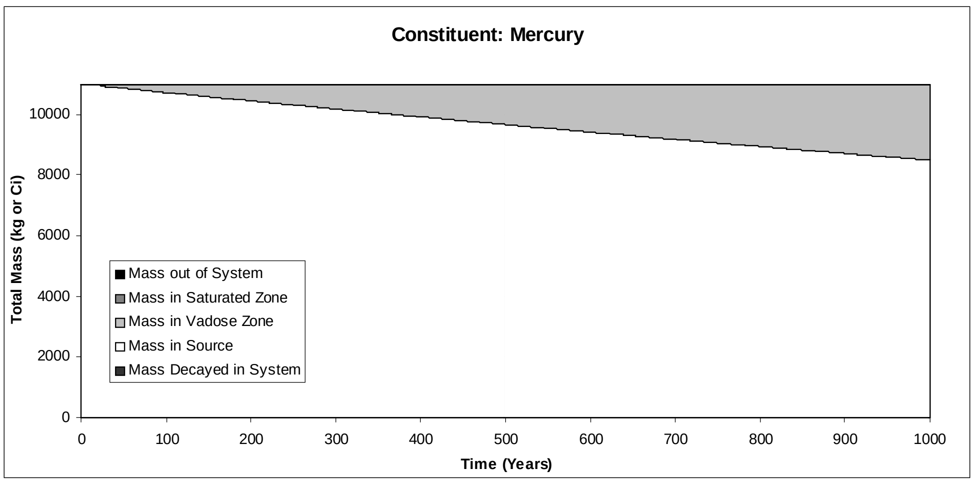



c) Tritium: Delayed Leaching Model Results

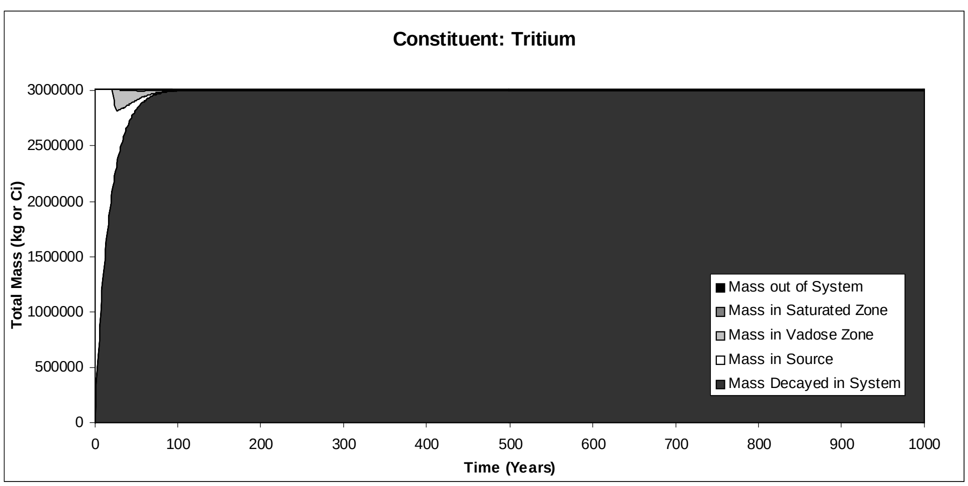
**Figure ES-6. Disposition of Total Mass (Activity) (all elements) for Delayed Leaching Model Results for Soil Cover (no barrier)**




a) Cadmium: Delayed Leaching Model Results

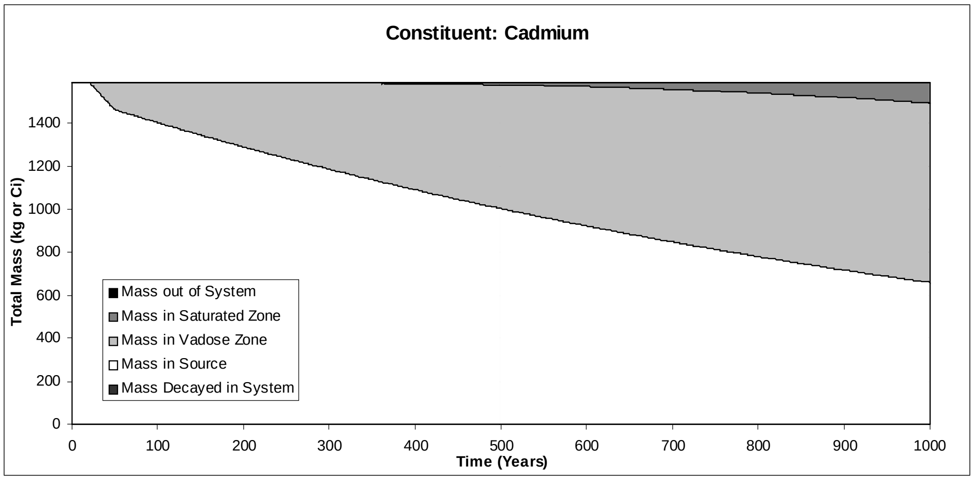



b) Mercury: Delayed Leaching Model Results

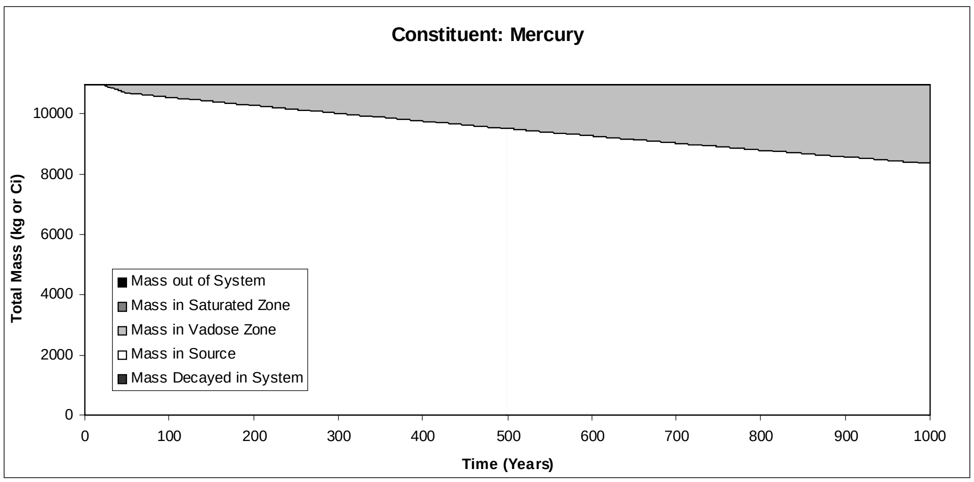



c) Tritium: Delayed Leaching Model Results

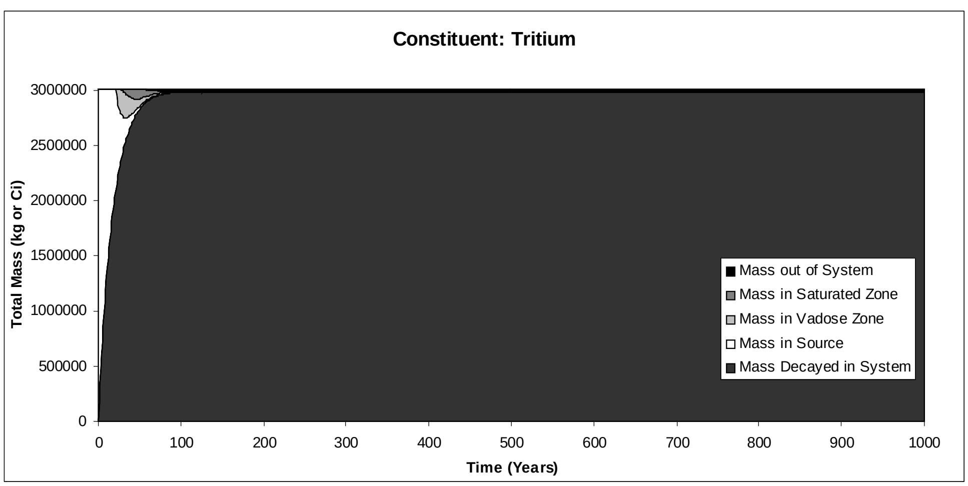
**Figure ES-7. Disposition of Total Mass (Activity) (all elements) for Delayed Leaching Model Results for RCRA Clay Cap w/ Barrier**




a) Cadmium: "Trigger" Model Results




b) Mercury: "Trigger" Model Results




c) Tritium: "Trigger" Model Results

**Figure ES-8. Disposition of Total Mass (Activity) (all elements) for "Trigger" Model Results for RCRA Clay Cap w/ Barrier**

## Table ES-1 Summary of COI Responses to Scenarios

| Group/COI | Summary of Results |
|---|---|
| Immobile, Persistent | |
| C-14 | Most stays in source. For that small portion that moves, most reaches seep independent of the remedial alternative. |
| Pu-239 | Most stays in source. Doesn't get past vadose zone. |
| U-238 | Leaches to vadose zone, but doesn't migrate to seeps. |
| Np-237 | Most stays in source. |
| U-235 | Most stays in source and or the vadose zone. The portion that migrates to the saturated zone doesn't move to seep. |
| Pb | Most stays in source and/or the vadose zone. No significant migration to saturated zone, and no significant migration out of system (to seeps). |
| Hg | Response very similar to U-235. Most stays in source and/or the vadose zone. Only the small portion which migrates to the saturated zone makes it out of system (to seeps). Not sensitive to "triggered" remedial alternative installation timing. |
| Immobile, Short-lived | |
| Pu-238 | Stays in source and decays away. |
| Cs-137 | Stays in source and decays away. |
| Sr-90 | Most decays. Some movement to vadose zone. |
| Co-60 | Decays very quickly. No movement. |
| Mobile, Persistent | |
| Tc-99 | All activity ultimately migrates out of system (past seeps). Some remedial alternatives delay this migration, but do not stop it. Maximum concentrations at seep are around 10-20 pCi/ml for individual streamtubes. |
| I-129 | All activity ultimately migrates out of system (past seeps). Some remedial alternatives delay this migration, but do not stop it. Maximum concentrations at seep are less than 1 pCi/ml for individual streamtubes. |
| Cd | Moves through saturated zone, but very little mass migrates out of system (past seeps). Most sensitive to remedial alternatives with long-lived effects (i.e., barriers). Not sensitive to "triggered" remedial alternative installation timing. Maximum concentrations at seep are on the order of 1-20 ug/L for individual streamtubes. |
| VOC | Rapid movement out of the system (past seeps). Various remedial alternatives only serve to delay the inevitable migration out of the system. Impact of delayed leaching same as Tritium – only on early-time fate and transport. |
| Mobile, Short-lived | |
| H-3 | Most decays, but significant amount migrates out of system (past seeps). Different remedial alternatives do not have significant effect on the maximum seep concentration or the amount of activity that migrates out of system. The only significant "effect" is caused by the delayed leaching – but that only effects early-time fate and transport and not maximum seep concentrations. |

## Table ES-2 Cumulative Activity Fluxes for Carbon-14 for Various Scenarios, Sum of All Elements

| Location | Scenario | Cover/Cap | Cumulative Activity Flux (Ci) at Year: 1995 | 2000 | 2024 | 2100 | 2500 | 2974 |
|---|---|---|---|---|---|---|---|---|
| Top of Vadose Zone | Constant Rate | Soil cover | 99 | 104 | 125 | 176 | 238 | 252 |
| | Variable Rate | Soil cover | 99 | 104 | 125 | 176 | 238 | 252 |
| | Delay | Soil cover | 0 | 9 | 46 | 136 | 236 | 250 |
| | Delay | RCRA clay w/ barrier | 0 | 9 | 20 | 53 | 155 | 198 |
| | Trigger | RCRA clay w/ barrier | 0 | 9 | 46 | 75 | 164 | 202 |
| Top of Water Table | Constant Rate | Soil cover | 4 | 7 | 40 | 128 | 234 | 248 |
| | Variable Rate | Soil cover | 4 | 5 | 11 | 54 | 233 | 246 |
| | Delay | Soil cover | 0 | 0 | 0 | 16 | 232 | 245 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 0 | <1 | 31 | 104 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | <1 | 1 | 40 | 113 |
| Seep Line | Constant Rate | Soil cover | 0 | 0 | 0 | <1 | 152 | 229 |
| | Variable Rate | Soil cover | 0 | 0 | 0 | 0 | 130 | 227 |
| | Delay | Soil cover | 0 | 0 | 0 | 0 | 113 | 226 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 2 | 50 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 5 | 59 |

Note: <1 denotes values that are less than 1, but greater than 0.01.
Initial total activity for carbon-14 was 3778 Ci.

## Table ES-3 Cumulative Activity Fluxes for Tritium for Various Scenarios, Sum of All Elements

| Location | Scenario | Cover/Cap | Cumulative Activity Flux (Ci) at Year: 1995 | 2000 | 2024 | 2100 | 2500 | 2974 |
|---|---|---|---|---|---|---|---|---|
| Top of Vadose Zone | Constant Rate | Soil cover | 2401300 | 2403400 | 2405700 | 2405800 | 2405800 | 2405800 |
| | Variable Rate | Soil cover | 2401300 | 2403400 | 2405700 | 2405800 | 2405800 | 2405800 |
| | Delay | Soil cover | 0 | 224300 | 479000 | 493700 | 493700 | 493700 |
| | Delay | RCRA clay w/ barrier | 0 | 224300 | 331000 | 351800 | 351900 | 351900 |
| | Trigger | RCRA clay w/ barrier | 0 | 224300 | 479000 | 486000 | 486000 | 486000 |
| Top of Water Table | Constant Rate | Soil cover | 1785400 | 1807600 | 1815600 | 1815800 | 1815800 | 1815800 |
| | Variable Rate | Soil cover | 1785400 | 1795000 | 1806800 | 1807600 | 1807600 | 1807600 |
| | Delay | Soil cover | 0 | 3450 | 169820 | 210420 | 210430 | 210430 |
| | Delay | RCRA clay w/ barrier | 0 | 2440 | 28170 | 49310 | 49500 | 49500 |
| | Trigger | RCRA clay w/ barrier | 0 | 2440 | 169870 | 187110 | 187200 | 187200 |
| Seep Line | Constant Rate | Soil cover | 9010 | 29970 | 212970 | 253050 | 253050 | 253050 |
| | Variable Rate | Soil cover | 9010 | 29970 | 212320 | 251930 | 251930 | 251930 |
| | Delay | Soil cover | 0 | 0 | 1250 | 29350 | 29450 | 29450 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 240 | 6700 | 6970 | 6970 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 1180 | 26100 | 26240 | 26240 |

Initial total activity for tritium was 3014457 Ci.

**Table ES-4 Cumulative Mass Fluxes for Cadmium for Various Scenarios, Sum of All Elements**

| Location | Scenario | Cover/Cap | Cumulative Mass Flux (kg) at Year: | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1995 | 2000 | 2024 | 2100 | 2500 | 2974 |
| Top of Vadose Zone | Constant Rate | Soil cover | 296 | 314 | 398 | 662 | 1570 | 1588 |
| | Variable Rate | Soil cover | 296 | 314 | 398 | 662 | 1570 | 1588 |
| | Delay | Soil cover | 0 | 22 | 126 | 450 | 1566 | 1588 |
| | Delay | RCRA clay w/ barrier | 0 | 22 | 54 | 148 | 558 | 896 |
| | Trigger | RCRA clay w/ barrier | 0 | 22 | 126 | 216 | 606 | 928 |
| Top of Water Table | Constant Rate | Soil cover | <1 | 1 | 12 | 158 | 1401 | 1582 |
| | Variable Rate | Soil cover | <1 | <1 | 1 | 18 | 1392 | 1582 |
| | Delay | Soil cover | 0 | 0 | 0 | 2 | 1362 | 1581 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 7 | 79 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 0 | <1 | 11 | 94 |
| Seep Line | Constant Rate | Soil cover | 0 | 0 | 0 | 0 | 6 | 384 |
| | Variable Rate | Soil cover | 0 | 0 | 0 | 0 | 2 | 343 |
| | Delay | Soil cover | 0 | 0 | 0 | 0 | 1 | 309 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 1 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 1 |

Note: <1 denotes values that are less than 1, but greater than 0.01.
Initial total mass for cadmium was 1588 kg.

**Table ES-5 Cumulative Mass Fluxes for Mercury for Various Scenarios, Sum of All Elements**

| Location | Scenario | Cover/Cap | Cumulative Mass Flux (kg) at Year: | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1995 | 2000 | 2024 | 2100 | 2500 | 2974 |
| Top of Vadose Zone | Constant Rate | Soil cover | 678 | 723 | 937 | 1686 | 8217 | 10321 |
| | Variable Rate | Soil cover | 678 | 723 | 937 | 1686 | 8217 | 10321 |
| | Delay | Soil cover | 0 | 48 | 276 | 1075 | 8035 | 10278 |
| | Delay | RCRA clay w/ barrier | 0 | 48 | 116 | 328 | 1377 | 2487 |
| | Trigger | RCRA clay w/ barrier | 0 | 48 | 276 | 485 | 1519 | 2612 |
| Top of Water Table | Constant Rate | Soil cover | 0 | 0 | <1 | 25 | 2331 | 6976 |
| | Variable Rate | Soil cover | 0 | 0 | <1 | <1 | 2334 | 6949 |
| | Delay | Soil cover | 0 | 0 | 0 | <1 | 2013 | 6784 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | <1 | 5 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | <1 | 7 |
| Seep Line | Constant Rate | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Variable Rate | Soil cover | 0 | 0 | 0 | 0 | 0 | <1 |
| | Delay | Soil cover | 0 | 0 | 0 | 0 | 0 | <1 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Note: <1 denotes values that are less than 1, but greater than 0.01.
Initial total mass for mercury was 10975 kg.

## Table ES-6 Cumulative Mass Fluxes for VOC for Various Scenarios, Sum of All Elements

| Location | Scenario | Cover/Cap | Cumulative Mass Flux (kg) at Year: | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1995 | 2000 | 2024 | 2100 | 2500 | 2974 |
| Top of Vadose Zone | Constant Rate | Soil cover | 259610 | 260270 | 261640 | 262000 | 262000 | 262000 |
| | Variable Rate | Soil cover | 259610 | 260270 | 261640 | 262000 | 262000 | 262000 |
| | Delay | Soil cover | 0 | 72510 | 221990 | 261870 | 262000 | 262000 |
| | Delay | RCRA clay w/ barrier | 0 | 72510 | 142220 | 233980 | 261900 | 261900 |
| | Trigger | RCRA clay w/ barrier | 0 | 72510 | 221990 | 252640 | 262000 | 262000 |
| Top of Water Table | Constant Rate | Soil cover | 249820 | 257210 | 261480 | 262000 | 262000 | 262000 |
| | Variable Rate | Soil cover | 249820 | 253050 | 260410 | 262000 | 262000 | 262000 |
| | Delay | Soil cover | 0 | 1370 | 130970 | 260970 | 261830 | 261830 |
| | Delay | RCRA clay w/ barrier | 0 | 1370 | 22930 | 159130 | 262000 | 262000 |
| | Trigger | RCRA clay w/ barrier | 0 | 980 | 130180 | 219820 | 262000 | 262000 |
| Seep Line | Constant Rate | Soil cover | 1410 | 6850 | 144020 | 261850 | 261930 | 261930 |
| | Variable Rate | Soil cover | 1410 | 6850 | 143380 | 262000 | 262000 | 262000 |
| | Delay | Soil cover | 0 | 0 | 1000 | 235570 | 261830 | 261830 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 230 | 89310 | 261950 | 262000 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 900 | 181240 | 262000 | 262000 |

Note: <1 denotes values that are less than 1, but greater than 0.01.
Initial total mass for VOC was 262000 kg.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| Ci | Curies |
| CMS/FS | Corrective Measures Study/Feasibility Study |
| COI | constituent of interest |
| FMB | Fourmile Branch |
| ft | feet |
| GSA | General Separations Area |
| kg | kilogram |
| L | liter |
| m | meter |
| ml | milliliter |
| OOM | order-of-magnitude |
| ORWBG | Old Radioactive Waste Burial Ground |
| pCi | picoCuries |
| RCRA | Resource, Conservation and Recovery Act |
| SRS | Savannah River Site |
| ug | micrograms |
| US DOD | United States Department of Defense |
| US DOE | United States Department of Energy |
| WSRC | Westinghouse Savannah River Company |
| yr | year |

# 1.0 INTRODUCTION

## 1.1 Purpose of Modeling

The modeling described in this report is an extension of previous fate and transport modeling for the Old Radioactive Waste Burial Ground (ORWBG) Corrective Measures Study/Feasibility Study (CMS/FS) (HSI GeoTrans, 1999). The purpose of this and the previous modeling is to provide quantitative input to the screening of remedial alternatives for the CMS/FS for this site. This new modeling was undertaken to help address concerns about some of the assumptions used in the previous modeling. Specific concerns stated by the project's Core Team included: general underprediction of remedial alternative effectiveness and unequal prediction of future effectiveness of some alternatives. Addressing of these concerns is discussed below. For completeness and to aid readability, portions of text, figures, and tables from the previous modeling report (Appendix C of WSRC, 1999) have been incorporated in this report where appropriate.

Because of the uncertainty of the inputs and processes for any fate and transport analysis of the ORWBG (including the uncertainty of the source term magnitudes and precise locations, the unknown heterogeneity of the systems being modeled, and the long time-frame of the modeling), a "traditional" three-dimensional groundwater model is not warranted to assist in screening remedial alternative effectiveness. Thus, a simpler, but technically sufficient modeling approach which is compatible with the uncertainty of inputs and processes, was used. The results from this modeling should be considered rough approximations of mass and concentrations for each COI and are only order-of-magnitude estimates. No attempt should be made to compare the predicted concentrations with regulatory limits. However, the results are sufficient to be useful for comparison of remedial alternatives – which is the purpose of this modeling effort.

Specifically, this modeling addresses the fate and transport of 16 constituents of interest (COIs) from assumed source areas/configurations to seep-line exposure. The COIs include 12 radioactive constituents and four hazardous constituents, each with different initial source distributions, leaching rates, and geochemical properties. Three transport processes are modeled: leaching from source material to the vadose zone, transport in the vadose zone, and transport in the saturated zone. Mass and concentrations for each COI are computed at various locations along the flowpaths (i.e., exiting source, entering saturated zone, exiting saturated zone) of the fate and transport processes.

As with the previous modeling effort, the modeling presented here uses one-dimensional, simplified analytical solutions and finite difference approximations to equations that describe the complex processes of groundwater flow and transport. This modeling does not take into account any current or future groundwater remedial action between the ORWBG and Fourmile Branch (FMB). Modeling predictions of various remedial alternatives included various levels of capping with and without intruder/biological barriers.

The report is divided into four sections. Following this introduction, Section 2 outlines the method of investigation, including the conceptual model and mathematical models of fate and transport. Section 3 discusses results of this modeling, including a summary of the previous modeling results. Finally in Section 4, conclusions from the study are presented.

## 1.2 Background

The ORWBG is a 76-acre waste disposal facility located within the General Separations Area (GSA) of the Savannah River Site (SRS) (Figure 1-1). Waste in the form of solid radioactive waste produced at SRS and shipments from other United States Department of Energy (US DOE) and Department of Defense (US DOD) facilities were disposed at the ORWBG during the period of 1952 to 1972. Small quantities of waste, primarily in retrievable form, were deposited in 1973 and 1974. The ORWBG was also used for storage of contaminated equipment and contained several related facilities and operations. The operational configuration of the ORWBG included different areas to accommodate various levels and types of radioactive waste.

Most of the waste was placed directly in earthen trenches, of dimensions 6.1 m (20 ft) deep, 6.1 m (20 ft) wide, and length up to 210 m (700 ft) (Corey and Horton, 1971). Filled trenches were covered with 1.2 m (4 ft) or more of soil to reduce surface radiation. Other wastes were deposited in various forms, including cardboard boxes, cement culverts, etc.

In 1995, a low-permeability native soil cover was installed over a majority of the ORWGB. This soil cover was shaped and compacted to limit infiltration through the waste. Although reduction of infiltration through this soil cover is not of the magnitude of a Resource Conservation and Recovery Act (RCRA) Clay Cap, the soil cover does reduce infiltration compared to no cover system at all (i.e., infiltration with no cover is estimated around 0.48 m/yr; with the soil cover, 0.14 m/yr, and with a RCRA clay cap, 0.04 m/yr).

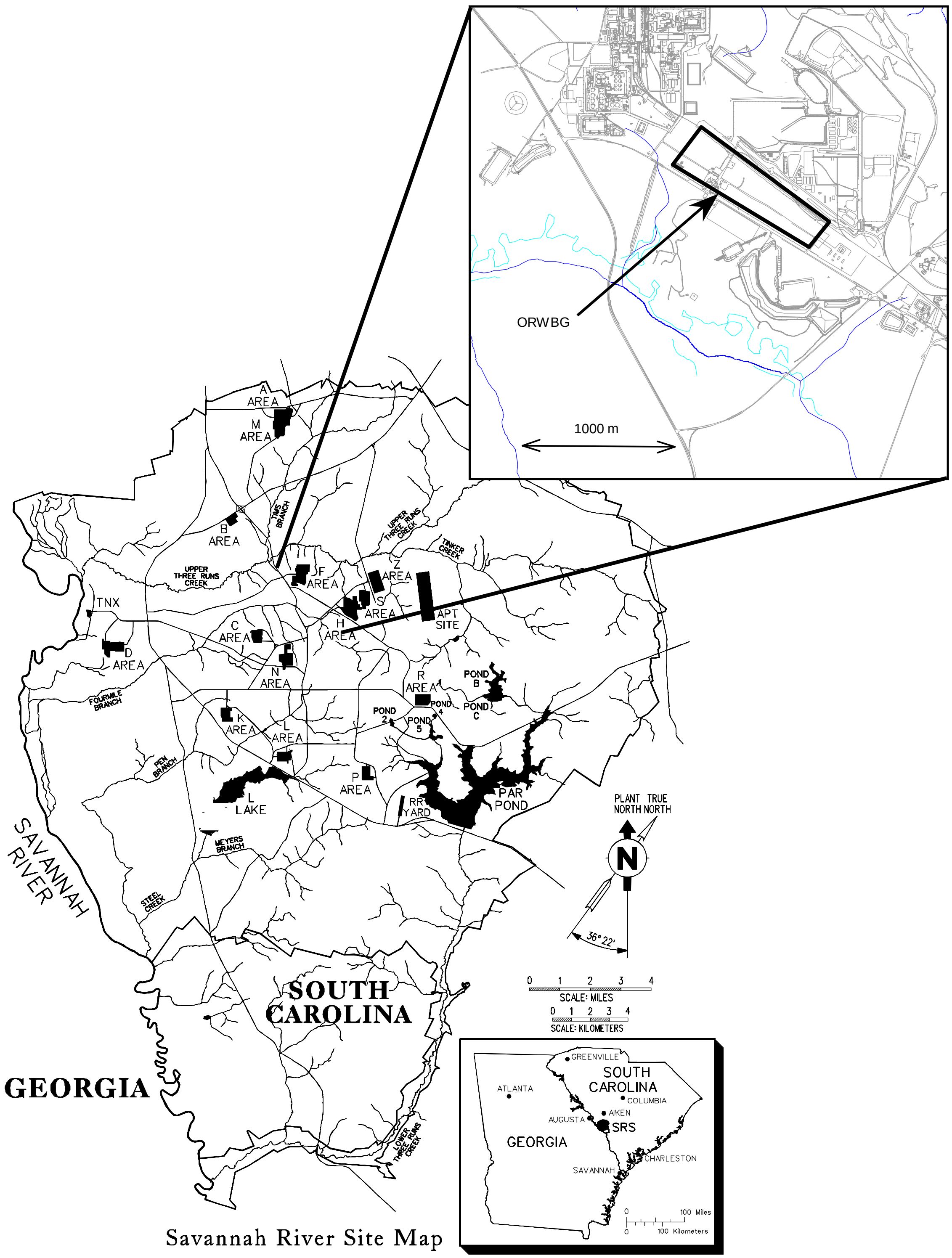



**Figure 1-1. Location of the Old Radioactive Waste Burial Ground and Site Features**

## 2.0 METHOD OF INVESTIGATION

This section describes the method of investigation for this modeling effort. As stated in the Introduction, this modeling effort is a continuation of the previously documented modeling for the ORWBG CMS/FS. The primary differences between this modeling and the previous effort are (1) the allowance of variable infiltration rates in the calculation of vadose zone transport, and (2) the use of different infiltration rates and remedial option scenarios.

The conceptual model of source term release from ORWBG trenches to the hydrologic system and transport of constituents to the seep line, the mathematical models that are used to represent the conceptual model, how these models are linked together, and details about the input and output associated with the model are given below.

### 2.1 Conceptual Model

A diagram of the conceptual model of fate and transport of constituents leaching from the ORWBG is given in Figure 2-1. The conceptual model considers processes associated with infiltration of water through the waste, leaching of constituents from the waste form into the vadose zone, fate and transport of constituents as they migrate through the vadose zone, fate and transport of the constituents through the saturated zone, and finally discharge of constituents at the seep. Numerous assumptions regarding the mechanisms of these individual processes and data associated with them are required to provide a quantitative description of the entire fate and transport process. The assumptions are necessary due to data limitations and the desire to keep the level of analysis consistent with the objectives of the study.

The distribution of COIs within the ORWBG posed an immediate challenge to providing the required analysis. The size of the ORWBG (approximately 1,100 m east-west and 270 m north-south) relative to the travel distance to Fourmile Branch (approximately 700 m) precludes treating the entire ORWBG as a single point source. In reality, distinct areas of the ORWBG will be predominantly responsible for concentration peaks. In addition, the groundwater flow paths (travel distance and time, outcrop location) will be different depending upon where they originate in the ORWBG.

To overcome this challenge, a “streamtube” approach was designed to represent specific source areas and hence allow computation of concentrations originating from these specific locations at various points along the “streamtube” system. The streamtube approach accounts for variable distribution of COIs in the ORWBG and for flowpaths that vary depending on location in the ORWBG. Rather than performing a single one-dimensional analysis with the entire ORWBG as the source, the streamtube approach essentially involves performing numerous one-dimensional analyses with individual elements of the ORWBG as the source.

The ORWBG was divided into 60 separate source areas (elements) (Figure 2-2) for which unique COI inventories were derived. For each element, the fate and transport conceptual model was used as individual "streamtubes". Summation of the individual streamtube results can provide a total picture of the fate and transport from the entire ORWBG. Limitations of this "streamtube" approach are given in a following section.

The first component of the streamtube conceptual model is the infiltration and subsequent leaching of constituents from source terms. Infiltration of water through the waste is a function of many factors including precipitation, evaporation, soil characteristics such as hydraulic conductivity, layering, moisture content, root zone of vegetation, and slope. Currently, a low-permeability native soil cover that has been shaped and compacted to limit infiltration through the waste overlies the ORWBG. Prior to 1995, when the low-permeability native soil cover was installed, infiltration through the waste was at a rate consistent with regional infiltration or recharge. Various capping alternatives that have been proposed serve to alter the overall infiltration rate and the time period over which these rates occur. Infiltration rates were calculated in the previous modeling for the various remedial alternatives using the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al., 1994). Because data do not exist to quantify the infiltration variability from one streamtube to the next, a single infiltration value pertains to all streamtubes.

The infiltration of water through the ORWBG causes it to come into contact with various waste forms. Constituents become dissolved in the water as it passes through the waste, a process referred to as leaching. The amount of leaching is highly dependent upon the characteristics of the waste form. For example, waste that has been contained in concrete will leach at a much slower rate than waste that has been contained in cardboard boxes or deposited directly in trenches. Leaching is therefore controlled by the hydraulic conductivity of the container, the distribution coefficient of the material surrounding it, and the geochemical characteristics of the surrounding material. Quantification of leaching requires identification of the location of wastes, the form of containment, and an overall inventory of constituents within a waste form.

Leached constituents move out of the source area into the vadose zone. They are transported through the vadose zone by gravity and hydraulic pressure differences. Transport through the vadose zone is assumed to be vertical, and any local deviations due to heterogeneity are not considered. The rate at which the constituents are transported is primarily dependent upon hydraulic conductivity, degree of saturation, and distribution coefficient. Decay, dispersion, and adsorption of constituents can occur along the flowpath through the vadose zone.

After the constituents pass through the vadose zone, they enter the saturated zone. The hydraulic processes in the saturated zone are similar to those in the vadose zone, except flow directions are defined by pressure differences, not gravity. As such, the dissolved constituents generally flow laterally toward a seepage point, which has a lower hydraulic pressure. The path of constituents through the saturated zone can be tortuous, depending upon localized hydraulic heterogeneities and diverging flowpaths. Some constituents may be diverted deeper into the saturated zone than others, depending upon their entry point. Decay, dispersion, and sorption govern the fate of constituents in the saturated zone.

Eventually, if they have not decayed completely, the dissolved constituents exit the system at a seepage point along Fourmile Branch.

## 2.2 Mathematical/Numeric Models

Conversion of the conceptual model described above to a mathematical model that meets the objectives of this study is challenging. Although numerical models exist that could conceivably consider all the processes described above in a three-dimensional sense, the data requirements and execution times would be immense. In addition, the rigorous treatment of all the processes is not warranted given the objectives of the study and basic uncertainties associated with the disposition and form of the waste. Therefore, a combined analytic/numeric approach that links several model codes designed to address individual processes was developed.

The previous modeling assumed a constant infiltration rate through the vadose zone and an analytic approach for the vadose zone was used. In the current modeling, the infiltration rate through the vadose zone can change over time, which required the use of a numeric approach for the vadose zone. A complete description of the current modeling follows.

### *2.2.1 Leaching*

Leaching of constituents from source elements is computed by assuming that the rate of mass (or radioactivity) removed from the waste is proportional to the amount of mass (or radioactivity) in the waste. This method, which is consistent with the approach of Baes and Sharp (1983), allows the calculation of a first-order leach rate, $\lambda$ [$T^{-1}$], using the equation

$$\lambda = \frac{I}{d\left(n + \rho K_d\right)}$$

where $I$ is the water infiltration rate [L/T], $d$ is the waste thickness [L], $n$ is the porosity of the waste [dimensionless], $\rho$ is the waste bulk density [$M/L^3$], and $K_d$ [$L^3/M$] is the partitioning coefficient for the solute and the waste medium (e.g. soil, concrete). Using this definition of the leach rate, the change in waste mass (or radioactivity) $\Delta M$, over a time period, $t$, is given by

$$\Delta M = -M_0\left(1 - e^{-(k+\lambda)t}\right)$$

where $k$ is the first order (radioactive) decay rate [$T^{-1}$] and $M_0$ is the initial mass (activity) in the waste. The average rate of mass (activity) flux due to leaching, $\dot{m}_{leach}$ [M/T], during the time period, $t$, is then given by

$$\dot{m}_{leach} = -\Delta M \frac{\lambda}{(k+\lambda)t}$$

Solution to these analytical leaching equations are performed using a FORTRAN subroutine called LEACH (see Appendix A). Inputs to the subroutine include time-varying infiltration (derived from the previously performed HELP simulations), waste-medium porosity and bulk density, waste thickness, sorption coefficient ($K_d$), initial mass, radioactive decay rate, and the definition of time steps for solution. The equations are solved separately for each COI and each streamtube to derive a mass (activity) flux exiting the source and entering the vadose zone.

The leaching subroutine also keeps track of the amount of mass (activity) remaining in the source at the end of each time step, and the amount of radioactive decay in the source. The concentration of solute in the leachate water, $c_{leach}$ [$M/L^3$] is calculated using the relationship $c_{leach} = \dot{m}_{leach} / Q$, where the vadose-zone water flow rate, Q [$L^3/T$], is the product of the source area and the time-dependent infiltration rate, $I$.

Although many constituents have waste forms that may provide some delay or reduction in leaching, the only waste form that has been taken credit for is encapsulation in concrete. Even in the case of concrete, the water flow through the waste is assumed to be unaffected (i.e., same as in soil), however the sorption properties are changed, resulting in a lower $K_d$ for some COIs. This assumption results in an overestimation of concentrations and an underestimation of travel times. This assumption tends to predict quicker-than-actual release of waste from the source to the vadose zone, and thus may underpredict the effectiveness of caps that are installed in the future, after much of a COI's inventory has leached out of the waste in the model.

### *2.2.2 Vadose Zone Transport*

Vadose-zone transport was computed in the original modeling using the AT123D code (Yeh, 1981). The AT123D code computes the concentration exiting the vadose zone considering decay, adsorption, and longitudinal dispersion for a constant infiltration rate. Since this current modeling required the consideration of time-dependent infiltration, an analytic solution was not appropriate and a numeric (finite-difference) approach was used.

The 1D advection-dispersion differential equation:

$$R\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - v\frac{\partial C}{\partial x} - R\lambda C$$

can be represented by an explicit-central approximation of the solution using (derived from equation 12.1.8 of Bear and Verruijt, 1987):

$$c_{x,t+1} = \frac{\Delta t}{R}\left[\frac{D}{\Delta x^2}\left(c_{x+1,t} - 2c_{x,t} + c_{x-1,t}\right) - \frac{v}{2\Delta x}\left(c_{x+1,t} - c_{x-1,t}\right) - \lambda R c_{x,t}\right] + c_{x,t} \quad .$$

To minimize the impact of the outflow boundary (where the second derivative is assumed to be zero), a total simulation length of twice the problem length is used. To minimize numerical dispersion and to maximize assurance of stability, the following are required:

Peclet: $\Delta x = \alpha$ Courant: $\Delta t = \frac{\Delta x}{v}$

with the delta-time value being no larger that the overall simulation time-step size (Spitz and Moreno, 1996).

The finite-difference approach computed the concentration exiting the vadose zone for each streamtube and each COI using the leachate mass (activity) flux computed in the LEACH routine. A one-dimensional vertical calculation is made that considers decay, adsorption, and longitudinal dispersion for time-dependent infiltration rates. Lateral dispersion is assumed to be negligible and is not considered. The distance from the waste form to the water table may vary from element to element, and is determined based on water-table elevation beneath each element. Advective velocity through the vadose zone is derived from the time-dependent infiltration rate, divided by porosity and saturation. Since the time-period of the modeling is extensive, the velocity was considered steady-state within each time step, thus negating complicated unsaturated flow conditions and allowing the simulation of the vadose zone in a simplified manner equivalent to saturated zone flow and transport.

Sorption and decay are included in the computation of outflow (water-table) concentration, based on $K_d$ and the first-order decay constant, respectively, as input. The mass (activity) flux entering the saturated groundwater system is calculated by multiplying the water table concentration by the time-dependent water flow rate, $\dot{m}_{wt} = IAc_{wt}/n$. This mass (activity) flux at the water table is the end result of the unsaturated zone analysis and is used as input to the saturated zone analysis.

### *2.2.3 Saturated Zone Transport*

A necessary parameter for this evaluation is the definition of the flowpath lengths for COIs from source to discharge for each streamtube. The groundwater flowpath distances for each streamtube were conservatively selected to be the shortest distance from each source element centroid to the closest seep point, as shown in Figure 2-3. The end-point of each streamtube flow path distance has little geographical significance; it is merely used to establish the shortest (i.e., conservative) groundwater flow distance. Also note that although the flowpath distance lines cross on Figure 2-3, this figure is only used to establish distances and not actual flow paths as each streamtube is independent of each other streamtube. No commingling of streamtubes is assumed to occur.

Saturated zone transport is computed using AT123D. Concentrations are computed based on velocity, adsorption, and decay. Sorption and decay are included based on $K_d$ and first-order decay constant, respectively, as input. Velocity is computed based on saturated hydraulic conductivity, hydraulic gradient, and porosity. Hydraulic gradient is calculated from the change in elevation from the water table (entry point) to the elevation of the seep (discharge point) divided by the distance from centroid of the source element to the discharge point (discussed earlier). The area of the saturated streamtube is set to allow the same mass (activity) flow through the saturated zone that was calculated for the vadose zone. This is done with the equation $A_{sat} = Q/(KJ)$, where $K$ is the hydraulic conductivity [L/T] and $J$ is the computed hydraulic gradient (dimensionless).

Dispersion is considered in the longitudinal direction, but not laterally. This is a conservative assumption and allows streamtubes to be considered separately, without interference from or interaction with other streamtubes. Note that because the streamtubes represent groundwater flowpaths and originate from distinct elements, the only interaction with other streamtubes should be through dispersion. Therefore, concentrations computed by this model are not directly additive. The computed concentration at the end of the flowtube represents the concentration in the groundwater just before reaching the seeps.

### *2.2.4 Combined Model*

The leaching algorithm, the finite-difference subroutine, and the AT123D subroutine are all called from a master driver program named LVSTRAN (Leaching Vadose Saturated Transport) that computes the required output for all constituents and all elements as one simulation. Figure 2-4 is a conceptual diagram of the hydrologic processes and the models that are used to solve them. The program loops through each COI for each element, simulating the fate and transport for the time period specified in the input parameters. A complete listing of the modeling code is given in Appendix A. The documentation of the code verification is given in Appendix B.

## 2.3 Input Parameters

The input structure for the program is the same as that used in the previous modeling, and is described in Appendix C of this report. The program reads data that are pertinent to the hydrogeologic system, the model simulation, the source element, and to particular COIs.

Data pertaining to the hydrogeologic system and model simulation generally are not COI-specific. This information includes time stepping, hydraulic conductivity, porosity, etc. Values for these data are given in Table 2-1. Data pertaining to the source elements are also generally not COI-specific. This information includes elevation of the bottom of waste, distance of saturated zone flow, etc. Values for these data are provided in Table 2-2. Data pertaining to constituents include distribution coefficients, half-lives, etc. Values for constituent-specific data are given in Table 2-3. In general, the data used in this modeling is the same as that used previously.

Each constituent has an initial inventory associated with each source element. This information, which is the same as that used in the previous modeling, is presented in Table 2-4. The total inventory was obtained from an earlier report of ORWBG hot spot delineation (WSRC, 1997b). Information from that report and the current CMS/FS was used to determine the inventory of all radionuclide COIs except iodine-129 and cobalt-60 in the 21 defined radionuclide hot-spot source elements (Hot01 through Hot21). The remaining inventory was spread evenly (proportional to element area) among the other 39 source elements. A mercury hot spot has also been identified. The inventory associated with that hot spot was spread evenly into the four source elements that comprise the mercury hot spot (HotHg, Hot14, Hot15, and Hot17). The remaining inventory was spread throughout the remaining 56 source elements. No hot-spot delineation has been made for iodine-129, cobalt-60, cadmium, lead, or volatile organic compounds (VOCs). Therefore, the inventory for these COIs was spread through all 60 source elements of the ORWBG.

Infiltration rates used to calculate leaching mass (activity) flux are time-dependent and scenario specific. The individual scenario information for each remedial alternative and initial condition assumption is presented below.

## 2.4 Output File Format

The output structure for this modeling was the same as the previous modeling. A description of the outputs is included in Appendix C of this report. The main output consists of a database file from which tables and graphics can be generated. This file provides data on concentrations at various locations, mass (activity) in various zones (source, vadose zone, etc), and mass (activity) decayed for each time step. This information is produced for each source element and each COI. The data produced in the output file can be further reduced to identify source elements of interest, including those that cause the highest receptor concentrations or fastest transit times. A second output file is also produced by LVSTRAN that echoes the input data (for checking) and summarizes the results for each COI.

## 2.5 Modeled Scenarios

There are five remedial alternatives modeled in the following scenarios: (a) native soil cover without a biological/human barrier, (b) native soil cover with a biological/human barrier, (c) a RCRA quality synthetic cap without a biological/human barrier, (d) a RCRA quality clay cap without a biological/human barrier, and (e) a RCRA quality clay cap with a biological/human barrier. The basic differences amongst these alternatives is with the effectiveness of reducing infiltration (with the RCRA clay cap being the most effective), and with the expected life of the reduced infiltration. The expected life of the non-barrier alternatives is assumed to be 100 years (30 years for the RCRA synthetic cap), corresponding to the expected time-frame of institutional controls at the ORWBG. The expected life of the alternatives with the biological/human barrier is greater than 1000 years. Specific engineering details of each of these options can be found in the ORWBG CMS/FS (WSRC, 1999). For all alternative scenarios, the infiltration for the period between 1974 and 1995 assumes no reduction, with the soil cover beginning in 1995. The RCRA caps are assumed to be installed in 2000, except for the “trigger” scenarios discussed below.

The simulation runs were grouped into four major scenario categories: constant vadose zone infiltration modeling (i.e., Limited-Impact/Early-Timing), variable vadose zone infiltration modeling (i.e., Full-Impact/Early-Timing), delayed leaching modeling (i.e., Full-Impact/Late-Timing), and remedial actions at a “triggered” time modeling (i.e., Full-Impact/Late-Timing with Trigger). Limited- and Full-Impact refers to the amount of impact the remedial alternative would have on the processes. Limited-Impact means that the remedial option only affects the leaching rates, whereas Full-Impact means that the remedial option affects not only the leaching rates, but also the flow rates through the vadose zone. Early- and Late-Timing refers to the time when the constituents are allowed to first leach. Early-Timing means that the constituents begin leaching in 1974, whereas Late-Timing means that the constituents do not begin leaching until 1995 (though radioactive decay is allowed to occur from 1974 through 1995). Each of these scenario categories groups will be described in detail below, with the model results discussed in the next section.

### *2.5.1 Constant Vadose-Zone Infiltration Modeling Scenarios (Limited-Impact/Early-Timing)*

These modeling scenarios assume that leaching/transport starts in 1974, at the end of ORWBG disposal. The entire inventory is “placed” in the source elements when the model is initialized (1974), as it is assumed that no decay or leaching takes place during the burial period of 1955 to 1974. The advection rate through the vadose and saturated zones was constant for all individual scenarios, at the maximum infiltration rate. These scenarios are equivalent to that previously modeled (HSI GeoTrans, 1999).

The five remedial alternatives were modeled as given in Table 2-5. The resulting infiltration curves for each of the scenarios is shown in Figure 2-5.

### *2.5.2 Variable Vadose-Zone Infiltration Modeling Scenarios (Full-Impact/Early-Timing)*

The constant vadose zone infiltration modeling scenarios were rerun with a change to allow the vadose zone infiltration rate to vary during the modeled time-period. The saturated zone advection flow rate was held constant (as before), and all other assumed conditions were unchanged from the constant vadose zone infiltration modeling scenarios. The five remedial alternative scenarios were modeled as given in Table 2-5. The infiltration curves for each of the scenarios are the same as that for the constant vadose zone infiltration modeling (shown in Figure 2-5).

### *2.5.3 Delayed Leaching Modeling Scenarios (Full-Impact/Late-Timing)*

Unlike the constant vadose zone infiltration modeling and the variable vadose zone infiltration modeling, the delayed leaching modeling scenarios assume that the leaching from the source elements doesn’t start until 1995, at the time of the soil cover placement. Decay of radioactive constituents is the only fate and transport mechanism allowed from 1974 to 1995. After 1995, the advection flow rate through the vadose zone is allowed to vary, while the saturated zone flow rate is held constant.

Four of the five remedial alternative scenarios were modeled (the RCRA synthetic cap was not modeled), as given in Table 2-5. The resulting infiltration curves for each of the scenarios is shown in Figure 2-6.

### *2.5.4 Delayed Leaching with Triggered Remedial Actions Modeling Scenarios (Full-Impact/Late-Timing with Trigger)*

These scenarios are similar to the delayed leaching modeling scenarios except that the RCRA clay cap alternatives occur not in 2000, but at a time-frame determined by a “trigger”. The “trigger” was defined as a groundwater (saturated zone) concentration in any streamtube of 0.5 pCi/ml at a distance of 1/3 the saturated zone flow length, for Tritium, I-129, Tc-99, or C-14.

Until the "trigger" occurs, the soil cover is assumed to continue. After the trigger, a RCRA clay cap with/without a bio/human barrier is installed. Leaching from the source elements doesn't start until 1995, at the time of the soil cover installation. Decay of radioactive constituents is the only fate and transport mechanism allowed from 1974 to 1995. After 1995, the advection rate through the vadose zone was allowed to vary, while the saturated zone rate was held constant.

Based on the results of determining the "trigger" timeframe, the RCRA caps are assumed to be installed at 50 years (2024). A complete discussion of the determination of the "trigger" time is given in the Results section. The infiltration curves for the two "triggered" scenarios are shown in Figure 2-7.

## 2.6 Assumptions and Limitations

Several simplifying assumptions have been made in order to conduct this analysis. Some of these assumptions have been discussed as a part of the description of models of processes. In general, the assumptions are conservative and should tend to overestimate concentrations at the top of the water table and at the seep.

One of the biggest assumptions relates to the acceptance of the source term data. Although an intensive study to quantify burial locations, inventories, and waste forms has been conducted (WSRC, 1997a), there is a great deal of uncertainty associated with these values. In many instances, due to lack of information, it was assumed that the entire inventory of a constituent was evenly distributed across the ORWBG. Although this may appear to be a non-conservative assumption, it provides a consistent relative comparison for evaluation of capping and hot-spot removal alternatives.

Although many constituents have waste forms that may provide some delay or reduction in leaching, the only waste form that has been taken credit for is encapsulation in concrete. Even in the case of concrete, the water flow through the waste is assumed to be unaffected (same as in soil), however the sorption properties are changed, resulting in a lower $K_d$ for some COIs. This assumption overestimates concentrations and underestimates travel times. This assumption tends to predict quicker-than-actual release of waste from the source to the vadose zone, and thus may underpredict the effectiveness of caps that are installed in the future, after much of a COI's inventory has leached out of the waste in the model.

A one-dimensional flow tube that does not spread deep into the aquifer is assumed. This is a conservative assumption because the shortest possible flow length is modeled, without credit for a more tortuous path or attenuation in clay layers that underlie the water table aquifer. In addition, no lateral dispersion, which would tend to lower concentrations, has been taken credit for.

The assumed geochemical properties are based on best engineering judgement from studies conducted a the SRS. Although some of these values have been roughly verified by the presence or absence of constituents in groundwater, their exact quantification is uncertain. Furthermore, it is assumed that these parameters do not change as a result of the presence of other constituents (competition for sorption sites, facilitated transport, etc). Note that neither COI ingrowth nor daughter products are considered.

Finally, due to limitations and assumptions of the computer models (some of which are more fully discussed in other sections of this report), the results of this modeling should only be used to compare remedial alternatives and should not be used to predict specific vadose zone or saturated zone concentrations. Further, the comparison of alternatives/scenarios should only be to an order-of-magnitude level, with any differences between scenarios of less than a factor of 10 not considered significant. Additionally, although the computer code outputs concentration (and mass/activity) values at very low levels (i.e., 1.0E-45, etc.), any concentration (or mass/activity) value less than approximately 1.0E-5 should be considered as equivalent to zero.

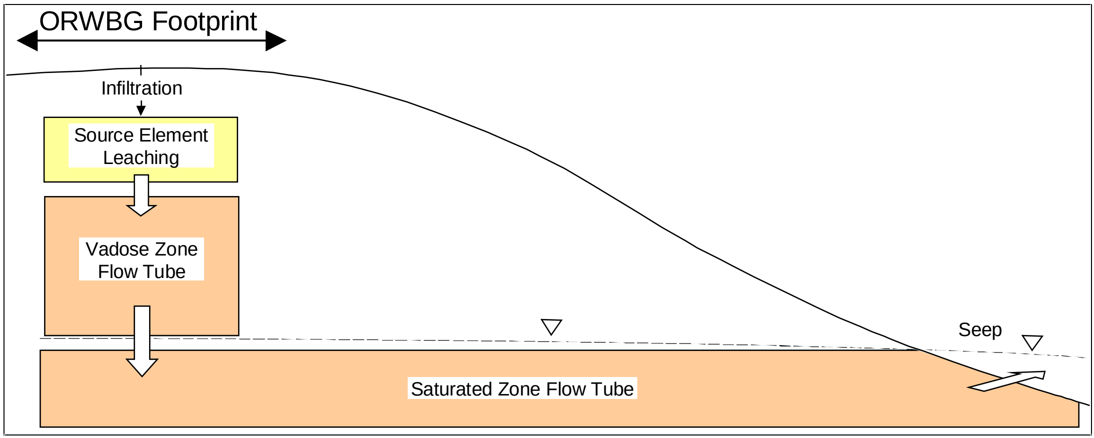
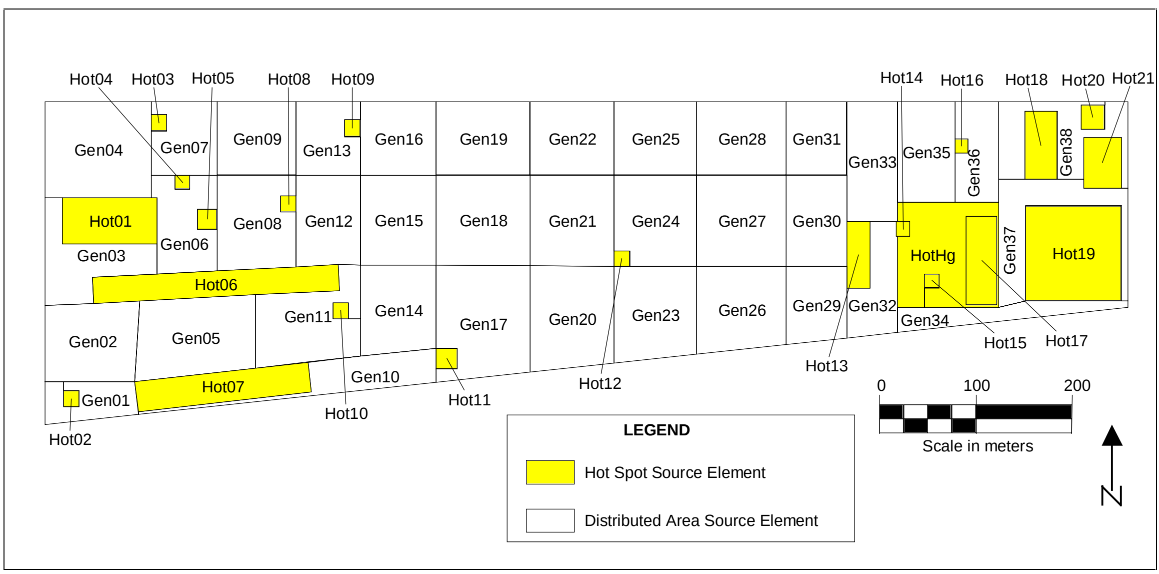



**Figure 2-1. Conceptual Model of the Hydrologic Processes**




Note: Elements do not overlap. Some general elements wrap around hot-spot elements.

**Figure 2-2. Schematic of Source Element Locations**

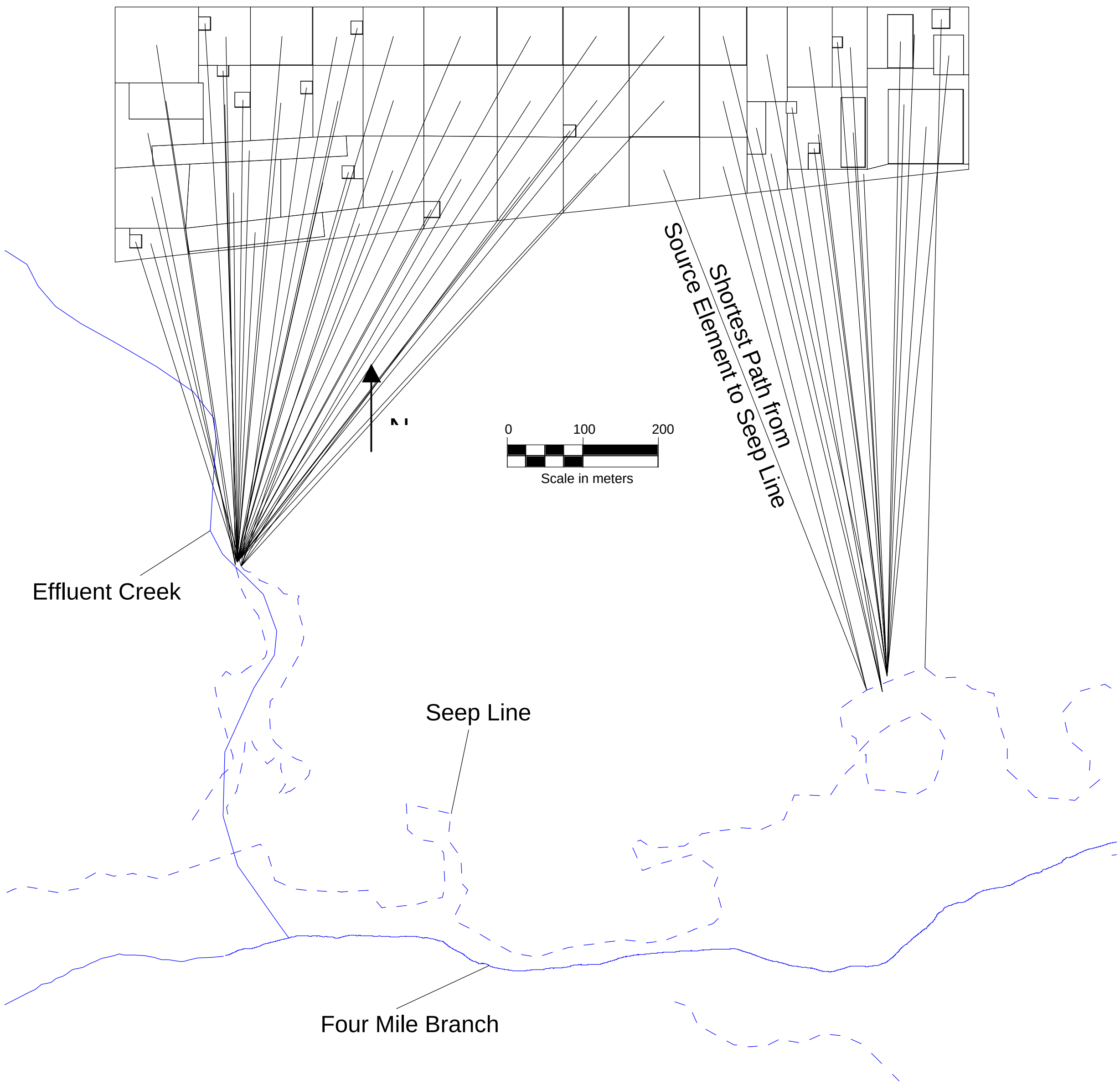
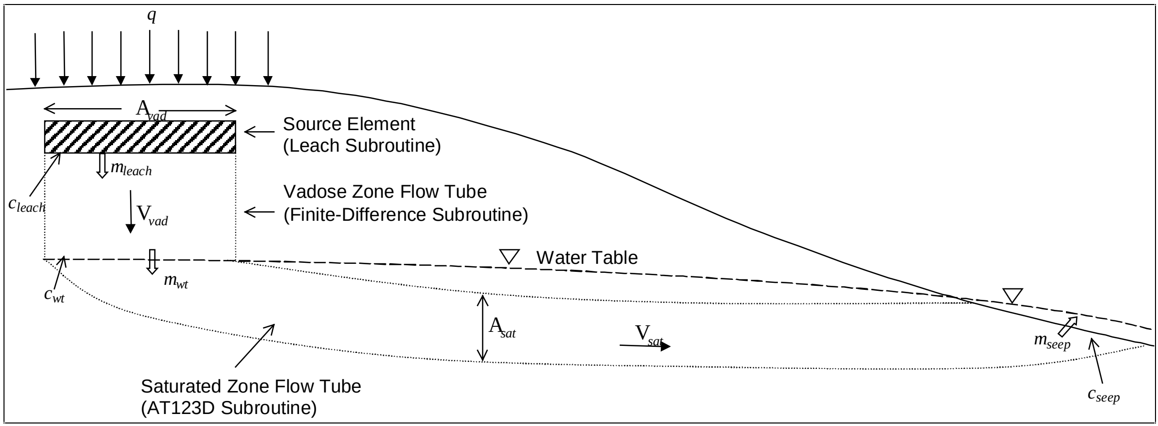


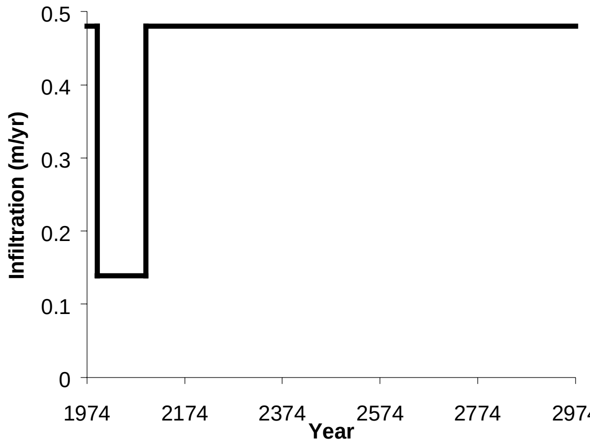

**Figure 2-3. Diagram Showing Saturated-Zone Flow Path Distance Determinations for Source Elements**



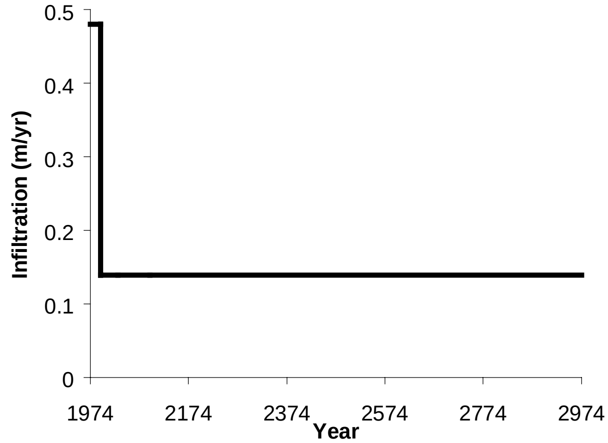

Symbols

$q$ = infiltration rate [L/T]
$A_{\mathrm{vad}}$ = source element area, vadose zone flow tube area [$L^2$]
$\dot{m}_{leach}$ = leachate mass (activity) flux [M/T]
$c_{leach}$ = leachate concentration [$M/L^3$]
$V_{\mathrm{vad}}$ = vadose zone groundwater velocity [L/T]
$\dot{m}_{wt}$ = mass (activity) flux across water table [M/T]
$c_{wt}$ = concentration at the water table [$M/L^3$]
$A_{\mathrm{sat}}$ = saturated zone flow tube area [$L^2$]
$V_{\mathrm{sat}}$ = saturated zone groundwater velocity [L/T]
$\dot{m}_{seep}$ = mass (activity) flux to seeps [M/T]
$c_{seep}$ = concentration at the water table [$M/L^3$]

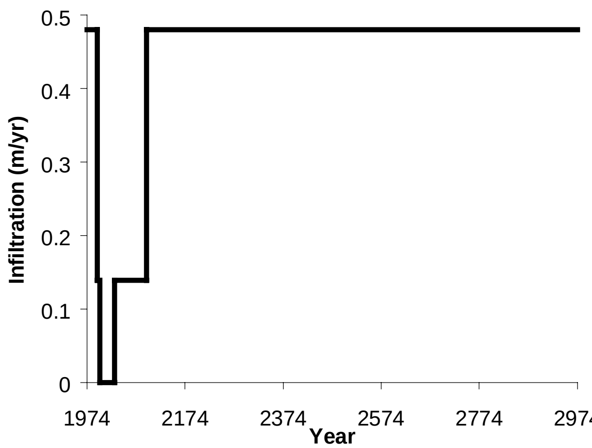
**Figure 2-4. Detailed Conceptual Model for each Streamtube**



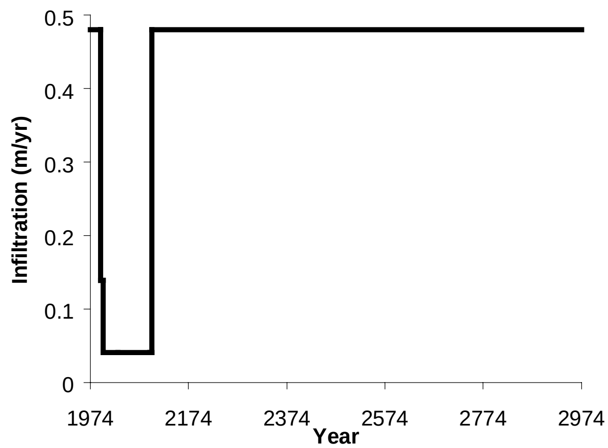

a) Soil Cover with 100-year control



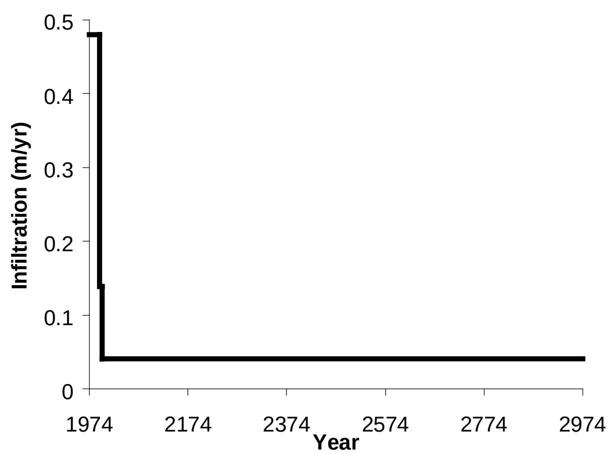

b) Soil Cover with-Barrier




c) RCRA Geosynthetic Cap (30-year Life)

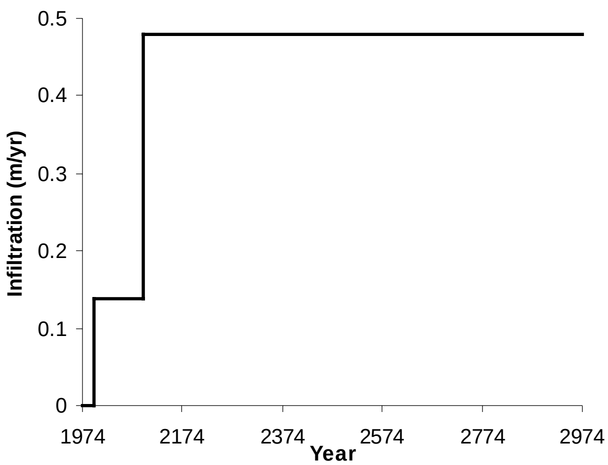



d) RCRA Clay Cap with 100-year Control

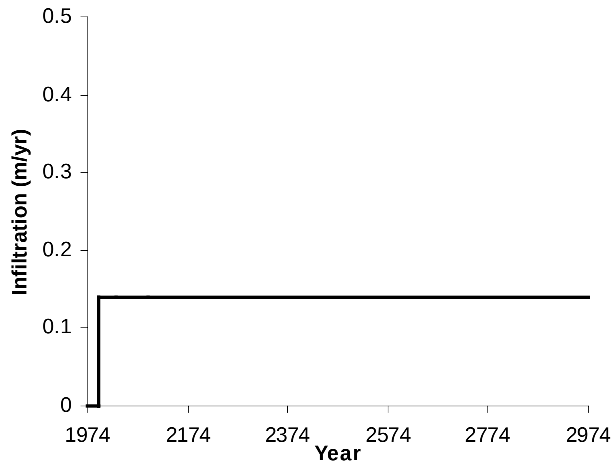



e) RCRA Clay Cap with Barrier

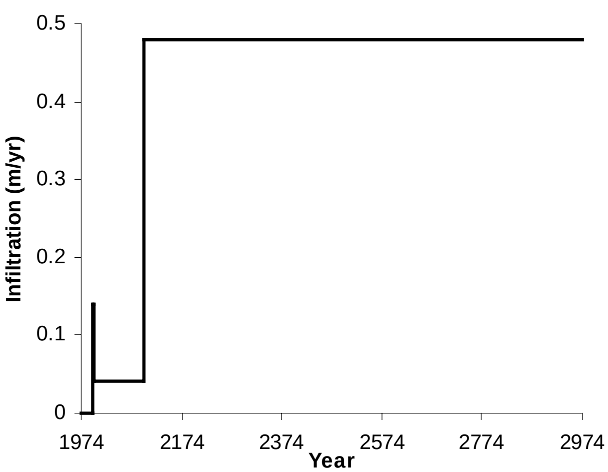
**Figure 2-5. Infiltration for the Cover/Cap Alternatives of the Constant Vadose Zone Infiltration Scenarios (Limited-Impact/Early-Timing) and the Variable Vadose Zone Infiltration Modeling Scenarios (Full-Impact/Early-Timing)**



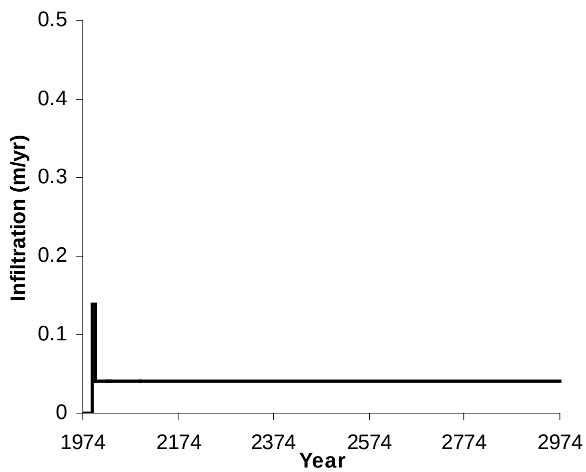

a) Soil Cover with 100-year control




b) Soil Cover with Barrier

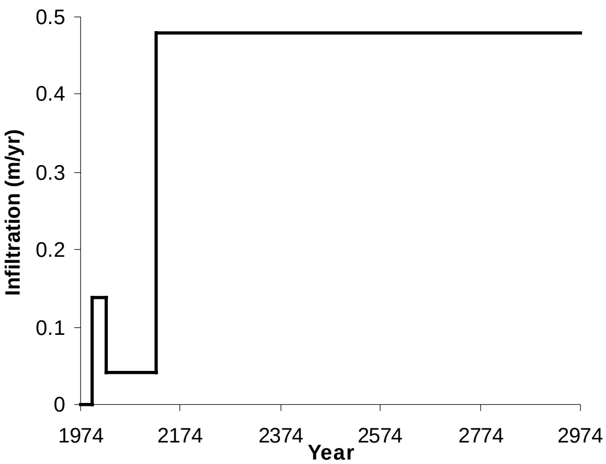



c) RCRA Clay Cap with 100-year Control

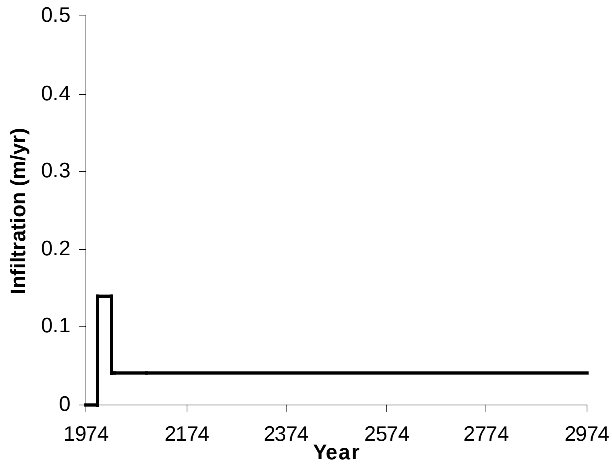



d) RCRA Clay Cap with Barrier

**Figure 2-6. Infiltration for the Cover/Cap Alternatives for the Delayed Leaching Scenarios (Full-Impact/Late-Timing)**




a) RCRA Clay Cap with 100-year Control




b) RCRA Clay Cap with Barrier

**Figure 2-7. Infiltration for the Alternatives for the "Trigger" Scenarios (Full-Impact/Late-Timing with Trigger)**

**Table 2-1. Hydrologic System and Simulation Parameter Values**

| Input Parameter | Value | Remarks |
|---|---|---|
| Simulation Time Steps | 1000 | 1974-2974 |
| Number of Source Elements | 60 | |
| Number of COIs | 16 | |
| Number of Waste Forms | 2 | soil, concrete |
| Time Step Length | 1 yr | |
| Vadose Zone Degree of Saturation | 0.7 | |
| Vadose Longitudinal Dispersivity | 2 m | (1/10th of saturated value) |
| Saturated Longitudinal Dispersivity | 20 m | |
| Saturated Hydraulic Conductivity | 800 m/yr | |
| Bulk Density | 1600 kg/m$^3$ | both soil & concrete |
| Porosity | 0.44 | both soil & concrete |
| Seep Elevation | 64.0 m | all elements |
| Default Infiltration | 0.480 m/yr | pre-soil cover |

## Table 2-2. Source Element Properties

a) Hot Spot Source Element Properties

| Source Element | Element Number | Area ($m^2$) | Distance of Saturated Zone Flow (m) | Top of Source (m) | Bottom of Source (m) | Water Table Elevation (m) |
|---|---|---|---|---|---|---|
| Hot01 | 1 | 4682 | 620 | 83.19 | 78.31 | 69.55 |
| Hot02 | 2 | 830 | 470 | 83.17 | 78.29 | 69.01 |
| Hot03 | 3 | 277 | 730 | 84.93 | 80.06 | 69.78 |
| Hot04 | 4 | 223 | 660 | 84.72 | 79.84 | 69.77 |
| Hot05 | 5 | 418 | 620 | 84.35 | 79.48 | 69.78 |
| Hot06 | 6 | 6816 | 560 | 84.48 | 79.61 | 69.65 |
| Hot07 | 7 | 5679 | 450 | 82.50 | 77.62 | 69.26 |
| Hot08 | 8 | 277 | 650 | 85.21 | 80.34 | 70.06 |
| Hot09 | 9 | 290 | 730 | 87.79 | 82.91 | 70.33 |
| Hot10 | 10 | 277 | 540 | 86.05 | 81.18 | 69.89 |
| Hot11 | 11 | 476 | 540 | 84.47 | 79.59 | 70.21 |
| Hot12 | 12 | 263 | 720 | 84.75 | 79.88 | 71.42 |
| Hot13 | 13 | 1705 | 750 | 83.58 | 78.70 | 72.20 |
| Hot14 | 14 | 419 | 760 | 84.12 | 79.25 | 72.57 |
| Hot15 | 15 | 445 | 700 | 84.16 | 79.28 | 72.40 |
| Hot16 | 16 | 198 | 830 | 85.55 | 80.67 | 72.68 |
| Hot17 | 17 | 6064 | 720 | 85.99 | 81.12 | 72.57 |
| Hot18 | 18 | 2415 | 830 | 87.66 | 82.78 | 72.58 |
| Hot19 | 19 | 9817 | 720 | 87.80 | 82.92 | 72.35 |
| Hot20 | 20 | 635 | 860 | 88.12 | 83.25 | 72.35 |
| Hot21 | 21 | 2063 | 820 | 89.06 | 84.18 | 72.38 |
| HotHg | 22 | 8013 | 720 | 84.50 | 79.63 | 72.53 |

Notes: The top of source is taken as 1.22 m below the pre-soil cover topographic elevation.
The bottom of source is 4.88 m below the top of source.
The water table elevation is from observed data, see Figure 14 in Flach et al. (1996).

## Table 2-2. (con't) Source Element Properties

b) Distributed Area Source Element Properties

| Source Element | Element Number | Area ($m^2$) | Distance of Saturated Zone Flow (m) | Top of Source (m) | Bottom of Source (m) | Water Table Elevation (m) |
|---|---|---|---|---|---|---|
| Gen01 | 23 | 3502 | 450 | 83.35 | 78.47 | 69.03 |
| Gen02 | 24 | 7836 | 520 | 84.35 | 79.47 | 69.23 |
| Gen03 | 25 | 6232 | 600 | 83.61 | 78.73 | 69.41 |
| Gen04 | 26 | 10998 | 700 | 84.08 | 79.21 | 69.59 |
| Gen05 | 27 | 9809 | 500 | 84.10 | 79.23 | 69.37 |
| Gen06 | 28 | 5855 | 620 | 83.98 | 79.10 | 69.72 |
| Gen07 | 29 | 4952 | 710 | 85.20 | 80.32 | 69.82 |
| Gen08 | 30 | 7747 | 630 | 84.72 | 79.84 | 69.92 |
| Gen09 | 31 | 6274 | 710 | 85.28 | 80.41 | 70.02 |
| Gen10 | 32 | 5341 | 490 | 84.64 | 79.77 | 69.73 |
| Gen11 | 33 | 8226 | 520 | 85.14 | 80.26 | 69.71 |
| Gen12 | 34 | 6239 | 640 | 85.92 | 81.04 | 70.15 |
| Gen13 | 35 | 4778 | 710 | 86.73 | 81.85 | 70.24 |
| Gen14 | 36 | 7152 | 660 | 85.87 | 80.99 | 70.14 |
| Gen15 | 37 | 7393 | 660 | 86.74 | 81.87 | 70.38 |
| Gen16 | 38 | 6032 | 730 | 88.98 | 84.10 | 70.47 |
| Gen17 | 39 | 10864 | 600 | 84.85 | 79.97 | 70.54 |
| Gen18 | 40 | 9184 | 690 | 86.82 | 81.94 | 70.66 |
| Gen19 | 41 | 7452 | 770 | 86.95 | 82.08 | 70.77 |
| Gen20 | 42 | 9211 | 650 | 83.59 | 78.72 | 71.01 |
| Gen21 | 43 | 8257 | 720 | 85.47 | 80.60 | 71.15 |
| Gen22 | 44 | 6660 | 800 | 83.68 | 78.80 | 71.09 |
| Gen23 | 45 | 8249 | 690 | 83.69 | 78.81 | 71.34 |
| Gen24 | 46 | 7899 | 770 | 85.60 | 80.72 | 71.60 |
| Gen25 | 47 | 6566 | 840 | 85.35 | 80.48 | 71.43 |
| Gen26 | 48 | 8024 | 740 | 82.87 | 78.00 | 71.64 |
| Gen27 | 49 | 8836 | 810 | 84.64 | 79.76 | 71.83 |
| Gen28 | 50 | 7108 | 890 | 84.98 | 80.11 | 71.76 |
| Gen29 | 51 | 4854 | 710 | 82.51 | 77.63 | 71.90 |
| Gen30 | 52 | 5925 | 790 | 84.18 | 79.31 | 72.12 |
| Gen31 | 53 | 4766 | 870 | 84.54 | 79.67 | 71.99 |
| Gen32 | 54 | 4529 | 700 | 82.94 | 78.07 | 72.16 |
| Gen33 | 55 | 6573 | 840 | 85.06 | 80.19 | 72.39 |
| Gen34 | 56 | 3996 | 660 | 85.66 | 80.79 | 72.49 |
| Gen35 | 57 | 6234 | 830 | 85.25 | 80.37 | 72.56 |
| Gen36 | 58 | 4582 | 820 | 85.96 | 81.08 | 72.72 |
| Gen37 | 59 | 6821 | 750 | 86.50 | 81.63 | 72.43 |
| Gen38 | 60 | 6129 | 830 | 87.81 | 82.94 | 72.54 |

**Table 2-3. COI Properties**

| COI | HalfLife (yr) | Soil $K_d$ ($m^3/kg$) | Concrete $K_d$ ($m^3/kg$) | Rad Hot Spot Waste Form | Other Areas Waste Form |
|---|---|---|---|---|---|
| Carbon-14 | 5715 | 0.002 | 7 | concrete | soil |
| Plutonium-239 | 24390 | 0.1 | 5 | concrete | soil |
| Plutonium-238 | 87.4 | 0.1 | 5 | concrete | soil |
| Uranium-238 | 4.46E+09 | 0.035 | N/A | soil | soil |
| Technetium-99 | 2.13E+05 | 0.00033 | N/A | soil | soil |
| Iodine-129 | 1.57E+07 | 0.0006 | N/A | soil | soil |
| Neptunium-237 | 2.14E+06 | 0.005 | 5 | concrete | soil |
| Uranium-235 | 7.04E+08 | 0.035 | N/A | soil | soil |
| Cesium-137 | 30 | 0.17 | N/A | soil | soil |
| Strontium-90 | 29.12 | 0.008 | N/A | soil | soil |
| Tritium | 12.3 | 0 | N/A | soil | soil |
| Cobalt-60 | 5.27 | 0.01 | N/A | soil | soil |
| Cadmium | N/A | 0.006 | N/A | soil | soil |
| Lead | N/A | 0.1 | N/A | soil | soil |
| Mercury | N/A | 0.02 | N/A | soil | soil |
| Volatile Organic Compounds | N/A | 0 | N/A | soil | soil |

Note: $K_d$ values are taken from WSRC (1997a), WRSC (1997b), and Sheppard and Thibault (1990). If multiple values are reported, the lower $K_d$ value was chosen.
The $K_d$ value for mercury was lowered to better match observed groundwater concentrations.

## Table 2-4. Initial Inventory of Constituents

a) Initial COI Inventory in Hot-Spot Source Areas

| Source Element | C14 (Ci) | Pu238 (Ci) | Pu239 (Ci) | U238 (Ci) | Tc99 (Ci) | I129 (Ci) | Np237 (Ci) | U235 (Ci) |
|---|---|---|---|---|---|---|---|---|
| Hot01 | 0 | 1572.56 | 106.573 | 2.099 | 0.1971 | 0.1584 | 0.1680 | 0.08541 |
| Hot02 | 0 | 0.877 | 0 | 0 | 0.0020 | 0.0281 | 0 | 0 |
| Hot03 | 0 | 0 | 0 | 0 | 0 | 0.0094 | 0 | 0 |
| Hot04 | 75.680 | 0 | 0 | 0.063 | 0 | 0.0075 | 0 | 6.55E-04 |
| Hot05 | 0 | 0 | 0 | 0.860 | 9.08E-04 | 0.0141 | 0 | 7.53E-04 |
| Hot06 | 335.400 | 11151.8 | 458.669 | 1.05E-05 | 0.0413 | 0.2306 | 1.0719 | 9.31E-04 |
| Hot07 | 0 | 0.120 | 0 | 1.671 | 0.4654 | 0.1921 | 0 | 5.14E-04 |
| Hot08 | 0 | 0 | 0 | 7.25E-07 | 3.76E-05 | 0.0094 | 0 | 6.41E-05 |
| Hot09 | 0 | 0 | 0 | 0 | 0.2896 | 0.0098 | 0 | 0 |
| Hot10 | 0 | 212.450 | 0 | 0 | 0.0138 | 0.0094 | 0 | 0 |
| Hot11 | 0 | 0 | 0 | 6.27E-07 | 0 | 0.0161 | 0 | 5.59E-05 |
| Hot12 | 0 | 148.380 | 5.190 | 0 | 0 | 0.0089 | 0.0425 | 0 |
| Hot13 | 0 | 5385.819 | 379.449 | 0 | 0.0310 | 0.0577 | 0.6630 | 0 |
| Hot14 | 0 | 0 | 0.140 | 0 | 0.0016 | 0.0142 | 0 | 0 |
| Hot15 | 0 | 50.585 | 0.236 | 0 | 0.0032 | 0.0151 | 0 | 0 |
| Hot16 | 43.000 | 7.998 | 0 | 0 | 0.0430 | 0.0067 | 0 | 0 |
| Hot17 | 0 | 11.283 | 0 | 0 | 0.0661 | 0.2051 | 0 | 0 |
| Hot18 | 669.080 | 1.617 | 0 | 0 | 0.5348 | 0.0817 | 0 | 0 |
| Hot19 | 1885.120 | 1465.646 | 13.452 | 0.159 | 2.9110 | 0.3321 | 0 | 0.07475 |
| Hot20 | 442.900 | 0 | 0 | 0 | 0.1537 | 0.0215 | 0 | 0 |
| Hot21 | 100.620 | 58.669 | 0 | 0 | 0.3219 | 0.0698 | 0 | 0 |
| HotHg | 6.736 | 13.286 | 15.225 | 0.2962 | 0.2062 | 0.2711 | 0.00133 | 0.01301 |
| All Hot | 3559 | 20081 | 979 | 5.1 | 5.3 | 1.77 | 1.95 | 0.18 |
| ORWBG | 3778 | 20514 | 1475 | 14.8 | 12 | 10.6 | 1.99 | 0.6 |

| Source Element | Cs137 (Ci) | Sr90 (Ci) | H3 (Ci) | Co60 (Ci) | Cd (kg) | Pb (kg) | Hg (kg) | VOC (kg) |
|---|---|---|---|---|---|---|---|---|
| Hot01 | 628.0 | 589.2 | 228100 | 29289 | 23.73 | 678 | 134 | 3914 |
| Hot02 | 6.33 | 5.94 | 32338 | 5189 | 4.20 | 120 | 24 | 694 |
| Hot03 | 0 | 0 | 57481 | 1730 | 1.40 | 40 | 8 | 231 |
| Hot04 | 0 | 0 | 495 | 1393 | 1.13 | 32 | 6 | 186 |
| Hot05 | 2.89 | 2.71 | 59236 | 2614 | 2.12 | 60 | 12 | 349 |
| Hot06 | 131.6 | 123.5 | 145448 | 42642 | 34.54 | 987 | 196 | 5699 |
| Hot07 | 1482.8 | 1391.2 | 178105 | 35526 | 28.78 | 822 | 163 | 4748 |
| Hot08 | 0.120 | 0.113 | 58053 | 1730 | 1.40 | 40 | 8 | 231 |
| Hot09 | 922.5 | 865.5 | 0 | 1817 | 1.47 | 42 | 8 | 243 |
| Hot10 | 44.1 | 41.4 | 2143 | 1730 | 1.40 | 40 | 8 | 231 |
| Hot11 | 0 | 0 | 53864 | 2975 | 2.41 | 69 | 14 | 398 |
| Hot12 | 0 | 0 | 0 | 1644 | 1.33 | 38 | 8 | 220 |
| Hot13 | 98.6 | 92.5 | 0 | 10669 | 8.64 | 247 | 49 | 1426 |
| Hot14 | 5.13 | 4.81 | 46863 | 2621 | 2.12 | 61 | 68 | 350 |
| Hot15 | 10.32 | 9.68 | 41414 | 2786 | 2.26 | 64 | 72 | 372 |
| Hot16 | 137.0 | 128.5 | 1387 | 1239 | 1.00 | 29 | 6 | 166 |
| Hot17 | 210.7 | 197.7 | 273752 | 37933 | 30.73 | 878 | 980 | 5070 |
| Hot18 | 1703.8 | 1598.5 | 33918 | 15110 | 12.24 | 350 | 69 | 2019 |
| Hot19 | 9273.9 | 8700.9 | 167439 | 61414 | 49.75 | 1421 | 282 | 8208 |
| Hot20 | 489.5 | 459.3 | 47115 | 3974 | 3.22 | 92 | 18 | 531 |
| Hot21 | 1025.4 | 962.0 | 60846 | 12908 | 10.46 | 299 | 59 | 1725 |
| HotHg | 1265 | 1295 | 45454 | 50129 | 40.61 | 1160 | 1295 | 6700 |
| All Hot | 17438 | 16468 | 1533450 | 327064 | 265 | 7567 | 3486 | 43711 |
| ORWBG | 58657 | 58657 | 3014457 | 1960400 | 1588 | 45359 | 10975 | 262000 |

## Table 2-4. (con't) Initial Inventory of Constituents

b) Initial COI Inventory in Distributed-Area Source Elements, part 1.

| Source Element | C14 (Ci) | Pu238 (Ci) | Pu239 (Ci) | U238 (Ci) | Tc99 (Ci) | I129 (Ci) | Np237 (Ci) | U235 (Ci) |
|---|---|---|---|---|---|---|---|---|
| Gen01 | 2.944 | 5.806 | 6.654 | 0.1294 | 0.0901 | 0.1185 | 0.00058 | 0.00569 |
| Gen02 | 6.587 | 12.992 | 14.888 | 0.2897 | 0.2016 | 0.2651 | 0.00130 | 0.01272 |
| Gen03 | 5.238 | 10.333 | 11.841 | 0.2304 | 0.1603 | 0.2108 | 0.00103 | 0.01012 |
| Gen04 | 9.245 | 18.235 | 20.896 | 0.4065 | 0.2830 | 0.3720 | 0.00182 | 0.01785 |
| Gen05 | 8.245 | 16.264 | 18.638 | 0.3626 | 0.2524 | 0.3318 | 0.00162 | 0.01592 |
| Gen06 | 4.922 | 9.709 | 11.125 | 0.2165 | 0.1507 | 0.1981 | 0.00097 | 0.00951 |
| Gen07 | 4.162 | 8.210 | 9.408 | 0.1830 | 0.1274 | 0.1675 | 0.00082 | 0.00804 |
| Gen08 | 6.512 | 12.845 | 14.719 | 0.2864 | 0.1993 | 0.2620 | 0.00128 | 0.01258 |
| Gen09 | 5.274 | 10.402 | 11.920 | 0.2319 | 0.1614 | 0.2122 | 0.00104 | 0.01019 |
| Gen10 | 4.490 | 8.856 | 10.149 | 0.1974 | 0.1374 | 0.1807 | 0.00088 | 0.00867 |
| Gen11 | 6.915 | 13.639 | 15.629 | 0.3041 | 0.2116 | 0.2783 | 0.00136 | 0.01335 |
| Gen12 | 5.244 | 10.345 | 11.854 | 0.2306 | 0.1605 | 0.2110 | 0.00103 | 0.01013 |
| Gen13 | 4.017 | 7.923 | 9.079 | 0.1766 | 0.1229 | 0.1616 | 0.00079 | 0.00776 |
| Gen14 | 6.012 | 11.859 | 13.589 | 0.2644 | 0.1840 | 0.2419 | 0.00118 | 0.01161 |
| Gen15 | 6.214 | 12.258 | 14.046 | 0.2733 | 0.1902 | 0.2501 | 0.00122 | 0.01200 |
| Gen16 | 5.070 | 10.002 | 11.461 | 0.2230 | 0.1552 | 0.2040 | 0.00100 | 0.00979 |
| Gen17 | 9.132 | 18.014 | 20.642 | 0.4016 | 0.2795 | 0.3675 | 0.00180 | 0.01764 |
| Gen18 | 7.720 | 15.228 | 17.451 | 0.3395 | 0.2363 | 0.3107 | 0.00152 | 0.01491 |
| Gen19 | 6.264 | 12.356 | 14.159 | 0.2755 | 0.1917 | 0.2521 | 0.00123 | 0.01210 |
| Gen20 | 7.743 | 15.273 | 17.501 | 0.3405 | 0.2370 | 0.3116 | 0.00152 | 0.01495 |
| Gen21 | 6.941 | 13.691 | 15.688 | 0.3052 | 0.2124 | 0.2793 | 0.00137 | 0.01340 |
| Gen22 | 5.599 | 11.043 | 12.655 | 0.2462 | 0.1714 | 0.2253 | 0.00110 | 0.01081 |
| Gen23 | 6.934 | 13.677 | 15.672 | 0.3049 | 0.2122 | 0.2790 | 0.00136 | 0.01339 |
| Gen24 | 6.640 | 13.097 | 15.009 | 0.2920 | 0.2032 | 0.2672 | 0.00131 | 0.01282 |
| Gen25 | 5.519 | 10.886 | 12.475 | 0.2427 | 0.1689 | 0.2221 | 0.00109 | 0.01066 |
| Gen26 | 6.745 | 13.305 | 15.246 | 0.2966 | 0.2065 | 0.2714 | 0.00133 | 0.01303 |
| Gen27 | 7.427 | 14.651 | 16.788 | 0.3266 | 0.2273 | 0.2989 | 0.00146 | 0.01434 |
| Gen28 | 5.975 | 11.785 | 13.505 | 0.2627 | 0.1829 | 0.2404 | 0.00118 | 0.01154 |
| Gen29 | 4.080 | 8.048 | 9.222 | 0.1794 | 0.1249 | 0.1642 | 0.00080 | 0.00788 |
| Gen30 | 4.981 | 9.824 | 11.258 | 0.2190 | 0.1524 | 0.2004 | 0.00098 | 0.00962 |
| Gen31 | 4.007 | 7.903 | 9.056 | 0.1762 | 0.1226 | 0.1612 | 0.00079 | 0.00774 |
| Gen32 | 3.807 | 7.510 | 8.606 | 0.1674 | 0.1165 | 0.1532 | 0.00075 | 0.00735 |
| Gen33 | 5.525 | 10.899 | 12.489 | 0.2430 | 0.1691 | 0.2223 | 0.00109 | 0.01067 |
| Gen34 | 3.359 | 6.626 | 7.593 | 0.1477 | 0.1028 | 0.1352 | 0.00066 | 0.00649 |
| Gen35 | 5.240 | 10.336 | 11.844 | 0.2304 | 0.1604 | 0.2109 | 0.00103 | 0.01012 |
| Gen36 | 3.852 | 7.598 | 8.707 | 0.1694 | 0.1179 | 0.1550 | 0.00076 | 0.00744 |
| Gen37 | 5.733 | 11.309 | 12.959 | 0.2521 | 0.1755 | 0.2307 | 0.00113 | 0.01107 |
| Gen38 | 5.152 | 10.162 | 11.644 | 0.2265 | 0.1577 | 0.2073 | 0.00101 | 0.00995 |
| All Gen | 219 | 433 | 496 | 9.7 | 6.7 | 8.8 | 0.04 | 0.42 |
| ORWBG | 3778 | 20514 | 1475 | 14.8 | 12 | 10.6 | 1.99 | 0.6 |

## Table 2-4. (con't) Initial Inventory of Constituents

c) Initial COI Inventory in Distributed-Area Source Elements, part 2.

| Source Element | Cs137 (Ci) | Sr90 (Ci) | H3 (Ci) | Co60 (Ci) | Cd (kg) | Pb (kg) | Hg (kg) | VOC (kg) |
|---|---|---|---|---|---|---|---|---|
| Gen01 | 553 | 566 | 19864 | 21908 | 17.75 | 507 | 100 | 2928 |
| Gen02 | 1237 | 1266 | 44449 | 49020 | 39.71 | 1134 | 225 | 6551 |
| Gen03 | 984 | 1007 | 35351 | 38987 | 31.58 | 902 | 179 | 5210 |
| Gen04 | 1736 | 1777 | 62386 | 68802 | 55.73 | 1592 | 315 | 9195 |
| Gen05 | 1549 | 1585 | 55642 | 61365 | 49.71 | 1420 | 281 | 8201 |
| Gen06 | 924 | 946 | 33215 | 36632 | 29.67 | 848 | 168 | 4896 |
| Gen07 | 782 | 800 | 28088 | 30977 | 25.09 | 717 | 142 | 4140 |
| Gen08 | 1223 | 1252 | 43943 | 48463 | 39.26 | 1121 | 222 | 6477 |
| Gen09 | 990 | 1014 | 35588 | 39249 | 31.79 | 908 | 180 | 5245 |
| Gen10 | 843 | 863 | 30299 | 33415 | 27.07 | 773 | 153 | 4466 |
| Gen11 | 1299 | 1329 | 46662 | 51461 | 41.69 | 1191 | 236 | 6878 |
| Gen12 | 985 | 1008 | 35390 | 39030 | 31.62 | 903 | 179 | 5216 |
| Gen13 | 754 | 772 | 27105 | 29893 | 24.21 | 692 | 137 | 3995 |
| Gen14 | 1129 | 1156 | 40570 | 44743 | 36.24 | 1035 | 205 | 5980 |
| Gen15 | 1167 | 1195 | 41935 | 46248 | 37.46 | 1070 | 212 | 6181 |
| Gen16 | 952 | 975 | 34217 | 37736 | 30.57 | 873 | 173 | 5043 |
| Gen17 | 1715 | 1756 | 61627 | 67965 | 55.05 | 1573 | 312 | 9083 |
| Gen18 | 1450 | 1484 | 52099 | 57457 | 46.54 | 1329 | 263 | 7679 |
| Gen19 | 1177 | 1204 | 42272 | 46620 | 37.76 | 1079 | 214 | 6231 |
| Gen20 | 1454 | 1488 | 52250 | 57624 | 46.68 | 1333 | 264 | 7701 |
| Gen21 | 1304 | 1334 | 46837 | 51655 | 41.84 | 1195 | 237 | 6903 |
| Gen22 | 1052 | 1076 | 37781 | 41667 | 33.75 | 964 | 191 | 5569 |
| Gen23 | 1302 | 1333 | 46790 | 51603 | 41.80 | 1194 | 237 | 6896 |
| Gen24 | 1247 | 1276 | 44808 | 49417 | 40.03 | 1143 | 227 | 6604 |
| Gen25 | 1037 | 1061 | 37243 | 41074 | 33.27 | 950 | 188 | 5489 |
| Gen26 | 1267 | 1297 | 45518 | 50200 | 40.66 | 1162 | 230 | 6709 |
| Gen27 | 1395 | 1428 | 50122 | 55277 | 44.78 | 1279 | 253 | 7388 |
| Gen28 | 1122 | 1149 | 40319 | 44466 | 36.02 | 1029 | 204 | 5943 |
| Gen29 | 766 | 784 | 27533 | 30365 | 24.60 | 703 | 139 | 4058 |
| Gen30 | 935 | 957 | 33610 | 37067 | 30.03 | 858 | 170 | 4954 |
| Gen31 | 752 | 770 | 27037 | 29818 | 24.15 | 690 | 137 | 3985 |
| Gen32 | 715 | 732 | 25692 | 28334 | 22.95 | 656 | 130 | 3787 |
| Gen33 | 1038 | 1062 | 37286 | 41121 | 33.31 | 951 | 189 | 5496 |
| Gen34 | 631 | 646 | 22670 | 25001 | 20.25 | 578 | 115 | 3341 |
| Gen35 | 984 | 1007 | 35362 | 38999 | 31.59 | 902 | 179 | 5212 |
| Gen36 | 723 | 740 | 25994 | 28667 | 23.22 | 663 | 131 | 3831 |
| Gen37 | 1077 | 1102 | 38691 | 42670 | 34.56 | 987 | 196 | 5703 |
| Gen38 | 968 | 990 | 34764 | 38340 | 31.06 | 887 | 176 | 5124 |
| All Gen | 41219 | 42189 | 1481007 | 1633336 | 1323 | 37792 | 7489 | 218289 |
| ORWBG | 58657 | 58657 | 3014457 | 1960400 | 1588 | 45359 | 10975 | 262000 |

## Table 2-5. Modeling Scenarios Summary

### a) Summary Matrix

| Alternative Impact | | Source Timing: Early (mobile in 1974) | Source Timing: Late (mobile in 1995) |
|---|---|---|---|
| | **Limited** (only leach) | Soil Cover<br>Soil Cover with Barrier<br>RCRA Synthetic Cap<br>RCRA Clay Cap<br>RCRA Clay Cap with Barrier | -- |
| | **Full** (leach and vadose) | Soil Cover<br>Soil Cover with Barrier<br>RCRA Synthetic Cap<br>RCRA Clay Cap<br>RCRA Clay Cap with Barrier | Soil Cover<br>Soil Cover with Barrier<br>RCRA Clay Cap<br>RCRA Clay Cap with Barrier<br>"Triggered" RCRA Clay Cap<br>"Triggered" RCRA Clay Cap with Barrier |

### b) Summary Listing

| Group | Run#[1] | Description of Remedial Alternative | Life of Cover/Cap (years) |
|---|---|---|---|
| Constant Infiltration | 120 | Soil cover | 100 |
| (Limited-Impact/Early-Timing) | 121 | Soil cover w/ barrier | 1000+ |
| | 122 | RCRA synthetic cap | 30 |
| | 123 | RCRA clay | 100 |
| | 124 | RCRA clay w/ barrier | 1000+ |
| Variable Infiltration | 030 | Soil cover | 100 |
| (Full-Impact/Early-Timing) | 031 | Soil cover w/ barrier | 1000+ |
| | 032 | RCRA synthetic cap | 30 |
| | 033 | RCRA clay | 100 |
| | 034 | RCRA clay w/ barrier | 1000+ |
| Delayed Leaching | 040 | Soil cover | 100 |
| (Full-Impact/Late-Timing) | 041 | Soil cover w/ barrier | 1000+ |
| | 043 | RCRA clay | 100 |
| | 044 | RCRA clay w/ barrier | 1000+ |
| Trigger Scenarios | 053 | RCRA clay | 100 |
| (Full-Impact/Late-Timing) | 054 | RCRA clay w/ barrier | 1000+ |

1 – Run numbers are for bookkeeping purposes only and do not reflect input parameter values nor results.

## 3.0 MODEL RESULTS

As stated above, the computer model calculates mass (activity) and concentrations for each constituent at various points along each streamtube for each simulated year. Thus, for storing mass (activity) and concentrations at four locations (source, source/vadose interface, vadose/saturated interface, and seepage point), decayed mass (activity) at three locations (source, vadose zone, saturated zone), with 16 COIs, 60 elements, and for each of the 1000 years, a total of 10.56 million values are generated and stored for each model run. Obviously, a data reduction and/or selective presentation methodology is necessary for adequate comprehension of the model results.

To this end, three presentation methods have been developed for this modeling report: (1) tables of the maximum concentration (any element, any time) for each COI, (2) plots of concentration over time for the sum of all elements, and (3) plots of total COI mass (activity) over time. The first two methods were used in the previous modeling report, while (3) is new to this report.

The maximum water table and seep concentration information is useful to understand the potential magnitude of impact of remedial alternatives on ultimate concentrations of COIs entering/exiting the groundwater system. Identifying constituents with very low maximum concentrations is useful as a screen for no further analysis, whereas when maximum concentrations are relatively significant, those COIs can be tagged for additional investigation.

The presentation of the concentration over time is useful to understand when the “peak” occurs. An early “peak” can indicate a more mobile constituent, and a late “peak” (or if the concentrations are still rising at the end of the simulation time-frame) can indicate a less mobile constituent. Understanding the mobility of the constituents is important to understanding which constituents can be most affected by different remedial options.

The total constituent mass (activity) over time presentation provides an integrated indication of the performance of each remedial alternative on each constituent, as well as provides insight into the overall fate and transport characteristics of each COI. Performance of remedial options can be evaluated as a whole for each constituent by comparing differences in movement of mass (activity) from one zone (i.e., source, vadose zone, etc.) to another. In addition, an understanding of the mobility and persistence of each COI can be determined from examination of these plots.

A complete presentation of the results for all scenarios and COIs is given in Appendix D. Not all presentation methods are provided with each COI/element in the main body of this report, as that would require an excessive number of plots and maps. The electronic files containing the modeling and presentation programs, and scenario results are summarized in Appendix E. To make the main portion of this report manageable, the following discussion and presentation of modeling results will focus on cadmium, mercury, and tritium, as these three constituents demonstrate the main three characteristic (i.e., bounding) responses.

### 3.1 Constant Vadose Zone Infiltration Modeling Scenarios (Limited-Impact/Early-Timing)

Table 3-1 and Figures 3-1 through 3-4 provide presentations of selective results of the limited-impact/early-timing modeling scenarios. In general, the results from these modeling scenarios is equivalent to that documented in the previous modeling report (HSI GeoTrans, 1999).

The base case simulation consisted of the currently-in-place low-permeability native soil cover being intact for a 100-year institutional control period, followed by infiltration through the ORWBG at prevailing regional infiltration rates for natural ground cover. A large variability in the simulated maximum concentrations at the water table and seep exposure point, and the time to attain these maximums was observed for the range of constituents. Constituents with low distribution coefficients and relatively short half lives, such as plutonium-238, cesium-137, strontium-90, and cobalt-60 decay to very low concentrations prior to reaching the water table. Constituents with low distribution coefficients, such as plutonium-239, uranium-238, uranium-235, lead, and mercury are relatively immobile and produce rising maximum seep-line concentrations at the end of the 1000-year analysis period. Tritium and VOCs are readily leached and have essentially been removed from the source (and entire system) very early in the simulated time period.

Except for neptunium-237, which showed only approximately a one order-of-magnitude (OOM) lower maximum seep concentration for the RCRA Clay Cap w/ Barrier scenario, no other significant differences in maximum concentrations at the seep were observed. Since the neptunium-237 maximum seep concentrations were very low (approximately 1.0E-3 pCi/ml), the observed difference is not considered important. At the water table below the ORWBG, only lead showed a significant maximum concentration reduction (for the RCRA Clay Cap with barrier scenario). However, the difference occurs near the end of the simulation (where the most uncertainty exists). The long-lived remedial alternative scenarios (i.e., those involving a barrier) showed some COI mass (activity) flux decreases to the vadose zone and/or the saturated zone, but no affect on mass (activity) flux out of the system.

The four capping alternatives that were simulated were generally not effective in reducing peak concentrations at the seep or at the water table below the ORWBG. The reason for this seems to be that the maximum concentrations are driven by the maximum leached concentrations, which occurred when leaching began prior to installation of any remedial alternative. Once this initial leachate has entered the saturated zone, the capping has a limited effect on the maximum concentrations which occur as a result of fate and transport of that portion of the leachate. The capping does have an effect on the leach rates and transport of constituents that are within the vadose zone when the cap is emplaced, but this effect is relatively minor.

## 3.2 Variable Vadose Zone Infiltration Scenarios (Full-Impact/Early-Timing)

Table 3-2 and Figures 3-5 through 3-8 present selective results of the variable vadose zone infiltration modeling scenarios.

Generally, the variable vadose zone infiltration scenario results were similar to the limited-impact/early-timing modeling scenarios – maximum seep concentrations were all within 1 OOM (except for mercury), maximum water table concentrations were all similar (except for lead and mercury), and mass (activity) fate and transport results were similar. As was seen in the limited-impact/early-timing modeling, the long-lived barrier scenarios showed some COIs exhibiting a decrease in mass (activity) to the vadose and/or saturated zone, but only cadmium showed a significant decrease in mass exiting of the system.

## 3.3 Delayed Leaching Scenarios (Full-Impact/Late-Timing)

Table 3-3 and Figures 3-9 through 3-12 present selective results of the delayed leaching modeling scenarios.

The delayed leaching scenarios showed no significant difference in results when compared with the full-impact/early-timing scenarios, except for tritium, which showed lower maximum seep concentrations and lower mass (activity) exiting the system for all remedial alternatives. Comparing remedial alternatives amongst the full-impact/late-timing scenarios shows only a few COIs (mercury, cadmium, and tritium) with lower maximum seep concentrations for the long-lived alternatives, but a number of COIs (Pu-239, U-238, Sr-90, lead, and mercury) showed lower maxium water table concentrations. Overall, the long-lived barrier scenarios showed less movement of the COIs to the vadose and/or saturated zones, and in the case of cadmium, less mass exiting the system.

### 3.4 "Trigger" Scenarios (Full-Impact/Late-Timing with Trigger)

The "trigger" modeling scenarios were originally designed around a "trigger" of 0.5 pCi/ml for carbon-14, technetium-99, iodine-129, or tritium. However, the results showed that the "trigger" occurred much sooner for tritium than the other three constituents, and that the resulting RCRA Cap installation time-frame would be the same as that already modeling in other scenarios (i.e. installation around year 2000). Thus, the tritium "trigger" was ignored and an installation of the RCRA Cap at 50 years (year 2024) was assumed based on the "trigger" times for the other three constituents. (The minimum "trigger" times for carbon-14 was 126 years; for technetium-99, 54 years; and for iodine-129, 101 years.)

Table 3-4 and Figures 3-9, 3-10, and 3-13 present selective results of the "trigger" modeling scenarios.

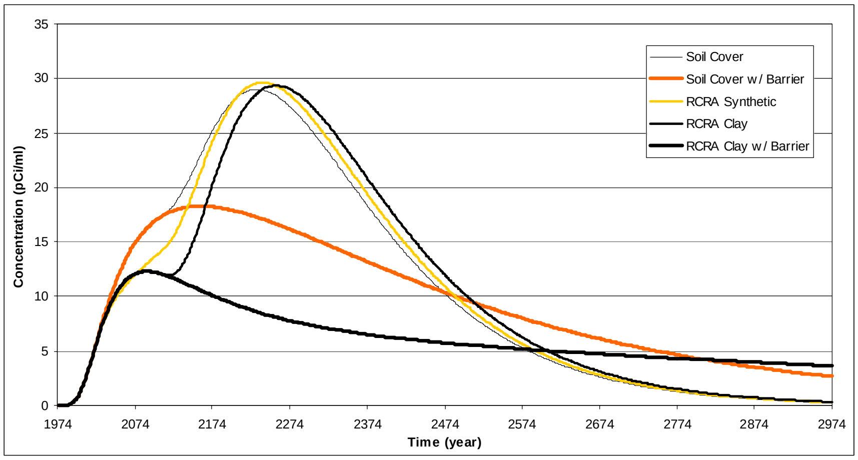
The results of the "trigger" modeling showed no fundamental difference from results seen in the delayed leaching scenarios, except for tritium, which showed that delay of the cap installation would increase the maximum seep concentration. The delay of RCRA Cap installation had no appreciable effect on fate and transport of the other COIs.

### 3.5 COI Summaries for All Groupings and Scenarios

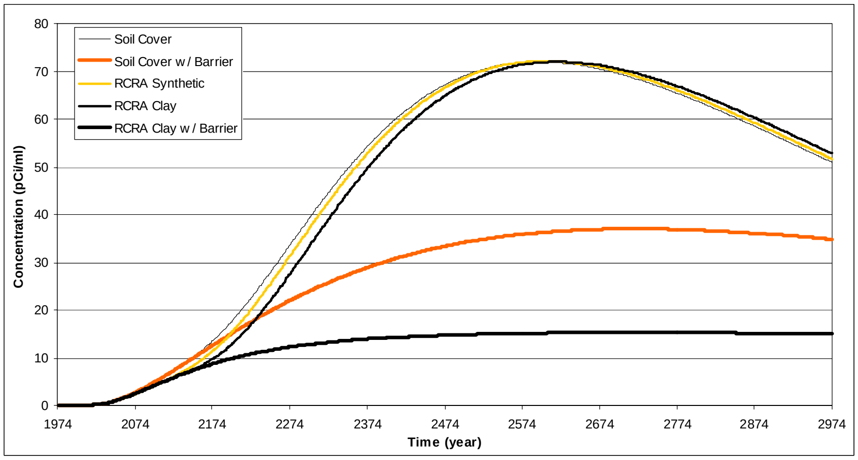
Analysis of all the scenarios in each grouping has resulted in the identification of four groups of COIs: (1) relatively immobile persistent constituents (carbon-14, plutonium-239, uranium-238, neptunium-237, uranium-235, lead, and mercury), (2) relatively immobile, short-lived constituents (plutonium-238, cesium-137, strontium-90, and cobalt-60), (3) mobile short-lived constituents (tritium), and (4) mobile persistent constituents (technitium-99, iodine-129, cadmium, and VOCs). Of these four groups, the mobile persistent constituents appear to be the most important to evaluating remedial alternatives, with cadmium demonstrating the most impact (with respect to ultimate mass movement out of the system) by different remedial alternatives. A summary of the observed responses of each COI is given in Table 3-5. Computed cumulative mass (activity) fluxes for into the vadose zone, into the saturated zone, and out of the system, are given for select constituents in Tables 3-6 through 3-10. Tables 3-11 and 3-12 give the computed cummulative mass/activity fluxes for all COIs for all scenarios (into the saturated zone and out of the system, respectively).

## 3.6 Comparison of Results

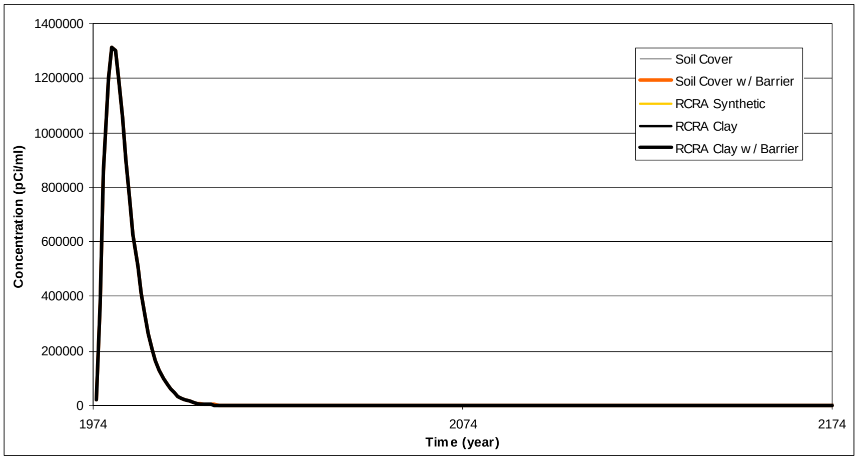
The results of this modeling indicate that although computed water table concentrations are slightly different for some COIs, the use of a variable vadose zone infiltration rate vs. a constant vadose zone infiltration rate has no impact on assessment of remedial alternatives, as shown by the examples in Figure 3-14. Further, the use of the delayed leaching assumption only effectively impacted tritium fate and transport as seen in Figures 3-15 and 3-16, but with no significant impact to the comparison of remedial alternatives. The results for the “trigger” scenarios indicate that delayed installation of a RCRA Clay Cap does not significantly affect water table or seep concentrations, except for tritium (see Figure 3-17). In particular, it is important to note that there is no significant difference in total mass flux to the water table or to the seep for cadmium or mercury between the RCRA clay cap (with barrier) installed in year 2000 versus year 2024.




a) Cadmium

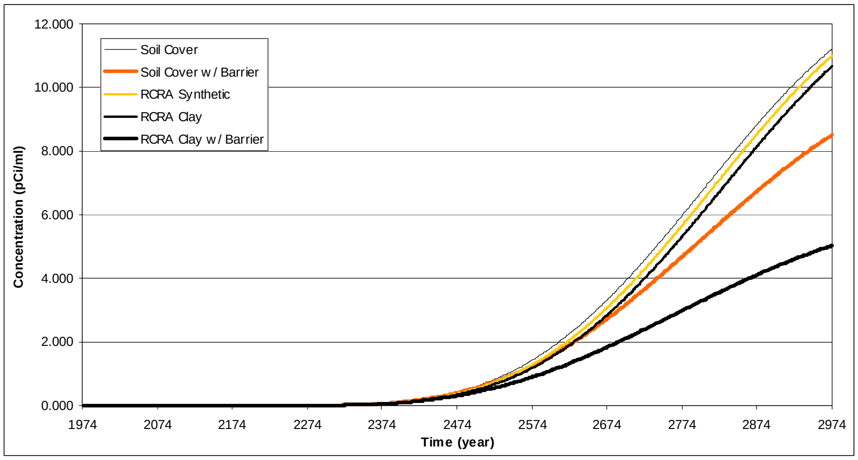



b) Mercury

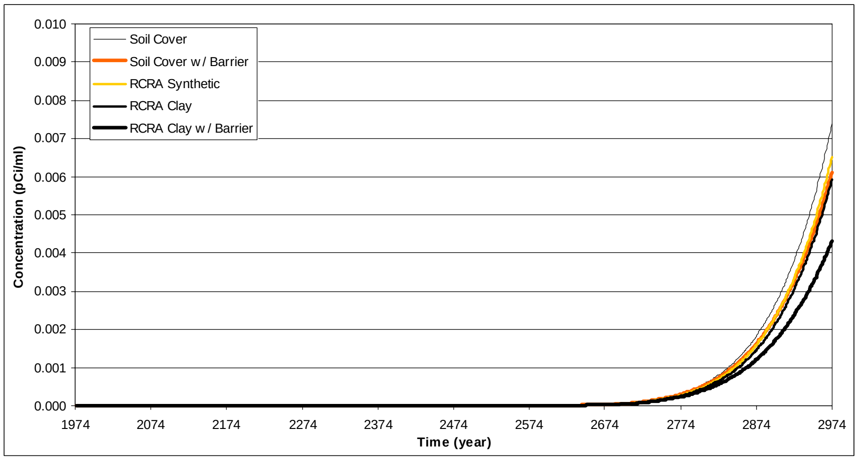



c) Tritium

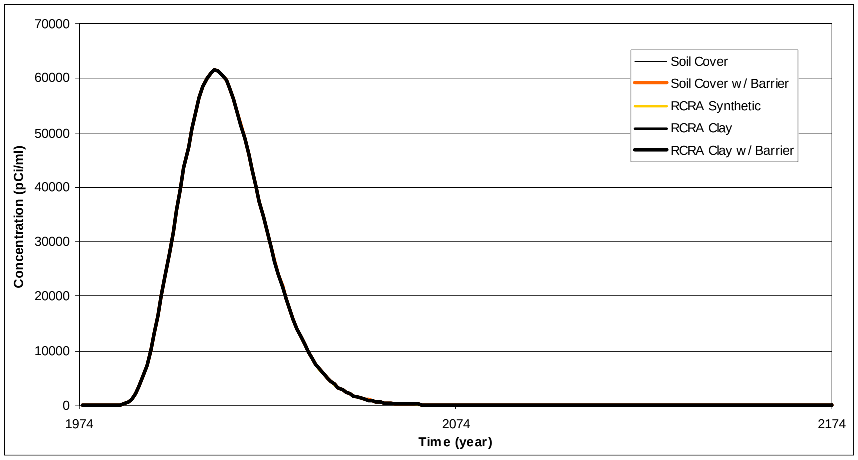
**Figure 3-1. Concentration in Saturated Zone below ORWBG vs. Time: Limited-Impact/Early-Timing Model Results for Sum of All Elements**




a) Cadmium

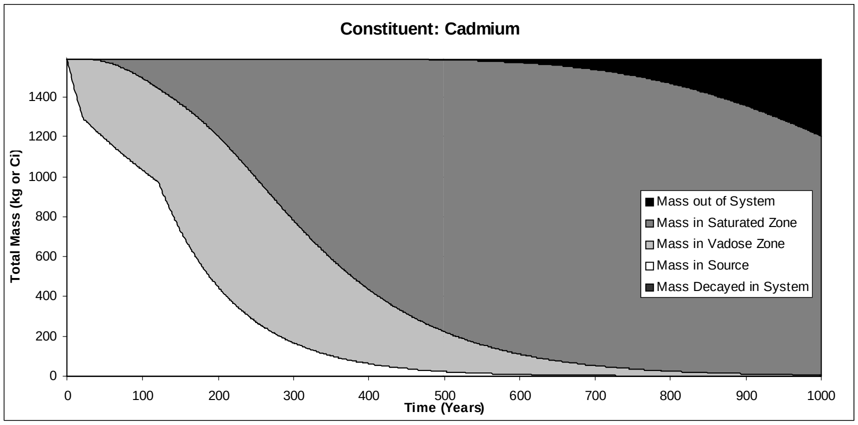



b) Mercury

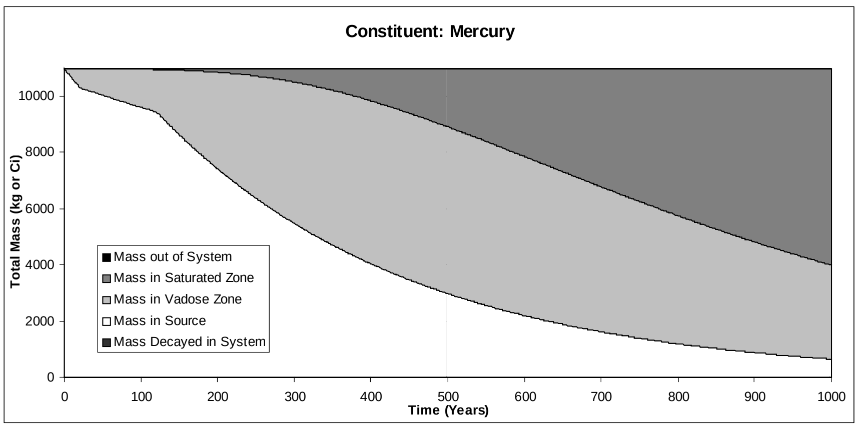



c) Tritium

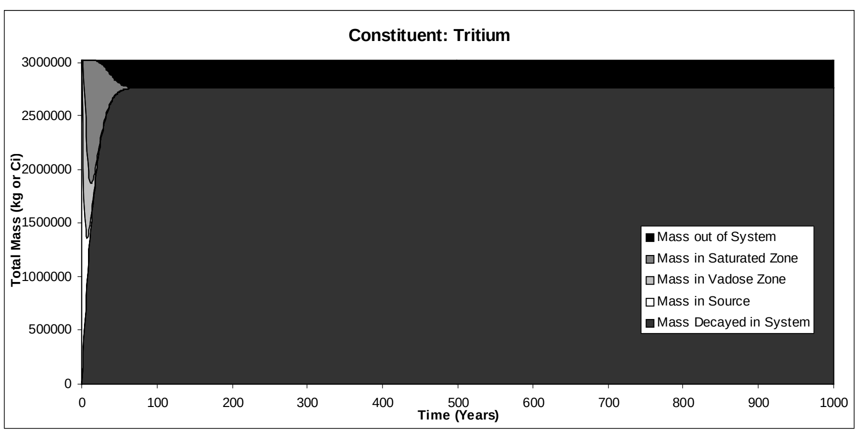
**Figure 3-2. Concentration at Seep Line vs. Time: Limited-Impact/Early-Timing Model Results for Sum of All Elements**




a) Cadmium

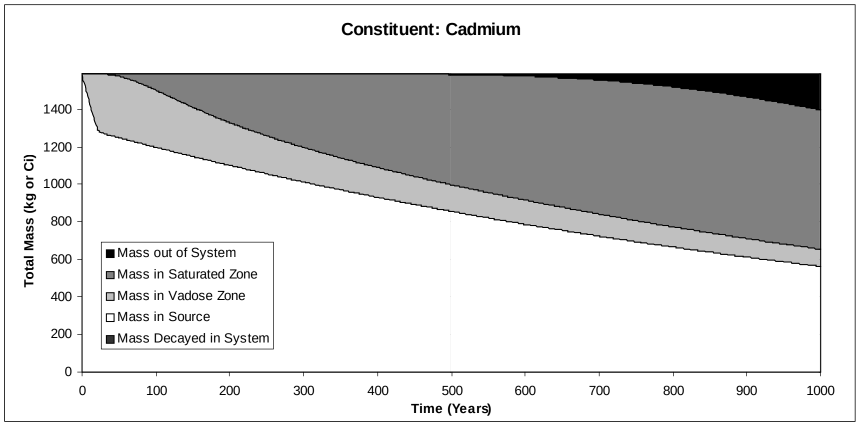



b) Mercury

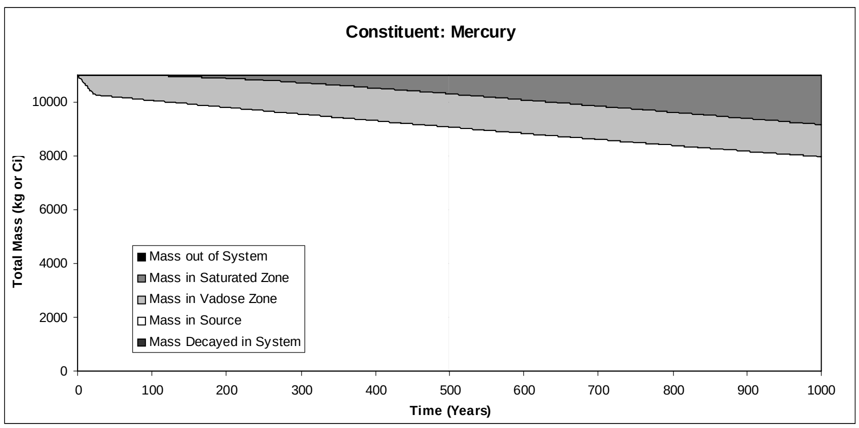



c) Tritium

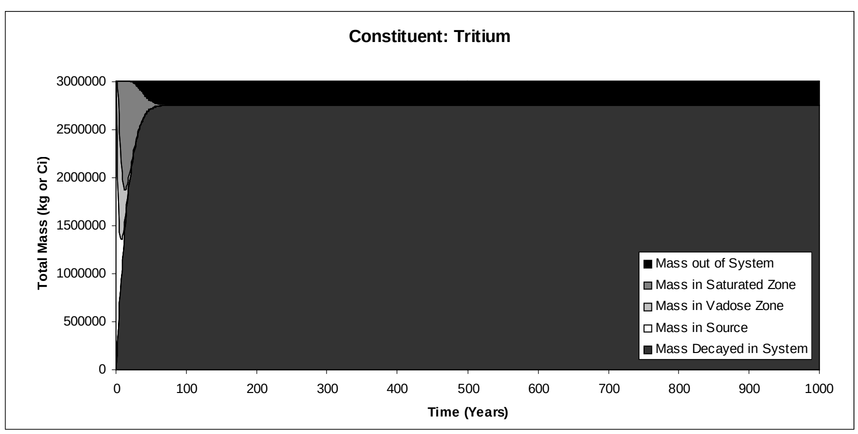
**Figure 3-3. Disposition of Total Mass (Activity) for Soil Cover (no barrier): Limited-Impact/Early-Timing Model Results for Sum of All Elements**




a) Cadmium

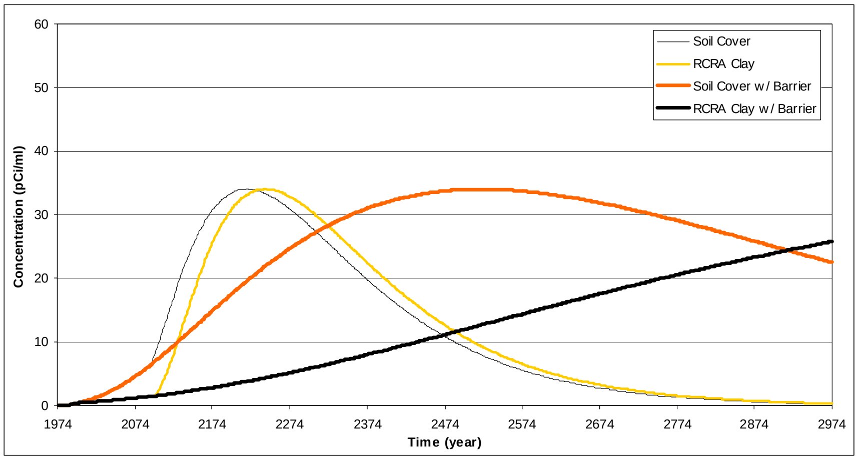



b) Mercury

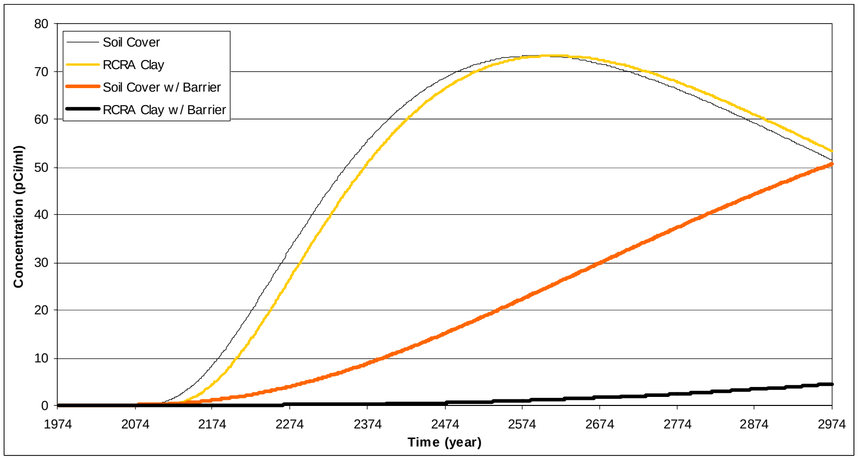



c) Tritium

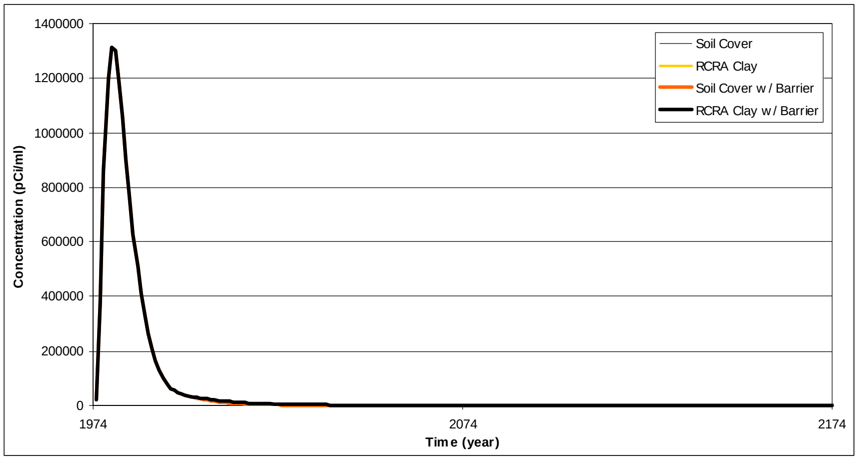
**Figure 3-4. Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Limited-Impact/Early-Timing Model Results for Sum of All Elements**




a) Cadmium

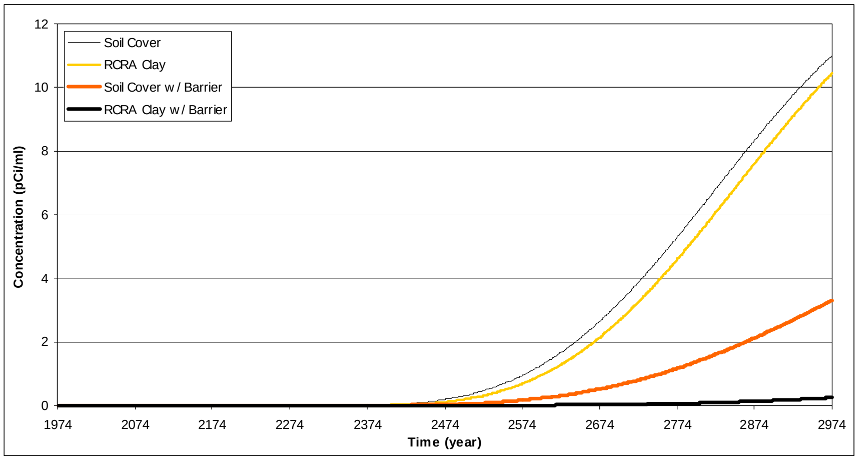



b) Mercury

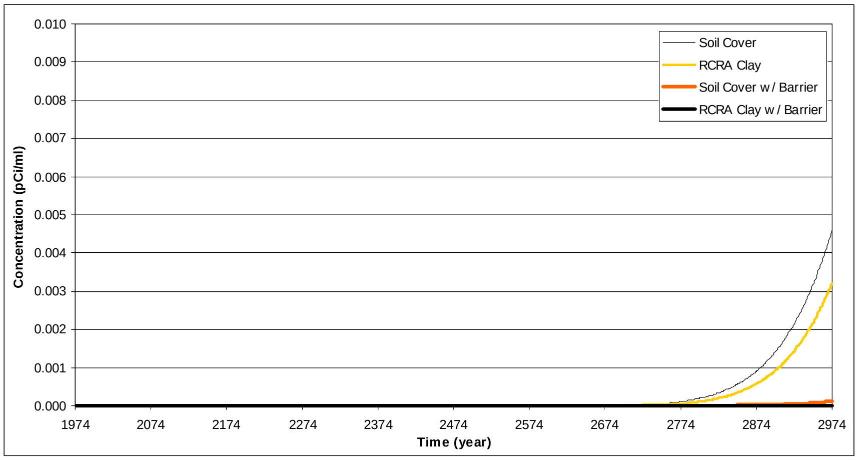



c) Tritium

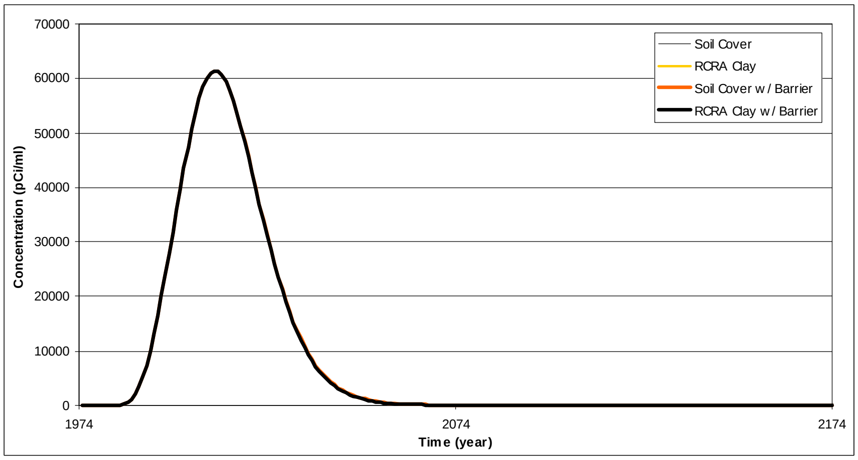
**Figure 3-5. Concentration in Saturated Zone below ORWBG vs. Time: Full-Impact/Early-Timing Infiltration Model Results for Sum of All Elements**




a) Cadmium

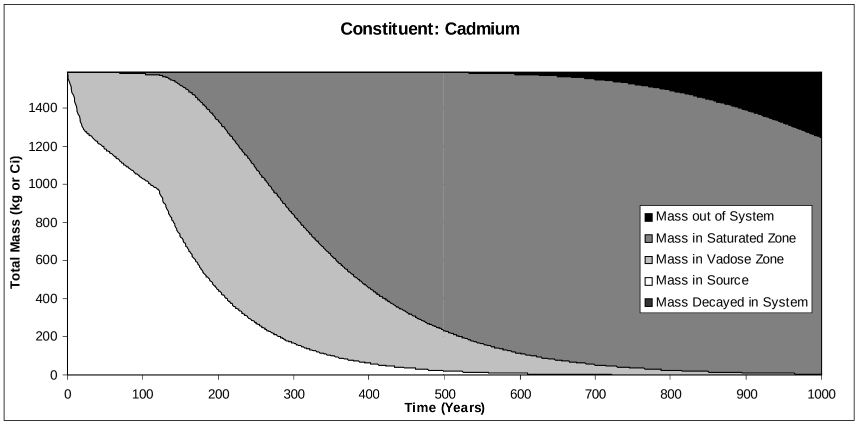



b) Mercury

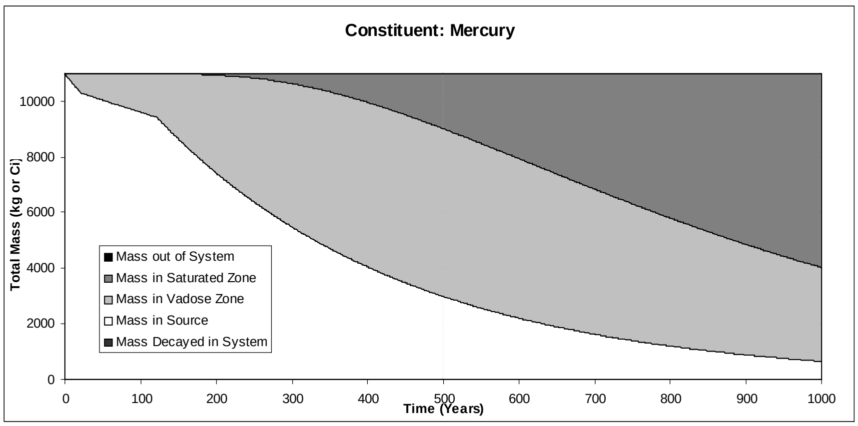



c) Tritium

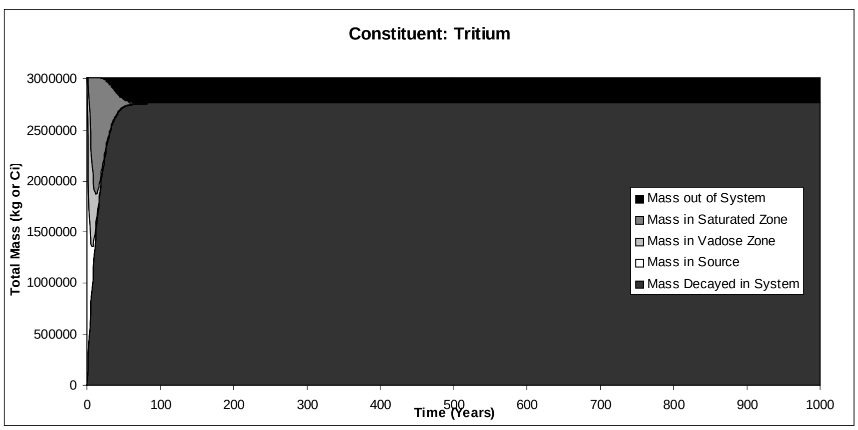
**Figure 3-6. Concentration at Seep Line vs. Time: Full-Impact/Early-Timing Model Results for Sum of All Elements**




a) Cadmium

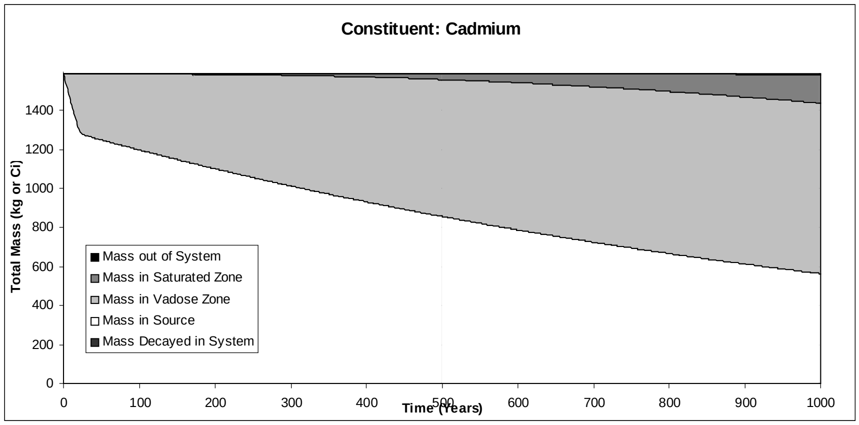



b) Mercury

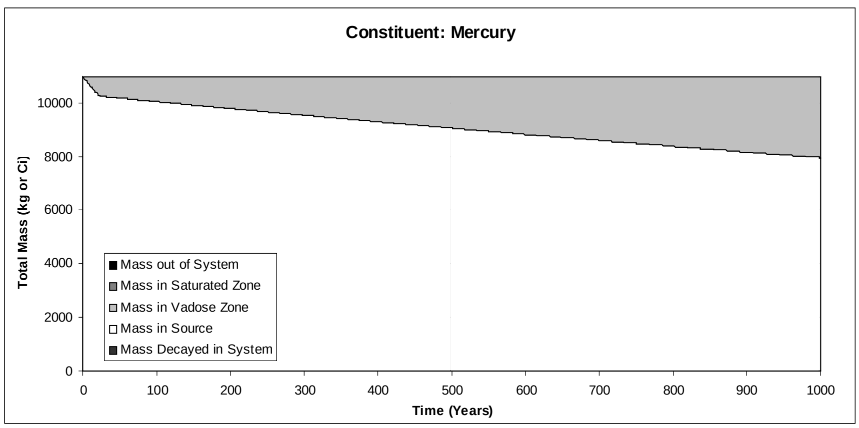



c) Tritium

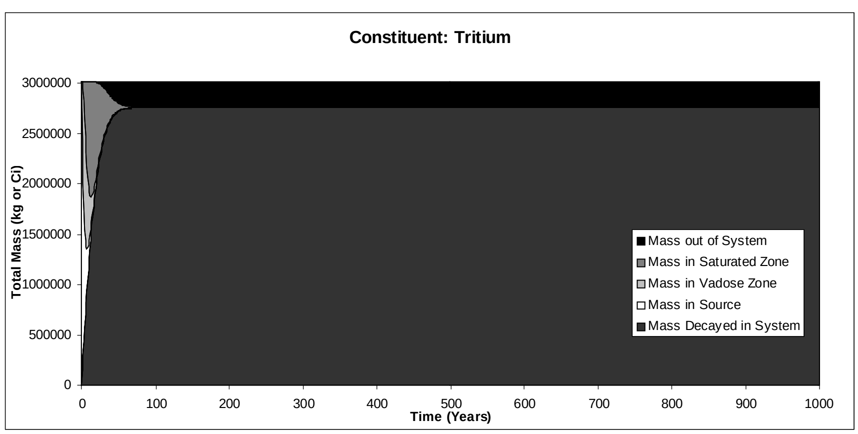
**Figure 3-7. Disposition of Total Mass (Activity) for Soil Cover (no barrier): Full-Impact/Early-Timing Model Results (Sum of All Elements)**




a) Cadmium

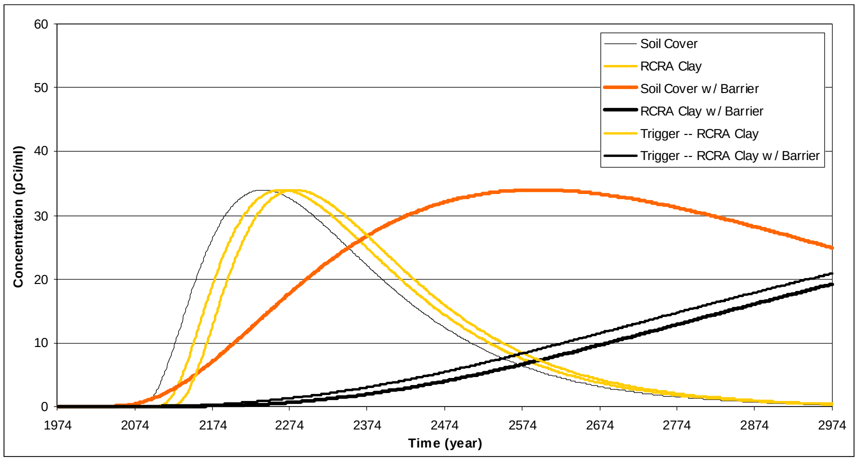



b) Mercury

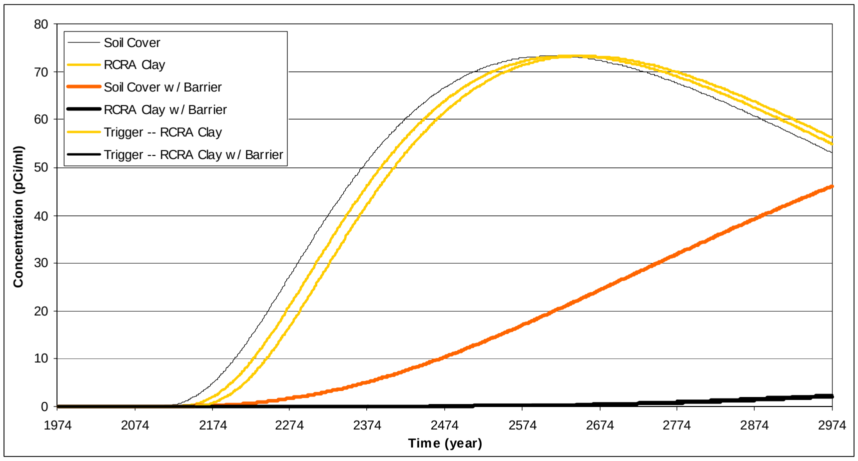



c) Tritium

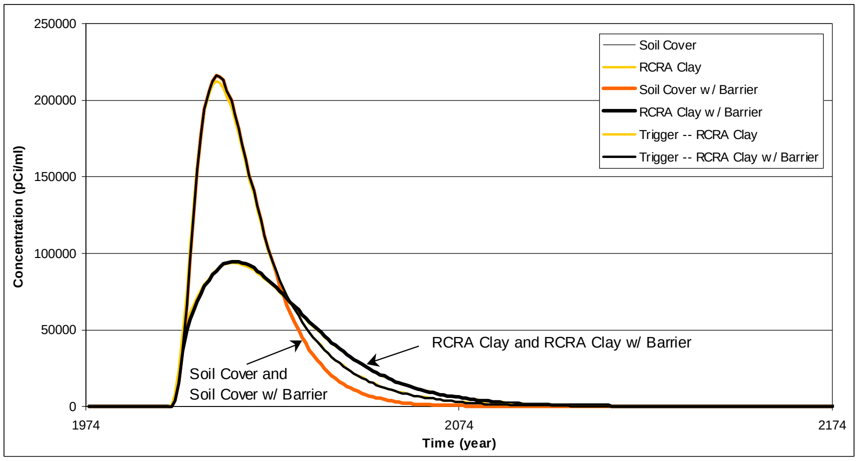
**Figure 3-8. Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Full-Impact/Early-Timing Model Results (Sum of All Elements)**




a) Cadmium

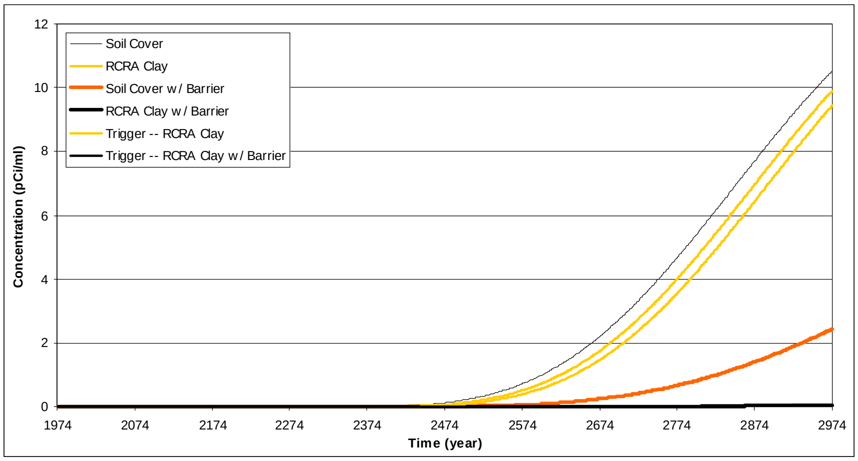



b) Mercury

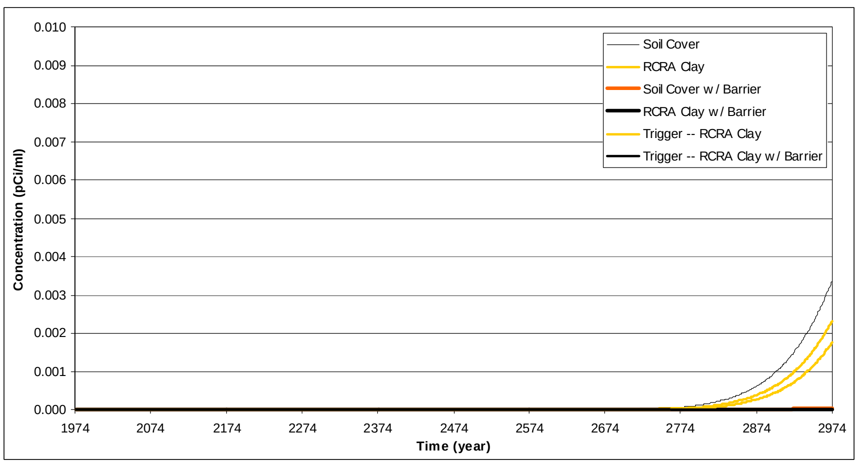



c) Tritium

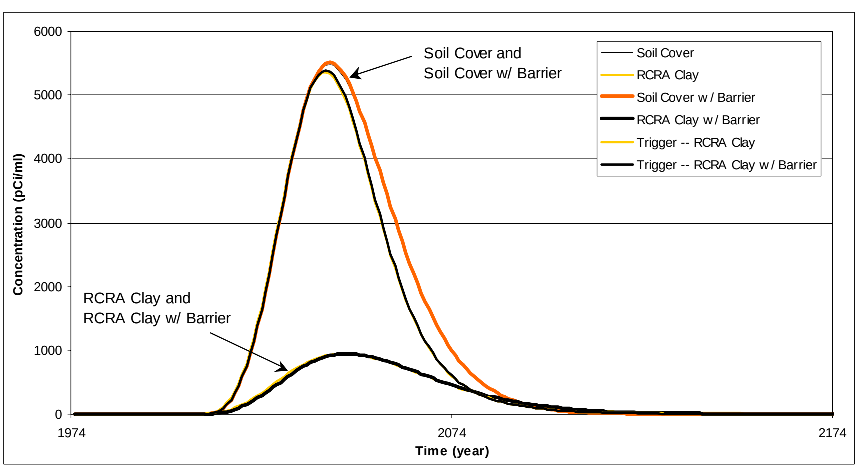
**Figure 3-9. Concentration in Saturated Zone below ORWBG vs. Time: Full-Impact/Late-Timing Model Results for Sum of All Elements**




a) Cadmium

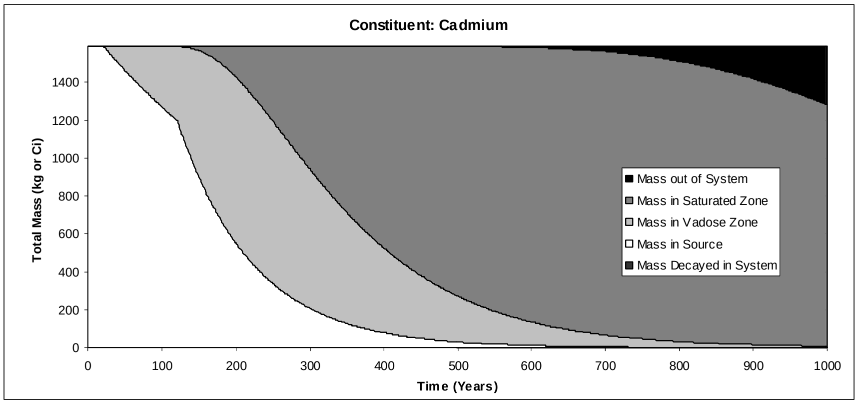



b) Mercury

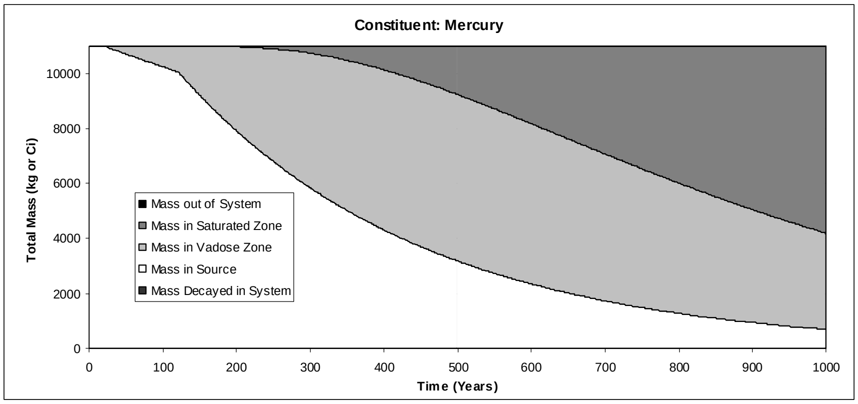



c) Tritium

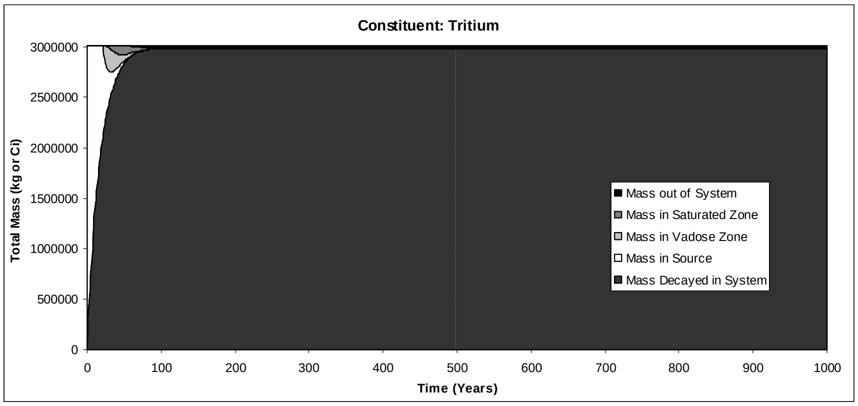
**Figure 3-10. Concentration at Seep Line vs. Time: Full-Impact/Late-Timing Model Results for Sum of All Elements**




a) Cadmium

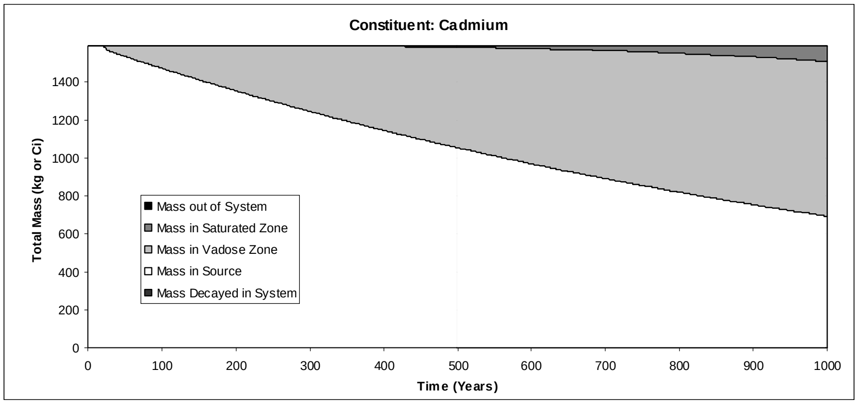



b) Mercury

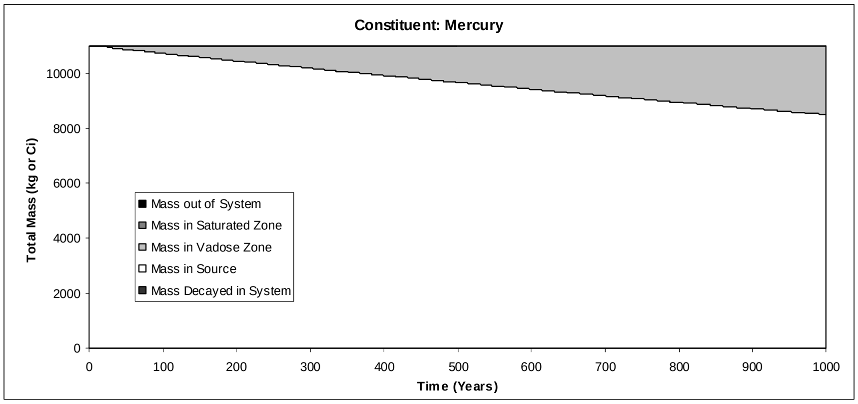



c) Tritium

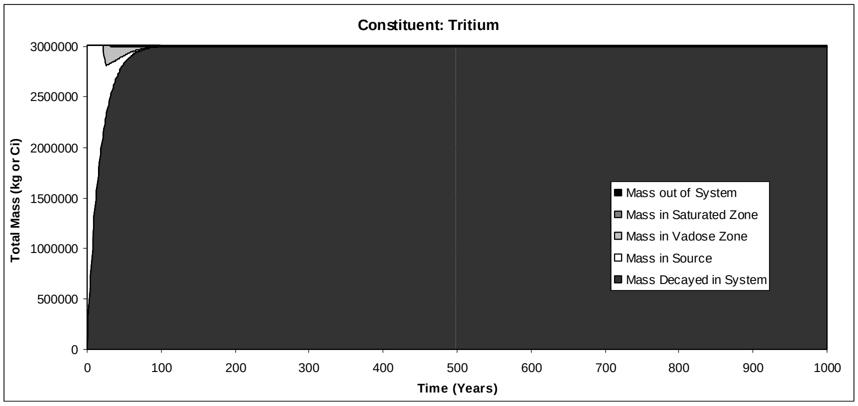
**Figure 3-11. Disposition of Total Mass (Activity) for Soil Cover (no barrier): Full-Impact/Late-Timing Model Results for Sum of All Elements**




a) Cadmium

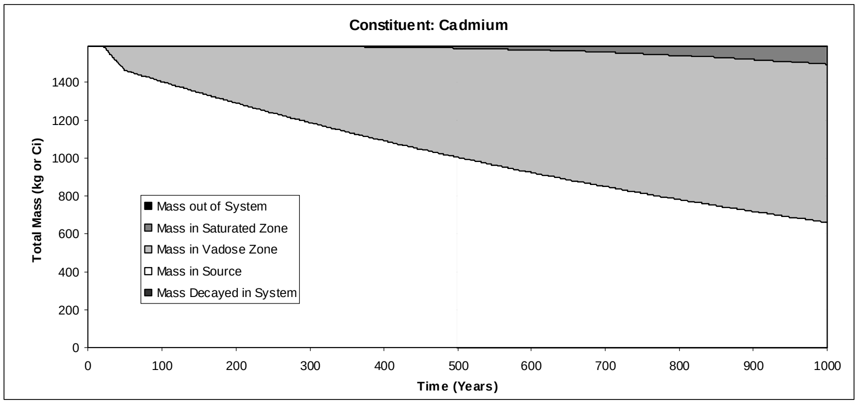



b) Mercury

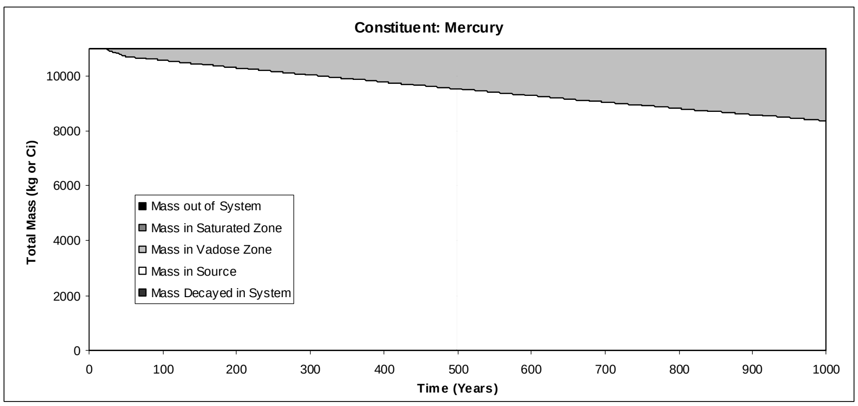



c) Tritium

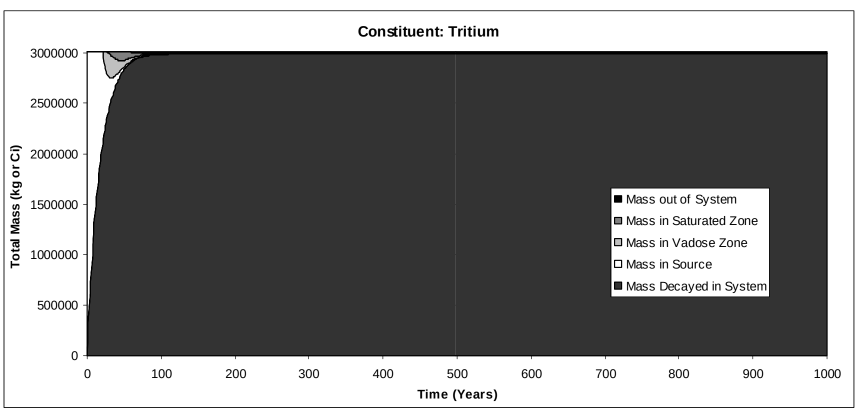
**Figure 3-12. Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Full-Impact/Late-Timing Model Results for Sum of All Elements**




a) Cadmium

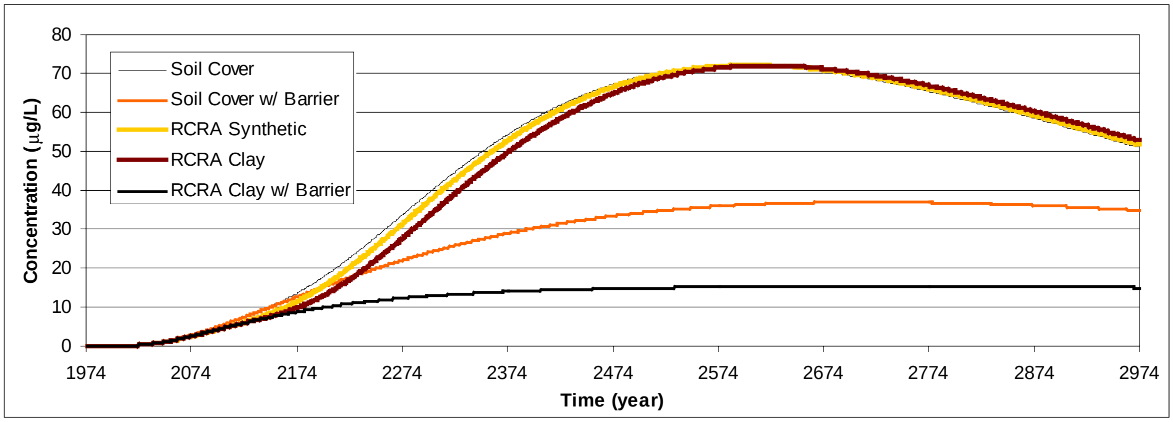



b) Mercury

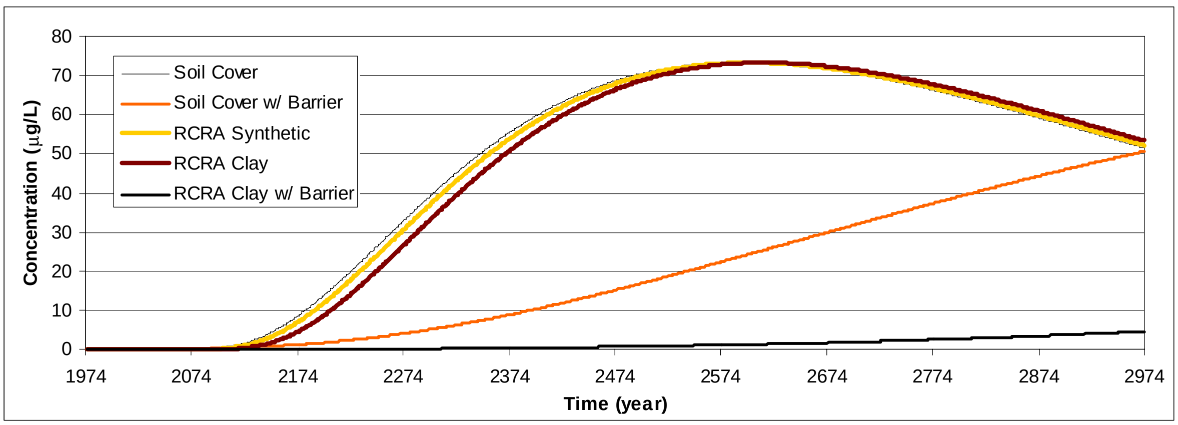



c) Tritium

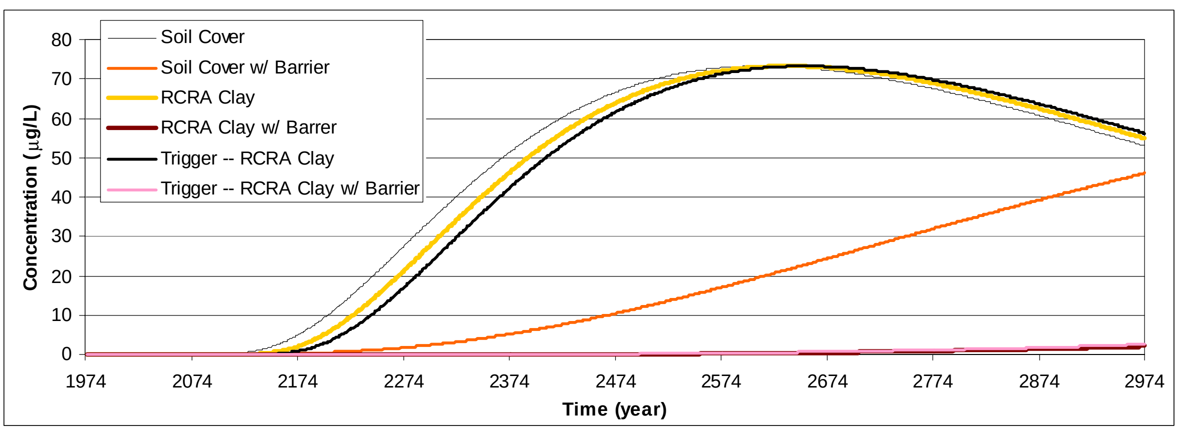
**Figure 3-13. Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Full-Impact/Late-Timing ("trigger") Infiltration Model Results for Sum of All Elements**




a) Constant Infiltration Modeling Results

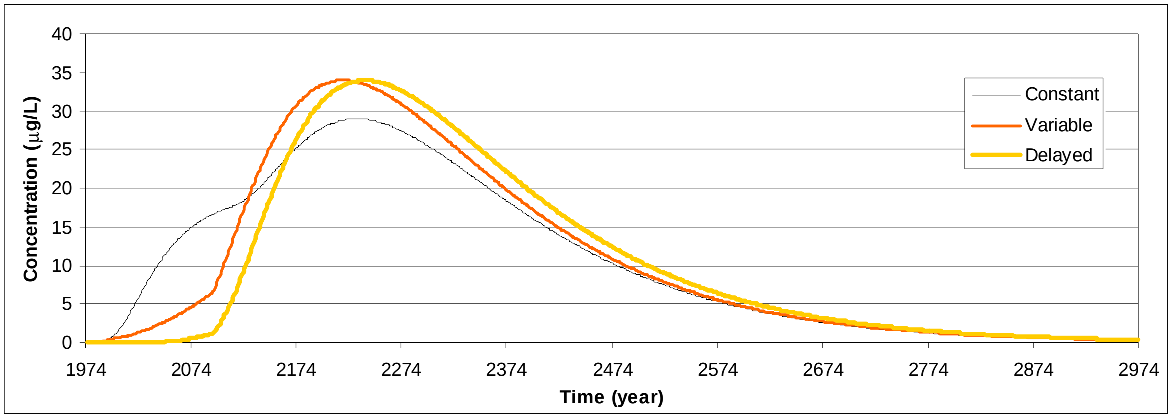



b) Variable Infiltration Modeling Results

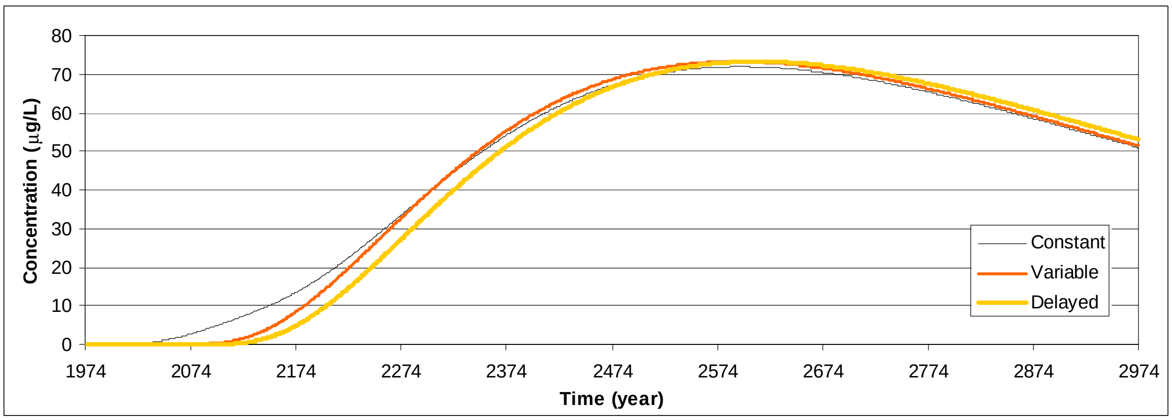



c) Delayed Infiltration Modeling Results

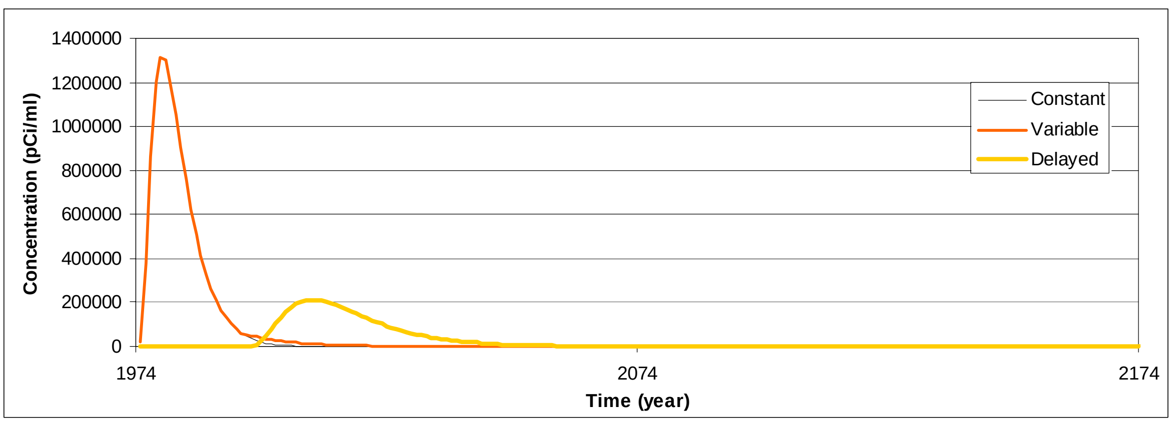
**Figure 3-14. Concentration in Saturated Zone below ORWBG vs. Time for Mercury: Sum of All Elements**




a) Cadmium: Sum of All Elements

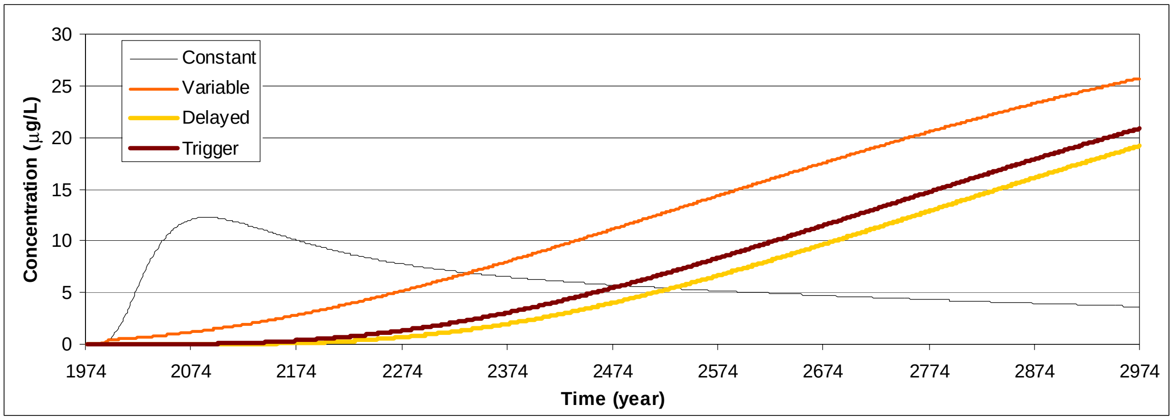



b) Mercury: Sum of All Elements

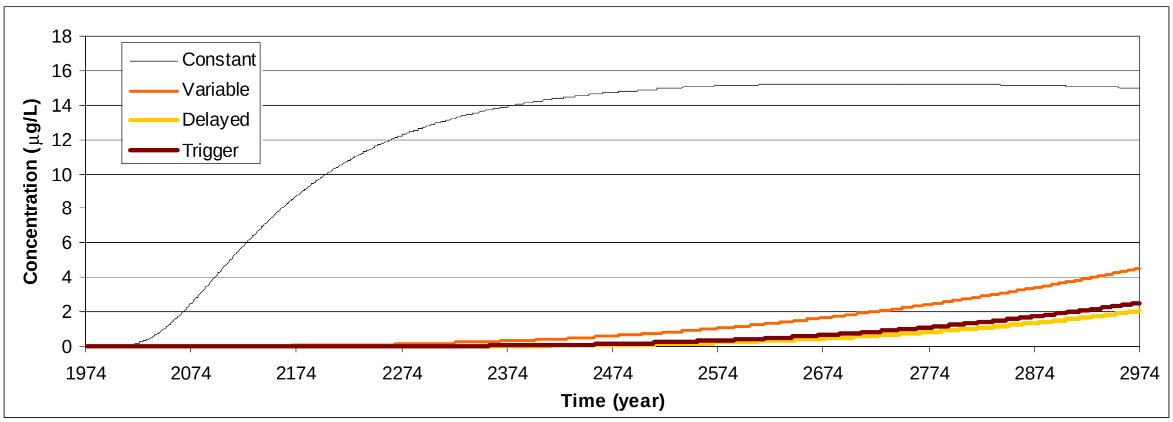



c) Tritium: Sum of All Elements (note time axis scale difference)

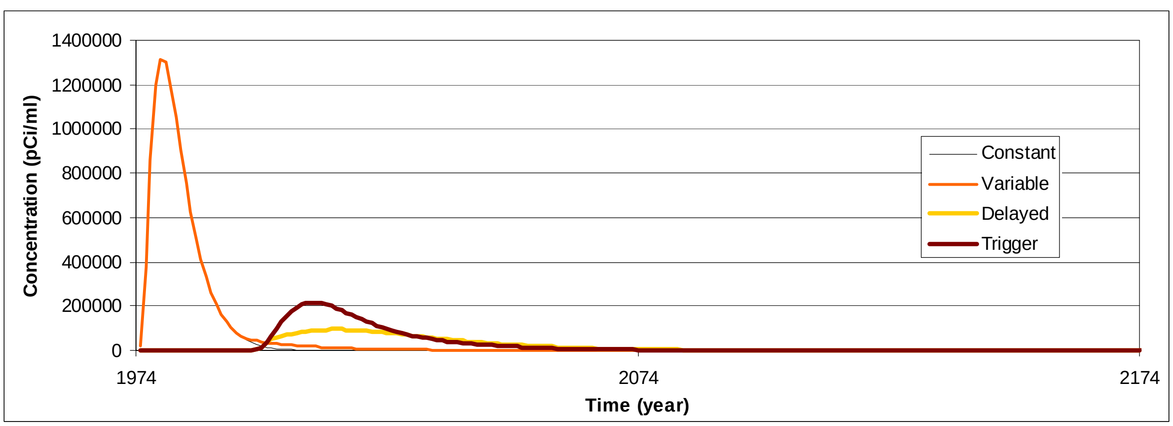
**Figure 3-15. Concentration in Saturated Zone below ORWBG vs. Time: Various Model Results for Soil Cover (no barrier)**




a) Cadmium: Sum of All Elements

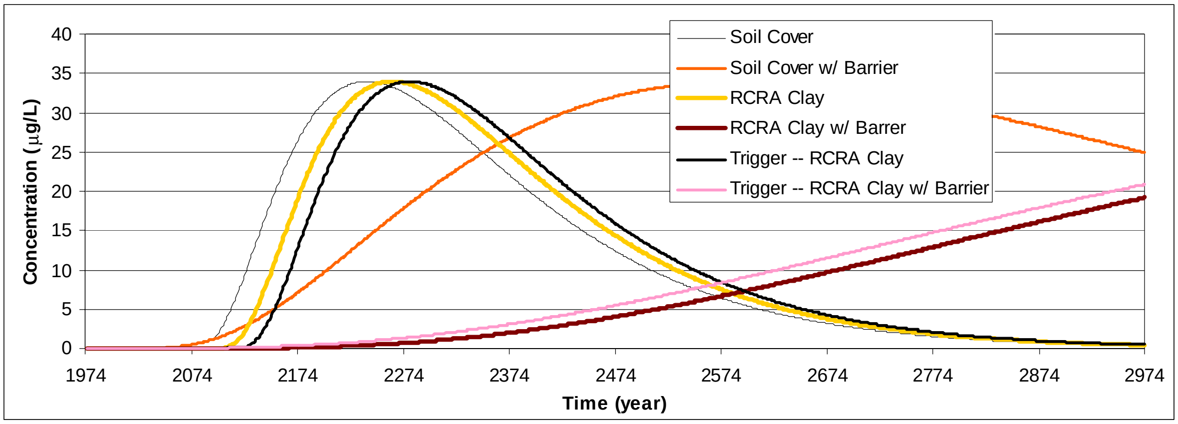



b) Mercury: Sum of All Elements

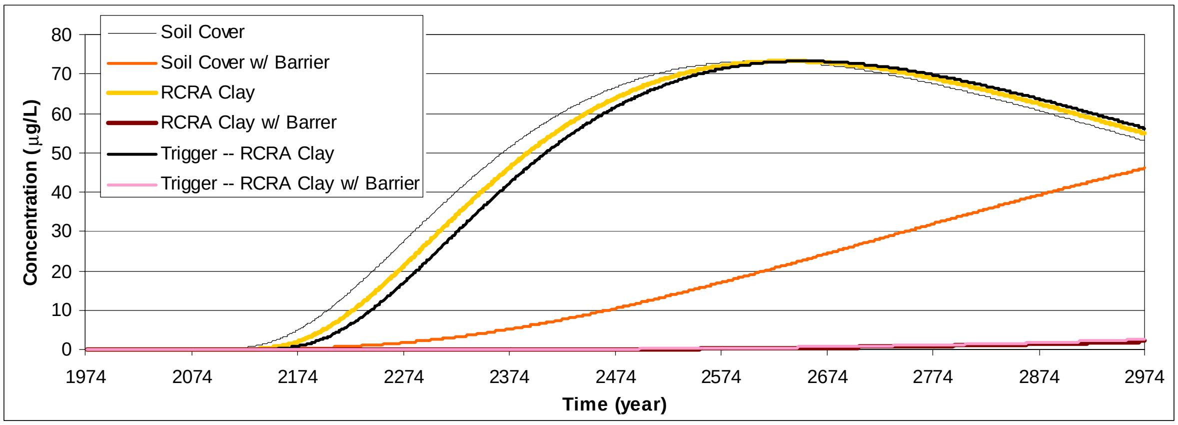



c) Tritium: Sum of All Elements (note time axis scale difference)

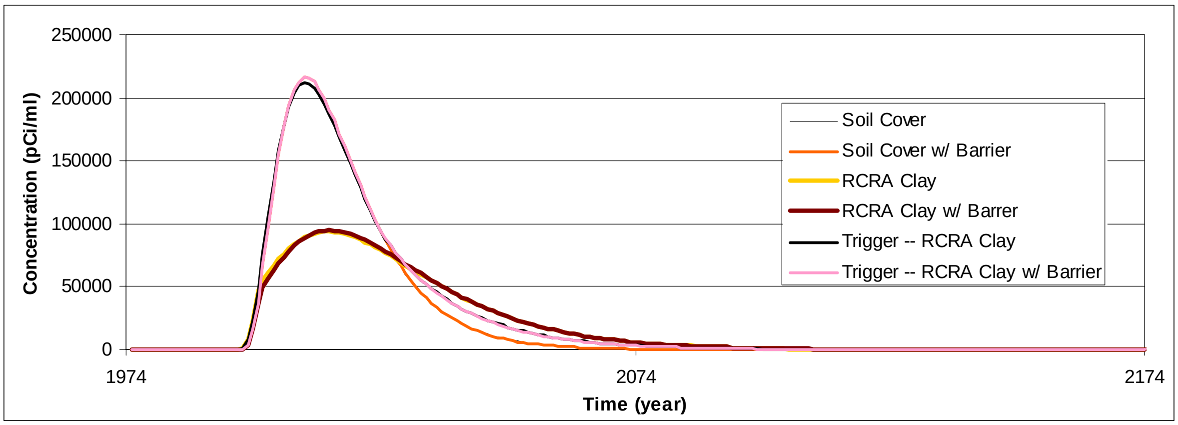
**Figure 3-16. Concentration in Saturated Zone below ORWBG vs. Time: Various Model Results for RCRA Clay Cap with Barrier**




a) Cadmium: Sum of All Elements




b) Mercury: Sum of All Elements




c) Tritium: Sum of All Elements (note time axis scale difference)

**Figure 3-17. Concentration in Saturated Zone below ORWBG vs. Time: Full-Impact/Late-Timing Model Results (including "Trigger") for all Remedial Alternatives**

## Table 3-1 Maximum Concentrations at Water Table Top and at Seep for Constant Vadose Zone Infiltration Modeling Scenarios

| | | Maximum at Water Table Top | | | Maximum at Seep | | |
|---|---|---|---|---|---|---|---|
| Model Scenario | COI | Element Number | Concentration (pCi/ml or ug/L) | Simulation Time (years since 1974) | Element Number | Concentration (pCi/ml or ug/L) | Simulation Time (years since 1974) |
| Soil Cover | C-14 | 51 | 1.74E+01 | 29 | 20 | 1.14E+01 | 892 |
| | Pu-239 | 13 | 1.48E+00 | 1000 | 23 | 9.95E-26 | 1000 |
| | Pu-238 | 13 | 6.88E-02 | 463 | 23 | 3.23E-29 | 1000 |
| | U-238 | 5 | 2.40E+00 | 1000 | 7 | 1.74E-07 | 1000 |
| | Tc-99 | 9 | 6.81E+01 | 21 | 9 | 2.84E+01 | 127 |
| | I-129 | 51 | 2.12E+00 | 15 | 7 | 9.38E-01 | 94 |
| | Np-237 | 13 | 9.88E-03 | 716 | 13 | 6.52E-03 | 1000 |
| | U-235 | 1 | 2.26E-02 | 1000 | 23 | 1.86E-10 | 1000 |
| | Cs-137 | 51 | 2.24E-04 | 225 | 7 | 8.37E-49 | 1000 |
| | Sr-90 | 16 | 1.59E+02 | 71 | 7 | 3.80E-04 | 426 |
| | H-3 | 8 | 2.75E+07 | 6 | 11 | 1.70E+06 | 30 |
| | Co-60 | 51 | 3.49E+01 | 28 | 7 | 4.49E-18 | 219 |
| | Cd | 51 | 3.38E+01 | 207 | 7 | 1.98E+01 | 760 |
| | Pb | 51 | 5.35E+01 | 1000 | 7 | 3.78E-22 | 1000 |
| | Hg | 14 | 3.84E+02 | 493 | 7 | 2.62E-01 | 1000 |
| | VOC | 51 | 1.87E+05 | 4 | 7 | 8.41E+04 | 29 |
| Soil Cover w/ barrier | C-14 | 51 | 1.74E+01 | 29 | 23 | 6.67E+00 | 270 |
| | Pu-239 | 13 | 5.25E-01 | 1000 | 23 | 9.95E-26 | 1000 |
| | Pu-238 | 13 | 4.59E-02 | 386 | 23 | 3.22E-29 | 1000 |
| | U-238 | 5 | 1.12E+00 | 1000 | 7 | 1.66E-07 | 1000 |
| | Tc-99 | 9 | 6.81E+01 | 21 | 9 | 2.84E+01 | 127 |
| | I-129 | 51 | 2.12E+00 | 15 | 7 | 9.38E-01 | 94 |
| | Np-237 | 13 | 2.88E-03 | 654 | 13 | 2.45E-03 | 1000 |
| | U-235 | 1 | 1.07E-02 | 1000 | 23 | 1.79E-10 | 1000 |
| | Cs-137 | 51 | 2.22E-04 | 222 | 7 | 8.37E-49 | 1000 |
| | Sr-90 | 16 | 1.59E+02 | 71 | 7 | 3.77E-04 | 424 |
| | H-3 | 8 | 2.75E+07 | 6 | 11 | 1.70E+06 | 30 |
| | Co-60 | 51 | 3.49E+01 | 28 | 7 | 4.49E-18 | 219 |
| | Cd | 51 | 2.24E+01 | 77 | 7 | 1.39E+01 | 763 |
| | Pb | 51 | 2.06E+01 | 1000 | 7 | 3.78E-22 | 1000 |
| | Hg | 14 | 1.84E+02 | 567 | 7 | 2.13E-01 | 1000 |
| | VOC | 51 | 1.87E+05 | 4 | 7 | 8.41E+04 | 29 |
| RCRA Synthetic Cap | C-14 | 51 | 1.74E+01 | 29 | 20 | 1.13E+01 | 896 |
| | Pu-239 | 13 | 1.46E+00 | 1000 | 23 | 9.34E-26 | 1000 |
| | Pu-238 | 13 | 6.34E-02 | 476 | 23 | 3.03E-29 | 1000 |
| | U-238 | 5 | 2.40E+00 | 1000 | 7 | 1.51E-07 | 1000 |
| | Tc-99 | 9 | 6.81E+01 | 21 | 9 | 2.76E+01 | 126 |
| | I-129 | 51 | 2.12E+00 | 15 | 7 | 9.02E-01 | 92 |
| | Np-237 | 13 | 9.88E-03 | 721 | 13 | 6.39E-03 | 1000 |
| | U-235 | 1 | 2.26E-02 | 1000 | 23 | 1.61E-10 | 1000 |
| | Cs-137 | 51 | 1.91E-04 | 221 | 7 | 8.14E-49 | 1000 |
| | Sr-90 | 16 | 1.47E+02 | 67 | 7 | 3.32E-04 | 423 |
| | H-3 | 8 | 2.75E+07 | 6 | 11 | 1.70E+06 | 30 |
| | Co-60 | 51 | 3.49E+01 | 28 | 7 | 4.47E-18 | 219 |
| | Cd | 51 | 3.51E+01 | 211 | 7 | 1.99E+01 | 771 |
| | Pb | 51 | 5.29E+01 | 1000 | 7 | 3.53E-22 | 1000 |
| | Hg | 14 | 3.86E+02 | 501 | 7 | 2.33E-01 | 1000 |
| | VOC | 51 | 1.87E+05 | 4 | 7 | 8.41E+04 | 29 |

Note: See Table 2-2 for cross-reference of Element Number to Element Name.

## Table 3-1 (con't) Maximum Concentrations at Water Table Top and at Seep for Constant Vadose Zone Infiltration Modeling Scenarios

| Model Scenario | COI | Maximum at Water Table Top Element Number | Maximum at Water Table Top Concentration (pCi/ml or ug/L) | Maximum at Water Table Top Simulation Time (years since 1974) | Maximum at Seep Element Number | Maximum at Seep Concentration (pCi/ml or ug/L) | Maximum at Seep Simulation Time (years since 1974) |
|---|---|---|---|---|---|---|---|
| **RCRA Clay** | C-14 | 51 | 1.74E+01 | 29 | 20 | 1.13E+01 | 911 |
| | Pu-239 | 13 | 1.42E+00 | 1000 | 23 | 9.45E-26 | 1000 |
| | Pu-238 | 13 | 5.66E-02 | 487 | 23 | 3.06E-29 | 1000 |
| | U-238 | 5 | 2.38E+00 | 1000 | 7 | 1.44E-07 | 1000 |
| | Tc-99 | 9 | 6.81E+01 | 21 | 9 | 2.79E+01 | 126 |
| | I-129 | 51 | 2.12E+00 | 15 | 7 | 9.13E-01 | 92 |
| | Np-237 | 13 | 9.88E-03 | 736 | 13 | 6.09E-03 | 1000 |
| | U-235 | 1 | 2.26E-02 | 1000 | 23 | 1.55E-10 | 1000 |
| | Cs-137 | 51 | 1.88E-04 | 215 | 7 | 8.20E-49 | 1000 |
| | Sr-90 | 16 | 1.50E+02 | 68 | 7 | 3.28E-04 | 419 |
| | H-3 | 8 | 2.75E+07 | 6 | 11 | 1.70E+06 | 30 |
| | Co-60 | 51 | 3.49E+01 | 28 | 7 | 4.47E-18 | 219 |
| | Cd | 51 | 3.52E+01 | 226 | 7 | 1.96E+01 | 787 |
| | Pb | 51 | 5.20E+01 | 1000 | 7 | 3.57E-22 | 1000 |
| | Hg | 14 | 3.85E+02 | 517 | 7 | 2.11E-01 | 1000 |
| | VOC | 51 | 1.87E+05 | 4 | 7 | 8.41E+04 | 29 |
| **RCRA Clay w/ barrier** | C-14 | 51 | 1.74E+01 | 29 | 23 | 5.26E+00 | 253 |
| | Pu-239 | 13 | 1.97E-01 | 1000 | 23 | 9.44E-26 | 1000 |
| | Pu-238 | 13 | 2.95E-02 | 347 | 23 | 3.06E-29 | 1000 |
| | U-238 | 5 | 4.44E-01 | 1000 | 7 | 1.33E-07 | 1000 |
| | Tc-99 | 9 | 6.81E+01 | 21 | 9 | 2.79E+01 | 126 |
| | I-129 | 51 | 2.12E+00 | 15 | 7 | 9.13E-01 | 92 |
| | Np-237 | 13 | 2.18E-03 | 59 | 13 | 9.43E-04 | 986 |
| | U-235 | 1 | 4.15E-03 | 1000 | 23 | 1.46E-10 | 1000 |
| | Cs-137 | 51 | 1.87E-04 | 214 | 7 | 8.20E-49 | 1000 |
| | Sr-90 | 16 | 1.50E+02 | 68 | 7 | 3.25E-04 | 417 |
| | H-3 | 8 | 2.75E+07 | 6 | 11 | 1.70E+06 | 30 |
| | Co-60 | 51 | 3.49E+01 | 28 | 7 | 4.47E-18 | 219 |
| | Cd | 51 | 1.96E+01 | 56 | 7 | 7.72E+00 | 716 |
| | Pb | 51 | 7.75E+00 | 1000 | 7 | 3.57E-22 | 1000 |
| | Hg | 14 | 7.59E+01 | 344 | 7 | 1.47E-01 | 1000 |
| | VOC | 51 | 1.87E+05 | 4 | 7 | 8.41E+04 | 29 |

Note: See Table 2-2 for cross-reference of Element Number to Element Name.

## Table 3-2 Maximum Concentrations at Water Table Top and at Seep for Variable Vadose Zone Infiltration Modeling Scenarios

| Model Scenario | COI | Maximum at Water Table Top | | | Maximum at Seep | | |
|---|---|---|---|---|---|---|---|
| | | Element Number | Concentration (pCi/ml or ug/L) | Simulation Time (years since 1974) | Element Number | Concentration (pCi/ml or ug/L) | Simulation Time (years since 1974) |
| Soil Cover | C-14 | 51 | 1.95E+01 | 83 | 20 | 1.14E+01 | 865 |
| | Pu-239 | 13 | 1.49E+00 | 1000 | 23 | 1.29E-27 | 1000 |
| | Pu-238 | 13 | 6.35E-02 | 491 | 23 | 4.19E-31 | 1000 |
| | U-238 | 5 | 2.42E+00 | 1000 | 7 | 5.30E-08 | 1000 |
| | Tc-99 | 9 | 6.81E+01 | 21 | 9 | 1.95E+01 | 130 |
| | I-129 | 51 | 2.12E+00 | 15 | 54 | 6.61E-01 | 126 |
| | Np-237 | 13 | 9.88E-03 | 695 | 13 | 6.65E-03 | 1000 |
| | U-235 | 1 | 2.27E-02 | 1000 | 23 | 4.93E-11 | 1000 |
| | Cs-137 | 51 | 7.25E-05 | 310 | 7 | 1.50E-51 | 1000 |
| | Sr-90 | 16 | 3.94E+01 | 154 | 7 | 1.05E-04 | 503 |
| | H-3 | 8 | 2.75E+07 | 6 | 11 | 1.70E+06 | 30 |
| | Co-60 | 51 | 2.66E+01 | 21 | 7 | 3.98E-19 | 203 |
| | Cd | 51 | 4.26E+01 | 181 | 7 | 2.10E+01 | 771 |
| | Pb | 51 | 5.36E+01 | 1000 | 7 | 6.08E-24 | 1000 |
| | Hg | 14 | 3.94E+02 | 485 | 7 | 1.74E-01 | 1000 |
| | VOC | 51 | 1.87E+05 | 4 | 7 | 8.41E+04 | 29 |
| Soil Cover w/ barrier | C-14 | 51 | 1.95E+01 | 83 | 54 | 4.49E+00 | 397 |
| | Pu-239 | 13 | 6.39E-02 | 1000 | 23 | 3.28E-29 | 1000 |
| | Pu-238 | 13 | 8.07E-04 | 622 | 23 | 1.06E-32 | 1000 |
| | U-238 | 5 | 3.45E-01 | 1000 | 7 | 5.76E-10 | 1000 |
| | Tc-99 | 9 | 6.81E+01 | 21 | 9 | 1.95E+01 | 130 |
| | I-129 | 51 | 2.12E+00 | 15 | 54 | 6.61E-01 | 126 |
| | Np-237 | 13 | 9.61E-03 | 1000 | 13 | 1.45E-03 | 1000 |
| | U-235 | 1 | 4.98E-03 | 1000 | 23 | 3.41E-13 | 1000 |
| | Cs-137 | 51 | 3.85E-07 | 269 | 7 | 5.97E-52 | 1000 |
| | Sr-90 | 51 | 3.47E+01 | 64 | 7 | 2.09E-05 | 457 |
| | H-3 | 8 | 2.75E+07 | 6 | 11 | 1.70E+06 | 30 |
| | Co-60 | 51 | 2.66E+01 | 21 | 7 | 3.98E-19 | 203 |
| | Cd | 51 | 4.26E+01 | 329 | 7 | 9.44E+00 | 1000 |
| | Pb | 51 | 4.71E+00 | 1000 | 7 | 1.54E-25 | 1000 |
| | Hg | 14 | 3.61E+02 | 1000 | 7 | 5.34E-03 | 1000 |
| | VOC | 51 | 1.87E+05 | 4 | 7 | 8.41E+04 | 29 |
| RCRA Synthetic Cap | C-14 | 51 | 1.94E+01 | 113 | 20 | 1.14E+01 | 873 |
| | Pu-239 | 13 | 1.46E+00 | 1000 | 23 | 7.00E-28 | 1000 |
| | Pu-238 | 13 | 5.92E-02 | 500 | 23 | 2.27E-31 | 1000 |
| | U-238 | 5 | 2.41E+00 | 1000 | 7 | 4.24E-08 | 1000 |
| | Tc-99 | 9 | 6.81E+01 | 21 | 9 | 1.35E+01 | 117 |
| | I-129 | 51 | 2.12E+00 | 15 | 10 | 5.54E-01 | 209 |
| | Np-237 | 13 | 9.88E-03 | 703 | 13 | 6.50E-03 | 1000 |
| | U-235 | 1 | 2.27E-02 | 1000 | 23 | 3.87E-11 | 1000 |
| | Cs-137 | 51 | 5.93E-05 | 319 | 7 | 4.76E-52 | 1000 |
| | Sr-90 | 16 | 3.21E+01 | 163 | 7 | 8.46E-05 | 514 |
| | H-3 | 8 | 2.75E+07 | 6 | 11 | 1.70E+06 | 30 |
| | Co-60 | 51 | 2.66E+01 | 21 | 7 | 2.70E-19 | 197 |
| | Cd | 51 | 4.26E+01 | 190 | 7 | 2.10E+01 | 780 |
| | Pb | 51 | 5.31E+01 | 1000 | 7 | 3.38E-24 | 1000 |
| | Hg | 14 | 3.94E+02 | 494 | 7 | 1.54E-01 | 1000 |
| | VOC | 51 | 1.87E+05 | 4 | 7 | 8.41E+04 | 29 |

Note: See Table 2-2 for cross-reference of Element Number to Element Name.

## Table 3-2 (con't) Maximum Concentrations at Water Table Top and at Seep for Variable Vadose Zone Infiltration Modeling Scenarios

| Model Scenario | COI | Maximum at Water Table Top | | | Maximum at Seep | | |
|---|---|---|---|---|---|---|---|
| | | Element Number | Concentration (pCi/ml or ug/L) | Simulation Time (years since 1974) | Element Number | Concentration (pCi/ml or ug/L) | Simulation Time (years since 1974) |
| **RCRA Clay** | C-14 | 51 | 1.94E+01 | 134 | 20 | 1.14E+01 | 888 |
| | Pu-239 | 13 | 1.42E+00 | 1000 | 23 | 2.35E-28 | 1000 |
| | Pu-238 | 13 | 5.25E-02 | 515 | 23 | 7.63E-32 | 1000 |
| | U-238 | 5 | 2.40E+00 | 1000 | 7 | 2.83E-08 | 1000 |
| | Tc-99 | 9 | 6.81E+01 | 21 | 9 | 1.49E+01 | 120 |
| | I-129 | 51 | 2.12E+00 | 15 | 10 | 6.21E-01 | 226 |
| | Np-237 | 13 | 9.88E-03 | 719 | 13 | 6.23E-03 | 1000 |
| | U-235 | 1 | 2.27E-02 | 1000 | 23 | 2.51E-11 | 1000 |
| | Cs-137 | 51 | 4.16E-05 | 334 | 7 | 1.57E-52 | 1000 |
| | Sr-90 | 51 | 2.35E+01 | 26 | 7 | 5.87E-05 | 529 |
| | H-3 | 8 | 2.75E+07 | 6 | 11 | 1.70E+06 | 30 |
| | Co-60 | 51 | 2.66E+01 | 21 | 7 | 2.93E-19 | 198 |
| | Cd | 51 | 4.26E+01 | 205 | 7 | 2.10E+01 | 795 |
| | Pb | 51 | 5.21E+01 | 1000 | 7 | 1.19E-24 | 1000 |
| | Hg | 14 | 3.94E+02 | 509 | 7 | 1.24E-01 | 1000 |
| | VOC | 51 | 1.87E+05 | 4 | 7 | 8.41E+04 | 29 |
| **RCRA Clay w/ barrier** | C-14 | 51 | 1.92E+01 | 209 | 51 | 1.58E+00 | 407 |
| | Pu-239 | 51 | 3.46E-04 | 1000 | 23 | 8.41E-31 | 1000 |
| | Pu-238 | 13 | 1.52E-06 | 677 | 23 | 2.73E-34 | 1000 |
| | U-238 | 51 | 3.27E-03 | 1000 | 7 | 1.99E-12 | 1000 |
| | Tc-99 | 9 | 6.81E+01 | 21 | 9 | 1.49E+01 | 120 |
| | I-129 | 51 | 2.12E+00 | 15 | 54 | 5.65E-01 | 119 |
| | Np-237 | 13 | 6.61E-03 | 1000 | 13 | 1.76E-04 | 1000 |
| | U-235 | 51 | 1.44E-04 | 1000 | 23 | 8.94E-16 | 1000 |
| | Cs-137 | 51 | 1.60E-09 | 130 | 7 | 8.09E-53 | 1000 |
| | Sr-90 | 51 | 2.35E+01 | 26 | 7 | 1.41E-06 | 393 |
| | H-3 | 8 | 2.75E+07 | 6 | 11 | 1.70E+06 | 30 |
| | Co-60 | 51 | 2.66E+01 | 21 | 7 | 2.93E-19 | 198 |
| | Cd | 51 | 4.25E+01 | 1000 | 54 | 1.34E+00 | 1000 |
| | Pb | 51 | 2.71E-02 | 1000 | 7 | 3.75E-27 | 1000 |
| | Hg | 14 | 6.39E+01 | 1000 | 7 | 3.10E-05 | 1000 |
| | VOC | 51 | 1.87E+05 | 4 | 7 | 8.41E+04 | 29 |

Note: See Table 2-2 for cross-reference of Element Number to Element Name.

## Table 3-3 Maximum Concentrations at Water Table Top and at Seep for Delayed Infiltration Modeling Scenarios

| Model Scenario | COI | Maximum at Water Table Top | | | Maximum at Seep | | |
|---|---|---|---|---|---|---|---|
| | | Element Number | Concentration (pCi/ml or ug/L) | Simulation Time (years since 1974) | Element Number | Concentration (pCi/ml or ug/L) | Simulation Time (years since 1974) |
| **Soil Cover** | C-14 | 51 | 1.94E+01 | 131 | 20 | 1.14E+01 | 885 |
| | Pu-239 | 13 | 1.43E+00 | 1000 | 23 | 2.92E-28 | 1000 |
| | Pu-238 | 13 | 5.37E-02 | 512 | 23 | 9.47E-32 | 1000 |
| | U-238 | 5 | 2.40E+00 | 1000 | 7 | 3.06E-08 | 1000 |
| | Tc-99 | 9 | 6.74E+01 | 92 | 9 | 2.14E+01 | 219 |
| | I-129 | 51 | 2.12E+00 | 71 | 32 | 7.75E-01 | 202 |
| | Np-237 | 13 | 9.88E-03 | 716 | 13 | 6.29E-03 | 1000 |
| | U-235 | 1 | 2.27E-02 | 1000 | 23 | 2.74E-11 | 1000 |
| | Cs-137 | 51 | 4.46E-05 | 331 | 7 | 1.07E-52 | 1000 |
| | Sr-90 | 16 | 2.39E+01 | 175 | 7 | 6.29E-05 | 526 |
| | H-3 | 8 | 4.10E+06 | 37 | 11 | 1.27E+05 | 62 |
| | Co-60 | 51 | 6.19E-03 | 65 | 7 | 6.26E-23 | 259 |
| | Cd | 51 | 4.26E+01 | 202 | 7 | 2.10E+01 | 792 |
| | Pb | 51 | 5.23E+01 | 1000 | 7 | 1.47E-24 | 1000 |
| | Hg | 14 | 3.94E+02 | 506 | 7 | 1.30E-01 | 1000 |
| | VOC | 51 | 1.86E+05 | 34 | 54 | 4.20E+04 | 72 |
| **Soil Cover w/ barrier** | C-14 | 51 | 1.93E+01 | 156 | 54 | 4.41E+00 | 472 |
| | Pu-239 | 13 | 4.71E-02 | 1000 | 23 | 4.05E-31 | 1000 |
| | Pu-238 | 13 | 4.55E-04 | 695 | 23 | 1.33E-34 | 1000 |
| | U-238 | 5 | 2.70E-01 | 1000 | 7 | 8.93E-11 | 1000 |
| | Tc-99 | 9 | 6.77E+01 | 92 | 9 | 1.63E+01 | 205 |
| | I-129 | 51 | 2.12E+00 | 71 | 54 | 4.98E-01 | 193 |
| | Np-237 | 13 | 9.53E-03 | 1000 | 13 | 1.14E-03 | 1000 |
| | U-235 | 1 | 4.05E-03 | 1000 | 23 | 4.74E-14 | 1000 |
| | Cs-137 | 51 | 7.23E-08 | 341 | 7 | 9.71E-55 | 1000 |
| | Sr-90 | 51 | 6.19E+00 | 136 | 7 | 3.73E-06 | 529 |
| | H-3 | 8 | 4.22E+06 | 37 | 11 | 1.28E+05 | 62 |
| | Co-60 | 51 | 6.24E-03 | 65 | 7 | 6.20E-23 | 257 |
| | Cd | 51 | 4.26E+01 | 402 | 7 | 8.94E+00 | 1000 |
| | Pb | 51 | 3.65E+00 | 1000 | 7 | 2.20E-27 | 1000 |
| | Hg | 14 | 3.45E+02 | 1000 | 7 | 1.77E-03 | 1000 |
| | VOC | 51 | 1.86E+05 | 34 | 54 | 4.20E+04 | 72 |

Note: See Table 2-2 for cross-reference of Element Number to Element Name.

## Table 3-3 (con't) Maximum Concentrations at Water Table Top and at Seep for Delayed Infiltration Modeling Scenarios

| Model Scenario | COI | Maximum at Water Table Top | | | Maximum at Seep | | |
|---|---|---|---|---|---|---|---|
| | | Element Number | Concentration (pCi/ml or ug/L) | Simulation Time (years since 1974) | Element Number | Concentration (pCi/ml or ug/L) | Simulation Time (years since 1974) |
| **RCRA Clay** | C-14 | 51 | 1.93E+01 | 155 | 20 | 1.13E+01 | 909 |
| | Pu-239 | 13 | 1.36E+00 | 1000 | 23 | 4.98E-29 | 1000 |
| | Pu-238 | 13 | 4.44E-02 | 536 | 23 | 1.61E-32 | 1000 |
| | U-238 | 5 | 2.38E+00 | 1000 | 7 | 1.59E-08 | 1000 |
| | Tc-99 | 9 | 6.76E+01 | 137 | 9 | 2.90E+01 | 244 |
| | I-129 | 51 | 2.12E+00 | 131 | 7 | 9.99E-01 | 212 |
| | Np-237 | 13 | 9.88E-03 | 740 | 13 | 5.83E-03 | 1000 |
| | U-235 | 1 | 2.27E-02 | 1000 | 23 | 1.35E-11 | 1000 |
| | Cs-137 | 51 | 2.56E-05 | 355 | 7 | 7.49E-54 | 1000 |
| | Sr-90 | 16 | 1.35E+01 | 199 | 7 | 3.56E-05 | 550 |
| | H-3 | 14 | 2.23E+06 | 33 | 15 | 2.20E+04 | 64 |
| | Co-60 | 51 | 8.07E-06 | 144 | 7 | 1.05E-24 | 336 |
| | Cd | 51 | 4.26E+01 | 226 | 7 | 2.10E+01 | 816 |
| | Pb | 51 | 5.07E+01 | 1000 | 7 | 2.70E-25 | 1000 |
| | Hg | 14 | 3.94E+02 | 530 | 7 | 9.11E-02 | 1000 |
| | VOC | 51 | 1.86E+05 | 54 | 10 | 3.94E+04 | 156 |
| **RCRA Clay w/ barrier** | C-14 | 51 | 1.86E+01 | 455 | 51 | 1.50E+00 | 778 |
| | Pu-239 | 51 | 8.30E-05 | 1000 | 23 | 6.02E-36 | 1000 |
| | Pu-238 | 13 | 2.18E-07 | 922 | 23 | 1.98E-39 | 1000 |
| | U-238 | 51 | 1.41E-03 | 1000 | 7 | 5.22E-15 | 1000 |
| | Tc-99 | 9 | 6.73E+01 | 249 | 9 | 5.64E+00 | 359 |
| | I-129 | 51 | 2.12E+00 | 179 | 51 | 1.77E-01 | 303 |
| | Np-237 | 13 | 5.51E-03 | 1000 | 13 | 5.19E-05 | 1000 |
| | U-235 | 51 | 6.19E-05 | 1000 | 23 | 1.87E-18 | 1000 |
| | Cs-137 | 51 | 5.62E-12 | 374 | 7 | 1.70E-59 | 1000 |
| | Sr-90 | 51 | 9.91E-02 | 202 | 7 | 4.87E-09 | 605 |
| | H-3 | 14 | 2.26E+06 | 33 | 15 | 2.20E+04 | 65 |
| | Co-60 | 51 | 7.70E-06 | 67 | 7 | 7.59E-27 | 257 |
| | Cd | 51 | 4.02E+01 | 1000 | 7 | 4.23E-01 | 1000 |
| | Pb | 51 | 6.51E-03 | 1000 | 7 | 3.56E-32 | 1000 |
| | Hg | 14 | 3.21E+01 | 1000 | 7 | 5.75E-07 | 1000 |
| | VOC | 51 | 1.86E+05 | 54 | 51 | 1.54E+04 | 93 |

Note: See Table 2-2 for cross-reference of Element Number to Element Name.

## Table 3-4 Maximum Concentrations at Water Table Top and at Seep for "Trigger" Scenarios

| Model Scenario | COI | Maximum at Water Table Top | | | Maximum at Seep | | |
|---|---|---|---|---|---|---|---|
| | | Element Number | Concentration (pCi/ml or ug/L) | Simulation Time (years since 1974) | Element Number | Concentration (pCi/ml or ug/L) | Simulation Time (years since 1974) |
| **RCRA Clay** | C-14 | 51 | 1.93E+01 | 172 | 20 | 1.13E+01 | 926 |
| | Pu-239 | 13 | 1.32E+00 | 1000 | 23 | 1.35E-29 | 1000 |
| | Pu-238 | 13 | 3.88E-02 | 553 | 23 | 4.36E-33 | 1000 |
| | U-238 | 5 | 2.36E+00 | 1000 | 7 | 9.72E-09 | 1000 |
| | Tc-99 | 9 | 6.74E+01 | 154 | 9 | 2.55E+01 | 263 |
| | I-129 | 51 | 2.12E+00 | 122 | 32 | 9.00E-01 | 241 |
| | Np-237 | 13 | 9.88E-03 | 757 | 13 | 5.49E-03 | 1000 |
| | U-235 | 1 | 2.26E-02 | 1000 | 23 | 7.99E-12 | 1000 |
| | Cs-137 | 51 | 1.73E-05 | 372 | 7 | 1.05E-54 | 1000 |
| | Sr-90 | 16 | 9.02E+00 | 216 | 7 | 2.37E-05 | 567 |
| | H-3 | 8 | 4.10E+06 | 37 | 11 | 1.27E+05 | 62 |
| | Co-60 | 51 | 3.22E-03 | 50 | 7 | 3.99E-24 | 231 |
| | Cd | 51 | 4.26E+01 | 243 | 7 | 2.10E+01 | 833 |
| | Pb | 51 | 4.96E+01 | 1000 | 7 | 7.72E-26 | 1000 |
| | Hg | 14 | 3.94E+02 | 547 | 7 | 6.99E-02 | 1000 |
| | VOC | 51 | 1.86E+05 | 34 | 54 | 4.14E+04 | 71 |
| **RCRA Clay w/ barrier** | C-14 | 51 | 1.88E+01 | 398 | 51 | 1.51E+00 | 720 |
| | Pu-239 | 51 | 1.20E-04 | 1000 | 23 | 1.75E-34 | 1000 |
| | Pu-238 | 13 | 3.43E-07 | 865 | 23 | 5.76E-38 | 1000 |
| | U-238 | 51 | 1.77E-03 | 1000 | 7 | 2.55E-14 | 1000 |
| | Tc-99 | 9 | 6.74E+01 | 191 | 9 | 5.65E+00 | 302 |
| | I-129 | 51 | 2.12E+00 | 122 | 51 | 1.79E-01 | 234 |
| | Np-237 | 13 | 5.80E-03 | 1000 | 13 | 7.50E-05 | 1000 |
| | U-235 | 51 | 7.76E-05 | 1000 | 23 | 9.72E-18 | 1000 |
| | Cs-137 | 51 | 2.10E-11 | 317 | 7 | 2.01E-57 | 1000 |
| | Sr-90 | 51 | 3.87E-01 | 145 | 7 | 1.89E-08 | 549 |
| | H-3 | 8 | 4.22E+06 | 37 | 11 | 1.28E+05 | 62 |
| | Co-60 | 51 | 3.17E-03 | 50 | 7 | 3.71E-24 | 231 |
| | Cd | 51 | 4.11E+01 | 1000 | 54 | 5.69E-01 | 1000 |
| | Pb | 51 | 9.43E-03 | 1000 | 7 | 9.25E-31 | 1000 |
| | Hg | 14 | 3.87E+01 | 1000 | 7 | 1.68E-06 | 1000 |
| | VOC | 51 | 1.86E+05 | 34 | 54 | 4.14E+04 | 71 |

Note: See Table 2-2 for cross-reference of Element Number to Element Name.

## Table 3-5 Summary of COI Responses to Scenarios

| Group/COI | Summary of Results |
|---|---|
| Immobile, Persistent | |
| C-14 | Most stays in source. For that small portion that moves, most reaches seep independent of the remedial alternative. |
| Pu-239 | Most stays in source. Doesn't get past vadose zone. |
| U-238 | Leaches to vadose zone, but doesn't migrate to seeps. |
| Np-237 | Most stays in source. |
| U-235 | Most stays in source and or the vadose zone. The portion that migrates to the saturated zone doesn't move to seep. |
| Pb | Most stays in source and/or the vadose zone. No significant migration to saturated zone, and no significant migration out of system (to seeps). |
| Hg | Response very similar to U-235. Most stays in source and/or the vadose zone. Only the small portion which migrates to the saturated zone makes it out of system (to seeps). Not sensitive to "triggered" remedial alternative installation timing. |
| Immobile, Short-lived | |
| Pu-238 | Stays in source and decays away. |
| Cs-137 | Stays in source and decays away. |
| Sr-90 | Most decays. Some movement to vadose zone. |
| Co-60 | Decays very quickly. No movement. |
| Mobile, Persistent | |
| Tc-99 | All activity ultimately migrates out of system (past seeps). Some remedial alternatives delay this migration, but do not stop it. Maximum concentrations at seep are around 10-20 pCi/ml for individual streamtubes. |
| I-129 | All activity ultimately migrates out of system (past seeps). Some remedial alternatives delay this migration, but do not stop it. Maximum concentrations at seep are less than 1 pCi/ml for individual streamtubes. |
| Cd | Moves through saturated zone, but very little mass migrates out of system (past seeps). Most sensitive to remedial alternatives with long-lived effects (i.e., barriers). Not sensitive to "triggered" remedial alternative installation timing. Maximum concentrations at seep are on the order of 1-20 ug/L for individual streamtubes. |
| VOC | Rapid movement out of the system (past seeps). Various remedial alternatives only serve to delay the inevitable migration out of the system. Impact of delayed leaching same as Tritium – only on early-time fate and transport. |
| Mobile, Short-lived | |
| H-3 | Most decays, but significant amount migrates out of system (past seeps). Different remedial alternatives do not have significant effect on the maximum seep concentration or the amount of activity that migrates out of system. The only significant "effect" is caused by the delayed leaching – but that only effects early-time fate and transport and not maximum seep concentrations. |

**Table 3-6 Cumulative Activity Fluxes for Carbon-14 for Various Scenarios, Sum of All Elements**

| | | | Cumulative Activity Flux (Ci) at Year: | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Location** | **Scenario** | **Cover/Cap** | **1995** | **2000** | **2045** | **2100** | **2500** | **2974** |
| Top of Vadose Zone | Constant Rate | Soil cover | 99 | 104 | 125 | 176 | 238 | 252 |
| | Variable Rate | Soil cover | 99 | 104 | 125 | 176 | 238 | 252 |
| | Delay | Soil cover | 0 | 9 | 46 | 136 | 236 | 250 |
| | Delay | RCRA clay w/ barrier | 0 | 9 | 20 | 53 | 155 | 198 |
| | Trigger | RCRA clay w/ barrier | 0 | 9 | 46 | 75 | 164 | 202 |
| Top of Water Table | Constant Rate | Soil cover | 4 | 7 | 40 | 128 | 234 | 248 |
| | Variable Rate | Soil cover | 4 | 5 | 11 | 54 | 233 | 246 |
| | Delay | Soil cover | 0 | 0 | 0 | 16 | 232 | 245 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 0 | <1 | 31 | 104 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | <1 | 1 | 40 | 113 |
| Seep Line | Constant Rate | Soil cover | 0 | 0 | 0 | <1 | 152 | 229 |
| | Variable Rate | Soil cover | 0 | 0 | 0 | 0 | 130 | 227 |
| | Delay | Soil cover | 0 | 0 | 0 | 0 | 113 | 226 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 2 | 50 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 5 | 59 |

Note: <1 denotes values that are less than 1, but greater than 0.01.
Initial total activity for carbon-14 was 3778 Ci.

**Table 3-7 Cumulative Activity Fluxes for Tritium for Various Scenarios, Sum of All Elements**

| | | | Cumulative Activity Flux (Ci) at Year: | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Location** | **Scenario** | **Cover/Cap** | **1995** | **2000** | **2045** | **2100** | **2500** | **2974** |
| Top of Vadose Zone | Constant Rate | Soil cover | 2401300 | 2403400 | 2405700 | 2405800 | 2405800 | 2405800 |
| | Variable Rate | Soil cover | 2401300 | 2403400 | 2405700 | 2405800 | 2405800 | 2405800 |
| | Delay | Soil cover | 0 | 224300 | 47900 | 493700 | 493700 | 493700 |
| | Delay | RCRA clay w/ barrier | 0 | 224300 | 331000 | 351800 | 351900 | 351900 |
| | Trigger | RCRA clay w/ barrier | 0 | 224300 | 479000 | 486000 | 486000 | 486000 |
| Top of Water Table | Constant Rate | Soil cover | 1785400 | 1807600 | 1815600 | 1815800 | 1815800 | 1815800 |
| | Variable Rate | Soil cover | 1785400 | 1795000 | 1806800 | 1807600 | 1807600 | 1807600 |
| | Delay | Soil cover | 0 | 3450 | 169820 | 210420 | 210430 | 210430 |
| | Delay | RCRA clay w/ barrier | 0 | 2440 | 28170 | 49310 | 49500 | 49500 |
| | Trigger | RCRA clay w/ barrier | 0 | 2440 | 169870 | 187110 | 187200 | 187200 |
| Seep Line | Constant Rate | Soil cover | 9010 | 29970 | 212970 | 253050 | 253050 | 253050 |
| | Variable Rate | Soil cover | 9010 | 29970 | 212320 | 251930 | 251930 | 251930 |
| | Delay | Soil cover | 0 | 0 | 1250 | 29350 | 29450 | 29450 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 240 | 6700 | 6970 | 6970 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 1180 | 26100 | 26240 | 26240 |

Initial total activity for tritium was 3014457 Ci.

**Table 3-8 Cumulative Mass Fluxes for Cadmium for Various Scenarios, Sum of All Elements**

| | | | Cumulative Mass Flux (kg) at Year: | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Location** | **Scenario** | **Cover/Cap** | **1995** | **2000** | **2045** | **2100** | **2500** | **2974** |
| Top of Vadose Zone | Constant Rate | Soil cover | 296 | 314 | 398 | 662 | 1570 | 1588 |
| | Variable Rate | Soil cover | 296 | 314 | 398 | 662 | 1570 | 1588 |
| | Delay | Soil cover | 0 | 22 | 126 | 450 | 1566 | 1588 |
| | Delay | RCRA clay w/ barrier | 0 | 22 | 54 | 148 | 558 | 896 |
| | Trigger | RCRA clay w/ barrier | 0 | 22 | 126 | 216 | 606 | 928 |
| Top of Water Table | Constant Rate | Soil cover | <1 | 1 | 12 | 158 | 1401 | 1582 |
| | Variable Rate | Soil cover | <1 | <1 | 1 | 18 | 1392 | 1582 |
| | Delay | Soil cover | 0 | 0 | 0 | 2 | 1362 | 1581 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 7 | 79 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 0 | <1 | 11 | 94 |
| Seep Line | Constant Rate | Soil cover | 0 | 0 | 0 | 0 | 6 | 384 |
| | Variable Rate | Soil cover | 0 | 0 | 0 | 0 | 2 | 343 |
| | Delay | Soil cover | 0 | 0 | 0 | 0 | 1 | 309 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 1 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 1 |

Note: <1 denotes values that are less than 1, but greater than 0.01.
Initial total mass for cadmium was 1588 kg.

**Table 3-9 Cumulative Mass Fluxes for Mercury for Various Scenarios, Sum of All Elements**

| | | | Cumulative Mass Flux (kg) at Year: | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Location** | **Scenario** | **Cover/Cap** | **1995** | **2000** | **2045** | **2100** | **2500** | **2974** |
| Top of Vadose Zone | Constant Rate | Soil cover | 678 | 723 | 937 | 1686 | 8217 | 10321 |
| | Variable Rate | Soil cover | 678 | 723 | 937 | 1686 | 8217 | 10321 |
| | Delay | Soil cover | 0 | 48 | 276 | 1075 | 8035 | 10278 |
| | Delay | RCRA clay w/ barrier | 0 | 48 | 116 | 328 | 1377 | 2487 |
| | Trigger | RCRA clay w/ barrier | 0 | 48 | 276 | 485 | 1519 | 2612 |
| Top of Water Table | Constant Rate | Soil cover | 0 | 0 | <1 | 25 | 2331 | 6976 |
| | Variable Rate | Soil cover | 0 | 0 | <1 | <1 | 2334 | 6949 |
| | Delay | Soil cover | 0 | 0 | 0 | <1 | 2013 | 6784 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | <1 | 5 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | <1 | 7 |
| Seep Line | Constant Rate | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Variable Rate | Soil cover | 0 | 0 | 0 | 0 | 0 | <1 |
| | Delay | Soil cover | 0 | 0 | 0 | 0 | 0 | <1 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Note: <1 denotes values that are less than 1, but greater than 0.01.
Initial total mass for mercury was 10975 kg.

## Table 3-10 Cumulative Mass Fluxes for VOC for Various Scenarios, Sum of All Elements

| Location | Scenario | Cover/Cap | Cumulative Mass Flux (kg) at Year: 1995 | 2000 | 2045 | 2100 | 2500 | 2974 |
|---|---|---|---|---|---|---|---|---|
| Top of Vadose Zone | Constant Rate | Soil cover | 259610 | 260270 | 261640 | 262000 | 262000 | 262000 |
| | Variable Rate | Soil cover | 259610 | 260270 | 261640 | 262000 | 262000 | 262000 |
| | Delay | Soil cover | 0 | 72510 | 221990 | 261870 | 262000 | 262000 |
| | Delay | RCRA clay w/ barrier | 0 | 72510 | 142220 | 233980 | 261900 | 261900 |
| | Trigger | RCRA clay w/ barrier | 0 | 72510 | 221990 | 252640 | 262000 | 262000 |
| Top of Water Table | Constant Rate | Soil cover | 249820 | 257210 | 261480 | 262000 | 262000 | 262000 |
| | Variable Rate | Soil cover | 249820 | 253050 | 260410 | 262000 | 262000 | 262000 |
| | Delay | Soil cover | 0 | 1370 | 130970 | 260970 | 261830 | 261830 |
| | Delay | RCRA clay w/ barrier | 0 | 1370 | 22930 | 159130 | 262000 | 262000 |
| | Trigger | RCRA clay w/ barrier | 0 | 980 | 130180 | 219820 | 262000 | 262000 |
| Seep Line | Constant Rate | Soil cover | 1410 | 6850 | 144020 | 261850 | 261930 | 261930 |
| | Variable Rate | Soil cover | 1410 | 6850 | 143380 | 262000 | 262000 | 262000 |
| | Delay | Soil cover | 0 | 0 | 1000 | 235570 | 261830 | 261830 |
| | Delay | RCRA clay w/ barrier | 0 | 0 | 230 | 89310 | 261950 | 262000 |
| | Trigger | RCRA clay w/ barrier | 0 | 0 | 900 | 181240 | 262000 | 262000 |

Note: <1 denotes values that are less than 1, but greater than 0.01.
Initial total mass for VOC was 262000 kg.

## Table 3-11 Cumulative Mass/Activity Fluxes for Various Scenarios, Sum of All Elements, at the Saturated Zone Below the ORWBG

| Cumulative Activity Flux (Ci) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 4 | 5 | 11 | 54 | 233 | 246 |
| | Soil cover w/ barrier | 4 | 5 | 11 | 47 | 198 | 224 |
| | RCRA clay | 4 | 5 | 6 | 13 | 232 | 245 |
| | RCRA clay w/ barrier | 4 | 5 | 6 | 13 | 72 | 138 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | <1 | 16 | 232 | 245 |
| | Soil cover w/ barrier | 0 | 0 | <1 | 12 | 184 | 221 |
| | RCRA clay | 0 | 0 | 0 | <1 | 230 | 244 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | <1 | 31 | 104 |
| | Triggered RCRA clay | 0 | 0 | <1 | <1 | 229 | 243 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | <1 | <1 | 40 | 113 |

Note: <1 denotes values that are less than 1, but greater than 0.01.
Initial total activity for carbon-14 was 3778 Ci

a) Carbon-14

| Cumulative Activity Flux (Ci) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | <1 | 7 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | <1 |
| | RCRA clay | 0 | 0 | 0 | 0 | <1 | 7 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | <1 | 7 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | <1 |
| | RCRA clay | 0 | 0 | 0 | 0 | <1 | 6 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | <1 | 6 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for plutonium-239 was 20514 Ci

b) Plutonium-239

| Cumulative Activity Flux (Ci) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | <1 | <1 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | <1 | <1 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | <1 | <1 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | <1 | <1 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | <1 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for plutonium-238 was 1475 Ci

c) Plutonium-238

| Cumulative Activity Flux (Ci) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | <1 | 4 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | <1 |
| | RCRA clay | 0 | 0 | 0 | 0 | <1 | 4 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | <1 | 4 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | <1 |
| | RCRA clay | 0 | 0 | 0 | 0 | <1 | 4 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | <1 | 4 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for uranium-238 was 14.8 Ci

d) Uranium-238

| Cumulative Activity Flux (Ci) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 6 | 6 | 8 | 12 | 12 | 12 |
| | Soil cover w/ barrier | 6 | 6 | 8 | 11 | 12 | 12 |
| | RCRA clay | 6 | 6 | 7 | 9 | 12 | 12 |
| | RCRA clay w/ barrier | 6 | 6 | 7 | 9 | 12 | 12 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | <1 | 9 | 12 | 12 |
| | Soil cover w/ barrier | 0 | 0 | <1 | 9 | 12 | 12 |
| | RCRA clay | 0 | 0 | <1 | 1 | 12 | 12 |
| | RCRA clay w/ barrier | 0 | 0 | <1 | 1 | 11 | 12 |
| | Triggered RCRA clay | 0 | 0 | <1 | 3 | 12 | 12 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | <1 | 3 | 11 | 12 |

Initial total activity for technetium-99 was 12 Ci

e) Technetium-99

| Cumulative Activity Flux (Ci) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 3 | 3 | 5 | 9 | 11 | 11 |
| | Soil cover w/ barrier | 3 | 3 | 5 | 9 | 11 | 11 |
| | RCRA clay | 3 | 3 | 4 | 5 | 11 | 11 |
| | RCRA clay w/ barrier | 3 | 3 | 4 | 5 | 10 | 11 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | <1 | 6 | 11 | 11 |
| | Soil cover w/ barrier | 0 | 0 | <1 | 5 | 11 | 11 |
| | RCRA clay | 0 | 0 | 0 | <1 | 11 | 11 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | <1 | 8 | 10 |
| | Triggered RCRA clay | 0 | 0 | <1 | 1 | 11 | 11 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | <1 | 1 | 8 | 10 |

Initial total activity for iodine-129 was 10.6 Ci

f) Iodine-129

| Cumulative Activity Flux (Ci) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | <1 | <1 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | <1 | <1 |
| | RCRA clay | 0 | 0 | 0 | 0 | <1 | <1 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | <1 | <1 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | <1 | <1 |
| | RCRA clay | 0 | 0 | 0 | 0 | <1 | <1 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | <1 | <1 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for neptunium-237was 1.99 Ci

g) Neptunium-237

| Cumulative Activity Flux (Ci) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | <1 | <1 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | <1 | <1 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | <1 | <1 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | <1 | <1 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | <1 | <1 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for uranium-235 was 0.6 Ci

h) Uranium-235

| Cumulative Activity Flux (Ci) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for cesium-137 was 58657 Ci

i) Cesium-137

| Cumulative Activity Flux (Ci) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | <1 | 1 | 4 | 20 | 133 | 133 |
| | Soil cover w/ barrier | <1 | 1 | 4 | 17 | 31 | 31 |
| | RCRA clay | <1 | 1 | 2 | 3 | 73 | 73 |
| | RCRA clay w/ barrier | <1 | 1 | 2 | 3 | 3 | 3 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 1 | 76 | 76 |
| | Soil cover w/ barrier | 0 | 0 | 0 | <1 | 6 | 6 |
| | RCRA clay | 0 | 0 | 0 | 0 | 43 | 43 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | <1 | <1 |
| | Triggered RCRA clay | 0 | 0 | 0 | <1 | 29 | 29 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | <1 | <1 | <1 |

Initial total activity for strontium-90 was 58657 Ci

j) Strontium-90

| Cumulative Activity Flux (Ci x $10^3$) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 1785 | 1795 | 1807 | 1808 | 1808 | 1808 |
| | Soil cover w/ barrier | 1785 | 1795 | 1807 | 1808 | 1808 | 1808 |
| | RCRA clay | 1785 | 1795 | 1800 | 1801 | 1801 | 1801 |
| | RCRA clay w/ barrier | 1785 | 1795 | 1800 | 1801 | 1801 | 1801 |
| Full-Impact Late-Timing | Soil cover | 0 | 3 | 170 | 210 | 210 | 210 |
| | Soil cover w/ barrier | 0 | 2 | 170 | 210 | 210 | 210 |
| | RCRA clay | 0 | 3 | 29 | 50 | 51 | 51 |
| | RCRA clay w/ barrier | 0 | 2 | 28 | 49 | 50 | 50 |
| | Triggered RCRA clay | 0 | 3 | 170 | 187 | 187 | 187 |
| | Triggered RCRA clay w/ barrier | 0 | 2 | 170 | 187 | 187 | 187 |

Initial total activity for tritium was 3014457 Ci

k) Tritium

| Cumulative Activity Flux (Ci) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 1 | 2 | 2 | 2 | 2 | 2 |
| | Soil cover w/ barrier | 1 | 2 | 2 | 2 | 2 | 2 |
| | RCRA clay | 1 | 2 | 2 | 2 | 2 | 2 |
| | RCRA clay w/ barrier | 1 | 2 | 2 | 2 | 2 | 2 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for cobalt-60 was 1960400 Ci

l) Cobalt-60

| Cumulative Mass Flux (kg) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | <1 | <1 | 1 | 18 | 1392 | 1582 |
| | Soil cover w/ barrier | <1 | <1 | 1 | 14 | 439 | 1050 |
| | RCRA clay | <1 | <1 | <1 | 2 | 1357 | 1581 |
| | RCRA clay w/ barrier | <1 | <1 | <1 | 2 | 33 | 151 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 2 | 1362 | 1581 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 1 | 333 | 975 |
| | RCRA clay | 0 | 0 | 0 | 0 | 1321 | 1580 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 7 | 79 |
| | Triggered RCRA clay | 0 | 0 | 0 | <1 | 1288 | 1579 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | <1 | 11 | 94 |

Initial total mass for cadmium was 1588 kg

m) Cadmium

| Cumulative Mass Flux (kg) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 27 | 606 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | <1 | 3 |
| | RCRA clay | 0 | 0 | 0 | 0 | 21 | 549 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 21 | 556 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | <1 | 2 |
| | RCRA clay | 0 | 0 | 0 | 0 | 16 | 502 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 13 | 466 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total mass for lead was 45359 kg

n) Lead

| Cumulative Mass Flux (kg) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | <1 | 2234 | 6949 |
| | Soil cover w/ barrier | 0 | 0 | 0 | <1 | 110 | 818 |
| | RCRA clay | 0 | 0 | 0 | 0 | 1983 | 6760 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 1 | 15 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | <1 | 2013 | 6784 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 64 | 665 |
| | RCRA clay | 0 | 0 | 0 | 0 | 1768 | 6590 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | <1 | 5 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 1599 | 6447 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | <1 | 7 |

Initial total mass for mercury was 10975 kg

o) Mercury

| Cumulative Mass Flux (kg x $10^3$) in Saturated Zone Below ORWBG at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 250 | 253 | 260 | 263 | 263 | 263 |
| | Soil cover w/ barrier | 250 | 253 | 260 | 263 | 263 | 263 |
| | RCRA clay | 250 | 253 | 256 | 261 | 263 | 263 |
| | RCRA clay w/ barrier | 250 | 253 | 256 | 261 | 263 | 263 |
| Full-Impact Late-Timing | Soil cover | 0 | 1 | 131 | 261 | 262 | 262 |
| | Soil cover w/ barrier | 0 | 1 | 130 | 260 | 262 | 262 |
| | RCRA clay | 0 | 1 | 23 | 159 | 256 | 256 |
| | RCRA clay w/ barrier | 0 | 1 | 22 | 159 | 262 | 262 |
| | Triggered RCRA clay | 0 | 1 | 131 | 220 | 262 | 262 |
| | Triggered RCRA clay w/ barrier | 0 | 1 | 130 | 220 | 263 | 263 |

Initial total mass for VOCs was 262000 kg

p) VOC

## Table 3-12 Cumulative Mass/Activity Fluxes for Various Scenarios, Sum of All Elements, at the Seep Line

| Cumulative Activity Flux (Ci) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 130 | 227 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 79 | 201 |
| | RCRA clay | 0 | 0 | 0 | 0 | 112 | 226 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 20 | 89 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 113 | 226 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 48 | 192 |
| | RCRA clay | 0 | 0 | 0 | 0 | 95 | 225 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 2 | 50 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 82 | 224 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 5 | 59 |

Note: <1 denotes values that are less than 1, but greater than 0.01.
Initial total activity for carbon-14 was 3778 Ci

a) Carbon-14

| Cumulative Activity Flux (Ci) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for plutonium-239 was 20514 Ci

b) Plutonium-239

| Cumulative Activity Flux (Ci) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for plutonium-238 was 1475 Ci

c) Plutonium-238

| Cumulative Activity Flux (Ci) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for uranium-238 was 14.8 Ci

d) Uranium-238

| Cumulative Activity Flux (Ci) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | <1 | 7 | 12 | 12 |
| | Soil cover w/ barrier | 0 | 0 | <1 | 7 | 12 | 12 |
| | RCRA clay | 0 | 0 | <1 | 6 | 12 | 12 |
| | RCRA clay w/ barrier | 0 | 0 | <1 | 6 | 12 | 12 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | <1 | 12 | 12 |
| | Soil cover w/ barrier | 0 | 0 | 0 | <1 | 12 | 12 |
| | RCRA clay | 0 | 0 | 0 | <1 | 12 | 12 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | <1 | 10 | 12 |
| | Triggered RCRA clay | 0 | 0 | 0 | <1 | 12 | 12 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | <1 | 11 | 12 |

Initial total activity for technetium-99 was 12 Ci

e) Technetium-99

| Cumulative Activity Flux (Ci) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 1 | 11 | 11 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 1 | 11 | 11 |
| | RCRA clay | 0 | 0 | 0 | 1 | 11 | 11 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 1 | 9 | 11 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | <1 | 11 | 11 |
| | Soil cover w/ barrier | 0 | 0 | 0 | <1 | 10 | 11 |
| | RCRA clay | 0 | 0 | 0 | 0 | 11 | 11 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 6 | 10 |
| | Triggered RCRA clay | 0 | 0 | 0 | <1 | 11 | 11 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | <1 | 7 | 10 |

Initial total activity for iodine-129 was 10.6 Ci

f) Iodine-129

| **Cumulative Activity Flux (Ci) at Seep Line at Year:** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | <1 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | <1 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | <1 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | <1 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | <1 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for neptunium-237was 1.99 Ci

g) Neptunium-237

| **Cumulative Activity Flux (Ci) at Seep Line at Year:** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for uranium-235 was 0.6 Ci

h) Uranium-235

| **Cumulative Activity Flux (Ci) at Seep Line at Year:** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for cesium-137 was 58657 Ci

i) Cesium-137

| Cumulative Activity Flux (Ci) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for strontium-90 was 58657 Ci

j) Strontium-90

| Cumulative Activity Flux (Ci x $10^3$) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 9 | 30 | 212 | 252 | 252 | 252 |
| | Soil cover w/ barrier | 9 | 30 | 212 | 252 | 252 | 252 |
| | RCRA clay | 9 | 30 | 212 | 251 | 251 | 251 |
| | RCRA clay w/ barrier | 9 | 30 | 212 | 251 | 251 | 251 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 1 | 29 | 29 | 29 |
| | Soil cover w/ barrier | 0 | 0 | 1 | 29 | 29 | 29 |
| | RCRA clay | 0 | 0 | 0 | 7 | 7 | 7 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 7 | 7 | 7 |
| | Triggered RCRA clay | 0 | 0 | 1 | 26 | 26 | 26 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 1 | 26 | 26 | 26 |

Initial total activity for tritium was 3014457 Ci

k) Tritium

| Cumulative Activity Flux (Ci) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total activity for cobalt-60 was 1960400 Ci

l) Cobalt-60

| Cumulative Mass Flux (kg) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 2 | 343 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | <1 | 84 |
| | RCRA clay | 0 | 0 | 0 | 0 | 1 | 304 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | <1 | 6 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 1 | 309 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | <1 | 53 |
| | RCRA clay | 0 | 0 | 0 | 0 | <1 | 272 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | <1 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | <1 | 247 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 1 |

Initial total mass for cadmium was 1588 kg

m) Cadmium

| Cumulative Mass Flux (kg) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | 0 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total mass for lead was 45359 kg

n) Lead

| Cumulative Mass Flux (kg) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | <1 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | <1 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 0 | 0 | 0 | <1 |
| | Soil cover w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | RCRA clay | 0 | 0 | 0 | 0 | 0 | <1 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |
| | Triggered RCRA clay | 0 | 0 | 0 | 0 | 0 | <1 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 0 | 0 | 0 | 0 |

Initial total mass for mercury was 10975 kg

o) Mercury

| Cumulative Mass Flux (kg x $10^3$) at Seep Line at Year: | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Scenario** | **Alternative** | **1995** | **2000** | **2024** | **2100** | **2500** | **2974** |
| Full-Impact Early-Timing | Soil cover | 1 | 7 | 143 | 262 | 263 | 263 |
| | Soil cover w/ barrier | 1 | 7 | 143 | 262 | 263 | 263 |
| | RCRA clay | 1 | 7 | 143 | 259 | 263 | 263 |
| | RCRA clay w/ barrier | 1 | 7 | 143 | 259 | 263 | 263 |
| Full-Impact Late-Timing | Soil cover | 0 | 0 | 1 | 236 | 262 | 262 |
| | Soil cover w/ barrier | 0 | 0 | 1 | 236 | 262 | 262 |
| | RCRA clay | 0 | 0 | 0 | 89 | 256 | 256 |
| | RCRA clay w/ barrier | 0 | 0 | 0 | 89 | 262 | 262 |
| | Triggered RCRA clay | 0 | 0 | 1 | 182 | 262 | 262 |
| | Triggered RCRA clay w/ barrier | 0 | 0 | 1 | 181 | 263 | 263 |

Initial total mass for VOCs was 262000 kg

p) VOC

## 4.0 CONCLUSIONS

This study involved developing and applying an approach to assess fate and transport of 16 designated COIs for the ORWBG. In particular, the maximum concentration at the water table and at the seep point, and the overall mass (activity) disposition were presented and analyzed. This study was a continuation of the previous modeling effort for the ORWBG. A 1000-year simulation strategy was developed that considered infiltration, leaching of constituents from their waste form, vadose zone solute transport, and saturated zone solute transport. Many simplifying assumptions were made which introduce uncertainty into the analysis. However, the approach is consistent with the reliability of the available data and the objectives of the study.

Four groups of modeled scenarios were considered: modeling of five remedial alternatives using a constant infiltration rate through the vadose zone (the previous modeling), remodeling of those same five remedial alternatives allowing a variable infiltration rate through the vadose zone, modeling of four remedial alternatives (the RCRA synthetic cap was not modeled) assuming that any leaching of the source COIs would not occur until the Soil Cover was placed (only decay was allowed prior to leaching), and finally, modeling of RCRA Cap alternatives with the placement of the cap dependant on a “trigger” level of contamination of selective constituents. Four presentation methods were used to aid in the data reduction and analysis due to the overwhelming data generated with each modeling run.

With the amount of data generated during each modeling run and the ability of the computer to generate very precise numbers, it can be tempting to consider slight changes in either concentration or mass (activity) values as important. However, due to the limitations and assumptions of the computer models used in this modeling effort, these modeling results should only be used to compare remedial alternatives at an OOM level, with any differences between scenarios of less than a factor of 10 not considered significant. Additionally, although the computer code calculates and outputs concentration (and mass/activity) values at very low levels (i.e., 1.0E-45, etc.), any concentration (or mass/activity) value less than approximately 1.0E-5 should be considered as equivalent to zero.

The results indicate essentially no difference between use of a variable vadose zone infiltration rate or a constant vadose zone infiltration rate. Further, the use of delayed leaching only effectively impacted tritium fate and transport, but with no significant impact to the amount of mass (activity) leaving the system.

The overall conclusion from this modeling exercise is that, for the most part, the COIs are relatively unaffected by the remedial alternatives. Although some COIs show a reduction in mass/activity entering the saturated zone with a RCRA Clay Cap compared to the Soil Cover, except for cadmium, there is no significant reduction in mass/activity leaving the system (i.e., seeping from the saturated zone). However, there appears to be some benefit in reducing transport of mass (activity) to the vadose and saturated zones by using barriers – whether for the existing Soil Cover system, or a RCRA Clay Cap.

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## Appendix A

### Program Listing

The computer code used for this modeling effort was written in FORTRAN90. A complete listing follows:

```
C     LVStran2.for
C     Greg Council  Jan 7, 1999
C     SRS OBG Source term modeling (SRS Task 13) Project I021-000
C       This program simulates transport of constituents in three phases:
C         1) vertical leaching from waste units
C         2) vertical transport through the vadose zone
C         3) horizontal transport through the saturated zone to a receptor
c
c     Program modified to accomodate variable vadose zone infiltration rates by:
c     Kevin Brewer, Ph.D.
c     BSRI
c     11/23/99 - 12/31/99
c

      program LVStran
        implicit none
        integer :: Ntime, Nelem, Ncoc, Nform, Itime, Ielem, Icoc,
     &    Form1, IeleMax, Tmax
        real(kind=8) :: TimeStep, Dispersivity, SatCond, Decay, Csat1,
     &    ConvFact1, VadSat, Rho1, Kd1, Area1, ThkSrc,
     &    Dvad, Dsat, M0, M1, M2, Por, SrcDecay1, VadDecay1,
     &    SatDecay1, OutMass1, Qdef, Vdef, Idef1, Grad, Cmax, C0, C1
        real(kind=8), allocatable :: Density(:), Area(:), TopSrc(:),
     &    Wtable(:), DistRecep(:), ElevRecep(:), Infiltration(:,:),
     &    HalfLife(:), Csat(:), ConvFactor(:), Kd(:,:), Inventory(:,:),
     &    Porosity(:), SrcMass(:), VadMass(:), SatMass(:),
     &    OutMass(:), SrcDecay(:), VadDecay(:), SatDecay(:), Cleach(:),
     &    Cwt(:), Crecep(:), KKd(:), PPor(:), RRho(:), Mx(:),
     &    Idef(:), Q(:), BotSrc(:)
        integer, allocatable :: WasteForm(:,:,:)
c KEB added following 3 lines
        integer :: Inf_Period, Vad_start, new_calc, III
        real(kind=8), allocatable :: Cwt_Vad(:), lin_vel(:), e_time(:)
        real(kind=8) :: Idef_Vad, d_length, d_time, disp

        character*80 :: Title

C       Open input file & read
        print *, 'Input File: '
        read *, Title
        open(unit=1,file=Title,status='old')
        print *, 'Output / Echo File: '
        read *, Title
        open (unit=33,file=Title)

        read(1,*) Ntime, Nelem, Ncoc, Nform
        write(33,1) Ntime, Nelem, Ncoc, Nform
```

```
        allocate (Density(Nform), Area(Nelem), TopSrc(Nelem),
     &    BotSrc(Nelem), Wtable(Nelem), DistRecep(Nelem),
     &    ElevRecep(Nelem), Infiltration(Ntime,Nelem),
     &    HalfLife(Ncoc), Csat(Ncoc), WasteForm(Ntime,Nelem,Ncoc),
     &    ConvFactor(Ncoc), Kd(Nform,Ncoc), Inventory(Nelem,Ncoc),
     &    Porosity(Nform),IDef(Nelem))


        read(1,*) TimeStep, VadSat, Dispersivity, SatCond
        write(33,2) TimeStep, VadSat, Dispersivity, SatCond
        read(1,*) Density(:)
        write(33,11) Density(1), Density(Nform)
        read(1,*) Porosity(:)
        write(33,12) Porosity(1), Porosity(Nform)

        do Ielem = 1, Nelem
          write(33,3) Ielem
          read(1,*) Area(Ielem), TopSrc(Ielem), BotSrc(Ielem),
     &      Wtable(Ielem), DistRecep(Ielem), ElevRecep(Ielem),
     &      Idef(Ielem)
          write(33,4) Area(Ielem), TopSrc(Ielem), BotSrc(Ielem),
     &      Wtable(Ielem), DistRecep(Ielem), ElevRecep(Ielem),
     &      Idef(Ielem)
          read(1,*) Infiltration(:,Ielem)
          write(33,5) Infiltration(1,Ielem), Infiltration(Ntime,Ielem)

        enddo

        do Icoc = 1, Ncoc
          write(33,7) Icoc
          read(1,*) HalfLife(Icoc), Csat(Icoc), ConvFactor(Icoc),
     &      Kd(:,Icoc)
          write(33,8) HalfLife(Icoc), Csat(Icoc), ConvFactor(Icoc),
     &      Kd(1,Icoc), Kd(Nform,Icoc)

          do Ielem = 1, Nelem
            read(1,*) Inventory(Ielem,Icoc), WasteForm(:,Ielem,Icoc)
            write(33,9) Ielem, Inventory(Ielem,Icoc),
     &        WasteForm(1,Ielem,Icoc), WasteForm(Ntime,Ielem,Icoc)
          enddo
        enddo

        close(1)
        write(33,10)

C       Open Output file
        print *, 'Output Data (Binary) File: '
        read *, Title
        open(unit=1,file=Title,form='unformatted')
        write(1) Ntime, Nelem, Ncoc, TimeStep

C       Allocate & initialize working/output variables
        allocate (Cleach(Ntime), Cwt(Ntime),Crecep(Ntime),
     &    SrcMass(0:Ntime), VadMass(Ntime), SatMass(Ntime),
     &    OutMass(Ntime), SrcDecay(Ntime), VadDecay(Ntime),
     &    SatDecay(Ntime), Mx(Ntime), Q(Ntime+1), KKd(Ntime),
     &    RRho(Ntime), PPor(Ntime))
        Rho1 = Density(1)
        Por = Porosity(1)
c KEB added following line
        allocate (Cwt_Vad(Ntime), lin_vel(Ntime), e_time(Ntime))
```

```
C       Step through constituents
        do Icoc = 1, Ncoc
          if (HalfLife(Icoc) .le. 0.0) then
            Decay = 0.0
          else
            Decay = log(2.0)/HalfLife(Icoc)
          endif
          ConvFact1 = ConvFactor(Icoc)
          Csat1 = Csat(Icoc) / ConvFact1
          Kd1 = Kd(1,Icoc)
          Cmax = 0.0
          IeleMax = 0
          Tmax = 0

C         Step through source elements
          do Ielem = 1, Nelem
            Area1 = Area(Ielem)
            ThkSrc = TopSrc(Ielem) - BotSrc(Ielem)
            Dvad = BotSrc(Ielem) - Wtable(Ielem)
            Dsat = DistRecep(Ielem)
            Grad = (Wtable(Ielem) - ElevRecep(Ielem))/Dsat
            SrcMass(0) = Inventory(Ielem,Icoc)
            Idef1= Idef(Ielem)
            Qdef = IDef1 * Area1
            Vdef = Qdef * TimeStep

            do Itime = 1, Ntime
              Q(Itime) = Infiltration(Itime,Ielem)
              Form1 = WasteForm(Itime,Ielem,Icoc)
              if (Form1.le.0) then
                KKd(Itime) = -1.0
                RRho(Itime) = Rho1
                PPor(Itime) = Por
              else
                KKd(Itime) = Kd(Form1,Icoc)
                RRho(Itime) = Density(Form1)
                PPor(Itime) = Porosity(Form1)
              endif
            enddo

C           LEACH
            call Leach(SrcMass, Ntime, TimeStep, KKd, PPor, ThkSrc, Q,
     &        RRho, Decay, Mx, SrcDecay)
            do Itime = 1, Ntime
c KEB modification to following line to account for variable leaching rates to
c vadose zone
c             Cleach(Itime) = Mx(Itime) / Vdef
              Cleach(Itime) = Mx(Itime) /
     &                        (Infiltration(Itime,Ielem)*Area1*TimeStep)
c KEB addition of the following line to calculate the average linear
c velocity of the vadose-zone for input to the finite difference subroutine
              lin_vel(Itime) = Infiltration(Itime,Ielem)/(Por*VadSat)
c             lin_vel(Itime) = Idef1/(Por*VadSat)
            enddo
            KKd = Mx

C           VADOSE

c  KEB MODIFICATION TO HANDLE VARIABLE VADOSE ZONE RATES
c  =====================================================
c
```

```
c  The finite-difference solution subroutine was created to handle
c  variable rate 1D transport.

            Title = 'Vadose'

            disp = Dispersivity / 10.0

            call fdt1d(Dvad,TimeStep,Ntime,disp,Kd1,
     &       HalfLife(Icoc),
     &        Rho1,Por*VadSat,lin_vel,Cleach,Cwt,e_time,
     &        d_length,d_time)

c  Do some bookkeeping for later output
c   i.e., determine VadDecay[...] and VadMass[...]
c         and determine Mx[...] for the next step.
c   all from Cwt
c     M0 is the Vadose Zone Mass from the previous step
c     M1 is the Outflow Mass Flux for the current step
c     M2 is the Vadose Zone Mass Decay from M0
c     C0 is the Concentration in the Outflow from the previous step
c     C1 is the Concentration in the Outflow for the current step
            M0 = 0.0
            C0 = 0.0
            do Itime = 1, Ntime
c     calculate the decay mass from the stored mass of the previous time step
              M2 = M0*(1.0 - exp(-TimeStep*Decay))
              VadDecay(Itime) = M2
c     calculate the outflow mass
              C1 = Cwt(Itime)
              M1 = Cwt(Itime)*Infiltration(Itime,Ielem)*Area1*TimeStep
c             M1 = Cwt(Itime)*Vdef
              M0 = M0 - M2 + Mx(Itime) - M1
              VadMass(Itime) = M0
              Mx(Itime) = M1
              C0 = C1
            enddo

c THE REMAINING CODE WAS NOT ALTERED.

c           SATURATED
            Title = 'Saturated'
            Q(1) = Mx(1)/2.0
            do Itime = 2, Ntime
              Q(Itime) = Mx(Itime-1)/2.0 +Mx(Itime)/2.0
            enddo
            Q(Ntime+1) = Mx(Ntime)/2.0

            Area1 = Qdef / Grad / SatCond
            call at123d(Title,1,1,1,1000,2,Ntime+1,1,1,
     &        Ntime+1,1,3,1,1,-1,1.0D0,Area1,0.0D0,0.0D0,0.0D0,Area1,
     &        0.0D0,1.0D0,Por,SatCond,Grad,Dispersivity,0.01D0,
     &        0.01D0,Kd1,0.0D0,0.0D0, Decay, Rho1, 1.0D3, -1.0D0,
     &        TimeStep,TimeStep*Ntime,1.0D0,Dsat,0.0D0,
     &        0.0D0,Q,Crecep, KKd, Ntime)
            M0 = 0.0
            do Itime = 1, Ntime
              M2 = M0*(1.0 - exp(-TimeStep*Decay))
              SatDecay(Itime) = M2
              M1 = Crecep(Itime)*Vdef
              M0 = M0 - M2 + Mx(Itime) - M1
              SatMass(Itime) = M0
              OutMass(Itime) = M1
```

```
            enddo

c           ACCUMULATE & PRINT
            SrcDecay1 = 0.0
            VadDecay1 = 0.0
            SatDecay1 = 0.0
            OutMass1 = 0.0
            do Itime = 1, Ntime
              SrcDecay1 = SrcDecay(Itime) + SrcDecay1
              VadDecay1 = VadDecay(Itime) + VadDecay1
              SatDecay1 = SatDecay(Itime) + SatDecay1
              OutMass1 = OutMass(Itime) + OutMass1
              if(Crecep(Itime).gt.Cmax) then
                Cmax = Crecep(Itime)
                IeleMax = Ielem
                Tmax = Itime
              endif
              write(1) Cleach(Itime)*ConvFact1, Cwt(Itime)*ConvFact1,
     &          Crecep(Itime)*ConvFact1, SrcMass(Itime),
     &          VadMass(Itime), SatMass(Itime), OutMass1, SrcDecay1,
     &          VadDecay1, SatDecay1
c             write(1,21) Ielem, Icoc, Itime*TimeStep,
c    &          Cleach(Itime)*ConvFact1, Cwt(Itime)*ConvFact1,
c    &          Crecep(Itime)*ConvFact1, SrcMass(Itime),
c    &          VadMass(Itime), SatMass(Itime), OutMass1, SrcDecay1,
c    &          VadDecay1, SatDecay1
            enddo

          enddo
C         End of element loop

          write(33,40) Icoc, IeleMax, Tmax*TimeStep, Cmax*ConvFact1
          print 40, Icoc, IeleMax, Tmax*TimeStep, Cmax*ConvFact1

        enddo
C       End of constituent loop

        stop

    1   format(' Problem dimensions:',/,
     &    ' Number of time steps      (Ntime) =',I10,/,
     &    ' Number of source elements (Nelem) =',I10,/,
     &    ' Number of constituents    (Ncoc)  =',I10,/,
     &    ' Number of waste forms     (Nform) =',I10)
    2   format(/,' Input values:',/,
     &    ' Time step length           =',1PG14.5,/,
     &    ' Vadose Zone Saturation     =',1PG14.5,/,
     &    ' Dispersivity               =',1PG14.5,/,
     &    ' Hyd. conductivity-Sat. zone=',1PG14.5)
   11   format(
     &    ' Density(Soil)              =',1PG14.5,/,' ...',/,
     &    ' Density(Nform)             =',1PG14.5)
   12   format(
     &    ' Porosity(Soil)             =',1PG14.5,/,' ...',/,
     &    ' Porosity(Nform)            =',1PG14.5)
    3   format(/,' Element No.',I5,':')
    4   format(
     &    '   Area                     =',1PG14.5,/,
     &    '   Top of waste             =',1PG14.5,/,
     &    '   Bottom of waste          =',1PG14.5,/,
     &    '   Water table elevation    =',1PG14.5,/,
     &    '   Distance to receptor     =',1PG14.5,/,
```

```
     &    '   Receptor elevation       =',1PG14.5,/,
     &    '   Default Infiltration     =',1PG14.5)
    5   format(
     &    '   Infiltration(1)          =',1PG14.5,/,'   ...',/,
     &    '   Infiltration(Ntime)      =',1PG14.5)
    7   format(/,' Constituent No.',I5,':')
    8   format(
     &    '   Half Life                =',1PG14.5,/,
     &    '   Saturation Concentration =',1PG14.5,/,
     &    '   Conc. Conversion Factor  =',1PG14.5,/,
     &    '   Kd(Soil)                 =',1PG14.5,/,'   ...',/,
     &    '   Kd(Nform)                =',1PG14.5)
    9   format('   Element',I5,':  Inventory =',1PG14.5,
     &    ', Waste form =',I5,' ...',I5)
   10   format(/,' Processing of input is complete.')
   20   format('Element,Constituent,Time,LeachConc,WtConc,RecepConc,',
     &    'SrcMass,VadMass,SatMass,RecepMass,SrcMassDecayed,',
     &    'VadMassDecayed,SatMassDecayed')
   21   format(I10,',',I10,14(',',ES15.5E3))
   40   format(' Max. Seep c. for COI',I5,
     &    ' is at element',I5,', time',f10.2,':',1PG14.5)
      end program

      subroutine at123d(TITLE,NX,NY,NZ,NROOT,NBGTI,NEDTI,NPRINT,INSTAN,
     &  NSOURS,INTER,ICASE,IWID,IDEP,IBUG,DEPTH,WIDTH,RL1,RL2,RB1,RB2,
     &  RH1,RH2,POR,HCOND,HGRAD,AELONG,
     &  ATRANV,AVERTI,AKD,AKE,AMTAU,
     &  RAMADA,RHOB,RHOW,ACCU,DT,TDISP,Q,
     &  X_DM,YDIM,ZDIM,QS,conc,ctime,
     &  nconc)
c
c The only changes to the original at123d subroutine are the following comment lines
c that describe the input/output variables.
c
c Kevin Brewer, Ph.D.
c BSRI
c 11/29/99
c
c
c
c TITLE           Description of problem (characters)
c NX,NY,NZ        Domain array lengths (number of array items)
c NROOT           Number of roots
c NBGTI           No. of beginning time steps
c NEDTI           No. of ending time step
c NPRINT          No. of time intervals for printing
c INSTAN          Instantaneous source control (0 is instant source, 1 is continuous
source)
c NSOURS          Source condition control (0 is for steady source, 1 is for variable
source)
c INTER           Intermittent output control (0 is for no such output control)
c ICASE           Case control (1 is thermal, 2 is chemical, 3 is radioactive)
c IWID            Width control (0 is finite width, 1 is infinite width)
c IDEP            Depth control (0 is finite depth, 1 is infinite depth)
c IBUG            Write control for debugging (0 or less is no writing)
c DEPTH           Aquifer depth (0 for infininte depth)
c WIDTH           Aquifer width (0 for infininte width)
c RL1             BEGIN POINT OF X-SOURCE LOCATION
c RL2             END POINT OF X-SOURCE LOCATION
c RB1             BEGIN POINT OF Y-SOURCE LOCATION
c RB2             END POINT OF Y-SOURCE LOCATION
c RH1             BEGIN POINT OF Z-SOURCE LOCATION
```

```
c RH2               END POINT OF Z-SOURCE LOCATION
c POR               Porosity
c HCOND             Hydraulic conductivity
c HGRAD             Hydraulic gradient
c AELONG            Longitudinal dispersivity
c ATRANV            Lateral dispersivity
c AVERTI            Vertical dispersivity
c AKD               Distribution coefficient (KD)
c AKE               Heat exchange coefficient
c AMTAU             MOLECULAR DIFFUSION MULTIPLY BY POROSITY [L**2/T]
c RAMADA            DECAY CONSTANT
c RHOB              BULK DENSITY OF THE SOIL
c RHOW              DENSITY OF WATER
c ACCU              ACCURACY TOLERANCE FOR REACHING STEADY STATE
c DT                TIME INTERVAL SIZE FOR THE DESIRED SOLUTION
c TDISP             DISCHARGE TIME
c Q                 WASTE RELEASE RATE
c X_DM              Domain x dimension (array)
c YDIM              Domain y dimension (array)
c ZDIM              Domain z dimension (array)
c QS                LIST OF TRANSIENT SOURCE RELEASE RATE
c conc              Output concentration (array)
c ctime             Output simulation time (array)
c nconc             Length of output concentration  and output time arrays


      IMPLICIT REAL*8(A-H,O-Z)
C
      character*4 TITLE
      DIMENSION TITLE(20),X_DM(NX),YDIM(NY),ZDIM(NZ)
      DIMENSION QS(NEDTI)
      dimension conc(NX,NY,NZ,nconc), ctime(nconc)
      allocatable TEMP(:,:,:),TEMPO(:,:,:)
      allocatable RTY(:),AIY(:),PSIS(:),FCTY(:,:)
      allocatable RTZ(:),AIZ(:),PHIS(:),FCTZ(:,:)
C
      DATA CP,PAI/1.0D0,3.14159265358979D0/

      allocate(TEMP(NX,NY,NZ),TEMPO(NX,NY,NZ))
      allocate(RTY(NROOT),AIY(NROOT),PSIS(NROOT),FCTY(NY,NEDTI))
      allocate(RTZ(NROOT),AIZ(NROOT),PHIS(NROOT),FCTZ(NZ,NEDTI))
      TEMP=0.0
      TEMPO=0.0
      FCTZ=0.0
      FCTY=0.0
      RTY=0.0
      RTZ=0.0
      AIY=0.0
      AIZ=0.0

      IF(IWID.EQ.0) WIDTH=0.0
      IF(IDEP.EQ.0) DEPTH=0.0
C
C
C
C ------- Write title, system parameters and control inputs
C
      if (IBUG.ge.0) then
cigwmc-begin
      WRITE(6,9001)
cigwmc-end
```

```
      WRITE(6,1000) (TITLE(I),I=1,20)
      WRITE(6,1100) NX,NY,NZ,NROOT,NBGTI,NEDTI,NPRINT,INSTAN,NSOURS,
     > INTER,ICASE
      WRITE(6,1200) DEPTH,WIDTH,RL1,RL2,RB1,RB2,RH1,RH2
      WRITE(6,1300) POR,HCOND,HGRAD,AELONG,ATRANV,AVERTI,AKD,AKE
      WRITE(6,1400) AMTAU,RAMADA,RHOB,ACCU,RHOW,DT,TDISP,Q
      IF(NSOURS.NE.0) WRITE(6,2000) (QS(I),I=1,NSOURS)
      endif
C
C ------- Make some preliminary computations and assignments
C
      NTDISP=TDISP/DT + 1.0001D0
      XS=0.0
      YS=0.0
      ZS=0.0
      IF(RL1.EQ.RL2) XS=RL1
      IF(RB1.EQ.RB2) YS=RB1
      IF(RH1.EQ.RH2) ZS=RH1
      QTOTAL=Q
      IF(NSOURS.NE.0) Q=1.0D0
      do i = NSOURS+1, NEDTI
        QS(i) = 1.0D0
      enddo
C
c      FACTOR=1.0D0/(CP*RHOW)
c      IF(ICASE.EQ.2) FACTOR=1.0D3
c      IF(ICASE.EQ.3) FACTOR=1.0D6
      FACTOR = 1.0D0
      RATIO=1.0D0
cigwmc      IF(RL1.NE.RL2) RATIO=RATIO/(RL2-RL1)
cigwmc      IF(RB1.NE.RB2) RATIO=RATIO/(RB2-RB1)
cigwmc      IF(RH1.NE.RH2) RATIO=RATIO/(RH2-RH1)
cigwmc-begin
      IF(RL1.NE.RL2) RATIO=ABS(RATIO/(RL2-RL1))
      IF(RB1.NE.RB2) RATIO=ABS(RATIO/(RB2-RB1))
      IF(RH1.NE.RH2) RATIO=ABS(RATIO/(RH2-RH1))
cigwmc-end
C
C
C ------- Compute retarded velocity, dispersion coefficients, and
C         other parameters
C
      RETARD=1.0D0 + RHOB*AKD/POR
      UF=HCOND*HGRAD/(POR*RETARD)
      AKX=AELONG*UF+AMTAU/(POR*RETARD)
      AKY=ATRANV*UF+AMTAU/(POR*RETARD)
      AKZ=AVERTI*UF+AMTAU/(POR*RETARD)
      RKE=(AKE/(POR*RETARD))/AKZ
      ROTPAR=1.0D32
      IF(IDEP.NE.0) ROTPAR=RKE*DEPTH
C
      if (IBUG.ge.0) then
      WRITE(6,1500) RETARD,UF,AKX,AKY,AKZ
cigwmc-begin
      WRITE(6,9002)
cigwmc-end
      endif
C
C
C ------- Compute RTY(I) and AIY(I) for finite width case
C
      IF(IWID.EQ.0) GO TO 180
```

```
      DO 130 I=1,NROOT
      RTY(I)=DBLE(I)*PAI/WIDTH
  130 AIY(I)=2.0D0/WIDTH
C
C ------- Write out optional Y-Eigenvalues and Z-coefficients
C
      IF(IBUG.le.0) GO TO 180
      WRITE(6,3100) (RTY(I),I=1,NROOT)
      WRITE(6,3200) (AIY(I),I=1,NROOT)
C
C
C ------- Compute RTZ(I) and AIZ(I) for finite depth case
C
  180 IF(IDEP.EQ.0) GO TO 290
C
C ------- For the thermal case, i.e., AKE not equal to 0.0
C
      IF(ICASE.NE.1) GO TO 250
      DO 200 I=1,NROOT
  200 CALL ROOT(RTZ,I,ROTPAR,NROOT)
      DO 210 I=1,NROOT
      RTZ(I) = RTZ(I)/DEPTH
      DENOMT=DEPTH*(1.0D0+RKE**2/RTZ(I)**2) + RKE/RTZ(I)**2
  210 AIZ(I)=2.0D0/DENOMT
      GO TO 285
C
C ------- For the non-thermal cases
C
  250 DO 260 I=1,NROOT
      RTZ(I)=DBLE(I)*PAI/DEPTH
  260 AIZ(I)=2.0D0/DEPTH
C
C ------- Write out optional Z-Eigenvalues and Z-coefficients
C
  285 IF(IBUG.le.0) GO TO 290
      WRITE(6,3300) (RTZ(I),I=1,NROOT)
      WRITE(6,3400) (AIZ(I),I=1,NROOT)
C
C
C ------- Compute source part of each of the series terms
C
C
C ------- 1. Compute source part of each of Y-series
C
  290 IF(IWID.EQ.0) GO TO 310
      DO 300 I=1,NROOT
         IF(RB1.EQ.RB2) PSIS(I)=DCOS(RTY(I)*YS)
       IF(RB1.NE.RB2) PSIS(I)=(WIDTH/(DBLE(I)*PAI))*(DSIN(RTY(I)*RB2)
     > -  DSIN(RTY(I)*RB1))
  300 CONTINUE
C
C ------- 2. Compute source part of each of Z-series
C
  310 IF(IDEP.EQ.0) GO TO 330
      DO 320 I=1,NROOT
      IF(RH1.EQ.RH2) PHIS(I)=DCOS(RTZ(I)*ZS)+RKE/RTZ(I)*DSIN(RTZ(I)*ZS)
      IF(RH1.NE.RH2) PHIS(I)=(DSIN(RTZ(I)*RH2)-DSIN(RTZ(I)*RH1) -
     >  RKE/RTZ(I)*(DCOS(RTZ(I)*RH2)-DCOS(RTZ(I)*RH1)))/RTZ(I)
  320 CONTINUE
C
C ------- Write out the optional YS-series and ZS-series
C
```

```
  330 IF(IBUG.le.0) GO TO 350
      IF(IWID.NE.0) WRITE(6,3500) (PSIS(I),I=1,NROOT)
      IF(IDEP.NE.0) WRITE(6,3600) (PHIS(I),I=1,NROOT)
C
C
C ------- Compute the Y- and Z-part of the integrand for each
C         series term
C
  350 DO 490 IT=1,NEDTI
      TIMED=(DBLE(IT)-1.0D0)*DT
      IF(IT.EQ.1) TIMED=DT
C
      DO 440 IY=1,NY
      Y=YDIM(IY)
C
C ------- Evaluate the function Y1(Y,T;TAU) or Y2(Y,T;TAU)
C
      IF(IWID.EQ.0) GO TO 420
      IF(IT.NE.1) GO TO 410
      FCTY(IY,IT)=0.0
      IF(RB1.EQ.RB2 .AND. Y.EQ.YS) FCTY(IY,IT)=1.0D0
      IF((RB1.NE.RB2) .AND. (Y.GE.RB1 .AND. Y.LE.RB2)) FCTY(IY,IT)=1.0D0
      GO TO 440
  410  CALL SERIEY(SERY,Y,YS,RB1,RB2,WIDTH,TIMED,AKY,RTY,AIY,
     1       PSIS,NROOT,NROOT)
      IF(RB1.EQ.RB2) FCTY(IY,IT)=1.0D0/WIDTH+SERY
      IF(RB1.NE.RB2) FCTY(IY,IT)=(RB2-RB1)/WIDTH+SERY
      IF(RB1.EQ.0.0 .AND. RB2.EQ.WIDTH) FCTY(IY,IT)=1.0D0
      IF(FCTY(IY,IT).LT.0.0) FCTY(IY,IT)=0.0
      GO TO 440
C
C ------- Evaluate the function Y3(Y,T;TAU) or Y4(Y,T;TAU)
C
C
C ------- 1. Compute function Y3
C
  420 IF(RB1.NE.RB2) GO TO 430
      IF(IT.NE.1) GO TO 425
      FCTY(IY,IT)=0.0
      IF(Y.EQ.YS) FCTY(IY,IT)=1.0D0
      GO TO 440
  425 Y1=DSQRT(4.0D0*PAI*AKY*TIMED)
      EARG=(Y-YS)*(Y-YS)/(4.0D0*AKY*TIMED)
      IF(DABS(EARG).GT.100.0D0) EARG=170.0D0
      FCTY(IY,IT)=(1.0D0/Y1)*(DEXP(-EARG))
      GO TO 440
C
C ------- 2. Compute function Y4
C
  430 IF(IT.NE.1) GO TO 435
      FCTY(IY,IT)=0.0
      IF(Y.GE.RB1 .AND. Y.LE.RB2) FCTY(IY,IT)=1.0D0
      GO TO 440
  435 SRT=DSQRT(4.0D0*AKY*TIMED)
      FCTY(IY,IT)=(DERF((Y-RB1)/SRT)-DERF((Y-RB2)/SRT))/2.0D0
  440 CONTINUE
C
      DO 480 IZ=1,NZ
      Z=ZDIM(IZ)
C
C ------- Evaluate the function Z1(Z,T;TAU) or Z2(Z,T;TAU)
C
```

```
      IF(IDEP.EQ.0) GO TO 460
      IF(IT.NE.1) GO TO 450
      FCTZ(IZ,IT)=0.0
      IF(RH1.EQ.RH2 .AND. Z.EQ.ZS) FCTZ(IZ,IT)=1.0D0
      IF((RH1.NE.RH2) .AND. (Z.GE.RH1 .AND. Z.LE.RH2)) FCTZ(IZ,IT)=1.0D0
      GO TO 480
  450 CALL SERIEZ(SERZ,Z,TIMED,AKZ,RKE,RTZ,AIZ,PHIS,NROOT,NROOT)
      FCTZ(IZ,IT)=SERZ
      IF(AKE.EQ.0. .AND. RH1.EQ.RH2) FCTZ(IZ,IT)=1.0D0/DEPTH+SERZ
      IF(AKE.EQ.0. .AND. RH1.NE.RH2) FCTZ(IZ,IT)=(RH2-RH1)/DEPTH+SERZ
      IF(RH1.EQ.0.0 .AND. RH2.EQ.DEPTH) FCTZ(IZ,IT)=1.0D0
      GO TO 480
C
C ------- Evaluate the function Z3(Z,T;TAU) or Z4(Z,T;TAU)
C
C
C ------- 1. Compute function Z3
C
  460 IF(RH1.NE.RH2) GO TO 470
      IF(IT.NE.1) GO TO 465
      FCTZ(IZ,IT)=0.0
      IF(Z.EQ.ZS) FCTZ(IZ,IT)=1.0D0
      GO TO 480
C
  465 AKZT=4.0D0*AKZ*TIMED
      AKZTPI=AKZT*PAI
      AKZT4S=AKZT/4.0D0
      EARG1=(Z-ZS)*(Z-ZS)/AKZT
      EARG2=(Z+ZS)*(Z+ZS)/AKZT
      EARG3=AKZ*RKE*RKE*TIMED+RKE*(Z+ZS)
      ARG=(Z+ZS)/DSQRT(AKZT) + RKE*DSQRT(AKZT4S)
      TERM1=0.0
      IF(EARG1.LT.100.0D0) TERM1=DEXP(-EARG1)/DSQRT(AKZTPI)
      TERM2=0.0
      IF(EARG2.LE.100.0D0) TERM2=DEXP(-EARG2)/DSQRT(AKZTPI)
      TERM3=0.0
      IF(EARG3.LT.100.0D0) TERM3=-RKE*DEXP(EARG3)*(1.0D0-DERF(ARG))
      FCTZ(IZ,IT)=TERM1+TERM2+TERM3
      GO TO 480
C
C ------- 2. Compute function Z4
C
  470 IF(IT.NE.1) GO TO 475
      FCTZ(IZ,IT)=0.0
      IF(Z.GE.RH1 .AND. Z.LE.RH2) FCTZ(IZ,IT)=1.0D0
      GO TO 480
C
  475 AKZT1=DSQRT(4.0D0*AKZ*TIMED)
      AKZT2=AKZT1/2.0D0
      ARG1=(Z+RH2)/AKZT1
      ARG2=(Z+RH1)/AKZT1
      ARG3=(Z-RH2)/AKZT1
      ARG4=(Z-RH1)/AKZT1
      ARG5=AKZ*RKE*RKE*TIMED + RKE*(Z+RH2)
      ARG6=AKZ*RKE*RKE*TIMED + RKE*(Z+RH1)
      TERMS4=0.5D0*(DERF(ARG1)-DERF(ARG2)-DERF(ARG3)+DERF(ARG4))
      TERM5=0.0
      IF(ARG5.LT.100.0D0) TERM5=-DEXP(ARG5)*(1.0D0-DERF(ARG1+RKE*AKZT2))
      TERM6=0.0
      IF(ARG6.LT.100.0D0) TERM6=DEXP(ARG6)*(1.0D0-DERF(ARG2+RKE*AKZT2))
      TERM78=-(DERF(ARG1)-DERF(ARG2))
      FCTZ(IZ,IT)=TERMS4+TERM5+TERM6+TERM78
```

```
C
  480 CONTINUE
  490 CONTINUE


C
C
C ------- Start transient loop computation
C
      TIME=0.0
      iconc = 1
      DO 800 ITT=NBGTI,NEDTI,NPRINT
C
      DO 710 IX=1,NX
      DO 710 IY=1,NY
      DO 710 IZ=1,NZ
  710 TEMPO(IX,IY,IZ)=TEMP(IX,IY,IZ)
C
      IF(INTER.EQ.0) GO TO 725
      if(IBUG.lt.0) goto 725
C
      IF(ICASE.EQ.1) WRITE(6,5100) TIME
      IF(ICASE.EQ.2) WRITE(6,5200) TIME
      IF(ICASE.EQ.3) WRITE(6,5300) TIME
C
      DO 720 IZOUT=1,NZ
      WRITE(6,6000) ZDIM(IZOUT)
  720 CALL ALLOUT(TEMP,X_DM,YDIM,IZOUT,NX,NY,
     >       NX,NY,NZ)
C
  725 TIME=(DBLE(ITT-1))*DT
C
      DO 760 IXX=1,NX
      X=X_DM(IXX)
      DO 750 IYY=1,NY
      Y=YDIM(IYY)
      DO 740 IZZ=1,NZ
      Z=ZDIM(IZZ)
C
C ------- Branch to instantaneous source or continuous source
C
      IF(INSTAN) 731,732,731
C
C ------- Case: continuous source for the duration of NTDISP
C
  731 IF(ITT.LE.NTDISP) CALL TINTEG(S,X,XS,RL1,RL2,
     >      FCTY,FCTZ,TIME,IYY,IZZ,ITT,UF,DT,AKX,RAMADA,QS,
     >             NY,NZ,NEDTI,INSTAN)
      IF(ITT.GT.NTDISP) CALL TINTEG(S,X,XS,RL1,RL2,
     >     FCTY,FCTZ,TIME,IYY,IZZ,NTDISP,UF,DT,AKX,RAMADA,QS,
     >             NY,NZ,NEDTI,INSTAN)
      GO TO 733
C
C ------- Case: instantaneous source release
C
  732 CALL TINTEG(S,X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,ITT,
     >     UF,DT,AKX,RAMADA,QS,NY,NZ,NEDTI,INSTAN)
      S=S*2.0D0/DT
  733 TEMP(IXX,IYY,IZZ)=S*Q*RATIO*FACTOR/(POR*RETARD)
      conc(IXX,IYY,IZZ,iconc) = TEMP(IXX,IYY,IZZ)
  740 CONTINUE
  750 CONTINUE
```

```
  760 CONTINUE
      ctime(iconc) = TIME
      iconc = iconc+1
C
      IF(ITT.EQ.NBGTI) GO TO 800
      IF(NSOURS.NE.0) GO TO 800
C
C ------- Check if steady-state solution has been obtained
C         before the final simulation time
C
      DIFMAX=0.0
      DO 770 IX=1,NX
      DO 770 IY=1,NY
      DO 770 IZ=1,NZ
      IF(TEMPO(IX,IY,IZ).EQ.0.0) GO TO 770
      DIF=DABS(TEMP(IX,IY,IZ)/TEMPO(IX,IY,IZ)-1.0D0)
      IF(DIF.LE.DIFMAX) GO TO 770
      DIFMAX=DIF
  770 CONTINUE
C
      IF(DIFMAX.LE.ACCU) GO TO 910
C
  800 CONTINUE
C
      if (IBUG.ge.0)WRITE(6,7000)
      GO TO 920
  910 if (IBUG.ge.0)WRITE(6,8000)
  920 CONTINUE
      if (IBUG .ge.0) then
      IF(ICASE.EQ.1) WRITE(6,5100) TIME
      IF(ICASE.EQ.2) WRITE(6,5200) TIME
      IF(ICASE.EQ.3) WRITE(6,5300) TIME
      DO 930 IZOUT=1,NZ
      WRITE(6,6000) ZDIM(IZOUT)
  930 CALL ALLOUT(TEMP,X_DM,YDIM,IZOUT,NX,NY,
     >    NX,NY,NZ)
      endif

      deallocate(TEMP,TEMPO)
      deallocate(RTY,AIY,PSIS,FCTY)
      deallocate(RTZ,AIZ,PHIS,FCTZ)

cigwmc  1000 FORMAT(1H1,////,5X,20A4,//)
cigwmc-begin
 1000 FORMAT(/////,5X,20A4/)
cigwmc-end
cigwmc  ----  IGWMC changed time units from hours to days
cigwmc-begin
 1100 FORMAT(/////,5X,
     > 'NO. OF POINTS IN X-DIRECTION ......................',I5/5X,
     > 'NO. OF POINTS IN Y-DIRECTION ......................',I5/5X,
     > 'NO. OF POINTS IN Z-DIRECTION ......................',I5/5X,
     > 'NO. OF ROOTS: NO. OF SERIES TERMS .................',I5/5X,
     > 'NO. OF BEGINNING TIME STEPS .......................',I5/5X,
     > 'NO. OF ENDING TIME STEP ...........................',I5/5X,
     > 'NO. OF TIME INTERVALS FOR PRINTED OUT SOLUTION ....',I5/5X,
     > 'INSTANTANEOUS SOURCE CONTROL = 0 FOR INSTANT SOURCE',I5/5X,
     > 'SOURCE CONDITION CONTROL = 0 FOR STEADY SOURCE ....',I5/5X,
     > 'INTERMITTENT OUTPUT CONTROL = 0 NO SUCH OUTPUT ....',I5/5X,
     > 'CASE CONTROL =1 THERMAL, = 2 FOR CHEMICAL, = 3 RAD ',I5/)
 1200 FORMAT(/////,5X,
     > 'AQUIFER DEPTH, = 0.0 FOR INFINITE DEEP [L] ........',E12.4/5X,
```

```
     > 'AQUIFER WIDTH, = 0.0 FOR INFINITE WIDE [L] ........',E12.4/5X,
     > 'BEGIN POINT OF X-SOURCE LOCATION [L] .............',E12.4/5X,
     > 'END POINT OF X-SOURCE LOCATION [L] ................',E12.4/5X,
     > 'BEGIN POINT OF Y-SOURCE LOCATION [L] .............',E12.4/5X,
     > 'END POINT OF Y-SOURCE LOCATION [L] ................',E12.4/5X,
     > 'BEGIN POINT OF Z-SOURCE LOCATION [L] .............',E12.4/5X,
     > 'END POINT OF Z-SOURCE LOCATION [L] ................',E12.4/)
 1300 FORMAT(//////,5X,
     > 'POROSITY [DIMENSIONLESS] .........................',E12.4/5X,
     > 'HYDRAULIC CONDUCTIVITY [L/T] .....................',E12.4/5X,
     > 'HYDRAULIC GRADIENT [DIMENSIONLESS] ................',E12.4/5X,
     > 'LONGITUDINAL DISPERSIVITY [L] ....................',E12.4/5X,
     > 'LATERAL DISPERSIVITY [L] .........................',E12.4/5X,
     > 'VERTICAL DISPERSIVITY [L] ........................',E12.4/5X,
     > 'DISTRIBUTION COEFFICIENT, KD [L**3/M] .............',E12.4/5X,
     > 'HEAT EXCHANGE COEFFICIENT [E/T-L**2-TEMP] .........',E12.4/)
 1400 FORMAT(/////,5X,
     > 'MOLECULAR DIFFUSION MULTIPLY BY POROSITY [L**2/T]  ',E12.4/5X,
     > 'DECAY CONSTANT [1/T]..............................',E12.4/5X,
     > 'BULK DENSITY OF THE SOIL [M/L**3] ................',E12.4/5X,
     > 'ACCURACY TOLERANCE FOR REACHING STEADY STATE ......',E12.4/5X,
     > 'DENSITY OF WATER [M/L**3] ........................',E12.4/5X,
     > 'TIME INTERVAL SIZE FOR THE DESIRED SOLUTION [T]    ',E12.4/5X,
     > 'DISCHARGE TIME [T]   .............................',E12.4/5X,
     > 'WASTE RELEASE RATE [E/D], [M/D], OR [A/D] .........',E12.4/)
 1500 FORMAT(/////,5X,
     > 'RETARDATION FACTOR ...............................',E12.4/5X,
     > 'RETARDED DARCY VELOCITY [L/T] ....................',E12.4/5X,
     > 'RETARDED LONGITUDINAL DISPERSION COEF. [L**2/T] ...',E12.4/5X,
     > 'RETARDED LATERAL DISPERSION COEFFICIENT [L**2/T] ..',E12.4/5X,
     > 'RETARDED VERTICAL DISPERSION COEFFICIENT [L**2/T]  ',E12.4/)
 2000 FORMAT(/////,4X,'LIST OF TRANSIENT SOURCE RELEASE RATE'/(5X,10E12.
     >3))
 3100 FORMAT(/////,4X,'LIST OF Y-EIGENVALUES'/(5X,10E12.4))
 3200 FORMAT(/////,4X,'LIST OF Y-COEFFICIENT'/(5X,10E12.4))
 3300 FORMAT(/////,4X,'LIST OF Z-EIGENVALUES'/(5X,10E12.4))
 3400 FORMAT(/////,4X,'LIST OF Z-COEFFICIENTS'/(5X,10E12.4))
 3500 FORMAT(/////,4X,'LIST OF YS-SERIES'/(5X,10E12.4))
 3600 FORMAT(/////,4X,'LIST OF ZS-SERIES'/(5X,10E12.4))
 5100 FORMAT(/////,4X,'TEMPERATURE DISTRIBUTION IN [TEMP] AT T=',E12.4)
 5200 FORMAT(/////,4X,'DISTRIBUTION OF CHEMICAL IN [M/L**3] AT T=',
     > E12.4)
 5300 FORMAT(/////,4X,'DISTRIBUTION OF RADIOACTIVE WASTE IN [A/M**3] '
     > 'AT T=',E12.4)
 6000 FORMAT(/////,20X,'Z = ',F10.2)
 7000 FORMAT(/////,'STEADY STATE SOLUTION HAS NOT BEEN REACHED BEFORE FI
     >NAL SIMULATING TIME'//)
 8000 FORMAT(/////,'STEADY STATE SOLUTION HAS BEEN OBTAINED BEFORE FINAL
     > SIMULATING TIME'//)
cigwmc
 9001 FORMAT(////,4X,'SIMULATION WITH AT123D (Modified)'//
     > 4X,'INPUT INFORMATION',/,4X,'-----------------',/)
 9002 FORMAT(/////,4X,'COMPUTATIONAL RESULTS',/,4X,
     >'---------------------',//)
cigwmc-end
      RETURN
      END
cigwmc
cigwmc -----------------------------------------------------------------
      SUBROUTINE ROOT(RTZ,I,ROTPAR,MAXRUT)
C
      IMPLICIT REAL*8(A-H,O-Z)
```

```
C
      DIMENSION RTZ(MAXRUT)
C
      ZL=RTZ(I)
      IF(I.GT.1) ZL=RTZ(I-1)+0.01D0
  100 ZL=ZL+0.01D0
      FZL=ZL*DSIN(ZL)-ROTPAR*DCOS(ZL)
      ZR=ZL+0.01D0
      FZR=ZR*DSIN(ZR)-ROTPAR*DCOS(ZR)
      IF(FZL*FZR.LT.0.0) GO TO 200
      GO TO 100
  200 FZL=ZL*DSIN(ZL)-ROTPAR*DCOS(ZL)
      DO 300 J=1,6
      ZH=(ZL+ZR)/2.0D0
      FZH=ZH*DSIN(ZH)-ROTPAR*DCOS(ZH)
      IF(FZH*FZL.LE.0.0) GO TO 400
      ZL=ZH
      FZL=FZH
      GO TO 300
  400 ZR=ZH
  300 CONTINUE
      RTZ(I)=(ZL+ZR)/2.0D0
      RETURN
      END
cigwmc
cigwmc -----------------------------------------------------------------
      SUBROUTINE SERIEY(SER,Y,YS,RB1,RB2,B,TIMED,AKY,RTY,AIY,
     > PSIS,MAXRUT,NROOT)
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION RTY(MAXRUT),AIY(MAXRUT),PSIS(MAXRUT)
      DIMENSION YTEUL(15)
C
      EPS=0.0001D0
      IER=1
      I=1
      M=1
      N=1
      ASSIGN 100 TO IFC
      GO TO 500
  100 YTEUL(1)=FCT
      SUM=YTEUL(1)*0.5D0
    3 J=0
    4 I=I+1
      IF(I-NROOT) 5,5,12
    5 N=I
      ASSIGN 200 TO IFC
      GO TO 500
  200 AMN=FCT
      DO 6 K=1,M
      AMP=(AMN+YTEUL(K))*0.5D0
      YTEUL(K)=AMN
    6 AMN=AMP
      IF(DABS(AMN)-DABS(YTEUL(M))) 7,9,9
    7 IF(M-15) 8,9,9
    8 M=M+1
      YTEUL(M)=AMN
      AMN=0.5D0*AMN
    9 SUM=SUM+AMN
      IF(DABS(AMN)-EPS*DABS(SUM)) 10,10,3
   10 J=J+1
```

```
      IF(J-5) 4,11,11
   11 IER=0
   12 SER=SUM
      IF(IER.NE.0) WRITE(6,1000) Y,TIMED
      RETURN
C
C ------- Evaluate N-th term of Y1(Y,T;TAU) or Y2(Y,T;TAU)
C
  500 AKYTB=AKY*TIMED/(B*B)
      IF(AKYTB.LE.0.0000014D0) GO TO 510
      EARG=RTY(N)*RTY(N)*AKY*TIMED
      IF(EARG.GT.100.0D0) FCT=0.0
      IF(EARG.LE.100.D0) FCT=AIY(N)*(DCOS(RTY(N)*Y))*PSIS(N)*DEXP(-EARG)
      GO TO 590
  510 IF(RB1.NE.RB2) GO TO 520
      AKYTPI=4.0D0*3.14159265358979D0*AKY*TIMED
      AKYT=4.0D0*AKY*TIMED
      EARG1=((Y-YS)-2.0D0*DBLE(N)*B)*((Y-YS)-2.0D0*DBLE(N)*B)/AKYT
      EARG2=((Y-YS)-2.0D0*DBLE(N-1)*B)*((Y-YS)-2.0D0*DBLE(N-1)*B)/
     > AKYT
      EARG3=((Y+YS)-2.0D0*DBLE(N+1)*B)*((Y+YS)-2.0D0*DBLE(N+1)*B)/
     > AKYT
      EARG4=((Y+YS)-2.0D0*DBLE(N)*B)*((Y+YS)-2.0D0*DBLE(N)*B)/AKYT
      FCT=(DEXP(-EARG1)+DEXP(-EARG2)+DEXP(-EARG3)+DEXP(-EARG4))/
     1 DSQRT(AKYTPI)
      GO TO 590
  520 AKY=DSQRT(4.0D0*AKY*TIMED)
      ARG1=Y-RB1-2.0D0*DBLE(N)*B
      ARG2=Y-RB2-2.0D0*DBLE(N)*B
      ARG3=Y-RB1-2.0D0*DBLE(N-1)*B
      ARG4=Y-RB2-2.0D0*DBLE(N-1)*B
      ARG5=Y+RB1-2.0D0*DBLE(N+1)*B
      ARG6=Y+RB2-2.0D0*DBLE(N+1)*B
      ARG7=Y+RB1-2.0D0*DBLE(N)*B
      ARG8=Y+RB2-2.0D0*DBLE(N)*B
      FCT=0.5D0*(DERF(ARG1)-DERF(ARG2)+DERF(ARG3)-DERF(ARG4)
     > -DERF(ARG5)+DERF(ARG6)-DERF(ARG7)+DERF(ARG8))
  590 GO TO IFC, (100,200)
C
 1000 FORMAT(1H0,10X,'WARNING: SERIESY AT Y =',F8.2,'  TIMED=',F8.2,'
     1NEEDS MORE TERMS')
      END
cigwmc
cigwmc ---------------------------------------------------------------
      SUBROUTINE SERIEZ(SER,Z,TIMED,AKZ,RKE,RTZ,AIZ,PHIS,MAXRUT,NROOT)
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION RTZ(MAXRUT),AIZ(MAXRUT),PHIS(MAXRUT)
      DIMENSION YTEUL(15)
C
      EPS=0.0001D0
      IER=1
      I=1
      M=1
      N=1
      ASSIGN 100 TO IFC
      GO TO 500
  100 YTEUL(1)=FCT
      SUM=YTEUL(1)*0.5D0
    3 J=0
    4 I=I+1
```

```
      IF(I-NROOT) 5,5,12
    5 N=I
      ASSIGN 200 TO IFC
      GO TO 500
  200 AMN=FCT
      DO 6 K=1,M
      AMP=(AMN+YTEUL(K))*0.5D0
      YTEUL(K)=AMN
    6 AMN=AMP
      IF(DABS(AMN)-DABS(YTEUL(M))) 7,9,9
    7 IF(M-15) 8,9,9
    8 M=M+1
      YTEUL(M)=AMN
      AMN=0.5D0*AMN
    9 SUM=SUM+AMN
      IF(DABS(AMN)-EPS*DABS(SUM)) 10,10,3
   10 J=J+1
      IF(J-5) 4,11,11
   11 IER=0
   12 SER=SUM
      IF(IER.NE.0) WRITE(6,1000) Z,TIMED
      RETURN
C
C ------- Evaluate the N-th term of Z1(Z,T;TAU) or Z2(Z,T;TAU)
C
  500 EARG=RTZ(N)**2*AKZ*TIMED
      IF(EARG.GT.100.0D0) FCT=0.0
      IF(EARG.LE.100.D0) FCT=AIZ(N)*(DCOS(RTZ(N)*Z)+RKE/RTZ(N)*
     1 DSIN(RTZ(N)*Z))*PHIS(N)*DEXP(-EARG)
      GO TO IFC, (100,200)
C
 1000 FORMAT(1H0,10X,'WARNING: SERIESZ AT Z =',F8.2,'  TIMED=',F8.2,'
     1NEEDS MORE TERMS')
      END
cigwmc
cigwmc -----------------------------------------------------------------
      SUBROUTINE TINTEG(S,X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,ITT,
     > UF,DT,AKX,RAMADA,QS, MAXNY,MAXNZ,MAXNTI,INSTAN)
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION FCTY(MAXNY,MAXNTI),FCTZ(MAXNZ,MAXNTI),QS(MAXNTI)
C
      PAI=3.14159265358979D0
      ITTM1=ITT-1
      N=ITTM1/2
      SUMEND=0.0
      SUMMID=0.0
      S=0.0
      ITAU=1
cigwmc
cigwmc       In the following section IGWMC replaced the assigned GO TO
cigwmc       with a subroutine call to avoid passing control back to a
cigwmc       statement within a DO loop
cigwmc
cigwmc  ASSIGN 100 TO M
cigwmc  GO TO 800
cigwmc-begin
      CALL XFUN(X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,FIT,
     > UF,DT,AKX,RAMADA,QS,MAXNY,MAXNZ,MAXNTI,ITAU,ITT,PAI)
cigwmc-end
  100 FIT1=FIT
```

```
C
C ------- If N .LT. 1 there is only one interval
C
      IF(INSTAN.EQ.0) GO TO 700
      IF(N.LT.1) GO TO 700
      DO 400 K=1,N
cigwmc   ASSIGN 200 TO M
      ITAU=K+K-1
cigwmc   GO TO 800
cigwmc-begin
      CALL XFUN(X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,FIT,
     > UF,DT,AKX,RAMADA,QS,MAXNY,MAXNZ,MAXNTI,ITAU,ITT,PAI)
cigwmc-end
  200 SUMEND=SUMEND+FIT
cigwmc   ASSIGN 300 TO M
      ITAU=K+K
cigwmc   GO TO 800
cigwmc-begin
      CALL XFUN(X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,FIT,
     > UF,DT,AKX,RAMADA,QS,MAXNY,MAXNZ,MAXNTI,ITAU,ITT,PAI)
cigwmc-end
  300 SUMMID=SUMMID+FIT
  400 CONTINUE
C
C ------- If N*2 .NE. ITTM1 there are odd numbers of intervals
C
      IF(N*2 .NE. ITTM1) GO TO 500
cigwmc      S=(2.0D0*SUMEND+4.0D0*SUMMID-FIT1)*DT/3.0D0
cigwmc-begin
      S=DABS((2.0D0*SUMEND+4.0D0*SUMMID-FIT1)*DT/3.0D0)
cigwmc-end
      GO TO 900
cigwmc  500 ASSIGN 600 TO M
cigwmc-begin
  500 ITAU=ITTM1
cigwmc-end
cigwmc      GO TO 800
cigwmc-begin
      CALL XFUN(X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,FIT,
     > UF,DT,AKX,RAMADA,QS,MAXNY,MAXNZ,MAXNTI,ITAU,ITT,PAI)
cigwmc-end
cigwmc  600 S=(2.0D0*SUMEND+4.0D0*SUMMID-FIT1+FIT)*DT/3.0D0
cigwmc  700 S=S+(FIT)*DT/2.0D0
  600 S=DABS((2.0D0*SUMEND+4.0D0*SUMMID-FIT1+FIT)*DT/3.0D0)
  700 S=S+DABS((FIT)*DT/2.0D0)
cigwmc   GO TO 900
  900 RETURN
      END
C
C
C ------- Compute function value of the integrand function F(ITAU)
C
C
C
C ------- Evaluate the function X1(X,T;TAU) or X2(X,T;TAU)
C
cigwmc  Here is the subroutine the IGWMC used to replace the assigned
cigwmc  GO TO with to avoid passing control back within DO loop.
cigwmc  This function has retained most of the original statements.
cigwmc
cigwmc-begin
      SUBROUTINE XFUN(X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,FIT,
```

```
     > UF,DT,AKX,RAMADA,QS,MAXNY,MAXNZ,MAXNTI,ITAU,ITT,PAI)
cigwmc
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION FCTY(MAXNY,MAXNTI),FCTZ(MAXNZ,MAXNTI),QS(MAXNTI)
cigwmc
cigwmc   800 XPART=0.0
cigwmc
      XPART=0.0
cigwmc-end
      TIMD=TIME-DBLE(ITAU-1)*DT
      IF(ITAU.EQ.ITT) TIMD=0.01D0*DT
C
C ------- Point source in the X-direction
C
      IF(RL1.NE.RL2) GO TO 820
       IF(ITAU.NE.ITT) GO TO 810
      XPART=0.0
      IF(X.EQ.XS) XPART=1.0D0
      GO TO 850
  810 EARG=((X-XS)-UF*TIMD)**2/(4.0D0*AKX*TIMD)
      IF(DABS(EARG).GT.150.0D0) GO TO 850
      XPART=(1.0D0/(DSQRT(4.0D0*PAI*AKX*TIMD)))*DEXP(-EARG)
      GO TO 850
C
C ------- Line source in the X-direction
C
  820 IF(ITAU.NE.ITT) GO TO 830
      XPART=0.0
      IF(X.GE.RL1 .AND. X.LE.RL2) XPART=1.0D0
      GO TO 850
  830 SRT=DSQRT(4.0D0*AKX*TIMD)
      EAR=-UF*TIMD
      EARG1=(X-RL1+EAR)/SRT
      EARG2=(X-RL2+EAR)/SRT
      XPART=(DERF(EARG1)-DERF(EARG2))/2.0D0
C
C ------- Evaluate the integrand, FIJK(X,Y,Z,T;TAU), in equation 16
C
  850 IT=ITT-ITAU + 1
      FIT=XPART*FCTZ(IZZ,IT)*FCTY(IYY,IT)*QS(ITAU)*DEXP(-RAMADA*TIMD)
cigwmc      GO TO M,(100,200,300,600)
cigwmc  900 RETURN
cigwmc-begin
      RETURN
cigwmc-end
      END
cigwmc
cigwmc -----------------------------------------------------------------
      SUBROUTINE ALLOUT(FTV,X_DM,YDIM,IZ,NX,NY,
     > MAXNX,MAXNY,MAXNZ)
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION FTV(MAXNX,MAXNY,MAXNZ)
      DIMENSION X_DM(MAXNX),YDIM(MAXNY)
C
      JOUT=(NX-1)/10+1
      DO 96 MM=1,JOUT
      JAA=10*(MM-1)+1
      JZZ=10*MM
      IF(MM.EQ.JOUT) JZZ=NX
      IF(MM.GT.1) WRITE(6,225)
```

```
  225 FORMAT(1H0,50X,'CONTINUE')
      WRITE(6,222) (X_DM(J),J=JAA,JZZ)
  222 FORMAT(1H ,60X,'X'/1X,'  Y ',10F12.0)
      WRITE(6,223)
  223 FORMAT(1H ,'    ',10(4X,'        '))
      DO 97 NN=1,NY
      Y=YDIM(NN)
      WRITE(6,224) Y, (FTV(J,NN,IZ),J=JAA,JZZ)
  224 FORMAT(1H ,F5.0,10E12.3)
cigwmc-begin
      DO 5002 NPH=JAA,JZZ
c     WRITE(8,5001)NPH,NN,IZ,FTV(NPH,NN,IZ)
 5001 FORMAT(I5,5X,I5,5X,I5,5X,E10.3)
 5002 CONTINUE
cigwmc-end
   97 CONTINUE
   96 CONTINUE
      RETURN
      END
cigwmc
cigwmc  ***The folowing function is added by the IGWMC to the original
cigwmc     code by G.T. Yeh to replace ERF call to resident library
cigwmc
      DOUBLE PRECISION FUNCTION DERF(X)
      IMPLICIT REAL*8(A-H,O-Z)
      Z= DABS(X)
      P= 0.3275911
      T= 1/(1+P*Z)
      A1= 0.254829592
      A2= -.284496736
      A3= 1.421413741
      A4= -1.453152027
      A5= 1.061405429
      TERM= (A1*T)+(A2*T**2)+(A3*T**3)+(A4*T**4)+(A5*T**5)
        IF (X .EQ. 0)THEN
          DERF= 0.0
          RETURN
        ELSE
          IF (Z .LE. 3) DERF= 1.-(TERM*DEXP(-Z**2.))
          TERM2= DEXP(-Z**2.)
          IF (Z .GT. 3 .AND. Z .LT. 5) DERF= 1.-.5641896*DEXP(-Z*Z)
     1    /(Z+.5/(Z+1./(Z+1.5/(Z+2./(Z+2.5/(Z+1.))))))
          IF (Z .GE. 5) DERF= 1.0
          IF (X .LT. 0) DERF= -DERF
        END IF
      RETURN
      END


      subroutine fdt1d(Dvad,Time_Step,Ntime,Dispersivity,rKd1,HalfLife,
     &        Rho1,Por,a_lin_v,Cleach,Cwt,e_time,d_length,d_time)

C SUBROUTINE TO CALCULATE FINITE-DIFFERENCE SOLUTION TO 1D TRANSPORT PROBLEM
C
C AUTHOR:
C Kevin Brewer, Ph.D.
C BSRI/SRS
C 12/99

C REFERENCES:
C The finite-difference solution used in this subroutine is based on
C the explicit-central approximation as demonstrated in Equation 12.1.8
```

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C from "Modeling Groundwater FLow and Pollution" by Bear and Verruijt
C published as part of the series "Theory and Applications of Transport
C in Porous Media", dated 1987. Additional information came from "Numerical
C Methods in Subsurface Hydrology" by Remson, Hornberger, and Molz, dated
C 1971; and from "A Practical Guide to Groundwater and SOlute Transport
C Modeling" by Spitz and Moreno, dated 1996.

C INPUTS:
C Dvad           is the distance [L]
c Time_Step      is the time increment (and the first time value) [T]
c Ntime          is the maximum number of time increments [T]
c Dispersivity   is the dispersivity [L]
c rKd1           is the Kd []
c HalfLife       is the half-life [T] (if 0.0, then no decay)
c Rho1           is the bulk-density [M/L^3]
c Por            is the porosity []
c a_lin_v        is the average linear velocity [L/T]
c Cleach         is the array (length Ntime) of input concentrations [M/L^3]

c OUTPUTS:
c Cwt       is the relative concentration array (length is Ntime) [M/L^3]
c e_time    NOT USED ARRAY (length is Ntime)
c d_length  is the discretization length used in the solution [L]
c d_time    is the discretization time interval used in the solution [T]

      IMPLICIT REAL*8(a-H,O-Z)
      IMPLICIT INTEGER(i-N)
C
      real(kind=8), allocatable :: con(:,:),disp(:),D_coef(:),v_coef(:),
     &  Cin(:)
      dimension Cwt(Ntime), a_lin_v(Ntime),Cleach(Ntime), e_time(Ntime)
      integer :: I, J, Ncells, II, Nsteps, iDone, intervals, iDups
      real(kind=8) :: max_vel, min_vel, max_cleach, d_time_n,
     &  Rf, lamda, peclet, courant, d_time_p, sim_length

C Calculate some max and min values of the inputs.
      max_vel = 0.0
      min_vel = 10000000.0
      max_cleach = 0.0
      do I = 1,Ntime
        if(a_lin_v(I).gt.max_vel) max_vel = a_lin_v(I)
        if(a_lin_v(I).lt.min_vel) min_vel = a_lin_v(I)
        if(Cleach(I).gt.max_cleach) max_cleach = Cleach(I)
      enddo

C DETERMINE THE DISCRETIZATION LENGHT AND TIME INTERVAL
      d_length = 1.0*Dispersivity
      Ncells = 1 + ceiling(Dvad / d_length)
      if(Ncells.lt.11) Ncells = 11
      d_length = Dvad / (Ncells - 1)
      d_length_2 = d_length * d_length

c Make the domain twice as large as necessary to avoid boundary affects
c from outflow side.
c     e.g., if Ncells = 11 for a d_length of 1.0 and a Dvad of 10,
c           make Ncells = 21 for a d_length of 1.0 and a sim_length of 20
      Ncells = 2*Ncells-1

c now fine tune the time interval to be an integer division of the TIME_STEP
      d_time_p  = d_length/max_vel
      d_time_n  = 0.5*d_length*d_length/(Dispersivity*max_vel)
      if(d_time_n .lt. d_time_p) d_time_p = d_time_n
```

```
      iDone = 0
      do I = 1, 100
        if(iDone .eq. 0) then
          d_time = Time_Step/I
          intervals = Ntime*I
          iDups = I
          if(d_time .lt. d_time_p) iDone = 1
        endif
      enddo
      peclet = d_length/Dispersivity
      courant = max_vel*d_time/d_length

c     write(*,*) 'Peclet,  Courant: ', peclet, courant
c     write(*,*) 'Ncells, d_length: ', Ncells, d_length
c     write(*,*) 'iDups,    d_time: ', iDups, d_time

      allocate (con(intervals,Ncells), disp(intervals),
     &          Cin(intervals),D_coef(intervals), v_coef(intervals))

c SET UP THE SOLUTION COEFFICIENTS
      Rf = 1 + rKd1*Rho1/Por
      lamda = 0.0
      if(HalfLife.gt.0.0) lamda = log(2.0)/HalfLife

      II = 1
      do I = 1, Ntime
        do J = 1, iDups
          disp(II)   = a_lin_v(I)*Dispersivity
          D_coef(II) = disp(II)/d_length_2
          v_coef(II) = a_lin_v(I)/(2*d_length)
          Cin(II)    = Cleach(I)
          II = II + 1
        enddo
      enddo
c PERFORM THE CALCULATION FOR EACH TIME INTERVAL
c     FOR TIME=1 (Initial conditions)
      con(1,1) = Cin(1)
      do J = 2, Ncells
        con(1,J) = 0.0
      enddo
c     write(*,3) 1, con(1,1), con(1,2), con(1,3),' ---- ',
c    &           con(1,(Ncells-1)/2), ' ---- ', con(1,Ncells)

c     FOR EACH TIME INTERVAL -- I (starting at the second time step)
      do I = 2, intervals
c       ASSIGN THE BOUNDARY CONDITION CELL VALUE (LOCATION J=1)
        con(I,1) = Cin(I)
c       CALCULATE THE SECOND THROUGH NEXT TO LAST CELL VALUES (LOCATION J=2
c       to Ncells-1)
        do J = 2, Ncells-1
           con(I,J) = (d_time/Rf)*(
     &           D_coef(I-1)*(con(I-1,J+1)-2.0*con(I-1,J)+con(I-1,J-1))
     &          -v_coef(I-1)*(con(I-1,J+1)-con(I-1,J-1))
     &          -Rf*lamda*con(I-1,J))  +  con(I-1,J)
          if(con(I,J).lt.0.0) con(I,J) = 0.0
          if(con(I,J).gt.max_cleach) con(I,J) = max_cleach
        enddo
c       CALCULATE THE LAST CELL VALUE (LOCATION J=Ncells)
c           ASSUME THE FINAL DERIVATIVE CAN BE CALCULATED FROM THE SLOPE
c           OF THE Ncells to Ncells-1 DATA.
c
c           ASSUME THAT THE FINAL SECOND DERIVATIVE IS 0 (no dispersive term).
```

```
c
        con(I,Ncells) = (d_time/Rf)*(
c    &       D_coef(I-1)*(con(I-1,Ncells)-2.0*con(I-1,Ncells)+
c    &                    con(I-1,Ncells-1))
     &      -v_coef(I-1)*2.0*(con(I-1,Ncells)-con(I-1,Ncells-1))
     &      -Rf*lamda*con(I-1,Ncells))  +  con(I-1,Ncells)
         if(con(I,Ncells).lt.0.0) con(I,Ncells) = 0.0
         if(con(I,Ncells).gt.max_cleach) con(I,Ncells) = max_cleach

c        if(I.lt.6) write(*,3) I, con(I,1), con(I,2), con(I,3),' ---- ',
c    &                    con(I,(Ncells-1)/2), ' ---- ', con(I,Ncells)
       enddo

c      write(*,3) intervals, con(intervals,1), con(intervals,2),
c    &           con(intervals,3),' ---- ', con(intervals,(Ncells-1)/2),
c    &           ' ---- ', con(intervals,Ncells)

       do I = 1, Ntime
c        Cwt(I) = con((I-1)*iDups+1,(Ncells-1)/2)
         Cwt(I) = con(I*iDups,(Ncells-1)/2)
       enddo

c       open(unit=11,file='temp.dat')
c       do I = 1, Ntime
c         write(11,10) (con((I-1)*iDups+1,J),J=1,Ncells)
c       enddo
c      close(11)

c        write(*,*) (con(I,Ncells),I=1,Ntime)

    3  format(i5,3(2x,f6.3),2(2x,a6,2x,f6.3))
    4  format(20(f6.2))
   10 format(1000(f15.5))

       RETURN
       END

       subroutine Leach(M, Ntime, DelT, Kd, Por, Thk, Infil, Rho, Decay,
     &  Mleach, Mdecay)

         implicit none
         integer :: Ntime, I
         real(kind=8) :: M(0:Ntime), DelT, Kd(Ntime), Por(Ntime), Thk,
     &     Infil(Ntime), Rho(Ntime), Decay, Mleach(Ntime), Mdecay(Ntime),
     &     Lrate, DelM

         do I = 1, Ntime
           if (Kd(I).lt.0.0) then
             M(I) = 0.0
             Mleach(I) = 0.0
             Mdecay(I) = 0.0
C KEB added the following elseif section to handle zero infiltration rate case
           elseif(Infil(I).eq.0.0) then
             Lrate = 0.0
             M(I) = M(I-1)*exp(-(Decay)*DelT)
             DelM = M(I-1) - M(I)
             Mleach(I) = 0.0
             Mdecay(I) = DelM - Mleach(I)
           else
             Lrate = Infil(I)/Thk/(Por(I)+Kd(I)*Rho(I))
             M(I) = M(I-1)*exp(-(Decay+Lrate)*DelT)
             DelM = M(I-1) - M(I)
```

```
            Mleach(I) = DelM * Lrate/(Lrate+Decay)
            Mdecay(I) = DelM - Mleach(I)
          endif
        enddo

      end subroutine Leach

c     program Tester
c       implicit none
c       integer, parameter :: Ntime = 1000
c       integer :: I
c       real(kind=8) :: M(0:Ntime), DelT, Kd(Ntime), Por(Ntime), Thk,
c    &    Infil(Ntime), Rho(Ntime), Decay, Mleach(Ntime), Mdecay(Ntime)
c
c       M(0) = 1000.0
c       DelT = 1.0
c       Kd(:) = 0.01
c       Por(:) = 0.2
c       Thk = 10.0
c       Infil(:) = 0.38
c       Rho(:) = 1600.0
c       Decay = log(2.0)/29.12
c       print *, 'Decay =',Decay
c
c       call Leach(M, Ntime, DelT, Kd, Por, Thk, Infil, Rho, Decay,
c    &  Mleach, Mdecay)
c
c       do I = 1, Ntime
c         print 1, I, M(I), Mleach(I), Mdecay(I)
c       enddo
c   1   format(I5, 1p,3G15.5)
c     end program Tester
```

## Appendix B

### Verification of Transport Modeling Code

For this modeling effort, the transport modeling code used by the groundwater modeling subcontractor in the previous modeling effort was modified to allow variable vadose-zone infiltration rates and to accommodate different infiltration conditions. To ensure that the modeling calculations were performed correctly in this modeling effort, a number of verification checks of the new transport modeling code were performed. These checks are documented in the following sections.

### Verification of Original Modeling Code

The original modeling code was recompiled on the local PC, without major modification, and the BaseCase scenario was run. The outputs from the original modeling results and the recompiled model are given in Table B-1, and show no differences. Thus the transfer of the code from the subcontractor computer to the WSRC computer was considered successful.

## Table B-1. Outputs from Original Modeling Codes

**FROM THE ORIGINAL OUTPUT FILE:**

```
 Processing of input is complete.
 Max. receptor conc. for constituent    1 is at element   20:    8.4185
 Max. receptor conc. for constituent    2 is at element   23:   7.22643E-23
 Max. receptor conc. for constituent    3 is at element   23:   2.33211E-26
 Max. receptor conc. for constituent    4 is at element    7:   4.79357E-07
 Max. receptor conc. for constituent    5 is at element    9:    13.729
 Max. receptor conc. for constituent    6 is at element    7:   0.38146
 Max. receptor conc. for constituent    7 is at element   13:   2.61482E-03
 Max. receptor conc. for constituent    8 is at element   23:   8.81651E-10
 Max. receptor conc. for constituent    9 is at element    7:   2.15802E-45
 Max. receptor conc. for constituent   10 is at element    7:   2.25865E-04
 Max. receptor conc. for constituent   11 is at element   11:   6.53394E+05
 Max. receptor conc. for constituent   12 is at element    7:   4.44242E-17
 Max. receptor conc. for constituent   13 is at element    7:    8.2611
 Max. receptor conc. for constituent   14 is at element    7:   1.38797E-19
 Max. receptor conc. for constituent   15 is at element    7:   0.17018
 Max. receptor conc. for constituent   16 is at element    7:    36894.
```

**FROM THE NEW OUTPUT FILE:**

```
Processing of input is complete.
 Max. Seep c. for COI    1 is at element   20, time   1000.00:    8.4185
 Max. Seep c. for COI    2 is at element   23, time   1000.00:   7.22643E-23
 Max. Seep c. for COI    3 is at element   23, time   1000.00:   2.33211E-26
 Max. Seep c. for COI    4 is at element    7, time   1000.00:   4.79357E-07
 Max. Seep c. for COI    5 is at element    9, time    141.00:    13.729
 Max. Seep c. for COI    6 is at element    7, time    108.00:   0.38146
 Max. Seep c. for COI    7 is at element   13, time   1000.00:   2.61482E-03
 Max. Seep c. for COI    8 is at element   23, time   1000.00:   8.81651E-10
 Max. Seep c. for COI    9 is at element    7, time   1000.00:   2.15802E-45
 Max. Seep c. for COI   10 is at element    7, time    396.00:   2.25865E-04
 Max. Seep c. for COI   11 is at element   11, time     32.00:   6.53394E+05
 Max. Seep c. for COI   12 is at element    7, time    203.00:   4.44242E-17
 Max. Seep c. for COI   13 is at element    7, time    852.00:    8.2611
 Max. Seep c. for COI   14 is at element    7, time   1000.00:   1.38797E-19
 Max. Seep c. for COI   15 is at element    7, time   1000.00:   0.17018
 Max. Seep c. for COI   16 is at element    7, time     34.00:    36894.
```

## Verification of Vadose-Zone Transport Computer Code

For this modeling effort, vadose-zone transport is assumed to be one-dimensional and steady-state. The problem can be solved as a saturated problem, accounting for the saturation percentage (i.e., porosity time saturation). Although for each time interval the flow-field is steady-state, the flow velocities (infiltration rates) can be varied during the simulation time to simulate the effects of different burial-ground cover scenarios.

The verification of the computer code was accomplished by comparison of the finite-difference (FD) results for generic problems to known analytic solutions and numeric results. This appendix documents the verification of the finite-difference computer code used in this modeling task for vadose-zone transport. The following sections document this verification beginning with a discussion of the various solution techniques, continuing with a description of the test cases, and concluding with a discussion of the results.

### *Analytic Solution*

The analytic solution to the 1D ADE with retardation and decay and a constant input concentration is (from equations 41 and 42 of Javandel, et al., 1984):

$$\begin{aligned}\frac{C}{C_o} = {} & \frac{v}{v+U}\exp\left\{\frac{x(v-U)}{2D}\right\} ERFC\left\{\frac{Rx-Ut}{2\sqrt{DRt}}\right\} \\ & + \frac{v}{v-U}\exp\left\{\frac{x(v+U)}{2D}\right\} ERFC\left\{\frac{Rx+Ut}{2\sqrt{DRt}}\right\} \\ & + \frac{v^2}{2DR\lambda}\exp\left\{\frac{vx}{D}-\lambda t\right\} ERFC\left\{\frac{Rx+vt}{2\sqrt{DRt}}\right\}\end{aligned}$$

$$U = \sqrt{v^2 + 4DR\lambda}$$

where:

| | |
|---|---|
| C | is the concentration at a particular distance and time [M/L$^3$], |
| $C_o$ | is the concentration at the constant source [M/L$^3$], |
| x | is the distance [L], |
| R | is the retardation factor [no units], |
| D | is the dispersion coefficient (velocity times dispersivity) [L$^2$/T], |
| λ | is the decay constant (0.693/half-life) [1/T], |
| v | is the average linear velocity [L/T], |
| t | is the time [T]. |

For constituents where decay is not applicable, the analytic solution to the 1D ADE with retardation and a constant input concentration is (from equation 39 of Javandel, et al., 1984):

$$\frac{C}{C_o} = \frac{1}{2} ERFC\left\{\frac{Rx - vt}{2\sqrt{DRt}}\right\} + \sqrt{\frac{v^2 t}{\pi DR}} \exp\left\{-\frac{(Rx - vt)^2}{4DRt}\right\}$$
$$- \frac{1}{2}\left(1 + \frac{vx}{D} + \frac{v^2 t}{DR}\right) \exp\left\{\frac{vx}{D}\right\} ERFC\left\{\frac{Rx + vt}{2\sqrt{DRt}}\right\}$$

A computer program (see Listing B-1) was created to perform the analytic calculation for the various test cases.

### *AT123D Solution*

Vadose-zone transport can be computed using the AT123D code (Yeh, 1981). A one-dimensional calculation is made that considers decay, adsorption, and longitudinal dispersion. Lateral dispersion is assumed to be negligible and is not considered. The steady-state velocity through the unsaturated zone is derived from the infiltration rate, divided by porosity and saturation.

A computer program (see Listing B-1) from the previous ORWBG modeling effort was reused to perform the AT123D calculation for various test cases.

### *Finite-Difference Solution*

The 1D advection-dispersion differential equation:

$$R\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - v\frac{\partial C}{\partial x} - R\lambda C$$

can be represented by an explicit-central approximation of the solution using (derived from equation 12.1.8 of Bear and Verruijt, 1987):

$$c_{x,t+1} = \frac{\Delta t}{R}\left[\frac{D}{\Delta x^2}\left(c_{x+1,t} - 2c_{x,t} + c_{x-1,t}\right) - \frac{v}{2\Delta x}\left(c_{x+1,t} - c_{x-1,t}\right) - \lambda R c_{x,t}\right] + c_{x,t} \quad .$$

To minimize the impact of the outflow boundary (where the second derivative is assumed to be zero), a total simulation length of twice the problem length is used. To minimize numerical dispersion and to maximize assurance of stability, the following are required:

Peclet: $\Delta x = \alpha$ Courant: $\Delta t = \frac{\Delta x}{v}$

with the delta-time value being no larger than the overall simulation time-step size.

A computer program (see Listing B-1) was created to perform the finite-difference calculation for the test cases and for the current modeling task.

***Test Cases***

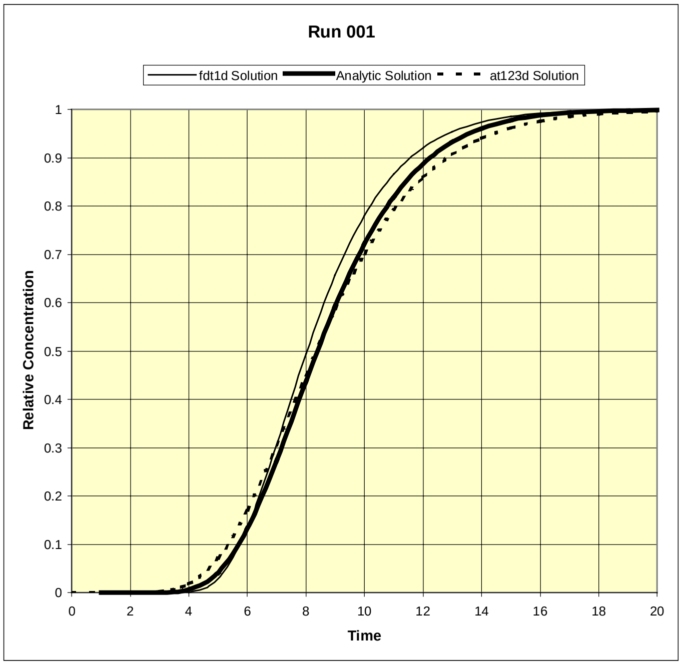
Nine constant velocity and one variable velocity test cases were used to check the finite-difference results with the AT123D results, analytic solutions, and MODFLOW/MT3D results. Table B-2 lists the parameters used in each test case.

***Comparison of Results***

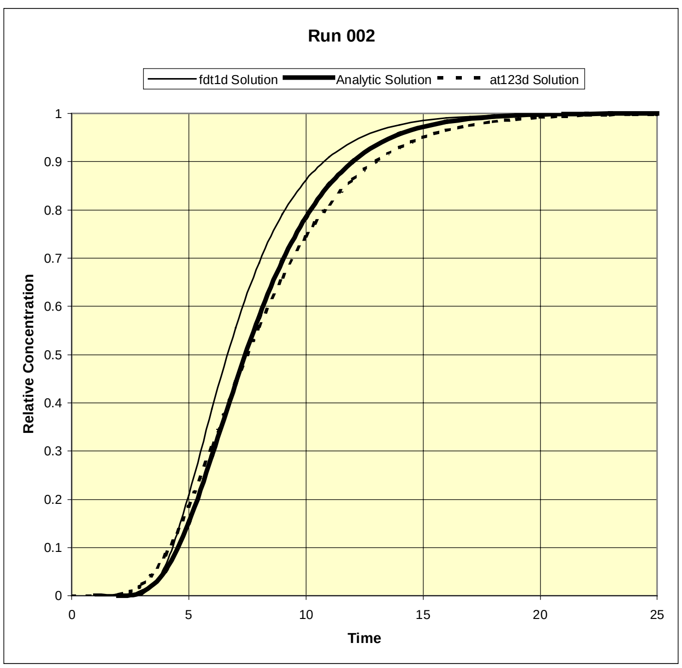
Overall, the finite-difference solutions are very close to the AT123D results, analytic solutions, and MODFLOW/MT3D results, as shown in Figure B-1. The slight differences in the results can be attributable to the slight differences in how each solution technique discretizes the problem domain.

***Verification Conclusion***

Because the FD computer code is based on documented solution techniques as discussed above, and because the Test Case results show good agreement between the FD computer code solutions and known (or previously verified) solutions, this FD computer code can be used to simulate the vadose-zone transport for the current modeling task.

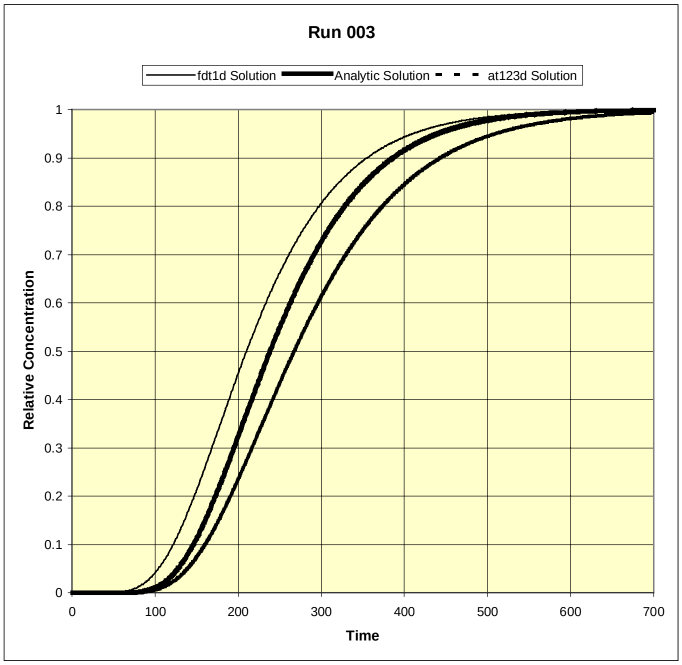



(a)

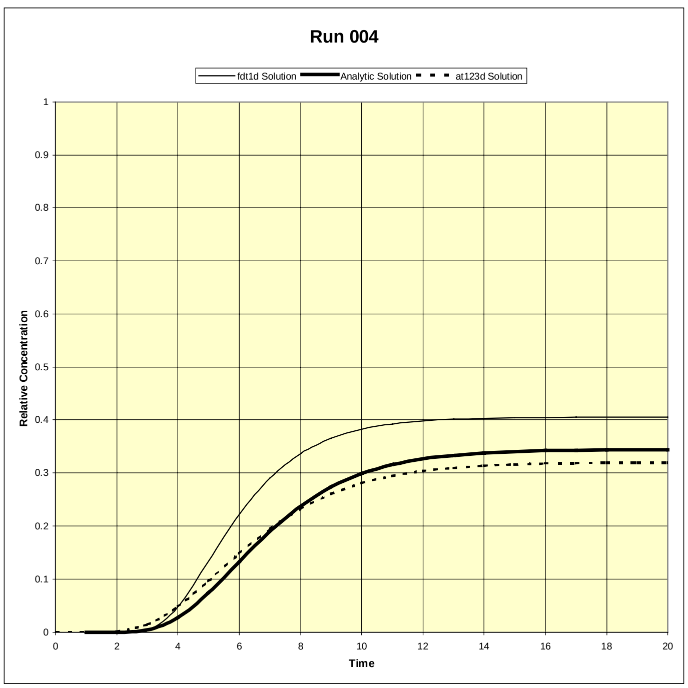



(b)

**Figure B-1. Comparison plots for test cases.**

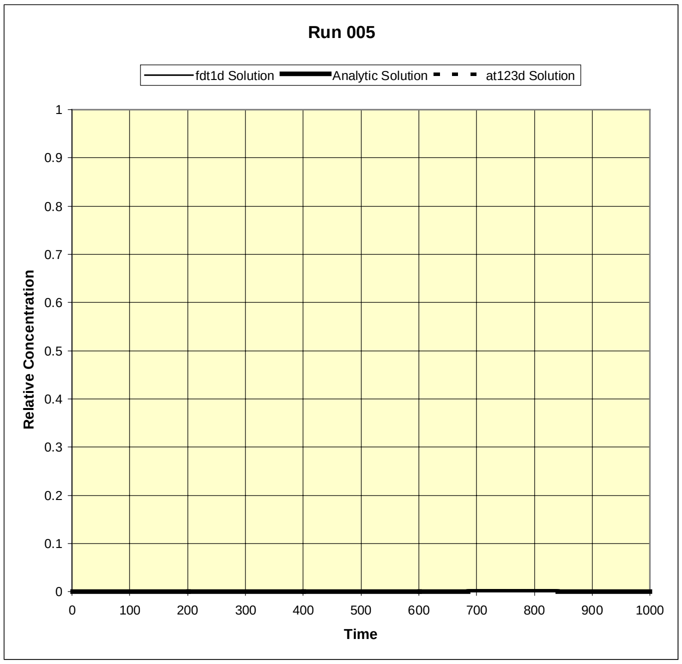



(c)

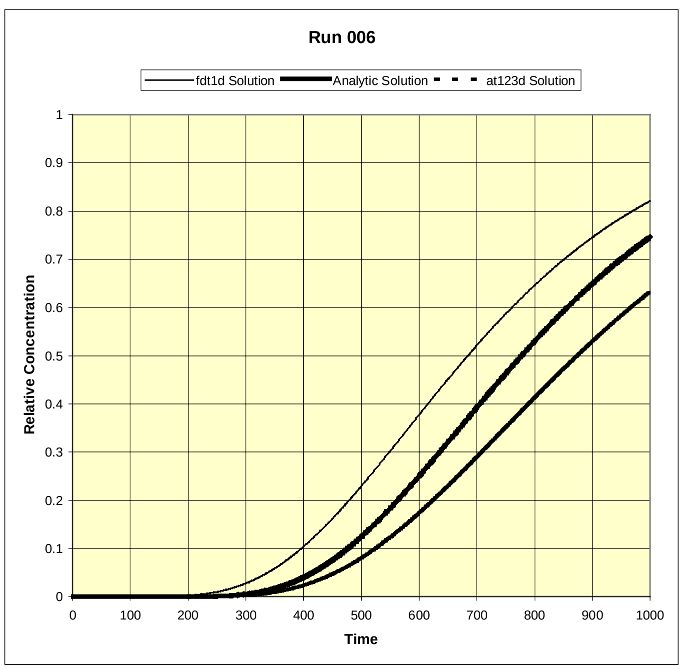



(d)

**Figure B-1 (con't). Comparison plots for test cases.**

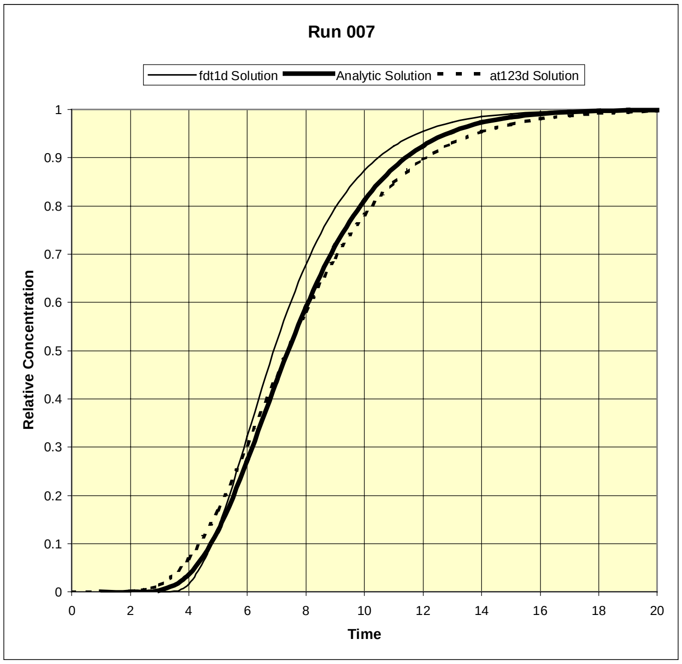



(e)

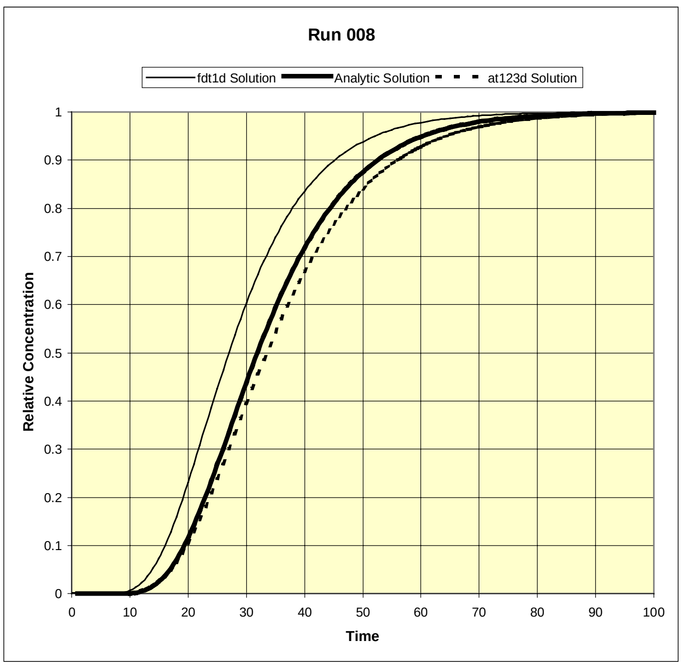



(f)

**Figure B-1 (con't). Comparison plots for test cases.**

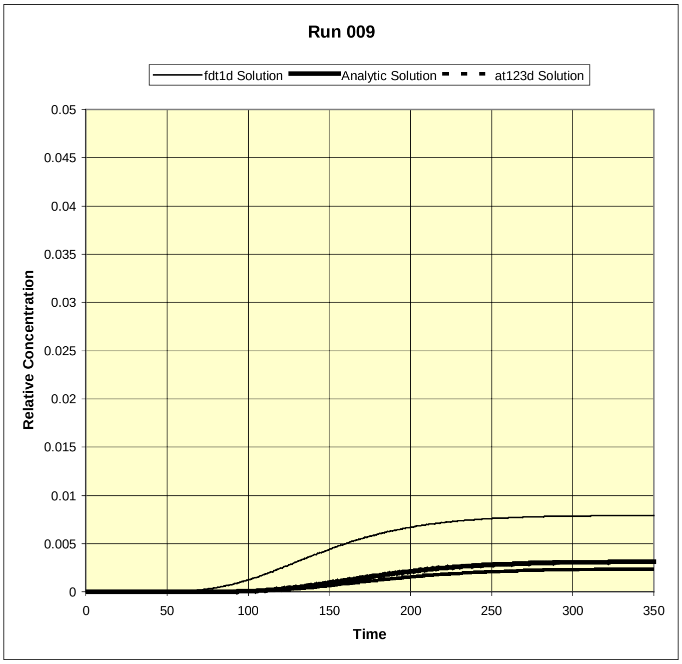



(g)

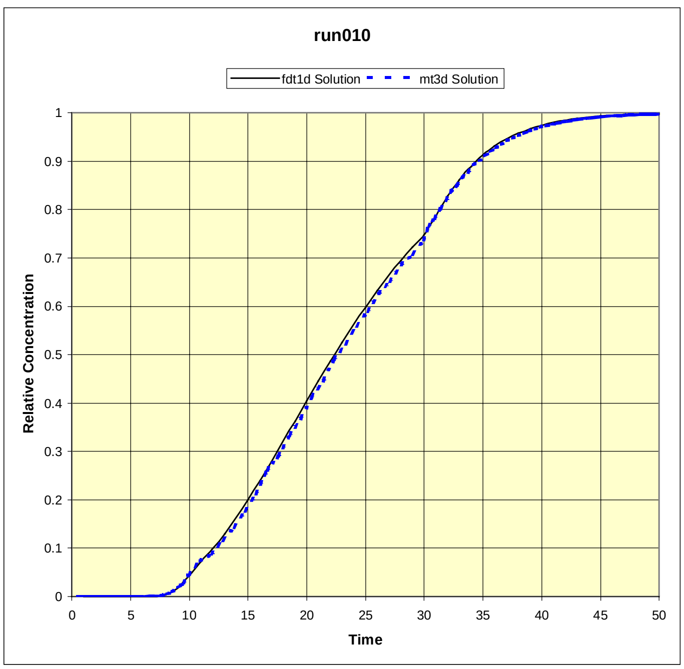



(h)

**Figure B-1 (con't). Comparison plots for test cases.**




(i)




(j)

**Figure B-1 (con't). Comparison plots for test cases.**

**Table B-2 Test Case Parameters**

| Case Number | Length | Linear Velocity | Dispersivity | Kd | Half-Life |
|---|---|---|---|---|---|
| 001 | 20 | 2.286 | 1 | 0 | 0 |
| 002 | 12 | 1.558 | 1 | 0 | 0 |
| 003 | 12 | 1.558 | 1 | 0.006 | 0 |
| 004 | 12 | 1.558 | 1 | 0 | 5 |
| 005 | 12 | 1.558 | 1 | 0.01 | 5.27 |
| 006 | 12 | 1.558 | 1 | 0.02 | 0 |
| 007 | 12 | 1.558 | 0.8 | 0 | 0 |
| 008 | 12 | 1.558 | 1 | 0.0006 | 1.57e07 |
| 009 | 12 | 1.558 | 1 | 0.008 | 29.12 |
| 010* | 18 | 1 | 1 | 0 | 0 |

Note: Lengths are in meters, time in years.

*Case 010 is a variable rate case using a velocity series of: 10 yrs. at 1, 20 yrs. at 0.5, then 70 years at 1.0. The comparison is to a MODFLOW/MT3D simulation.

## Listing B-1

The following is a listing of the computer codes used to calculate the analytic solution (*ant1d* subroutine), the AT123D solution (*at123d* subroutine) and the finite-difference solution (*fdt1d* subroutine). All code is FORTRAN90.

### <u>ant1d</u>

```
      subroutine ant1d(x,d_t,Ntime,alpha,rKd1,HalfLife,
     &        Rho1,Por,v,Cwt)

C SUBROUTINE TO CALCULATE ANALYTIC SOLUTION TO 1D TRANSPORT PROBLEM
C
C AUTHOR:
C Kevin Brewer, Ph.D.
C BSRI/SRS
C 12/99

C REFERENCES:
C The solutions used in this subroutine are based on Equations 39 and 41
C (with 42) from "Groundwater Transport: Handbook of Mathematical Models"
C by Javandal, Doughty, and Tsang published by the AGU as Water Resources
C Monograph 10, dated 1984.

C INPUTS:
C x         is the distance [L]
c d_t       is the time increment (and the first time value) [T]
c Ntime     is the maximum number of time increments [T]
c alpha     is the dispersivity [L]
c rKd1      is the Kd []
c HalfLife  is the half-life [T] (if 0.0, then no decay)
c Rho1      is the bulk-density [M/L^3]
c Por       is the porosity []
c v         is the average linear velocity [L/T]

c OUTPUT:
c Cwt       is the relative concentration array (length is Ntime) [M/L^3]

      IMPLICIT REAL*8(a-H,O-Z)
      IMPLICIT INTEGER(i-N)
C
      dimension Cwt(Ntime)
      integer :: I, J, Ncells, II, Nsteps, iDone, intervals, iDups
      real(kind=8) :: t, R, lamda

      DATA my_pi/3.14159265358979D0/

      R = 1 + rKd1*Rho1/Por
      D = v*alpha
      lamda = 0.0
      if(HalfLife.gt.0.0) lamda = log(2.0)/HalfLife

C Check to see if decay is "present"
      if(lamda .eq. 0.0) then
c      DECAY IS NOT PRESENT, DO THE SIMPLER SOLUTION (eqn. 39)
        do I = 1, Ntime
          t = I*d_t
```

```
          Cwt(I) = 0.0

          a1 = 0.0
          b1 = (R*x-v*t)/(2*sqrt(D*R*t))
          call exp_erfc(ee1,a1,b1)

          a2 = (v*x)/D
          b2 = (R*x+v*t)/(2*sqrt(D*R*t))
          call exp_erfc(ee2,a2,b2)

          Cwt(I) = 0.5*ee1+(sqrt((v*v*t)/(my_pi*D*R))*
     &                  exp((-1*(R*x-v*t)**2)/(4*D*R*t)))
     &            -0.5*(1+v*x/D+v*v*t/(D*R))*ee2
        enddo
      else
c      DECAY IS PRESENT, DO THE MORE COMPLEX SOLUTION (eqn. 41)
        U = sqrt(v*v+4*D*R*lamda)
        v1 = v/(v+U)
        v2 = v/(v-U)
        v3 = v*v/(2*D*R*lamda)

        do I = 1, Ntime
          t = I
          Cwt(I) = 0.0

          a1 = (x*(v-U))/(2*D)
          b1 = (R*x-U*t)/(2*sqrt(D*R*t))
          call exp_erfc(ee1,a1,b1)

          a2 = (x*(v+U))/(2*D)
          b2 = (R*x+U*t)/(2*sqrt(D*R*t))
          call exp_erfc(ee2,a2,b2)

          a3 = v*x/D - lamda*t
          b3 = (R*x+v*t)/(2*sqrt(D*R*t))
          call exp_erfc(ee3,a3,b3)

          Cwt(I) = v1*ee1+v2*ee2+v3*ee3
        enddo
      endif
      RETURN
      END

C =====================================================================
      subroutine exp_erfc(ee,a,b)

C SUBROUTINE TO CALCULATE EXP(a)*ERFC(b)

C AUTHOR:
C Kevin Brewer, Ph.D.
C BSRI/SRS
C 12/99

C REFERENCES:
C This subroutine is based on the EXER(A,B) subroutine given in Appendix B
C of "Groundwater Transport: Handbook of Mathematical Models" by Javandal,
C Doughty, and Tsang published by the AGU as Water Resources Monograph 10,
C dated 1984.

C The subroutine is originally from Van Genuchten and Alves (1982).
C ("Analytical solutions of the one-dimensional convective-dispersive solute
C transport equation, US Dept. of Agriculture Technical Bulletin 1661, 1982).
```

```
C INPUTS:
C a         is the exponential coefficient
c b         is the complementary error function coefficient

c OUTPUT:
c ee       is the result of exp(a)*erfc(b)

      IMPLICIT REAL*8(a-H,O-Z)
      IMPLICIT INTEGER(i-N)

      ee = 0.0
      if((dabs(a).gt.170.).and.(b.le.0.0)) return
      if(b.ne.0.0) goto 100
      ee = dexp(a)
      return
  100 c = a-b*b
      if((dabs(c).gt.170.).and.(b.gt.0.0)) return
      if(c.lt.-170.) goto 130
      x = dabs(b)
      if(x.gt.3.0) goto 110
      t = 1./(1.+.3275911*x)
      y=t*(.2548296-t*(0.2844967-t*(1.421414-t*(1.453152-1.061405*t))))
      goto 120
  110 y=0.5641896/(x+.5/(x+1./(x+1.5/(x+2./(x+2.5/(x+1.))))))
  120 ee = y*dexp(c)
  130 if(b.lt.0.0) ee = 2*dexp(a)-ee
      return
      end
```

## AT123D

```
      subroutine at123d(TITLE,NX,NY,NZ,NROOT,NBGTI,NEDTI,NPRINT,INSTAN,
     &  NSOURS,INTER,ICASE,IWID,IDEP,IBUG,DEPTH,WIDTH,RL1,RL2,RB1,RB2,
     &  RH1,RH2,POR,HCOND,HGRAD,AELONG,
     &  ATRANV,AVERTI,AKD,AKE,AMTAU,
     &  RAMADA,RHOB,RHOW,ACCU,DT,TDISP,Q,
     &  X_DM,YDIM,ZDIM,QS,conc,ctime,
     &  nconc)

c The only changes to the original at123d subroutine are the following
c comment lines that describe the input/output variables.

c Kevin Brewer, Ph.D.
c BSRI
c 11/29/99

c TITLE           Description of problem (characters)
c NX,NY,NZ        Domain array lengths (number of array items)
c NROOT           Number of roots
c NBGTI           No. of beginning time steps
c NEDTI           No. of ending time step
c NPRINT          No. of time intervals for printing
c INSTAN          Instantaneous source control (0 is instant source, 1 is
c                 continuous source)
c NSOURS          Source condition control (0 is for steady source, 1 is for
c                 variable source)
c INTER           Intermittent output control (0 is for no such output control)
c ICASE           Case control (1 is thermal, 2 is chemical, 3 is radioactive)
c IWID            Width control (0 is finite width, 1 is infinite width)
c IDEP            Depth control (0 is finite depth, 1 is infinite depth)
c IBUG            Write control for debugging (0 or less is no writing)
```

```
c DEPTH           Aquifer depth (0 for infininte depth)
c WIDTH           Aquifer width (0 for infininte width)
c RL1             BEGIN POINT OF X-SOURCE LOCATION
c RL2             END POINT OF X-SOURCE LOCATION
c RB1             BEGIN POINT OF Y-SOURCE LOCATION
c RB2             END POINT OF Y-SOURCE LOCATION
c RH1             BEGIN POINT OF Z-SOURCE LOCATION
c RH2             END POINT OF Z-SOURCE LOCATION
c POR             Porosity
c HCOND           Hydraulic conductivity
c HGRAD           Hydraulic gradient
c AELONG          Longitudinal dispersivity
c ATRANV          Lateral dispersivity
c AVERTI          Vertical dispersivity
c AKD             Distribution coefficient (KD)
c AKE             Heat exchange coefficient
c AMTAU           MOLECULAR DIFFUSION MULTIPLY BY POROSITY [L**2/T]
c RAMADA          DECAY CONSTANT
c RHOB            BULK DENSITY OF THE SOIL
c RHOW            DENSITY OF WATER
c ACCU            ACCURACY TOLERANCE FOR REACHING STEADY STATE
c DT              TIME INTERVAL SIZE FOR THE DESIRED SOLUTION
c TDISP           DISCHARGE TIME
c Q               WASTE RELEASE RATE
c X_DM            Domain x dimension (array)
c YDIM            Domain y dimension (array)
c ZDIM            Domain z dimension (array)
c QS              LIST OF TRANSIENT SOURCE RELEASE RATE
c conc            Output concentration (array)
c ctime           Output simulation time (array)
c nconc           Length of output concentration  and output time arrays


      IMPLICIT REAL*8(A-H,O-Z)
C
      character*4 TITLE
      DIMENSION TITLE(20),X_DM(NX),YDIM(NY),ZDIM(NZ)
      DIMENSION QS(NEDTI)
      dimension conc(NX,NY,NZ,nconc), ctime(nconc)
      allocatable TEMP(:,:,:),TEMPO(:,:,:)
      allocatable RTY(:),AIY(:),PSIS(:),FCTY(:,:)
      allocatable RTZ(:),AIZ(:),PHIS(:),FCTZ(:,:)
C
      DATA CP,PAI/1.0D0,3.14159265358979D0/

      allocate(TEMP(NX,NY,NZ),TEMPO(NX,NY,NZ))
      allocate(RTY(NROOT),AIY(NROOT),PSIS(NROOT),FCTY(NY,NEDTI))
      allocate(RTZ(NROOT),AIZ(NROOT),PHIS(NROOT),FCTZ(NZ,NEDTI))
      TEMP=0.0
      TEMPO=0.0
      FCTZ=0.0
      FCTY=0.0
      RTY=0.0
      RTZ=0.0
      AIY=0.0
      AIZ=0.0

      IF(IWID.EQ.0) WIDTH=0.0
      IF(IDEP.EQ.0) DEPTH=0.0
C
C
```

```
C
C ------- Write title, system parameters and control inputs
C
      if (IBUG.ge.0) then
cigwmc-begin
      WRITE(6,9001)
cigwmc-end
      WRITE(6,1000) (TITLE(I),I=1,20)
      WRITE(6,1100) NX,NY,NZ,NROOT,NBGTI,NEDTI,NPRINT,INSTAN,NSOURS,
     > INTER,ICASE
      WRITE(6,1200) DEPTH,WIDTH,RL1,RL2,RB1,RB2,RH1,RH2
      WRITE(6,1300) POR,HCOND,HGRAD,AELONG,ATRANV,AVERTI,AKD,AKE
      WRITE(6,1400) AMTAU,RAMADA,RHOB,ACCU,RHOW,DT,TDISP,Q
      IF(NSOURS.NE.0) WRITE(6,2000) (QS(I),I=1,NSOURS)
      endif
C
C ------- Make some preliminary computations and assignments
C
      NTDISP=TDISP/DT + 1.0001D0
      XS=0.0
      YS=0.0
      ZS=0.0
      IF(RL1.EQ.RL2) XS=RL1
      IF(RB1.EQ.RB2) YS=RB1
      IF(RH1.EQ.RH2) ZS=RH1
      QTOTAL=Q
      IF(NSOURS.NE.0) Q=1.0D0
      do i = NSOURS+1, NEDTI
        QS(i) = 1.0D0
      enddo
C
c      FACTOR=1.0D0/(CP*RHOW)
c      IF(ICASE.EQ.2) FACTOR=1.0D3
c      IF(ICASE.EQ.3) FACTOR=1.0D6
      FACTOR = 1.0D0
      RATIO=1.0D0
cigwmc      IF(RL1.NE.RL2) RATIO=RATIO/(RL2-RL1)
cigwmc      IF(RB1.NE.RB2) RATIO=RATIO/(RB2-RB1)
cigwmc      IF(RH1.NE.RH2) RATIO=RATIO/(RH2-RH1)
cigwmc-begin
      IF(RL1.NE.RL2) RATIO=ABS(RATIO/(RL2-RL1))
      IF(RB1.NE.RB2) RATIO=ABS(RATIO/(RB2-RB1))
      IF(RH1.NE.RH2) RATIO=ABS(RATIO/(RH2-RH1))
cigwmc-end
C
C
C ------- Compute retarded velocity, dispersion coefficients, and
C         other parameters
C
      RETARD=1.0D0 + RHOB*AKD/POR
      UF=HCOND*HGRAD/(POR*RETARD)
      AKX=AELONG*UF+AMTAU/(POR*RETARD)
      AKY=ATRANV*UF+AMTAU/(POR*RETARD)
      AKZ=AVERTI*UF+AMTAU/(POR*RETARD)
      RKE=(AKE/(POR*RETARD))/AKZ
      ROTPAR=1.0D32
      IF(IDEP.NE.0) ROTPAR=RKE*DEPTH
C
      if (IBUG.ge.0) then
      WRITE(6,1500) RETARD,UF,AKX,AKY,AKZ
cigwmc-begin
      WRITE(6,9002)
```

```
cigwmc-end
      endif
C
C
C ------- Compute RTY(I) and AIY(I) for finite width case
C
      IF(IWID.EQ.0) GO TO 180
      DO 130 I=1,NROOT
      RTY(I)=DBLE(I)*PAI/WIDTH
  130 AIY(I)=2.0D0/WIDTH
C
C ------- Write out optional Y-Eigenvalues and Z-coefficients
C
      IF(IBUG.le.0) GO TO 180
      WRITE(6,3100) (RTY(I),I=1,NROOT)
      WRITE(6,3200) (AIY(I),I=1,NROOT)
C
C
C ------- Compute RTZ(I) and AIZ(I) for finite depth case
C
  180 IF(IDEP.EQ.0) GO TO 290
C
C ------- For the thermal case, i.e., AKE not equal to 0.0
C
      IF(ICASE.NE.1) GO TO 250
      DO 200 I=1,NROOT
  200 CALL ROOT(RTZ,I,ROTPAR,NROOT)
      DO 210 I=1,NROOT
      RTZ(I) = RTZ(I)/DEPTH
      DENOMT=DEPTH*(1.0D0+RKE**2/RTZ(I)**2) + RKE/RTZ(I)**2
  210 AIZ(I)=2.0D0/DENOMT
      GO TO 285
C
C ------- For the non-thermal cases
C
  250 DO 260 I=1,NROOT
      RTZ(I)=DBLE(I)*PAI/DEPTH
  260 AIZ(I)=2.0D0/DEPTH
C
C ------- Write out optional Z-Eigenvalues and Z-coefficients
C
  285 IF(IBUG.le.0) GO TO 290
      WRITE(6,3300) (RTZ(I),I=1,NROOT)
      WRITE(6,3400) (AIZ(I),I=1,NROOT)
C
C
C ------- Compute source part of each of the series terms
C
C
C ------- 1. Compute source part of each of Y-series
C
  290 IF(IWID.EQ.0) GO TO 310
      DO 300 I=1,NROOT
         IF(RB1.EQ.RB2) PSIS(I)=DCOS(RTY(I)*YS)
       IF(RB1.NE.RB2) PSIS(I)=(WIDTH/(DBLE(I)*PAI))*(DSIN(RTY(I)*RB2)
     > -  DSIN(RTY(I)*RB1))
  300 CONTINUE
C
C ------- 2. Compute source part of each of Z-series
C
  310 IF(IDEP.EQ.0) GO TO 330
      DO 320 I=1,NROOT
```

```
      IF(RH1.EQ.RH2) PHIS(I)=DCOS(RTZ(I)*ZS)+RKE/RTZ(I)*DSIN(RTZ(I)*ZS)
      IF(RH1.NE.RH2) PHIS(I)=(DSIN(RTZ(I)*RH2)-DSIN(RTZ(I)*RH1) -
     >  RKE/RTZ(I)*(DCOS(RTZ(I)*RH2)-DCOS(RTZ(I)*RH1)))/RTZ(I)
  320 CONTINUE
C
C ------- Write out the optional YS-series and ZS-series
C
  330 IF(IBUG.le.0) GO TO 350
      IF(IWID.NE.0) WRITE(6,3500) (PSIS(I),I=1,NROOT)
      IF(IDEP.NE.0) WRITE(6,3600) (PHIS(I),I=1,NROOT)
C
C
C ------- Compute the Y- and Z-part of the integrand for each
C         series term
C
  350 DO 490 IT=1,NEDTI
      TIMED=(DBLE(IT)-1.0D0)*DT
      IF(IT.EQ.1) TIMED=DT
C
      DO 440 IY=1,NY
      Y=YDIM(IY)
C
C ------- Evaluate the function Y1(Y,T;TAU) or Y2(Y,T;TAU)
C
      IF(IWID.EQ.0) GO TO 420
      IF(IT.NE.1) GO TO 410
      FCTY(IY,IT)=0.0
      IF(RB1.EQ.RB2 .AND. Y.EQ.YS) FCTY(IY,IT)=1.0D0
      IF((RB1.NE.RB2) .AND. (Y.GE.RB1 .AND. Y.LE.RB2)) FCTY(IY,IT)=1.0D0
      GO TO 440
  410  CALL SERIEY(SERY,Y,YS,RB1,RB2,WIDTH,TIMED,AKY,RTY,AIY,
     1       PSIS,NROOT,NROOT)
      IF(RB1.EQ.RB2) FCTY(IY,IT)=1.0D0/WIDTH+SERY
      IF(RB1.NE.RB2) FCTY(IY,IT)=(RB2-RB1)/WIDTH+SERY
      IF(RB1.EQ.0.0 .AND. RB2.EQ.WIDTH) FCTY(IY,IT)=1.0D0
      IF(FCTY(IY,IT).LT.0.0) FCTY(IY,IT)=0.0
      GO TO 440
C
C ------- Evaluate the function Y3(Y,T;TAU) or Y4(Y,T;TAU)
C
C
C ------- 1. Compute function Y3
C
  420 IF(RB1.NE.RB2) GO TO 430
      IF(IT.NE.1) GO TO 425
      FCTY(IY,IT)=0.0
      IF(Y.EQ.YS) FCTY(IY,IT)=1.0D0
      GO TO 440
  425 Y1=DSQRT(4.0D0*PAI*AKY*TIMED)
      EARG=(Y-YS)*(Y-YS)/(4.0D0*AKY*TIMED)
      IF(DABS(EARG).GT.100.0D0) EARG=170.0D0
      FCTY(IY,IT)=(1.0D0/Y1)*(DEXP(-EARG))
      GO TO 440
C
C ------- 2. Compute function Y4
C
  430 IF(IT.NE.1) GO TO 435
      FCTY(IY,IT)=0.0
      IF(Y.GE.RB1 .AND. Y.LE.RB2) FCTY(IY,IT)=1.0D0
      GO TO 440
  435 SRT=DSQRT(4.0D0*AKY*TIMED)
      FCTY(IY,IT)=(DERF((Y-RB1)/SRT)-DERF((Y-RB2)/SRT))/2.0D0
```

```
  440 CONTINUE
C
      DO 480 IZ=1,NZ
      Z=ZDIM(IZ)
C
C ------- Evaluate the function Z1(Z,T;TAU) or Z2(Z,T;TAU)
C
      IF(IDEP.EQ.0) GO TO 460
      IF(IT.NE.1) GO TO 450
      FCTZ(IZ,IT)=0.0
      IF(RH1.EQ.RH2 .AND. Z.EQ.ZS) FCTZ(IZ,IT)=1.0D0
      IF((RH1.NE.RH2) .AND. (Z.GE.RH1 .AND. Z.LE.RH2)) FCTZ(IZ,IT)=1.0D0
      GO TO 480
  450 CALL SERIEZ(SERZ,Z,TIMED,AKZ,RKE,RTZ,AIZ,PHIS,NROOT,NROOT)
      FCTZ(IZ,IT)=SERZ
      IF(AKE.EQ.0. .AND. RH1.EQ.RH2) FCTZ(IZ,IT)=1.0D0/DEPTH+SERZ
      IF(AKE.EQ.0. .AND. RH1.NE.RH2) FCTZ(IZ,IT)=(RH2-RH1)/DEPTH+SERZ
      IF(RH1.EQ.0.0 .AND. RH2.EQ.DEPTH) FCTZ(IZ,IT)=1.0D0
      GO TO 480
C
C ------- Evaluate the function Z3(Z,T;TAU) or Z4(Z,T;TAU)
C
C
C ------- 1. Compute function Z3
C
  460 IF(RH1.NE.RH2) GO TO 470
      IF(IT.NE.1) GO TO 465
      FCTZ(IZ,IT)=0.0
      IF(Z.EQ.ZS) FCTZ(IZ,IT)=1.0D0
      GO TO 480
C
  465 AKZT=4.0D0*AKZ*TIMED
      AKZTPI=AKZT*PAI
      AKZT4S=AKZT/4.0D0
      EARG1=(Z-ZS)*(Z-ZS)/AKZT
      EARG2=(Z+ZS)*(Z+ZS)/AKZT
      EARG3=AKZ*RKE*RKE*TIMED+RKE*(Z+ZS)
      ARG=(Z+ZS)/DSQRT(AKZT) + RKE*DSQRT(AKZT4S)
      TERM1=0.0
      IF(EARG1.LT.100.0D0) TERM1=DEXP(-EARG1)/DSQRT(AKZTPI)
      TERM2=0.0
      IF(EARG2.LE.100.0D0) TERM2=DEXP(-EARG2)/DSQRT(AKZTPI)
      TERM3=0.0
      IF(EARG3.LT.100.0D0) TERM3=-RKE*DEXP(EARG3)*(1.0D0-DERF(ARG))
      FCTZ(IZ,IT)=TERM1+TERM2+TERM3
      GO TO 480
C
C ------- 2. Compute function Z4
C
  470 IF(IT.NE.1) GO TO 475
      FCTZ(IZ,IT)=0.0
      IF(Z.GE.RH1 .AND. Z.LE.RH2) FCTZ(IZ,IT)=1.0D0
      GO TO 480
C
  475 AKZT1=DSQRT(4.0D0*AKZ*TIMED)
      AKZT2=AKZT1/2.0D0
      ARG1=(Z+RH2)/AKZT1
      ARG2=(Z+RH1)/AKZT1
      ARG3=(Z-RH2)/AKZT1
      ARG4=(Z-RH1)/AKZT1
      ARG5=AKZ*RKE*RKE*TIMED + RKE*(Z+RH2)
      ARG6=AKZ*RKE*RKE*TIMED + RKE*(Z+RH1)
```

```
      TERMS4=0.5D0*(DERF(ARG1)-DERF(ARG2)-DERF(ARG3)+DERF(ARG4))
      TERM5=0.0
      IF(ARG5.LT.100.0D0) TERM5=-DEXP(ARG5)*(1.0D0-DERF(ARG1+RKE*AKZT2))
      TERM6=0.0
      IF(ARG6.LT.100.0D0) TERM6=DEXP(ARG6)*(1.0D0-DERF(ARG2+RKE*AKZT2))
      TERM78=-(DERF(ARG1)-DERF(ARG2))
      FCTZ(IZ,IT)=TERMS4+TERM5+TERM6+TERM78
C
  480 CONTINUE
  490 CONTINUE


C
C
C ------- Start transient loop computation
C
      TIME=0.0
      iconc = 1
      DO 800 ITT=NBGTI,NEDTI,NPRINT
C
      DO 710 IX=1,NX
      DO 710 IY=1,NY
      DO 710 IZ=1,NZ
  710 TEMPO(IX,IY,IZ)=TEMP(IX,IY,IZ)
C
      IF(INTER.EQ.0) GO TO 725
      if(IBUG.lt.0) goto 725
C
      IF(ICASE.EQ.1) WRITE(6,5100) TIME
      IF(ICASE.EQ.2) WRITE(6,5200) TIME
      IF(ICASE.EQ.3) WRITE(6,5300) TIME
C
      DO 720 IZOUT=1,NZ
      WRITE(6,6000) ZDIM(IZOUT)
  720 CALL ALLOUT(TEMP,X_DM,YDIM,IZOUT,NX,NY,
     >       NX,NY,NZ)
C
  725 TIME=(DBLE(ITT-1))*DT
C
      DO 760 IXX=1,NX
      X=X_DM(IXX)
      DO 750 IYY=1,NY
      Y=YDIM(IYY)
      DO 740 IZZ=1,NZ
      Z=ZDIM(IZZ)
C
C ------- Branch to instantaneous source or continuous source
C
      IF(INSTAN) 731,732,731
C
C ------- Case: continuous source for the duration of NTDISP
C
  731 IF(ITT.LE.NTDISP) CALL TINTEG(S,X,XS,RL1,RL2,
     >      FCTY,FCTZ,TIME,IYY,IZZ,ITT,UF,DT,AKX,RAMADA,QS,
     >             NY,NZ,NEDTI,INSTAN)
      IF(ITT.GT.NTDISP) CALL TINTEG(S,X,XS,RL1,RL2,
     >     FCTY,FCTZ,TIME,IYY,IZZ,NTDISP,UF,DT,AKX,RAMADA,QS,
     >             NY,NZ,NEDTI,INSTAN)
      GO TO 733
C
C ------- Case: instantaneous source release
C
```

```
  732 CALL TINTEG(S,X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,ITT,
     >     UF,DT,AKX,RAMADA,QS,NY,NZ,NEDTI,INSTAN)
      S=S*2.0D0/DT
  733 TEMP(IXX,IYY,IZZ)=S*Q*RATIO*FACTOR/(POR*RETARD)
      conc(IXX,IYY,IZZ,iconc) = TEMP(IXX,IYY,IZZ)
  740 CONTINUE
  750 CONTINUE
  760 CONTINUE
      ctime(iconc) = TIME
      iconc = iconc+1
C
      IF(ITT.EQ.NBGTI) GO TO 800
      IF(NSOURS.NE.0) GO TO 800
C
C ------- Check if steady-state solution has been obtained
C         before the final simulation time
C
      DIFMAX=0.0
      DO 770 IX=1,NX
      DO 770 IY=1,NY
      DO 770 IZ=1,NZ
      IF(TEMPO(IX,IY,IZ).EQ.0.0) GO TO 770
      DIF=DABS(TEMP(IX,IY,IZ)/TEMPO(IX,IY,IZ)-1.0D0)
      IF(DIF.LE.DIFMAX) GO TO 770
      DIFMAX=DIF
  770 CONTINUE
C
      IF(DIFMAX.LE.ACCU) GO TO 910
C
  800 CONTINUE
C
      if (IBUG.ge.0)WRITE(6,7000)
      GO TO 920
  910 if (IBUG.ge.0)WRITE(6,8000)
  920 CONTINUE
      if (IBUG .ge.0) then
      IF(ICASE.EQ.1) WRITE(6,5100) TIME
      IF(ICASE.EQ.2) WRITE(6,5200) TIME
      IF(ICASE.EQ.3) WRITE(6,5300) TIME
      DO 930 IZOUT=1,NZ
      WRITE(6,6000) ZDIM(IZOUT)
  930 CALL ALLOUT(TEMP,X_DM,YDIM,IZOUT,NX,NY,
     >    NX,NY,NZ)
      endif

      deallocate(TEMP,TEMPO)
      deallocate(RTY,AIY,PSIS,FCTY)
      deallocate(RTZ,AIZ,PHIS,FCTZ)

cigwmc  1000 FORMAT(1H1,////,5X,20A4,//)
cigwmc-begin
 1000 FORMAT(/////,5X,20A4/)
cigwmc-end
cigwmc  ----  IGWMC changed time units from hours to days
cigwmc-begin
 1100 FORMAT(/////,5X,
     > 'NO. OF POINTS IN X-DIRECTION ......................',I5/5X,
     > 'NO. OF POINTS IN Y-DIRECTION ......................',I5/5X,
     > 'NO. OF POINTS IN Z-DIRECTION ......................',I5/5X,
     > 'NO. OF ROOTS: NO. OF SERIES TERMS .................',I5/5X,
     > 'NO. OF BEGINNING TIME STEPS .......................',I5/5X,
     > 'NO. OF ENDING TIME STEP ...........................',I5/5X,
```

```
     > 'NO. OF TIME INTERVALS FOR PRINTED OUT SOLUTION ....',I5/5X,
     > 'INSTANTANEOUS SOURCE CONTROL = 0 FOR INSTANT SOURCE',I5/5X,
     > 'SOURCE CONDITION CONTROL = 0 FOR STEADY SOURCE ....',I5/5X,
     > 'INTERMITTENT OUTPUT CONTROL = 0 NO SUCH OUTPUT ....',I5/5X,
     > 'CASE CONTROL =1 THERMAL, = 2 FOR CHEMICAL, = 3 RAD ',I5/)
 1200 FORMAT(/////,5X,
     > 'AQUIFER DEPTH, = 0.0 FOR INFINITE DEEP [L] ........',E12.4/5X,
     > 'AQUIFER WIDTH, = 0.0 FOR INFINITE WIDE [L] ........',E12.4/5X,
     > 'BEGIN POINT OF X-SOURCE LOCATION [L] .............',E12.4/5X,
     > 'END POINT OF X-SOURCE LOCATION [L] ...............',E12.4/5X,
     > 'BEGIN POINT OF Y-SOURCE LOCATION [L] .............',E12.4/5X,
     > 'END POINT OF Y-SOURCE LOCATION [L] ...............',E12.4/5X,
     > 'BEGIN POINT OF Z-SOURCE LOCATION [L] .............',E12.4/5X,
     > 'END POINT OF Z-SOURCE LOCATION [L] ...............',E12.4/)
 1300 FORMAT(//////,5X,
     > 'POROSITY [DIMENSIONLESS] .........................',E12.4/5X,
     > 'HYDRAULIC CONDUCTIVITY [L/T] .....................',E12.4/5X,
     > 'HYDRAULIC GRADIENT [DIMENSIONLESS] ...............',E12.4/5X,
     > 'LONGITUDINAL DISPERSIVITY [L] ....................',E12.4/5X,
     > 'LATERAL DISPERSIVITY [L] .........................',E12.4/5X,
     > 'VERTICAL DISPERSIVITY [L] ........................',E12.4/5X,
     > 'DISTRIBUTION COEFFICIENT, KD [L**3/M] ............',E12.4/5X,
     > 'HEAT EXCHANGE COEFFICIENT [E/T-L**2-TEMP] .........',E12.4/)
 1400 FORMAT(/////,5X,
     > 'MOLECULAR DIFFUSION MULTIPLY BY POROSITY [L**2/T]  ',E12.4/5X,
     > 'DECAY CONSTANT [1/T]..............................',E12.4/5X,
     > 'BULK DENSITY OF THE SOIL [M/L**3] ................',E12.4/5X,
     > 'ACCURACY TOLERANCE FOR REACHING STEADY STATE ......',E12.4/5X,
     > 'DENSITY OF WATER [M/L**3] ........................',E12.4/5X,
     > 'TIME INTERVAL SIZE FOR THE DESIRED SOLUTION [T]    ',E12.4/5X,
     > 'DISCHARGE TIME [T]   ............................',E12.4/5X,
     > 'WASTE RELEASE RATE [E/D], [M/D], OR [A/D] .........',E12.4/)
 1500 FORMAT(/////,5X,
     > 'RETARDATION FACTOR ..............................',E12.4/5X,
     > 'RETARDED DARCY VELOCITY [L/T] ....................',E12.4/5X,
     > 'RETARDED LONGITUDINAL DISPERSION COEF. [L**2/T] ...',E12.4/5X,
     > 'RETARDED LATERAL DISPERSION COEFFICIENT [L**2/T] ..',E12.4/5X,
     > 'RETARDED VERTICAL DISPERSION COEFFICIENT [L**2/T]  ',E12.4/)
 2000 FORMAT(/////,4X,'LIST OF TRANSIENT SOURCE RELEASE RATE'/(5X,10E12.
     >3))
 3100 FORMAT(/////,4X,'LIST OF Y-EIGENVALUES'/(5X,10E12.4))
 3200 FORMAT(/////,4X,'LIST OF Y-COEFFICIENT'/(5X,10E12.4))
 3300 FORMAT(/////,4X,'LIST OF Z-EIGENVALUES'/(5X,10E12.4))
 3400 FORMAT(/////,4X,'LIST OF Z-COEFFICIENTS'/(5X,10E12.4))
 3500 FORMAT(/////,4X,'LIST OF YS-SERIES'/(5X,10E12.4))
 3600 FORMAT(/////,4X,'LIST OF ZS-SERIES'/(5X,10E12.4))
 5100 FORMAT(/////,4X,'TEMPERATURE DISTRIBUTION IN [TEMP] AT T=',E12.4)
 5200 FORMAT(/////,4X,'DISTRIBUTION OF CHEMICAL IN [M/L**3] AT T=',
     > E12.4)
 5300 FORMAT(/////,4X,'DISTRIBUTION OF RADIOACTIVE WASTE IN [A/M**3] '
     > 'AT T=',E12.4)
 6000 FORMAT(/////,20X,'Z = ',F10.2)
 7000 FORMAT(/////,'STEADY STATE SOLUTION HAS NOT BEEN REACHED BEFORE FI
     >NAL SIMULATING TIME'//)
 8000 FORMAT(/////,'STEADY STATE SOLUTION HAS BEEN OBTAINED BEFORE FINAL
     > SIMULATING TIME'//)
cigwmc
 9001 FORMAT(////,4X,'SIMULATION WITH AT123D (Modified)'//
     > 4X,'INPUT INFORMATION',/,4X,'-----------------',/)
 9002 FORMAT(/////,4X,'COMPUTATIONAL RESULTS',/,4X,
     >'---------------------',//)
cigwmc-end
```

```
      RETURN
      END
cigwmc
cigwmc ------------------------------------------------------------------
      SUBROUTINE ROOT(RTZ,I,ROTPAR,MAXRUT)
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION RTZ(MAXRUT)
C
      ZL=RTZ(I)
      IF(I.GT.1) ZL=RTZ(I-1)+0.01D0
  100 ZL=ZL+0.01D0
      FZL=ZL*DSIN(ZL)-ROTPAR*DCOS(ZL)
      ZR=ZL+0.01D0
      FZR=ZR*DSIN(ZR)-ROTPAR*DCOS(ZR)
      IF(FZL*FZR.LT.0.0) GO TO 200
      GO TO 100
  200 FZL=ZL*DSIN(ZL)-ROTPAR*DCOS(ZL)
      DO 300 J=1,6
      ZH=(ZL+ZR)/2.0D0
      FZH=ZH*DSIN(ZH)-ROTPAR*DCOS(ZH)
      IF(FZH*FZL.LE.0.0) GO TO 400
      ZL=ZH
      FZL=FZH
      GO TO 300
  400 ZR=ZH
  300 CONTINUE
      RTZ(I)=(ZL+ZR)/2.0D0
      RETURN
      END
cigwmc
cigwmc ------------------------------------------------------------------
      SUBROUTINE SERIEY(SER,Y,YS,RB1,RB2,B,TIMED,AKY,RTY,AIY,
     > PSIS,MAXRUT,NROOT)
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION RTY(MAXRUT),AIY(MAXRUT),PSIS(MAXRUT)
      DIMENSION YTEUL(15)
C
      EPS=0.0001D0
      IER=1
      I=1
      M=1
      N=1
      ASSIGN 100 TO IFC
      GO TO 500
  100 YTEUL(1)=FCT
      SUM=YTEUL(1)*0.5D0
    3 J=0
    4 I=I+1
      IF(I-NROOT) 5,5,12
    5 N=I
      ASSIGN 200 TO IFC
      GO TO 500
  200 AMN=FCT
      DO 6 K=1,M
      AMP=(AMN+YTEUL(K))*0.5D0
      YTEUL(K)=AMN
    6 AMN=AMP
      IF(DABS(AMN)-DABS(YTEUL(M))) 7,9,9
```

```
    7 IF(M-15) 8,9,9
    8 M=M+1
      YTEUL(M)=AMN
      AMN=0.5D0*AMN
    9 SUM=SUM+AMN
      IF(DABS(AMN)-EPS*DABS(SUM)) 10,10,3
   10 J=J+1
      IF(J-5) 4,11,11
   11 IER=0
   12 SER=SUM
      IF(IER.NE.0) WRITE(6,1000) Y,TIMED
      RETURN
C
C ------- Evaluate N-th term of Y1(Y,T;TAU) or Y2(Y,T;TAU)
C
  500 AKYTB=AKY*TIMED/(B*B)
      IF(AKYTB.LE.0.0000014D0) GO TO 510
      EARG=RTY(N)*RTY(N)*AKY*TIMED
      IF(EARG.GT.100.0D0) FCT=0.0
      IF(EARG.LE.100.D0) FCT=AIY(N)*(DCOS(RTY(N)*Y))*PSIS(N)*DEXP(-EARG)
      GO TO 590
  510 IF(RB1.NE.RB2) GO TO 520
      AKYTPI=4.0D0*3.14159265358979D0*AKY*TIMED
      AKYT=4.0D0*AKY*TIMED
      EARG1=((Y-YS)-2.0D0*DBLE(N)*B)*((Y-YS)-2.0D0*DBLE(N)*B)/AKYT
      EARG2=((Y-YS)-2.0D0*DBLE(N-1)*B)*((Y-YS)-2.0D0*DBLE(N-1)*B)/
     > AKYT
      EARG3=((Y+YS)-2.0D0*DBLE(N+1)*B)*((Y+YS)-2.0D0*DBLE(N+1)*B)/
     > AKYT
      EARG4=((Y+YS)-2.0D0*DBLE(N)*B)*((Y+YS)-2.0D0*DBLE(N)*B)/AKYT
      FCT=(DEXP(-EARG1)+DEXP(-EARG2)+DEXP(-EARG3)+DEXP(-EARG4))/
     1 DSQRT(AKYTPI)
      GO TO 590
  520 AKY=DSQRT(4.0D0*AKY*TIMED)
      ARG1=Y-RB1-2.0D0*DBLE(N)*B
      ARG2=Y-RB2-2.0D0*DBLE(N)*B
      ARG3=Y-RB1-2.0D0*DBLE(N-1)*B
      ARG4=Y-RB2-2.0D0*DBLE(N-1)*B
      ARG5=Y+RB1-2.0D0*DBLE(N+1)*B
      ARG6=Y+RB2-2.0D0*DBLE(N+1)*B
      ARG7=Y+RB1-2.0D0*DBLE(N)*B
      ARG8=Y+RB2-2.0D0*DBLE(N)*B
      FCT=0.5D0*(DERF(ARG1)-DERF(ARG2)+DERF(ARG3)-DERF(ARG4)
     > -DERF(ARG5)+DERF(ARG6)-DERF(ARG7)+DERF(ARG8))
  590 GO TO IFC, (100,200)
C
 1000 FORMAT(1H0,10X,'WARNING: SERIESY AT Y =',F8.2,'  TIMED=',F8.2,'
     1NEEDS MORE TERMS')
      END
cigwmc
cigwmc -----------------------------------------------------------------
      SUBROUTINE SERIEZ(SER,Z,TIMED,AKZ,RKE,RTZ,AIZ,PHIS,MAXRUT,NROOT)
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION RTZ(MAXRUT),AIZ(MAXRUT),PHIS(MAXRUT)
      DIMENSION YTEUL(15)
C
      EPS=0.0001D0
      IER=1
      I=1
      M=1
```

```
      N=1
      ASSIGN 100 TO IFC
      GO TO 500
  100 YTEUL(1)=FCT
      SUM=YTEUL(1)*0.5D0
    3 J=0
    4 I=I+1
      IF(I-NROOT) 5,5,12
    5 N=I
      ASSIGN 200 TO IFC
      GO TO 500
  200 AMN=FCT
      DO 6 K=1,M
      AMP=(AMN+YTEUL(K))*0.5D0
      YTEUL(K)=AMN
    6 AMN=AMP
      IF(DABS(AMN)-DABS(YTEUL(M))) 7,9,9
    7 IF(M-15) 8,9,9
    8 M=M+1
      YTEUL(M)=AMN
      AMN=0.5D0*AMN
    9 SUM=SUM+AMN
      IF(DABS(AMN)-EPS*DABS(SUM)) 10,10,3
   10 J=J+1
      IF(J-5) 4,11,11
   11 IER=0
   12 SER=SUM
      IF(IER.NE.0) WRITE(6,1000) Z,TIMED
      RETURN
C
C ------- Evaluate the N-th term of Z1(Z,T;TAU) or Z2(Z,T;TAU)
C
  500 EARG=RTZ(N)**2*AKZ*TIMED
      IF(EARG.GT.100.0D0) FCT=0.0
      IF(EARG.LE.100.D0) FCT=AIZ(N)*(DCOS(RTZ(N)*Z)+RKE/RTZ(N)*
     1 DSIN(RTZ(N)*Z))*PHIS(N)*DEXP(-EARG)
      GO TO IFC, (100,200)
C
 1000 FORMAT(1H0,10X,'WARNING: SERIESZ AT Z =',F8.2,'  TIMED=',F8.2,'
     1NEEDS MORE TERMS')
      END
cigwmc
cigwmc -----------------------------------------------------------------
      SUBROUTINE TINTEG(S,X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,ITT,
     > UF,DT,AKX,RAMADA,QS, MAXNY,MAXNZ,MAXNTI,INSTAN)
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION FCTY(MAXNY,MAXNTI),FCTZ(MAXNZ,MAXNTI),QS(MAXNTI)
C
      PAI=3.14159265358979D0
      ITTM1=ITT-1
      N=ITTM1/2
      SUMEND=0.0
      SUMMID=0.0
      S=0.0
      ITAU=1
cigwmc
cigwmc       In the following section IGWMC replaced the assigned GO TO
cigwmc       with a subroutine call to avoid passing control back to a
cigwmc       statement within a DO loop
cigwmc
```

```
cigwmc  ASSIGN 100 TO M
cigwmc  GO TO 800
cigwmc-begin
      CALL XFUN(X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,FIT,
     > UF,DT,AKX,RAMADA,QS,MAXNY,MAXNZ,MAXNTI,ITAU,ITT,PAI)
cigwmc-end
  100 FIT1=FIT
C
C ------- If N .LT. 1 there is only one interval
C
      IF(INSTAN.EQ.0) GO TO 700
      IF(N.LT.1) GO TO 700
      DO 400 K=1,N
cigwmc   ASSIGN 200 TO M
      ITAU=K+K-1
cigwmc   GO TO 800
cigwmc-begin
      CALL XFUN(X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,FIT,
     > UF,DT,AKX,RAMADA,QS,MAXNY,MAXNZ,MAXNTI,ITAU,ITT,PAI)
cigwmc-end
  200 SUMEND=SUMEND+FIT
cigwmc   ASSIGN 300 TO M
      ITAU=K+K
cigwmc   GO TO 800
cigwmc-begin
      CALL XFUN(X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,FIT,
     > UF,DT,AKX,RAMADA,QS,MAXNY,MAXNZ,MAXNTI,ITAU,ITT,PAI)
cigwmc-end
  300 SUMMID=SUMMID+FIT
  400 CONTINUE
C
C ------- If N*2 .NE. ITTM1 there are odd numbers of intervals
C
      IF(N*2 .NE. ITTM1) GO TO 500
cigwmc      S=(2.0D0*SUMEND+4.0D0*SUMMID-FIT1)*DT/3.0D0
cigwmc-begin
      S=DABS((2.0D0*SUMEND+4.0D0*SUMMID-FIT1)*DT/3.0D0)
cigwmc-end
      GO TO 900
cigwmc  500 ASSIGN 600 TO M
cigwmc-begin
  500 ITAU=ITTM1
cigwmc-end
cigwmc      GO TO 800
cigwmc-begin
      CALL XFUN(X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,FIT,
     > UF,DT,AKX,RAMADA,QS,MAXNY,MAXNZ,MAXNTI,ITAU,ITT,PAI)
cigwmc-end
cigwmc  600 S=(2.0D0*SUMEND+4.0D0*SUMMID-FIT1+FIT)*DT/3.0D0
cigwmc  700 S=S+(FIT)*DT/2.0D0
  600 S=DABS((2.0D0*SUMEND+4.0D0*SUMMID-FIT1+FIT)*DT/3.0D0)
  700 S=S+DABS((FIT)*DT/2.0D0)
cigwmc   GO TO 900
  900 RETURN
      END
C
C
C ------- Compute function value of the integrand function F(ITAU)
C
C
C
C ------- Evaluate the function X1(X,T;TAU) or X2(X,T;TAU)
```

```
C
cigwmc  Here is the subroutine the IGWMC used to replace the assigned
cigwmc  GO TO with to avoid passing control back within DO loop.
cigwmc  This function has retained most of the original statements.
cigwmc
cigwmc-begin
      SUBROUTINE XFUN(X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,FIT,
     > UF,DT,AKX,RAMADA,QS,MAXNY,MAXNZ,MAXNTI,ITAU,ITT,PAI)
cigwmc
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION FCTY(MAXNY,MAXNTI),FCTZ(MAXNZ,MAXNTI),QS(MAXNTI)
cigwmc
cigwmc   800 XPART=0.0
cigwmc
      XPART=0.0
cigwmc-end
      TIMD=TIME-DBLE(ITAU-1)*DT
      IF(ITAU.EQ.ITT) TIMD=0.01D0*DT
C
C ------- Point source in the X-direction
C
      IF(RL1.NE.RL2) GO TO 820
       IF(ITAU.NE.ITT) GO TO 810
      XPART=0.0
      IF(X.EQ.XS) XPART=1.0D0
      GO TO 850
  810 EARG=((X-XS)-UF*TIMD)**2/(4.0D0*AKX*TIMD)
      IF(DABS(EARG).GT.150.0D0) GO TO 850
      XPART=(1.0D0/(DSQRT(4.0D0*PAI*AKX*TIMD)))*DEXP(-EARG)
      GO TO 850
C
C ------- Line source in the X-direction
C
  820 IF(ITAU.NE.ITT) GO TO 830
      XPART=0.0
      IF(X.GE.RL1 .AND. X.LE.RL2) XPART=1.0D0
      GO TO 850
  830 SRT=DSQRT(4.0D0*AKX*TIMD)
      EAR=-UF*TIMD
      EARG1=(X-RL1+EAR)/SRT
      EARG2=(X-RL2+EAR)/SRT
      XPART=(DERF(EARG1)-DERF(EARG2))/2.0D0
C
C ------- Evaluate the integrand, FIJK(X,Y,Z,T;TAU), in equation 16
C
  850 IT=ITT-ITAU + 1
      FIT=XPART*FCTZ(IZZ,IT)*FCTY(IYY,IT)*QS(ITAU)*DEXP(-RAMADA*TIMD)
cigwmc      GO TO M,(100,200,300,600)
cigwmc  900 RETURN
cigwmc-begin
      RETURN
cigwmc-end
      END
cigwmc
cigwmc ------------------------------------------------------------------
      SUBROUTINE ALLOUT(FTV,X_DM,YDIM,IZ,NX,NY,
     > MAXNX,MAXNY,MAXNZ)
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION FTV(MAXNX,MAXNY,MAXNZ)
      DIMENSION X_DM(MAXNX),YDIM(MAXNY)
```

```
C
      JOUT=(NX-1)/10+1
      DO 96 MM=1,JOUT
      JAA=10*(MM-1)+1
      JZZ=10*MM
      IF(MM.EQ.JOUT) JZZ=NX
      IF(MM.GT.1) WRITE(6,225)
  225 FORMAT(1H0,50X,'CONTINUE')
      WRITE(6,222) (X_DM(J),J=JAA,JZZ)
  222 FORMAT(1H ,60X,'X'/1X,'  Y ',10F12.0)
      WRITE(6,223)
  223 FORMAT(1H ,'    ',10(4X,'        '))
      DO 97 NN=1,NY
      Y=YDIM(NN)
      WRITE(6,224) Y, (FTV(J,NN,IZ),J=JAA,JZZ)
  224 FORMAT(1H ,F5.0,10E12.3)
cigwmc-begin
      DO 5002 NPH=JAA,JZZ
c     WRITE(8,5001)NPH,NN,IZ,FTV(NPH,NN,IZ)
 5001 FORMAT(I5,5X,I5,5X,I5,5X,E10.3)
 5002 CONTINUE
cigwmc-end
   97 CONTINUE
   96 CONTINUE
      RETURN
      END
cigwmc
cigwmc  ***The folowing function is added by the IGWMC to the original
cigwmc     code by G.T. Yeh to replace ERF call to resident library
cigwmc
      DOUBLE PRECISION FUNCTION DERF(X)
      IMPLICIT REAL*8(A-H,O-Z)
      Z= DABS(X)
      P= 0.3275911
      T= 1/(1+P*Z)
      A1= 0.254829592
      A2= -.284496736
      A3= 1.421413741
      A4= -1.453152027
      A5= 1.061405429
      TERM= (A1*T)+(A2*T**2)+(A3*T**3)+(A4*T**4)+(A5*T**5)
        IF (X .EQ. 0)THEN
          DERF= 0.0
          RETURN
        ELSE
          IF (Z .LE. 3) DERF= 1.-(TERM*DEXP(-Z**2.))
          TERM2= DEXP(-Z**2.)
          IF (Z .GT. 3 .AND. Z .LT. 5) DERF= 1.-.5641896*DEXP(-Z*Z)
     1    /(Z+.5/(Z+1./(Z+1.5/(Z+2./(Z+2.5/(Z+1.))))))
          IF (Z .GE. 5) DERF= 1.0
          IF (X .LT. 0) DERF= -DERF
        END IF
      RETURN
      END
```

## fdt1d Subroutine

```
      subroutine fdt1d(Dvad,Time_Step,Ntime,Dispersivity,rKd1,HalfLife,
     &        Rho1,Por,a_lin_v,Cleach,Cwt,e_time,d_length,d_time)

C SUBROUTINE TO CALCULATE FINITE-DIFFERENCE SOLUTION TO 1D TRANSPORT PROBLEM
```

```
C AUTHOR:
C Kevin Brewer, Ph.D.
C BSRI/SRS
C 12/99

C REFERENCES:
C The finite-difference solution used in this subroutine is based on
C the explicit-central approximation as demonstrated in Equation 12.1.8
C from "Modeling Groundwater FLow and Pollution" by Bear and Verruijt
C published as part of the series "Theory and Applications of Transport
C in Porous Media", dated 1987. Additional information came from "Numerical
C Methods in Subsurface Hydrology" by Remson, Hornberger, and Molz, dated
C 1971; and from "A Practical Guide to Groundwater and Solute Transport
C Modeling" by Spitz and Moreno, dated 1996.

C INPUTS:
C Dvad           is the distance [L]
c Time_Step      is the time increment (and the first time value) [T]
c Ntime          is the maximum number of time increments [T]
c Dispersivity   is the dispersivity [L]
c rKd1           is the Kd []
c HalfLife       is the half-life [T] (if 0.0, then no decay)
c Rho1           is the bulk-density [M/L^3]
c Por            is the porosity []
c a_lin_v        is the average linear velocity [L/T]
c Cleach         is the array (length Ntime) of input concentrations [M/L^3]

c OUTPUTS:
c Cwt       is the relative concentration array (length is Ntime) [M/L^3]
c e_time    NOT USED (array -- length is Ntime)
c d_length  is the discretization length used in the solution [L]
c d_time    is the discretization time interval used in the solution [T]

      IMPLICIT REAL*8(a-H,O-Z)
      IMPLICIT INTEGER(i-N)
C
      real(kind=8), allocatable :: con(:,:),disp(:),D_coef(:),v_coef(:),
     &  Cin(:)
      dimension Cwt(Ntime), a_lin_v(Ntime),Cleach(Ntime), e_time(Ntime)
      integer :: I, J, Ncells, II, Nsteps, iDone, intervals, iDups
      real(kind=8) :: max_vel, min_vel, max_cleach, d_time_n,
     &  Rf, lamda, peclet, courant, d_time_p, sim_length

C Calculate some max and min values of the inputs.
      max_vel = 0.0
      min_vel = 10000000.0
      max_cleach = 0.0
      do I = 1,Ntime
        if(a_lin_v(I).gt.max_vel) max_vel = a_lin_v(I)
        if(a_lin_v(I).lt.min_vel) min_vel = a_lin_v(I)
        if(Cleach(I).gt.max_cleach) max_cleach = Cleach(I)
      enddo

C DETERMINE THE DISCRETIZATION LENGHT AND TIME INTERVAL
      d_length = 1.0*Dispersivity
      Ncells = 1 + ceiling(Dvad / d_length)
      if(Ncells.lt.11) Ncells = 11
      d_length = Dvad / (Ncells - 1)
      d_length_2 = d_length * d_length

c Make the domain twice as large as necessary to avoid boundary affects
```

```
c from outflow side.
c     e.g., if Ncells = 11 for a d_length of 1.0 and a Dvad of 10,
c           make Ncells = 21 for a d_length of 1.0 and a sim_length of 20
      Ncells = 2*Ncells-1

c now fine tune the time interval to be an even division of the TIME_STEP
      d_time_p  = d_length/max_vel
      d_time_n  = 0.5*d_length*d_length/(Dispersivity*max_vel)
      if(d_time_n .lt. d_time_p) d_time_p = d_time_n
      iDone = 0
      do I = 1, 100
        if(iDone .eq. 0) then
          d_time = Time_Step/I
          intervals = Ntime*I
          iDups = I
          if(d_time .lt. d_time_p) iDone = 1
        endif
      enddo
      peclet = d_length/Dispersivity
      courant = max_vel*d_time/d_length

c     write(*,*) 'Peclet,  Courant: ', peclet, courant
c     write(*,*) 'Ncells, d_length: ', Ncells, d_length
c     write(*,*) 'iDups,    d_time: ', iDups, d_time

      allocate (con(intervals,Ncells), disp(intervals),
     &          Cin(intervals),D_coef(intervals), v_coef(intervals))

c SET UP THE SOLUTION COEFFICIENTS
      Rf = 1 + rKd1*Rho1/Por
      lamda = 0.0
      if(HalfLife.gt.0.0) lamda = log(2.0)/HalfLife

      II = 1
      do I = 1, Ntime
        do J = 1, iDups
          disp(II)   = a_lin_v(I)*Dispersivity
          D_coef(II) = disp(II)/d_length_2
          v_coef(II) = a_lin_v(I)/(2*d_length)
          Cin(II)    = Cleach(I)
          II = II + 1
        enddo
      enddo
c PERFORM THE CALCULATION FOR EACH TIME INTERVAL
c     FOR TIME=1 (Initial conditions)
      con(1,1) = Cin(1)
      do J = 2, Ncells
        con(1,J) = 0.0
      enddo

c     FOR EACH TIME INTERVAL -- I (starting at the second time step)
      do I = 2, intervals
c       ASSIGN THE BOUNDARY CONDITION CELL VALUE (LOCATION J=1)
        con(I,1) = Cin(I)
c       CALCULATE THE SECOND THROUGH NEXT TO LAST CELL VALUES (LOCATION J=2
c       to Ncells-1)
        do J = 2, Ncells-1
           con(I,J) = (d_time/Rf)*(
     &           D_coef(I-1)*(con(I-1,J+1)-2.0*con(I-1,J)+con(I-1,J-1))
     &          -v_coef(I-1)*(con(I-1,J+1)-con(I-1,J-1))
     &          -Rf*lamda*con(I-1,J))  +  con(I-1,J)
          if(con(I,J).lt.0.0) con(I,J) = 0.0
```

```
          if(con(I,J).gt.max_cleach) con(I,J) = max_cleach
        enddo
c       CALCULATE THE LAST CELL VALUE (LOCATION J=Ncells)
c           ASSUME THE FINAL DERIVATIVE CAN BE CALCULATED FROM THE SLOPE
c           OF THE Ncells to Ncells-1 DATA.
c
c           ASSUME THAT THE FINAL SECOND DERIVATIVE IS 0 (no dispersive term).
c
       con(I,Ncells) = (d_time/Rf)*(
c    &       D_coef(I-1)*(con(I-1,Ncells)-2.0*con(I-1,Ncells)+
c    &                    con(I-1,Ncells-1))
     &      -v_coef(I-1)*2.0*(con(I-1,Ncells)-con(I-1,Ncells-1))
     &      -Rf*lamda*con(I-1,Ncells))  +  con(I-1,Ncells)
        if(con(I,Ncells).lt.0.0) con(I,Ncells) = 0.0
        if(con(I,Ncells).gt.max_cleach) con(I,Ncells) = max_cleach

      enddo


      do I = 1, Ntime
        Cwt(I) = con(I*iDups,(Ncells-1)/2)
      enddo


   3  format(i5,3(2x,f6.3),2(2x,a6,2x,f6.3))
   4  format(20(f6.2))
   10 format(1000(f15.5))

      RETURN
      END
```

## Appendix C

### Input and Output File Formats

## Input File Format

```
LVStran.for INPUT FILE

Ntime, Nelem, Ncoc, Nform
TimeStep, VadSat, Dispersivity, SatCond
Density (Iform=1,Nform)
Porosity (Iform=1,Nform)
[Ielem = 1, Nelem]
Area(Ielem),TopSrc(Ielem),BotSrc(Ielem),Wtable(Ielem),DistRecep(Ielem),ElevRecep(Ielem
),DefInfil(Ielem)
Infiltration (Itime=1,Ntime, Itime)
[Icoc = 1, Ncoc]
Halflife(Icoc), Csat(Icoc), ConvFactor(Icoc), Kd(Iform=1,Nform, Icoc)
[Ielem = 1, Nelem]
Inventory(Ielem, Icoc), WasteForm(Itime=1,Ntime, Ielem, Icoc)


Ntime                   =  # time steps, indexed by Itime
Nelem                   =  # source elements, indexed by Ielem
Ncoc                    =  # constituents, indexed by Icoc
Nform                   =  # of waste forms, indexed by Iform (see note 1)
TimeStep                =  Length of each time step [T]
VadSat                  =  Vadose zone degree of saturation [-]
Dispersivity            =  Longitudinal dispersivity [L]
SatCond                 =  Aquifer hydraulic conductivity along flow path [L/T]
Density(Iform)          =  Bulk density of soil/waste form [M/L3] (see note 1)
Porosity(Iform)         =  Effective soil/waste form porosity [-] (see note 1)
Area(Ielem)             =  Source element area [L2]
TopSrc(Ielem)           =  Waste top elevation [L]
Botsrc(Ielem)           =  Waste bottom elevation [L]
Wtable(Ielem)           =  Water table elevation [L]
DistRecep(Ielem)        =  Distance from water table to receptor along flow path [L]
ElevRecep(Ielem)        =  Elevation (Head) at the receptor location [L]
DefInfil(Ielem)         =  Default (constant with time) infiltration rate [L]
Infiltration(Itime,Ielem)  =  Water infiltration rate [L/T]
HalfLife(Icoc)          =  Constituent half-life [T] (see note 2)
Csat(Icoc)          =  Saturation concentration in water [A/L3] (see notes 3 and 4)
ConvFactor(Icoc)    =  Conversion factor applied to concentrations (see note 4)
Kd(Iform, Icoc)     =  Solid/water partitioning coefficient [L3/M] (see note 1)
Inventory(Ielem,Icoc)         =  Initial inventory of constituent [A] (see note 3)
WasteForm(Itime,Ielem,Icoc)   =  Waste Form Index # (see note 1)
```

Notes:

1. Waste form indices are used to identify absence/presence of a source and encasement material such as concrete. Waste form 1 refers to native soil. Waste forms 2-Nform refer to other encasement materials (e.g. 2 = concrete). If the source is removed, the waste form index is set to 0. Density, porosity, and Kd are specified for waste forms 1-Nform, with the first value being that for native soil. The waste form index is used to specify grouting or removal at some future time.

2. Specify a half-life of 0 for a non-decaying constituent.

3. Constituent mass and constituent activity are used interchangeably and are referred

in generic units of [A] which could be, for instance, kg or Ci. Concentration units are therefore in generic units of [A/L3].

4. A conversion factor is included to scale concentrations to a more usable system of units. The program first calculates concentration in the units of mass or activity and length implied by the input parameters. Subsequently, the concentrations are multiplied by the specified conversion factor so that reported concentrations are in a (potentially) different set of units. For example if Inventory units are in Ci and length units are in m, then a conversion factor of 106 will give concentrations in pCi/ml. Similarly a factor of 106 converts units of kg and m to concentration units of □g/L (ppb). All output concentrations are in the converted concentration units. Also, the saturation concentration (Csat) input values should be in converted units.

## Output File Format

LVStran.for MAIN (UNFORMATTED, BINARY) OUTPUT FILE

```
Ntime, Nelem, Ncoc, TimeStep
[Icoc = 1, Ncoc]
  [Ielem = 1, Nelem]
    [Itime = 1, Ntime]
      Cleach,Cwt,Crecep,SrcMass,VadMass,SatMass,OutMass,SrcDecay,VadDecay,SatDecay
```

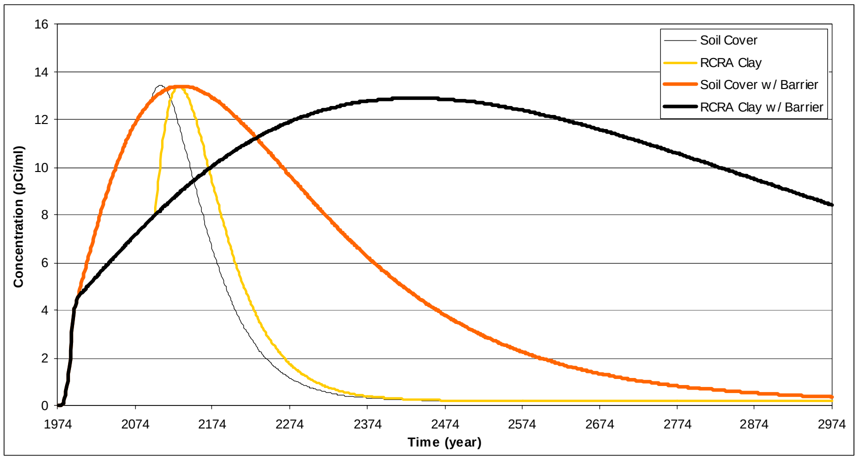
| | | |
|---|---|---|
| Ntime | = | # time steps, indexed by Itime |
| Nelem | = | # source elements, indexed by Ielem |
| Ncoc | = | # constituents, indexed by Icoc |
| TimeStep | = | Length of each time step [T] |
| Cleach | = | Concentration of leachate [$A/L^3$] |
| Cwt | = | Concentration at water-table [$A/L^3$] |
| Crecep | = | Concentration at receptor [$A/L^3$] |
| SrcMass | = | Mass/activity in the source [A] |
| VadMass | = | Mass/activity in the vadose zone [A] |
| SatMass | = | Mass/activity in the saturated zone [A] |
| OutMass | = | Mass/activity received at the receptor (cumulative)[A] |
| SrcDecay | = | Cumulative mass/activity decayed in the source [A] |
| VadDecay | = | Cumulative mass/activity decayed in the vadose zone [A] |
| SatDecay | = | Cumulative mass/activity decayed in the saturated zone [A] |

Notes:
Concentrations are in converted units.
All integers are stored as 4-bytes, reals as 8-bytes (double-precision)

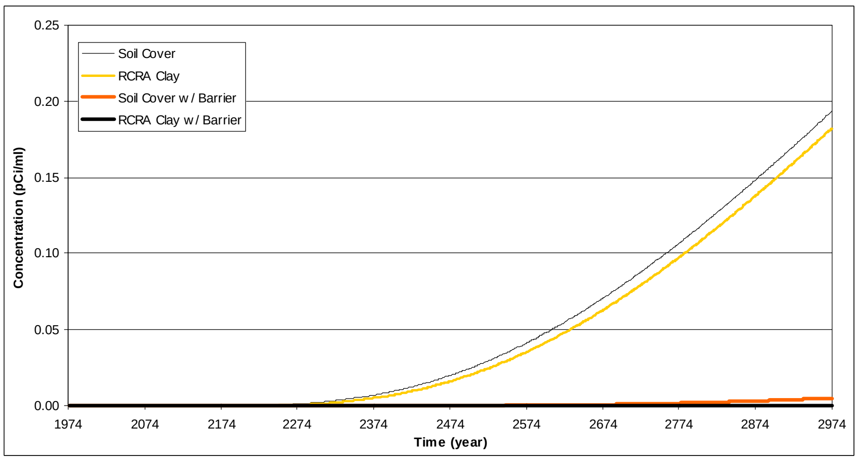
## Appendix D

### Presentation of Results for All COIs

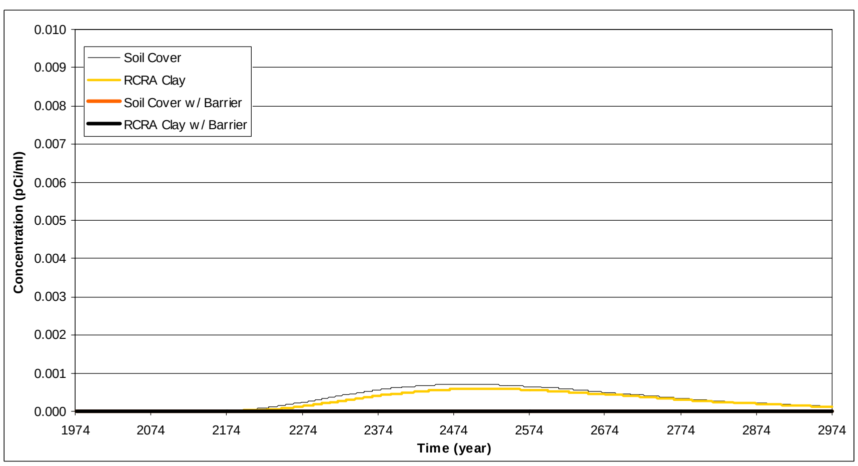
This appendix provides saturated zone concentration element plots, seep line concentration element plots, and total mass (activity) plots for all COIs and for all the remedial alternatives for three of the model leaching scenarios: 1) Full Impact/Early Timing - variable infiltration rate through vadose zone, 2) Full Impact/Late Timing - assuming no leaching (from 1974-1995) of source COIs but allowing source decay until the Soil Cover (no barrier) was placed, 3) Full Impact/Late Timing - modeling of RCRA Clay Cap alternatives with the placement of the cap dependant on a "trigger" level of contamination of selective contaminants. Additional plots for other scenarios can be generated using the software listed in Appendix E.




a) Carbon-14

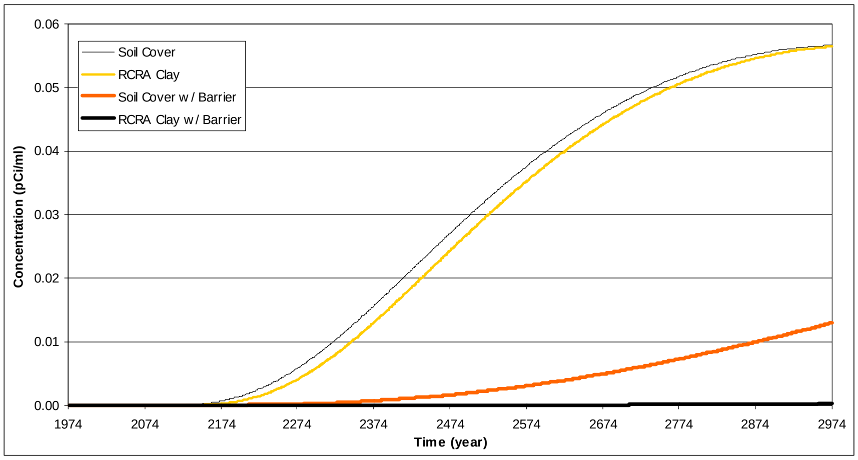



b) Plutonium-239

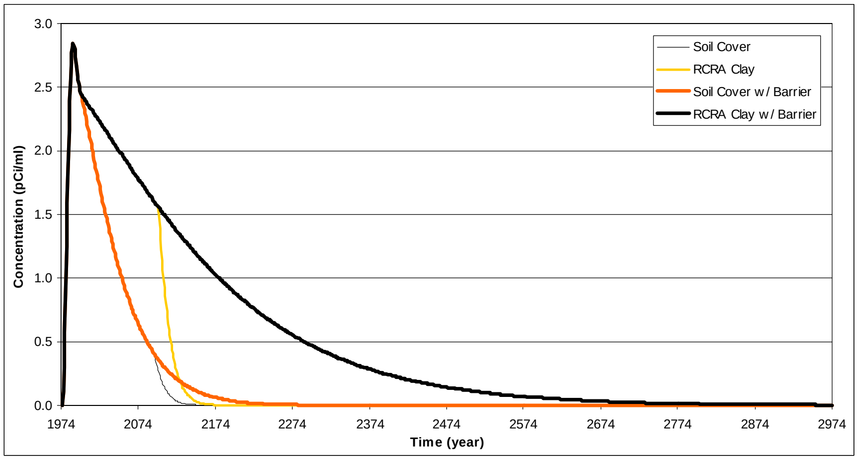



c) Plutonium-238

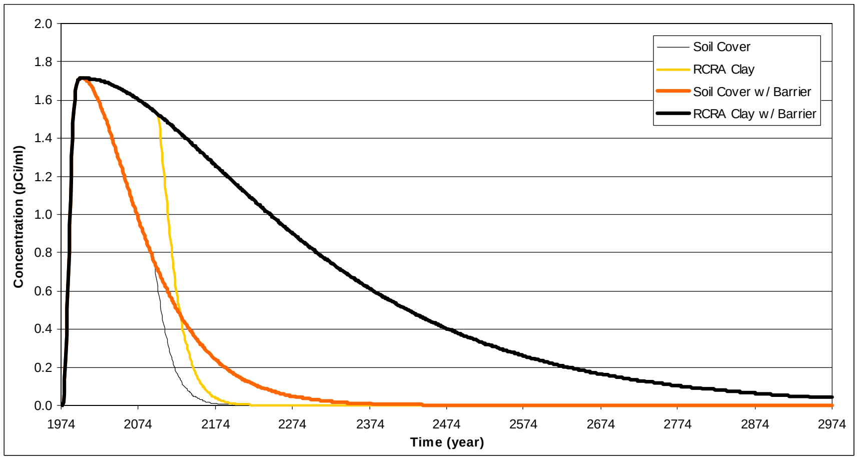
**Figure D-1. Concentration in Saturated Zone below ORWBG vs. Time: Sum of All Elements, Full Impact/Early Timing Model Results**




d) Uranium-238

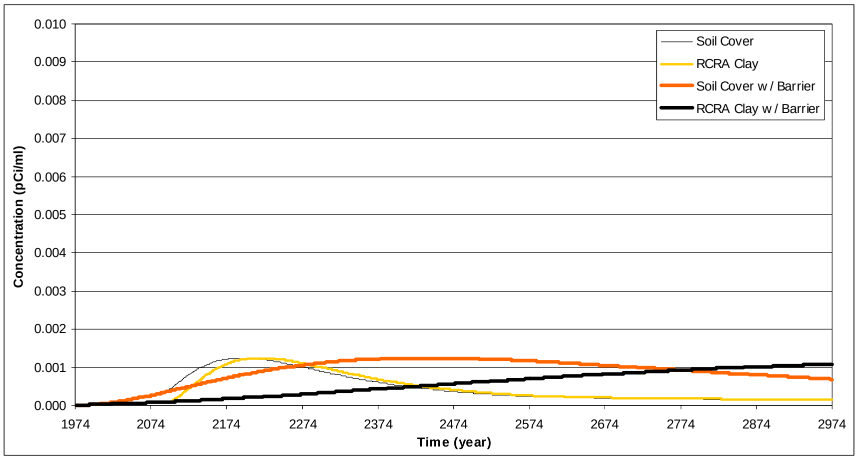



e) Technetium-99

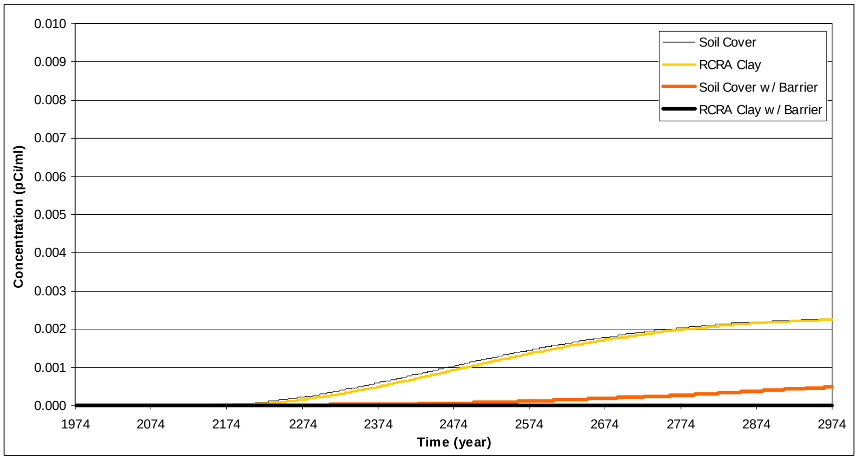



f) Iodine-129

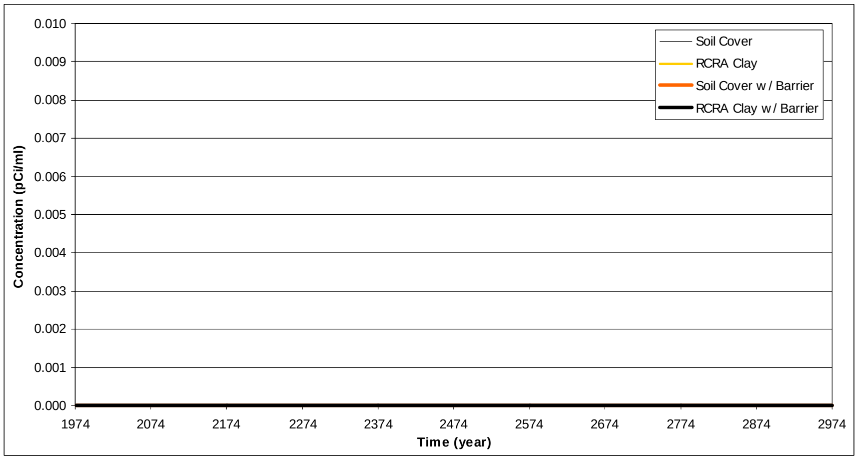
**Figure D-1. (con't) Concentration in Saturated Zone below ORWBG vs. Time: Sum of All Elements, Full Impact/Early Timing Model Results**




g) Neptunium-237

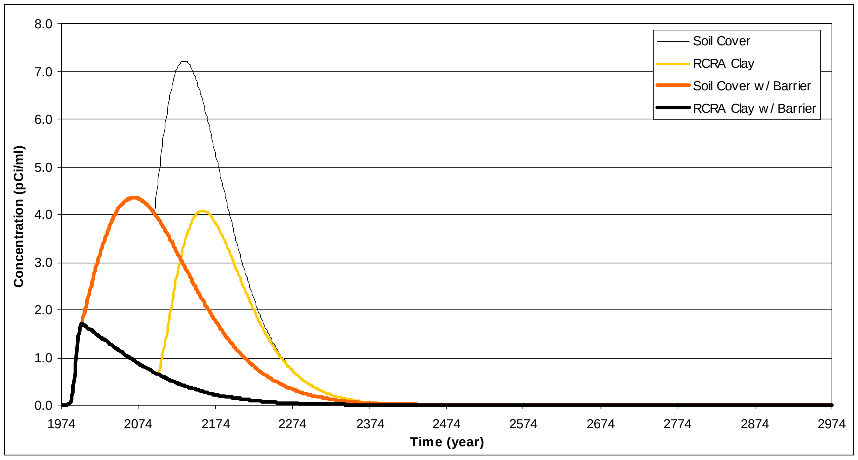



h) Uranium-235

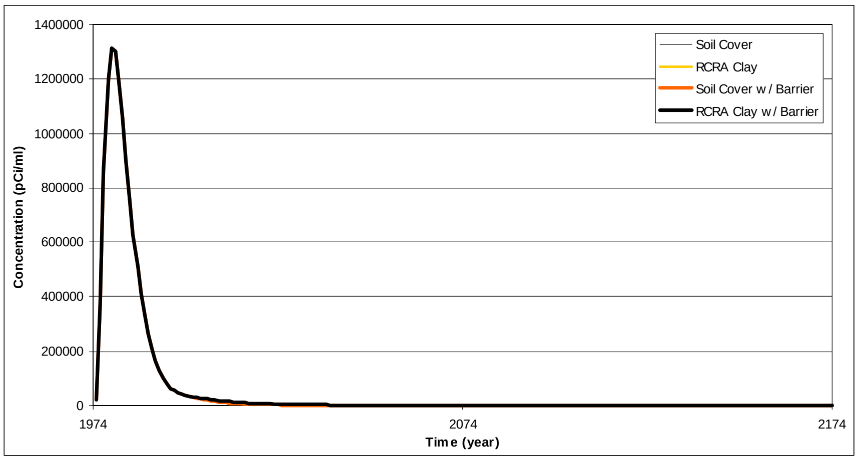



i) Cesium-137

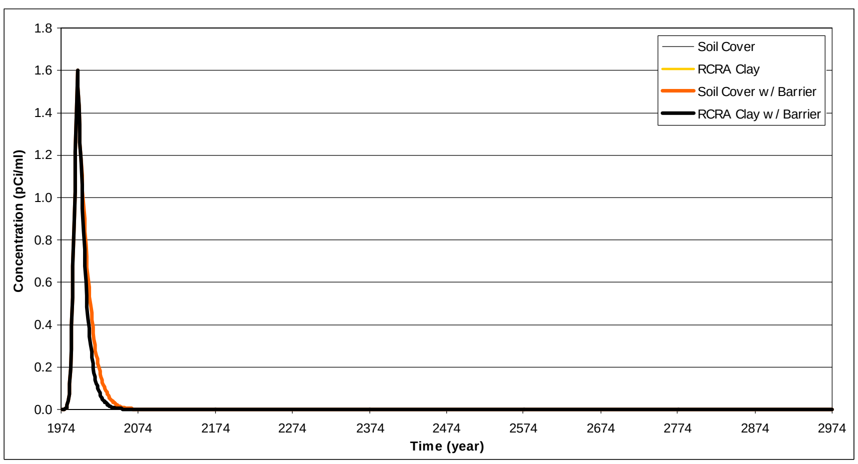
**Figure D-1. (con't) Concentration in Saturated Zone below ORWBG vs. Time: Sum of All Elements, Full Impact/Early Timing Model Results**




j) Strontium-90

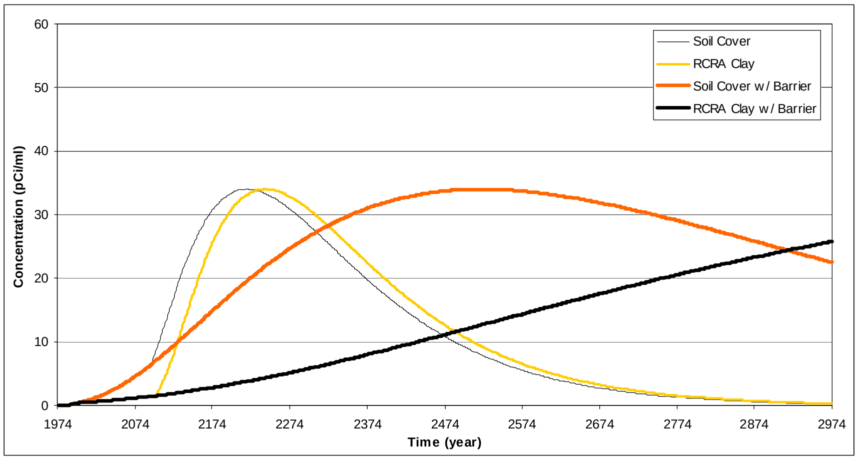



k) Tritium

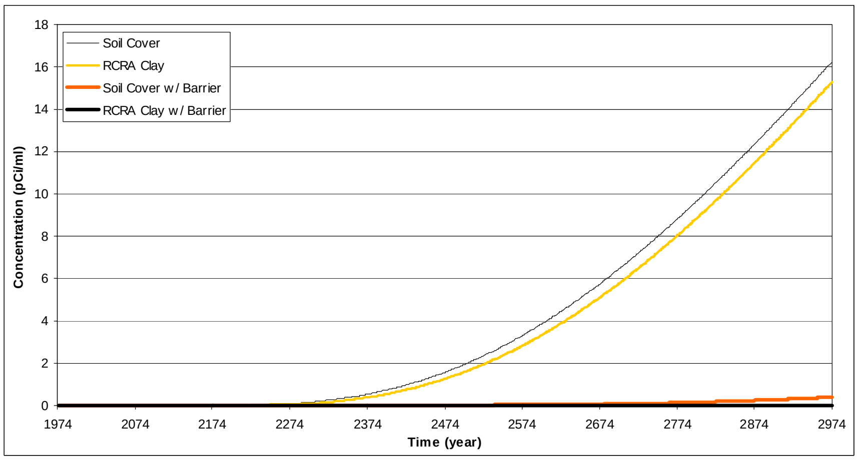



l) Cobalt-60

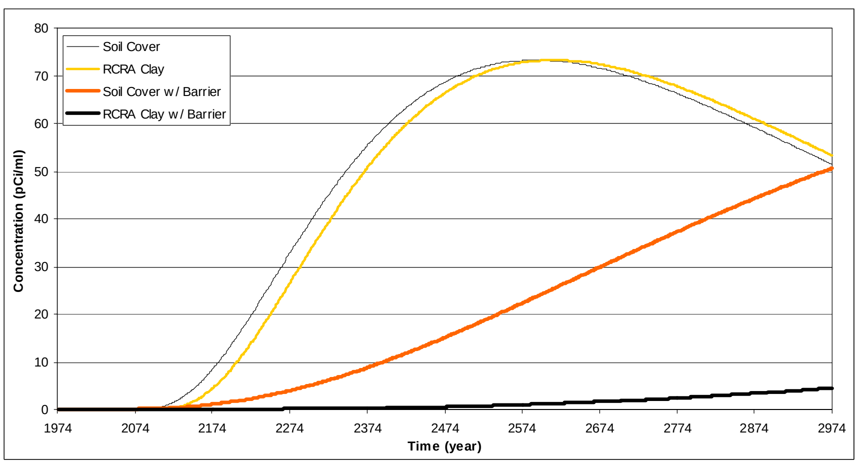
**Figure D-1. (con't) Concentration in Saturated Zone below ORWBG vs. Time: Sum of All Elements, Full Impact/Early Timing Model Results**




m) Cadmium

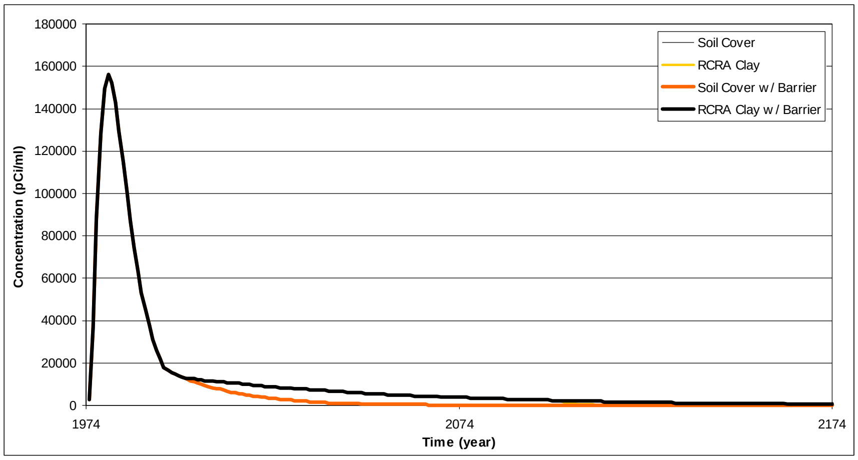



n) Lead



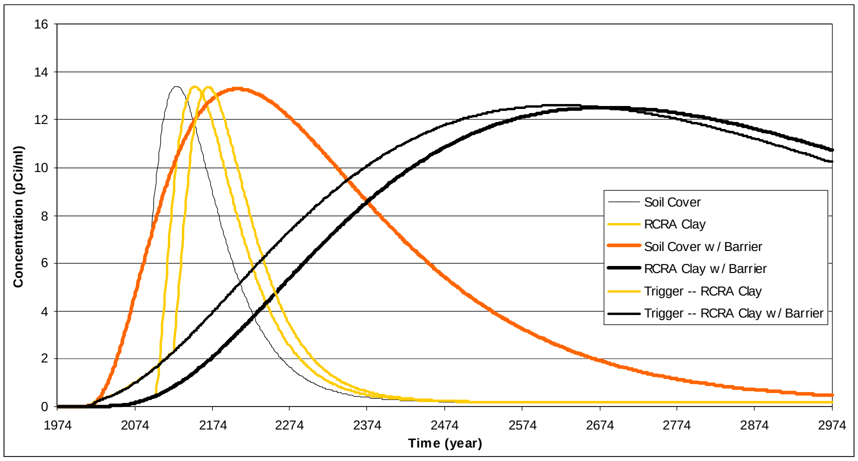

o) Mercury

**Figure D-1. (con't) Concentration in Saturated Zone below ORWBG vs. Time: Sum of All Elements, Full Impact/Early Timing Model Results**

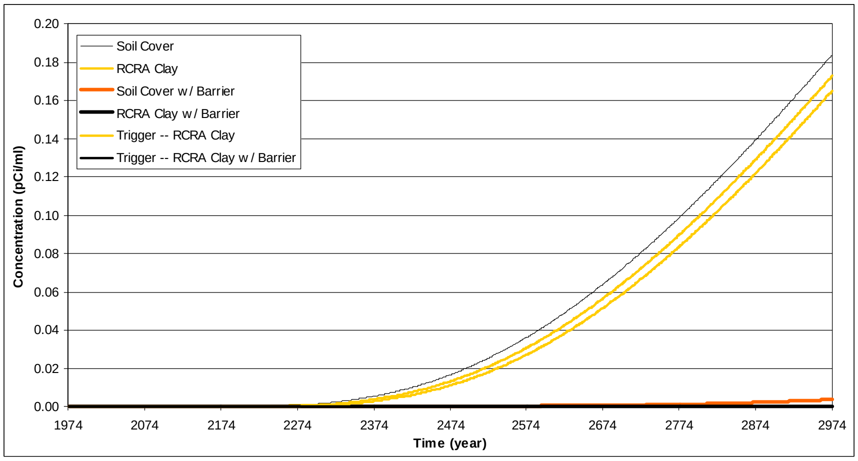



p) VOC

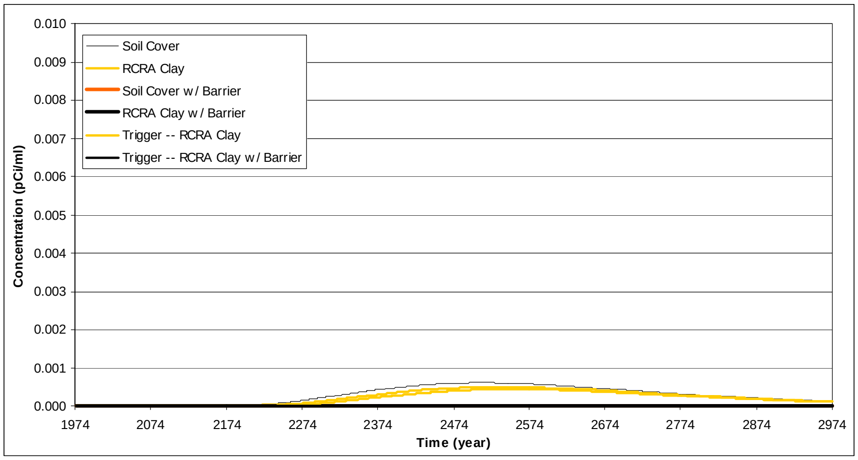
**Figure D-1. (con't) Concentration in Saturated Zone below ORWBG vs. Time: Sum of All Elements, Full Impact/Early Timing Model Results**




a) Carbon-14

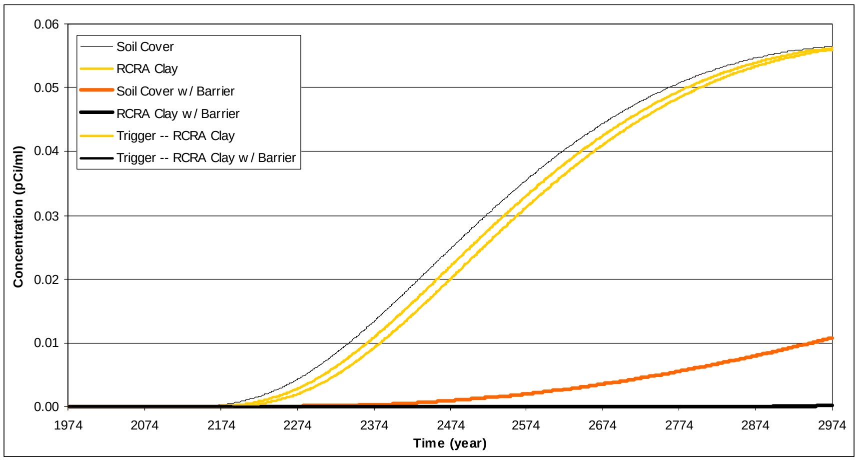



b) Plutonium-239

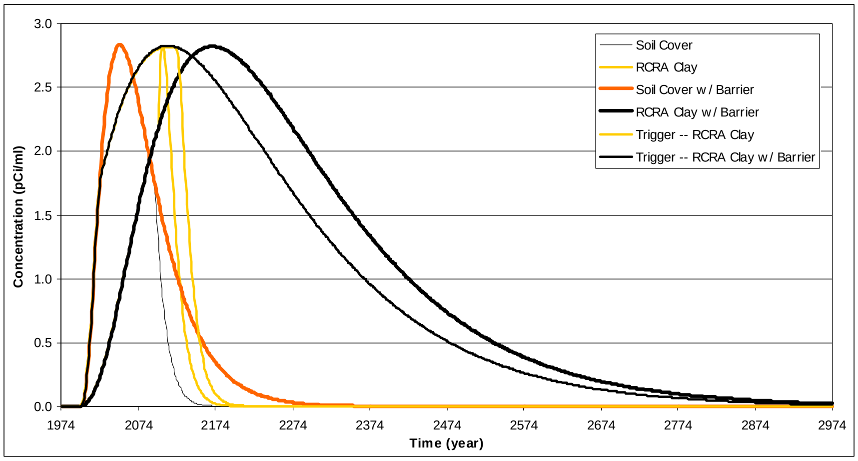



c) Plutonium-238

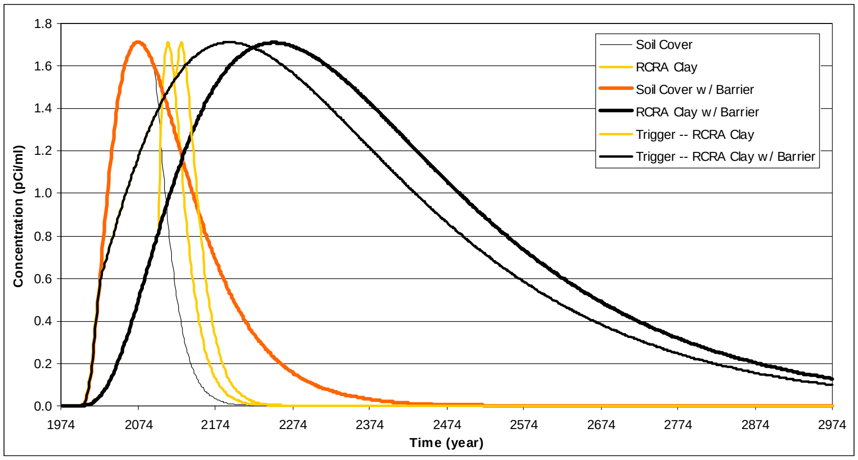
**Figure D-2. Concentration in Saturated Zone below ORWBG vs. Time: Sum of All Elements, Full Impact/Late Timing Model Results**




d) Uranium-238

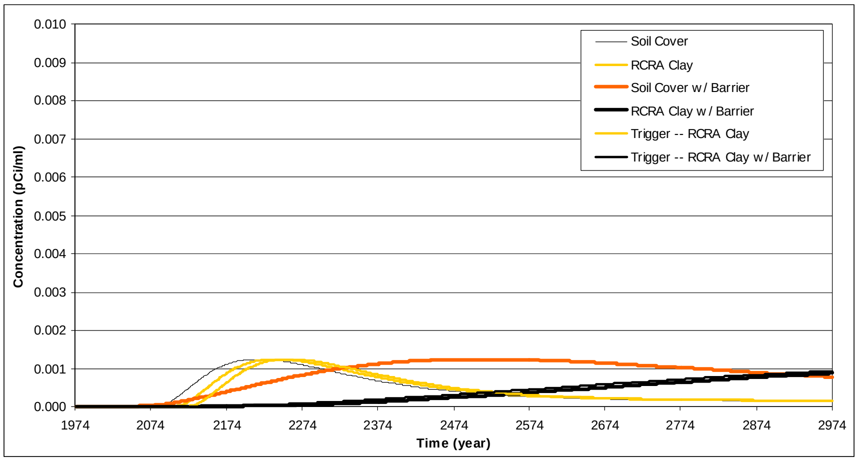



e) Technetium-99

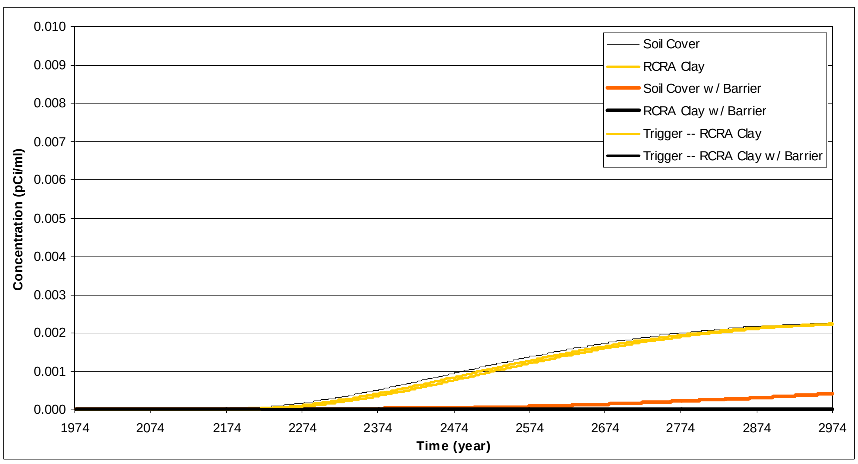



f) Iodine-129

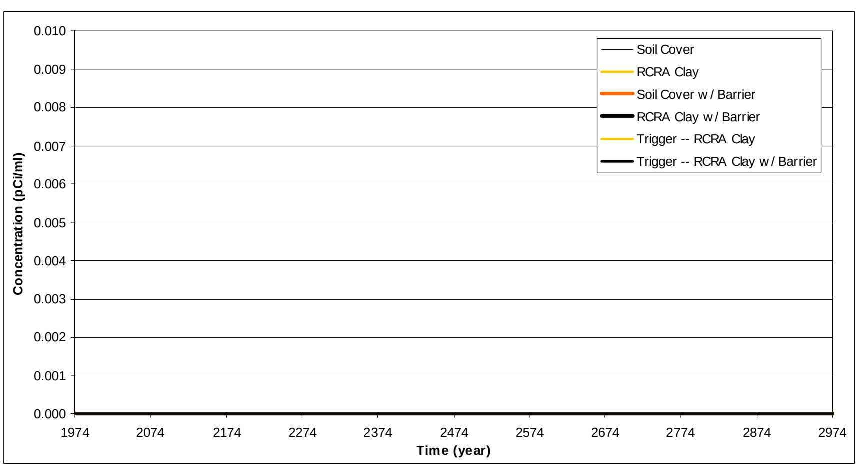
**Figure D-2. (con't) Concentration in Saturated Zone below ORWBG vs. Time: Sum of All Elements, Full Impact/Late Timing Model Results**




g) Neptunium-237

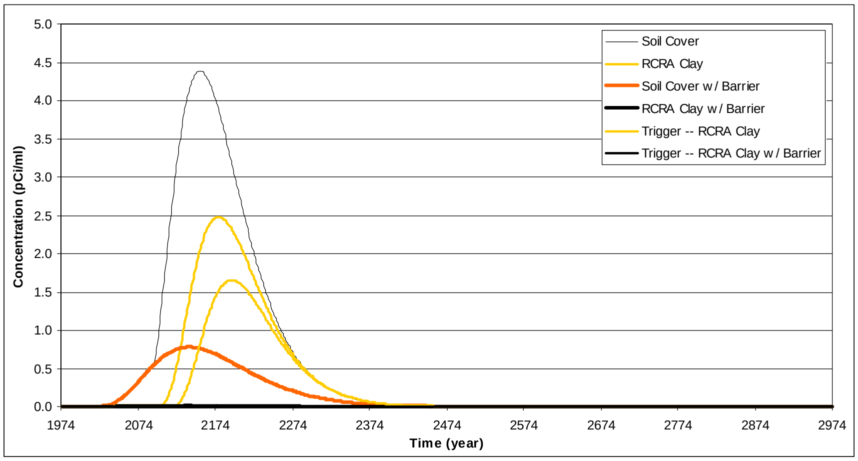



h) Uranium-235

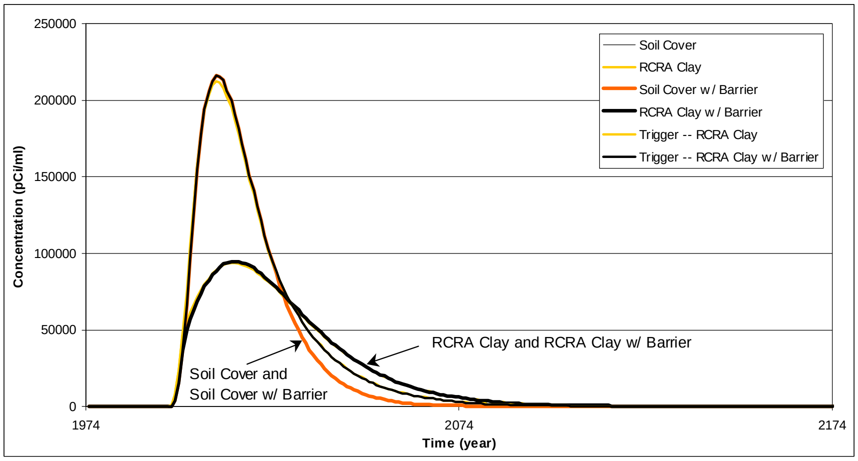



i) Cesium-137

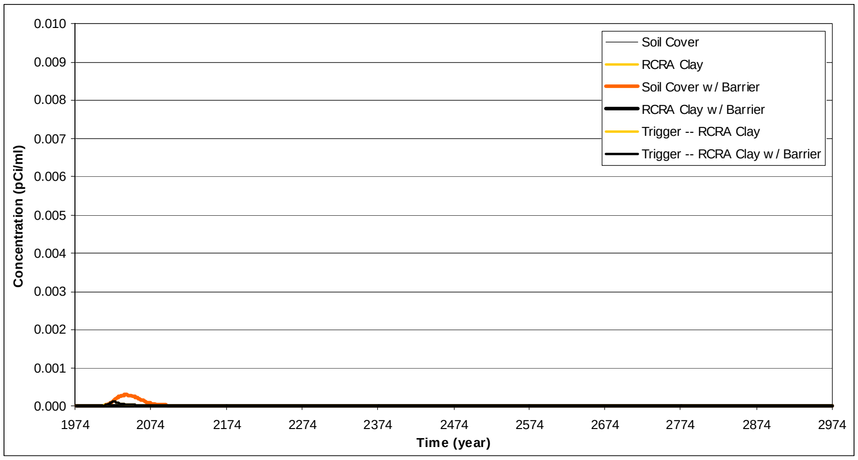
**Figure D-2. (con't) Concentration in Saturated Zone below ORWBG vs. Time: Sum of All Elements, Full Impact/Late Timing Model Results**




j) Strontium-90

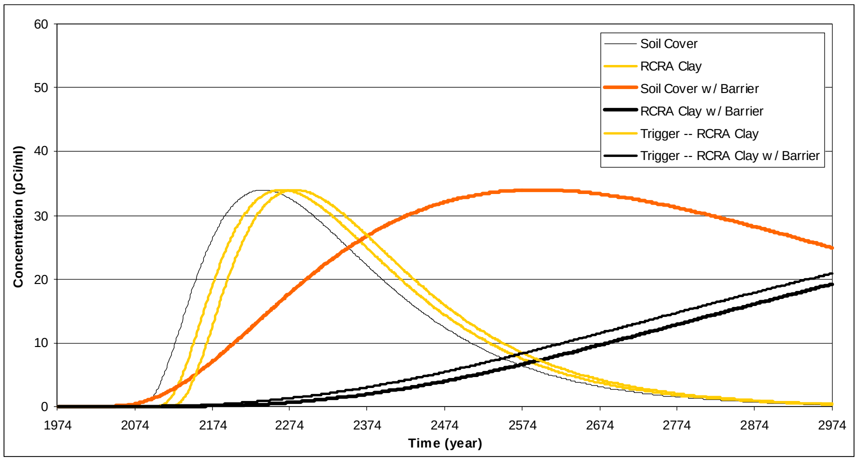



k) Tritium

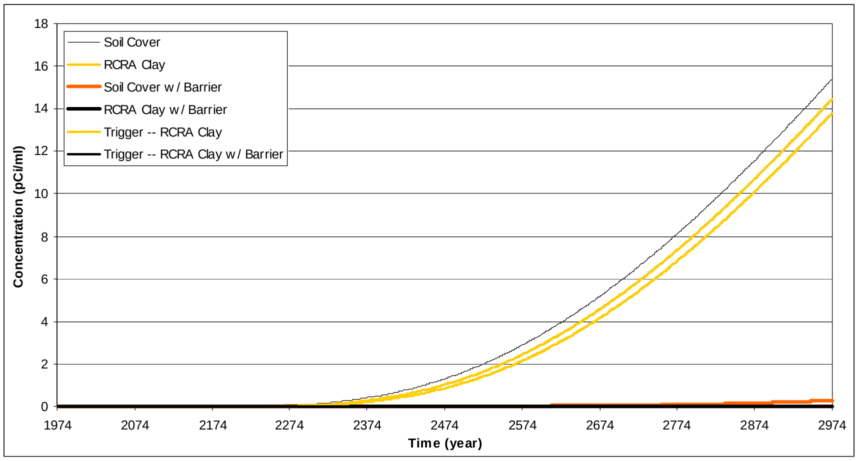



l) Cobalt-60

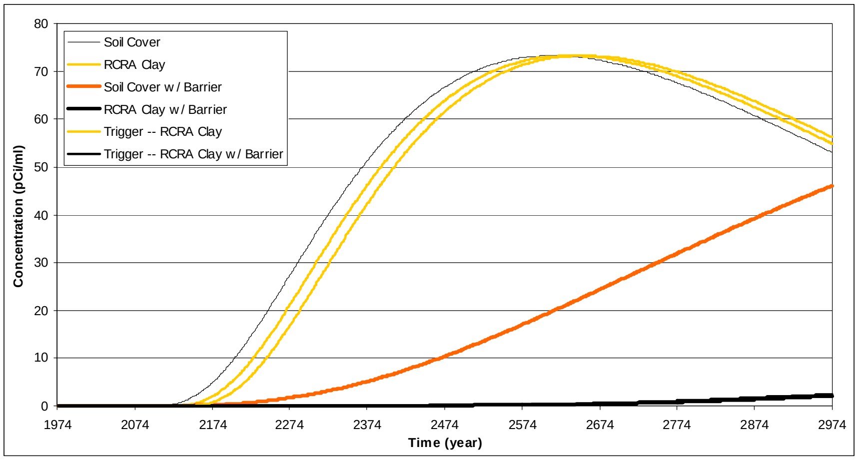
**Figure D-2. (con't) Concentration in Saturated Zone below ORWBG vs. Time: Sum of All Elements, Full Impact/Late Timing Model Results**




m) Cadmium

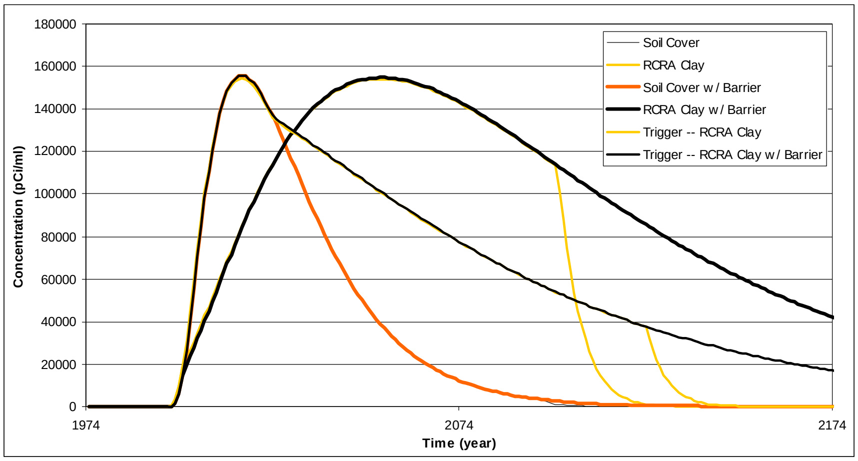



n) Lead



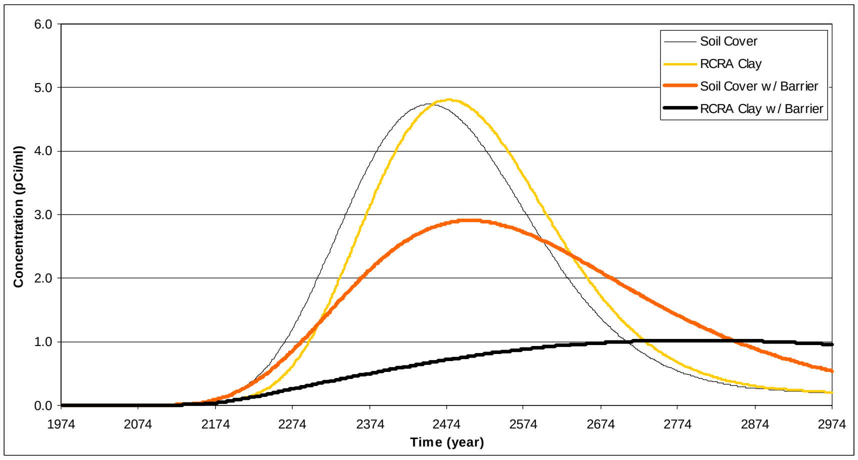

o) Mercury

**Figure D-2. (con't) Concentration in Saturated Zone below ORWBG vs. Time: Sum of All Elements, Full Impact/Late Timing Model Results**

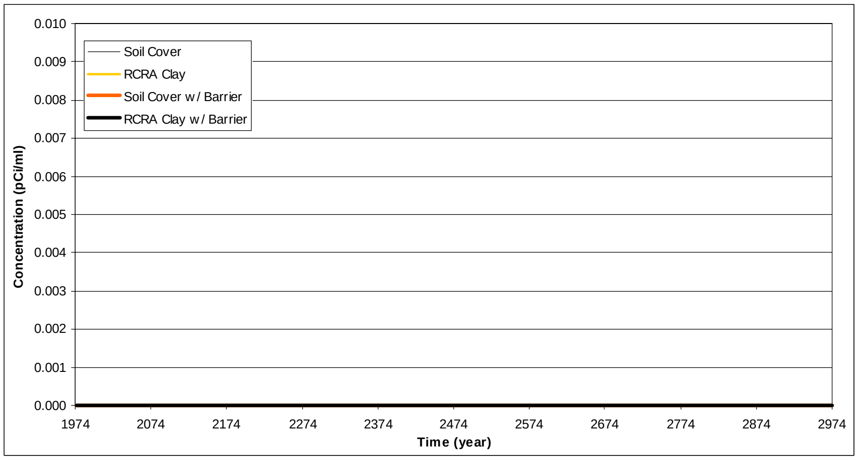



p) VOC

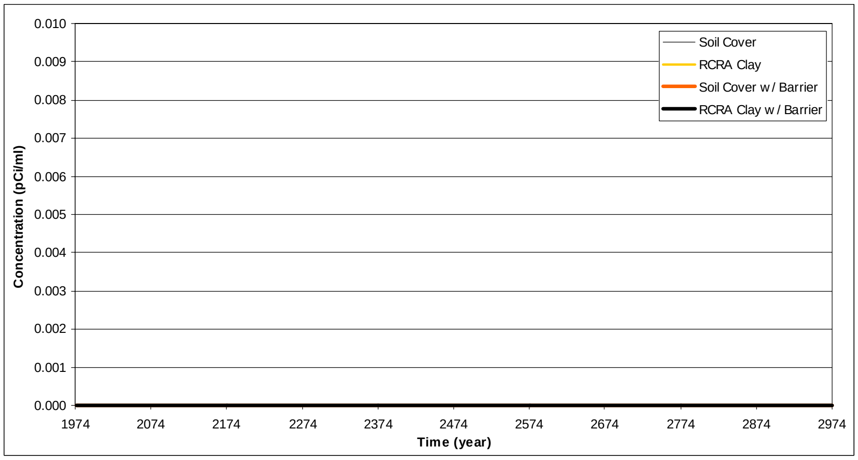
**Figure D-2. (con't) Concentration in Saturated Zone below ORWBG vs. Time: Sum of All Elements, Full Impact/Late Timing Model Results**




a) Carbon-14: Total ORWBG

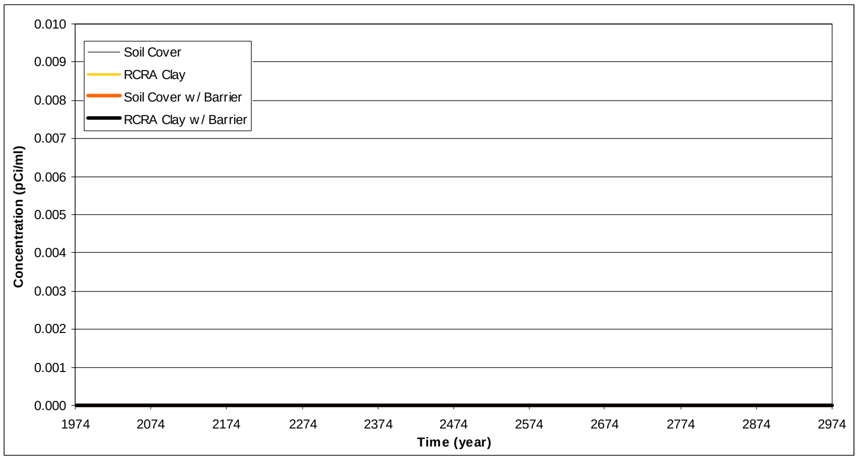



b) Plutonium-239: Total ORWBG

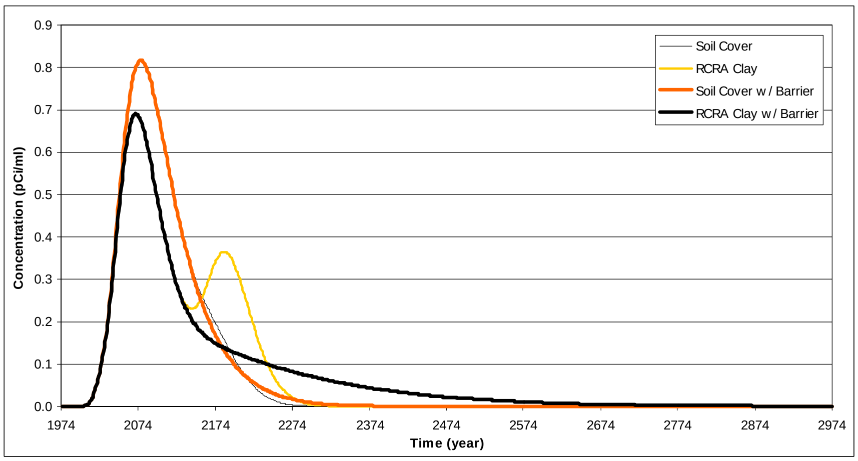



c) Plutonium-238: Total ORWBG

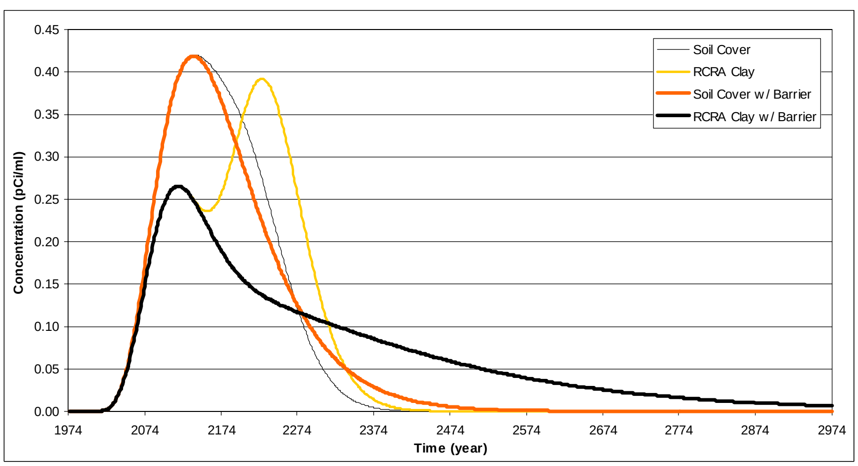
**Figure D-3. Concentration at Seep Line vs. Time: Sum of All Elements, Full Impact/Early Timing Model Results**




d) Uranium-238: Total ORWBG

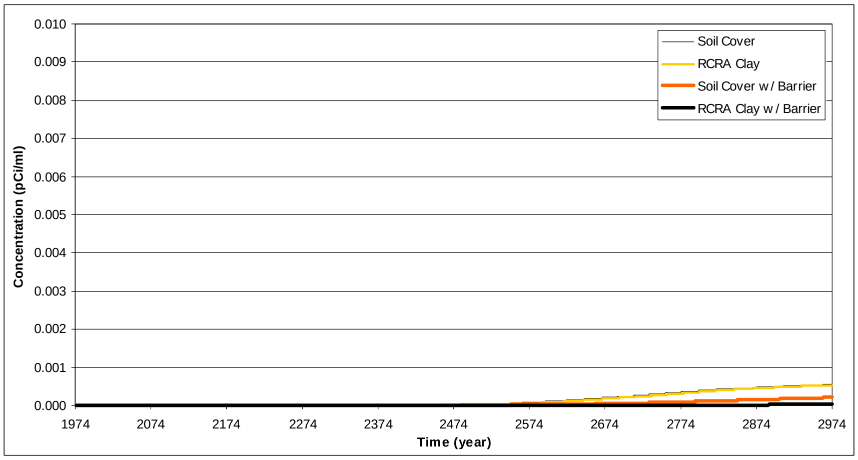



e) Technetium-99: Total ORWBG

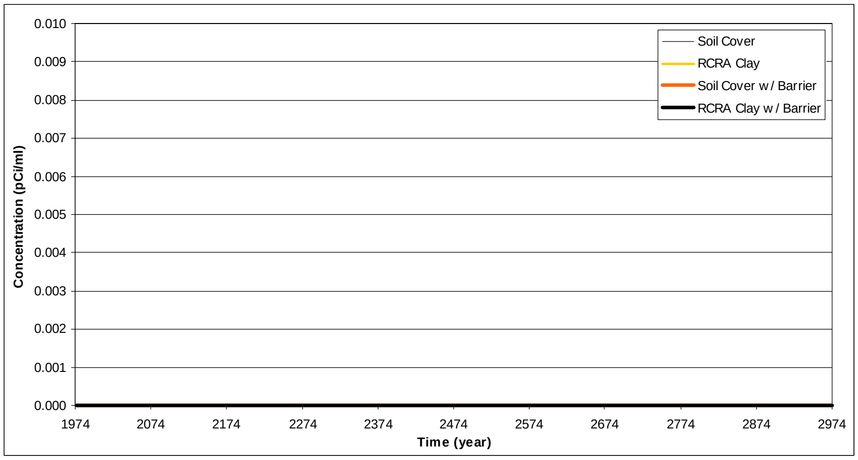



f) Iodine-129: Total ORWBG

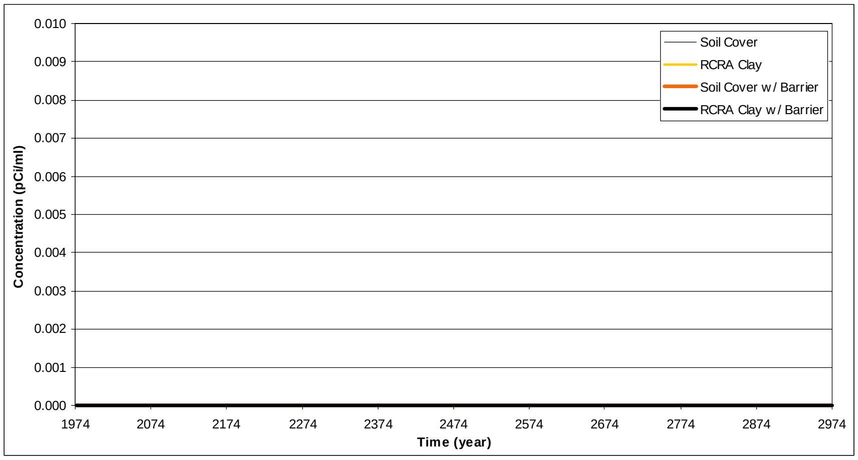
**Figure D-3. (con't) Concentration at Seep Line vs. Time: Sum of All Elements, Full Impact/Early Timing Model Results**




g) Neptunium-237: Total ORWBG

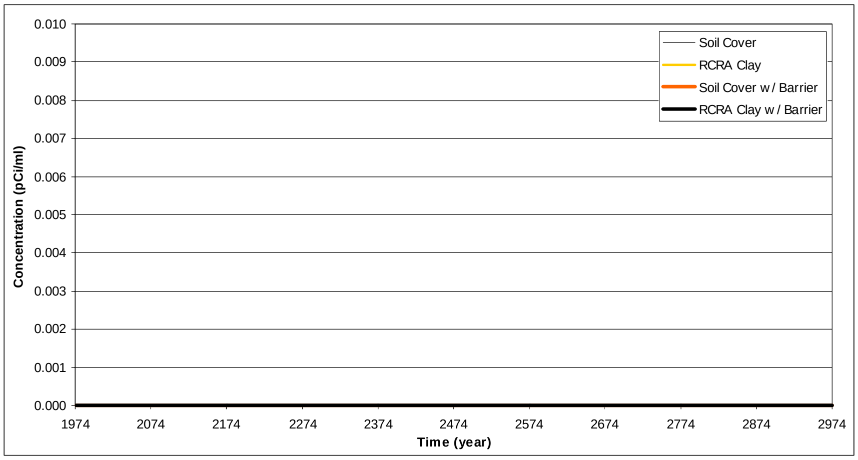



h) Uranium-235: Total ORWBG

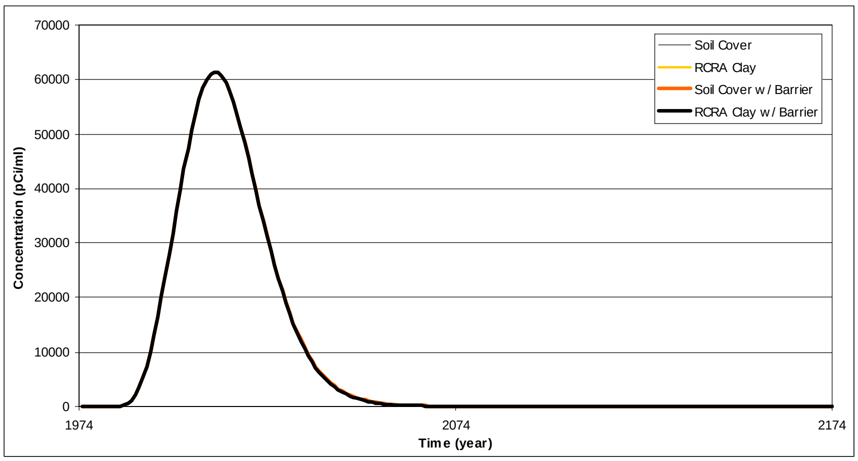



i) Cesium-137: Total ORWBG

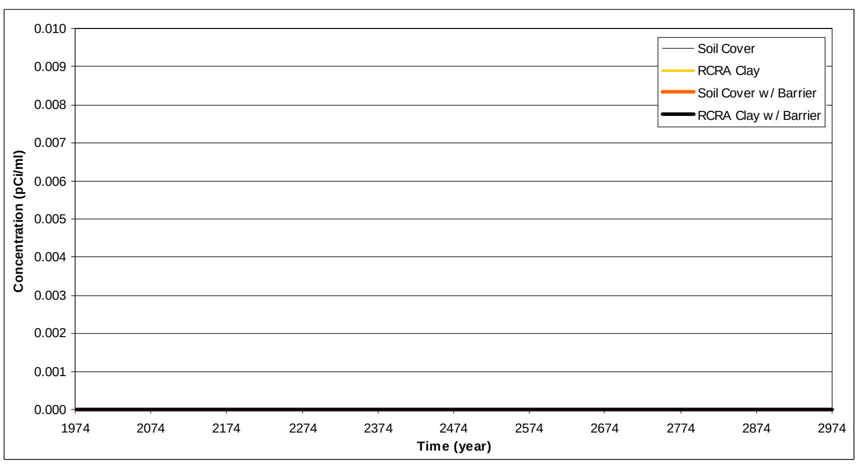
**Figure D-3. (con't) Concentration at Seep Line vs. Time: Sum of All Elements, Full Impact/Early Timing Model Results**




j) Strontium-90: Total ORWBG

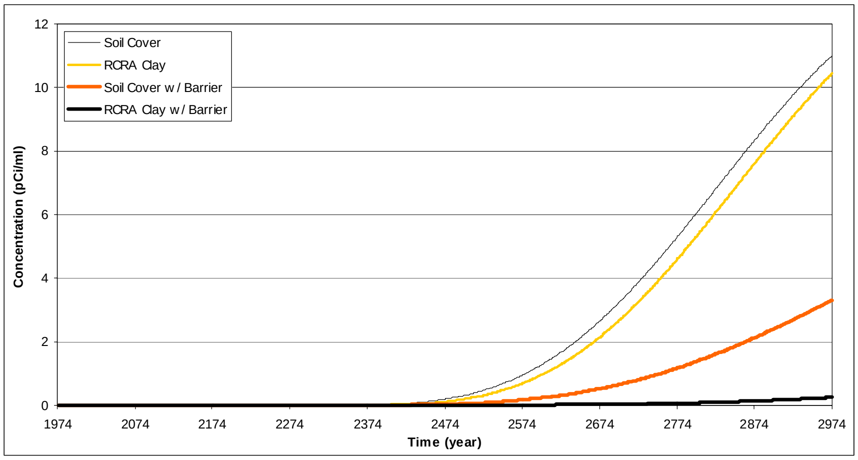



k) Tritium: Total ORWBG

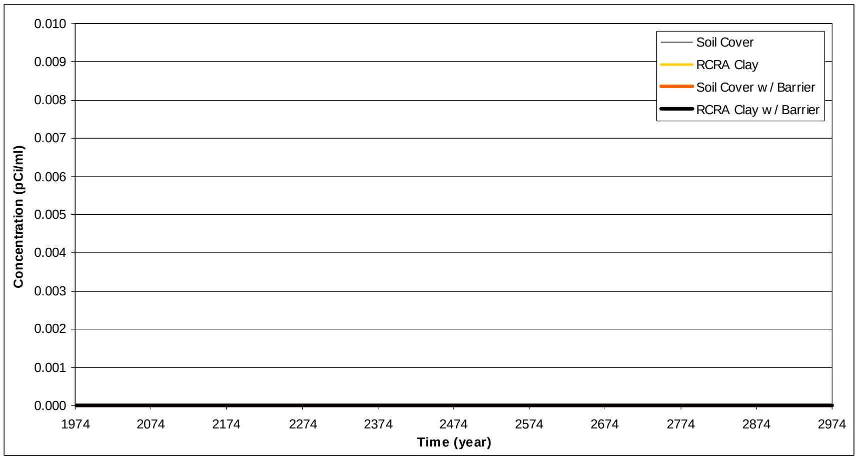



l) Cobalt-60: Total ORWBG

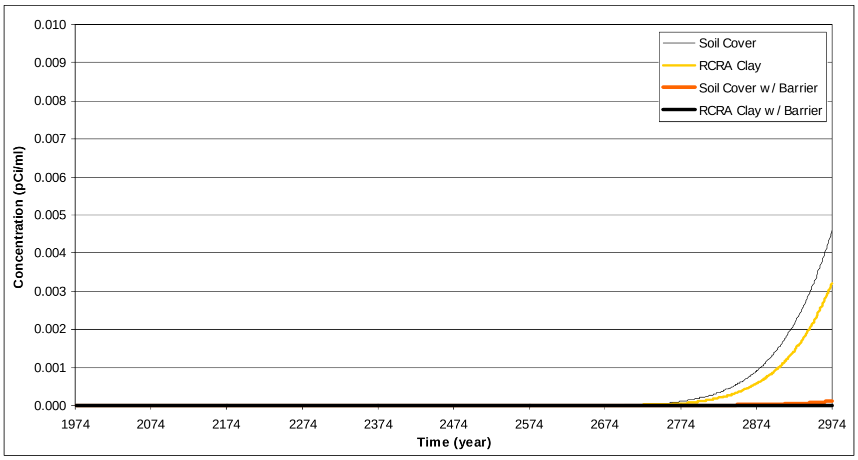
**Figure D-3. (con't) Concentration at Seep Line vs. Time: Sum of All Elements, Full Impact/Early Timing Model Results**




m) Cadmium: Total ORWBG

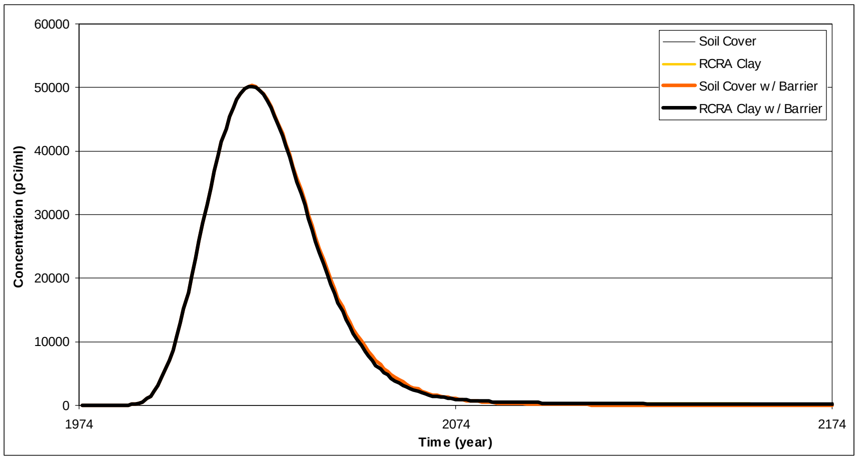



n) Lead: Total ORWBG



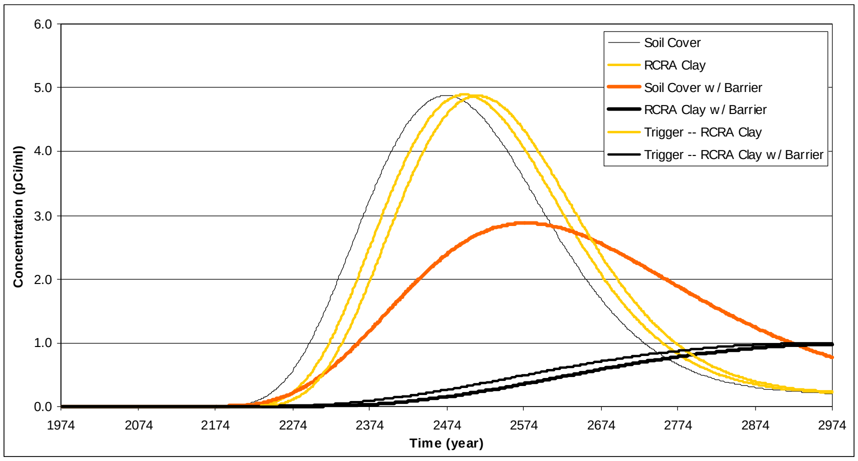

o) Mercury: Total ORWBG

**Figure D-3. (con't) Concentration at Seep Line vs. Time: Sum of All Elements, Full Impact/Early Timing Model Results**

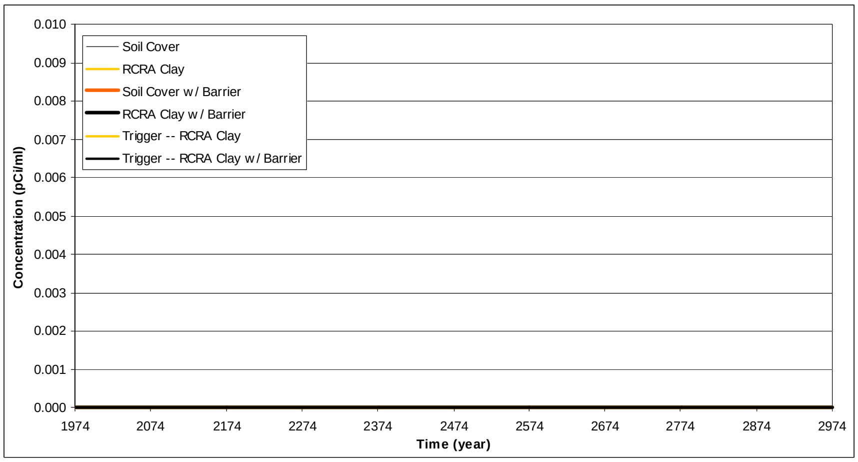



p) VOC: Total ORWBG

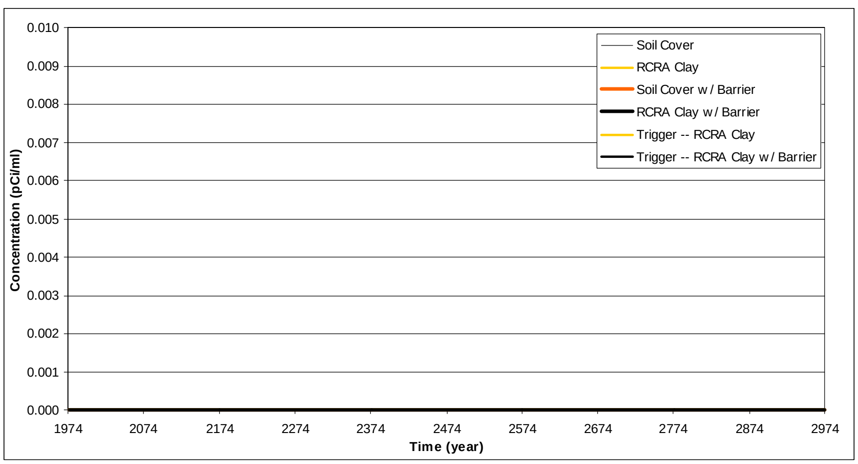
**Figure D-3. (con't) Concentration at Seep Line vs. Time: Sum of All Elements, Full Impact/Early Timing Model Results**




a) Carbon-14

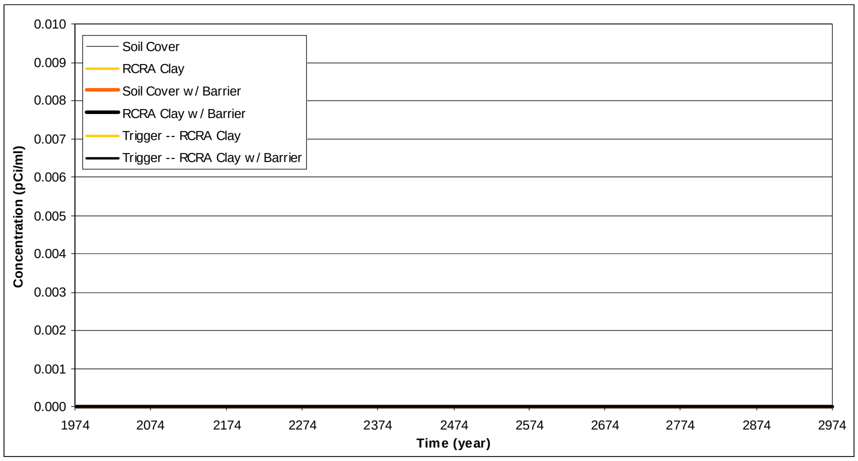



b) Plutonium-239

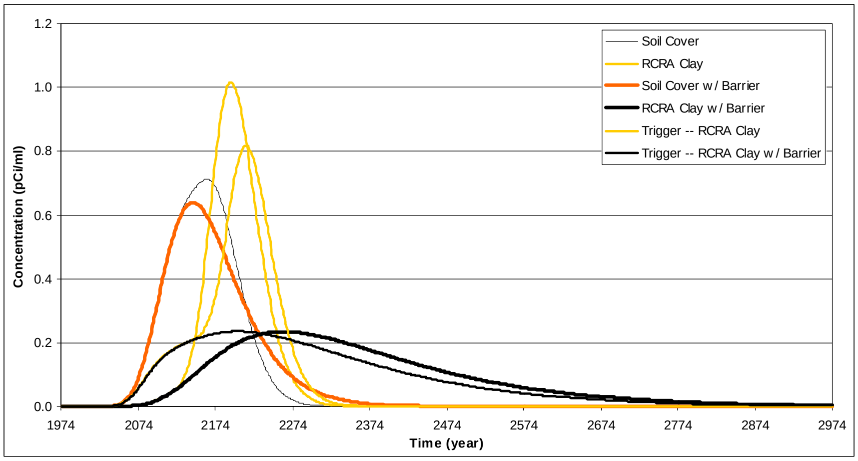



c) Plutonium-238

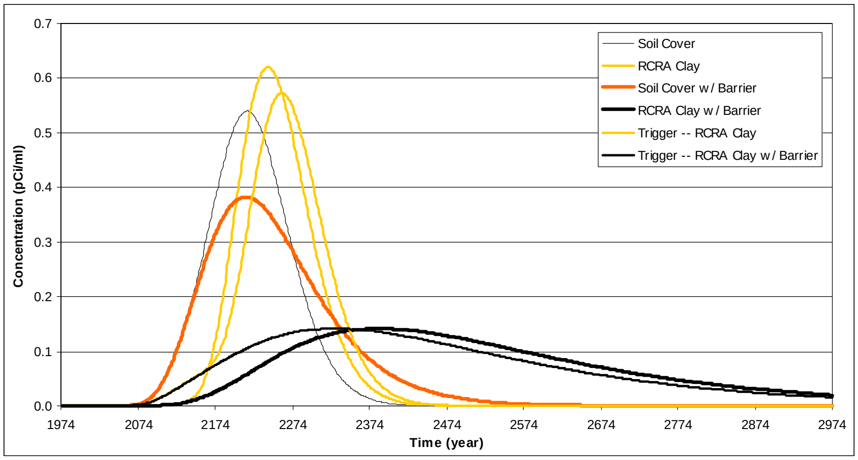
**Figure D-4. Concentration at Seep Line vs. Time:**
**Sum of All Elements, Full Impact/Late Timing Model Results**




d) Uranium-238

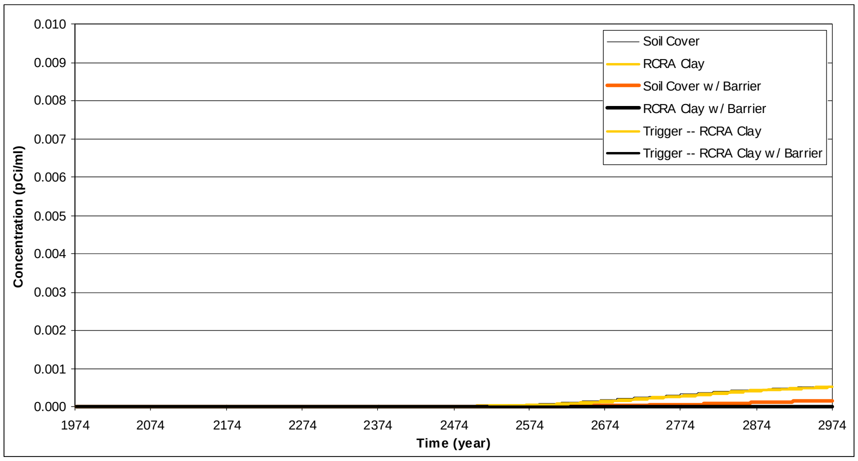



e) Technetium-99

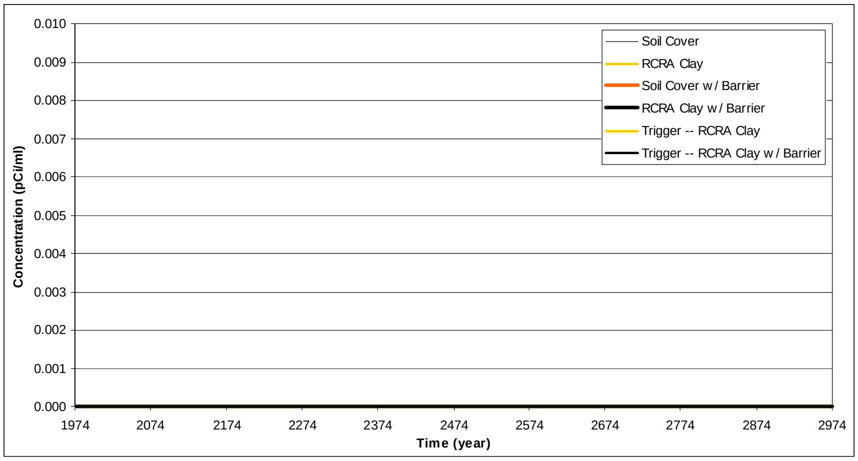



f) Iodine-129

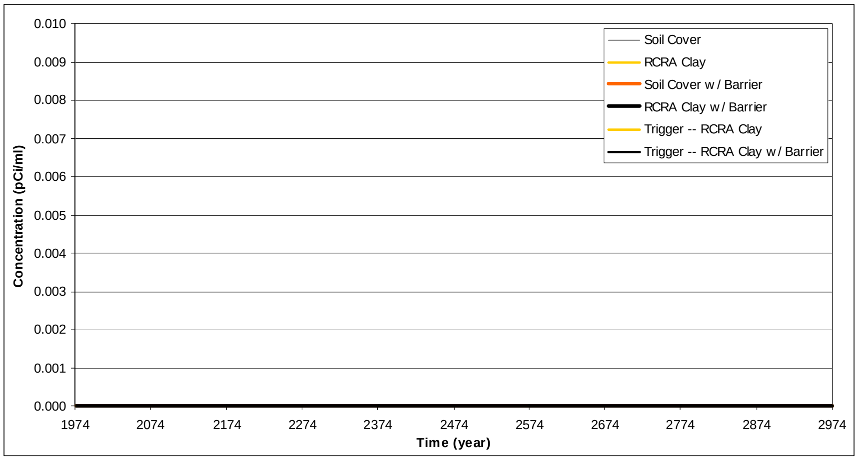
**Figure D-4. (con't) Concentration at Seep Line vs. Time: Sum of All Elements, Full Impact/Late Timing Model Results**




g) Neptunium-237

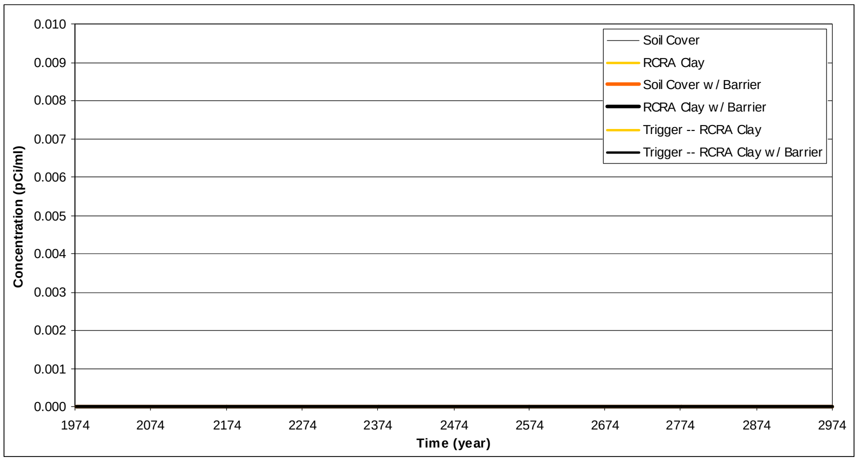



h) Uranium-235

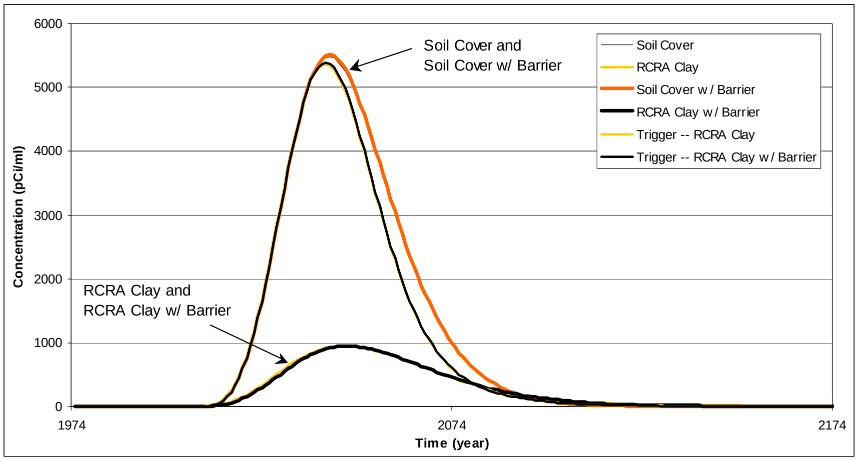



i) Cesium-137

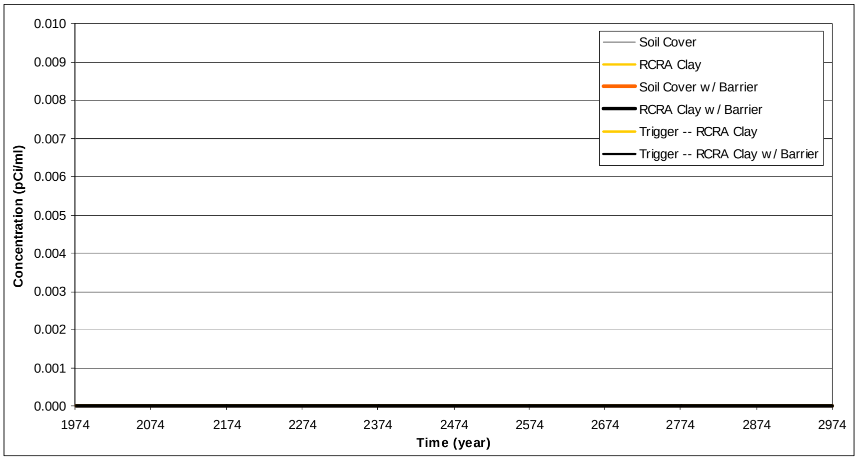
**Figure D-4. (con't) Concentration at Seep Line vs. Time: Sum of All Elements, Full Impact/Late Timing Model Results**




j) Strontium-90

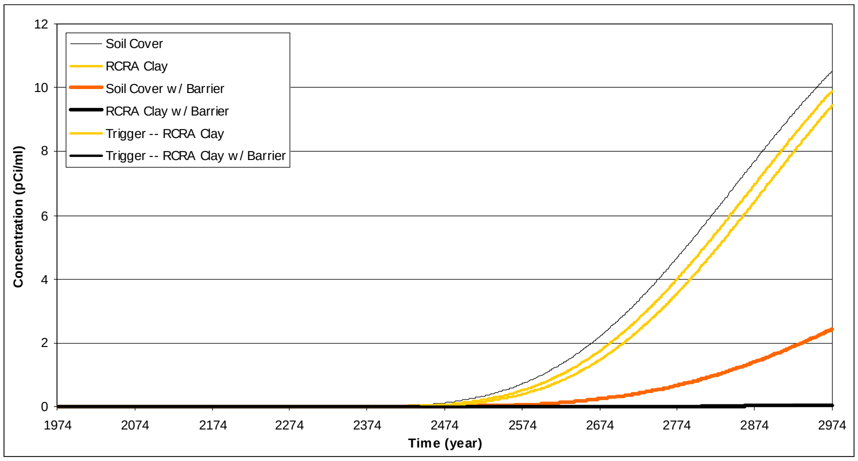



k) Tritium

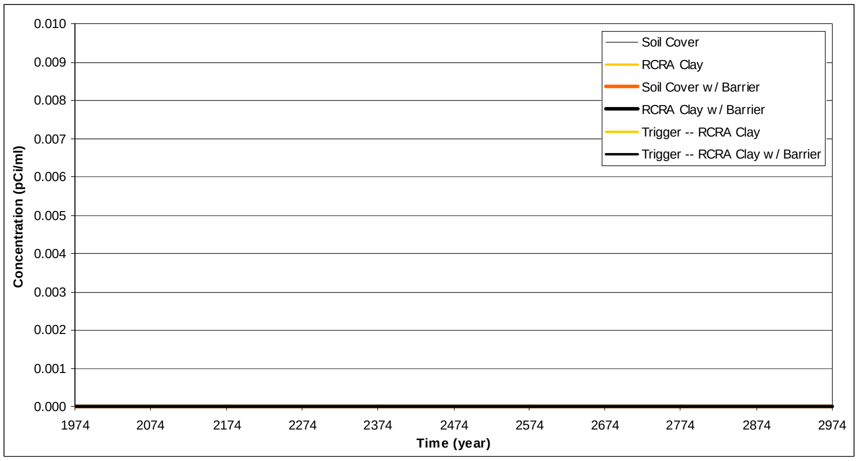



l) Cobalt-60

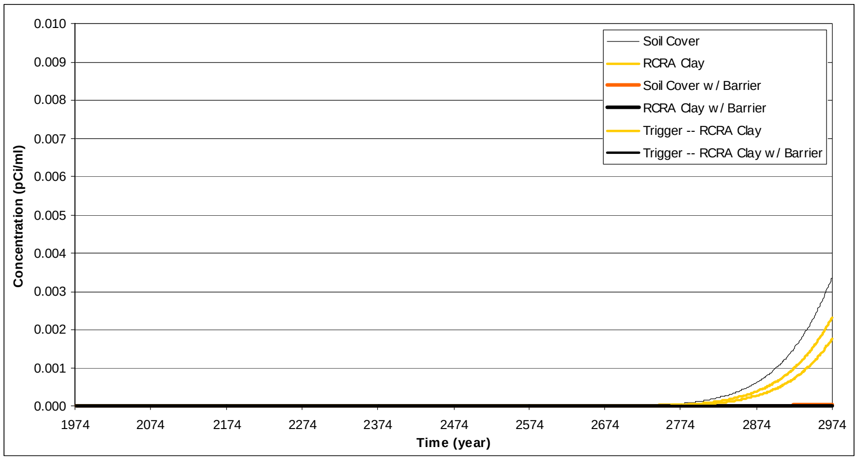
**Figure D-4. (con't) Concentration at Seep Line vs. Time: Sum of All Elements, Full Impact/Late Timing Model Results**




m) Cadmium

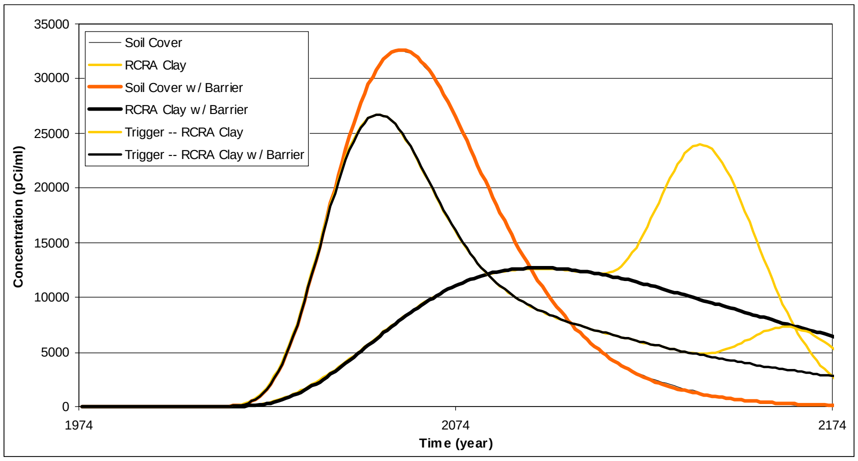



n) Lead



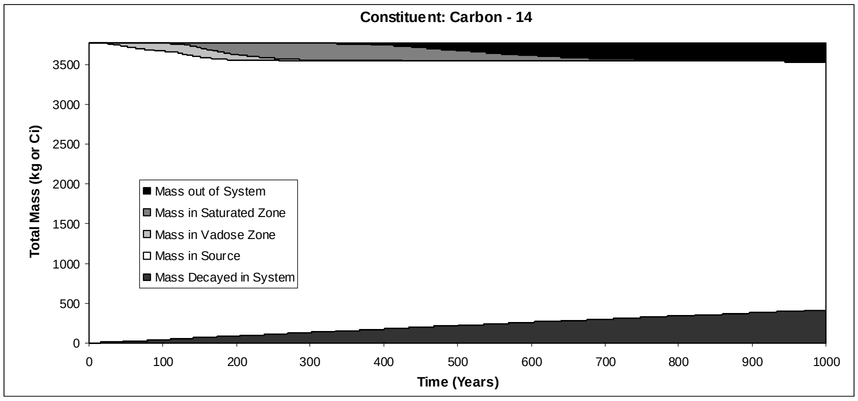

o) Mercury

**Figure D-4. (con't) Concentration at Seep Line vs. Time: Sum of All Elements, Full Impact/Late Timing Model Results**

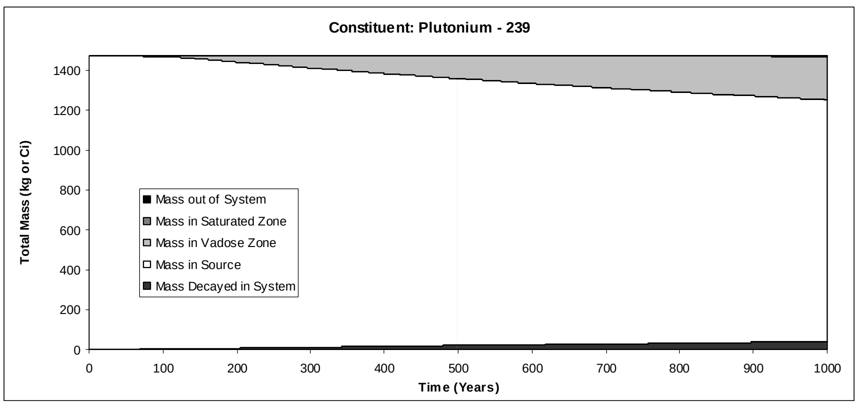



p) VOC

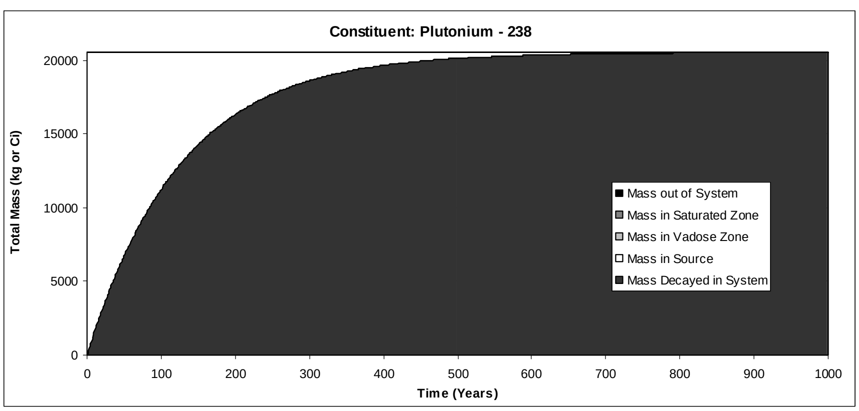
**Figure D-4. (con't) Concentration at Seep Line vs. Time: Sum of All Elements, Full Impact/Late Timing Model Results**




a) Carbon-14

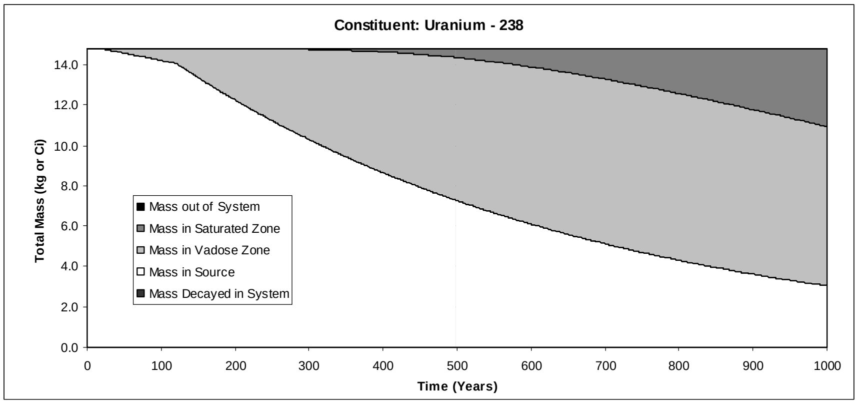



b) Plutonium-239

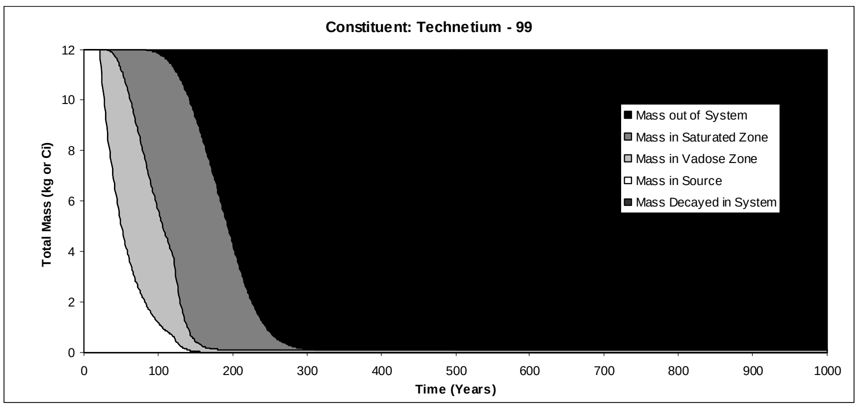



c) Plutonium-238

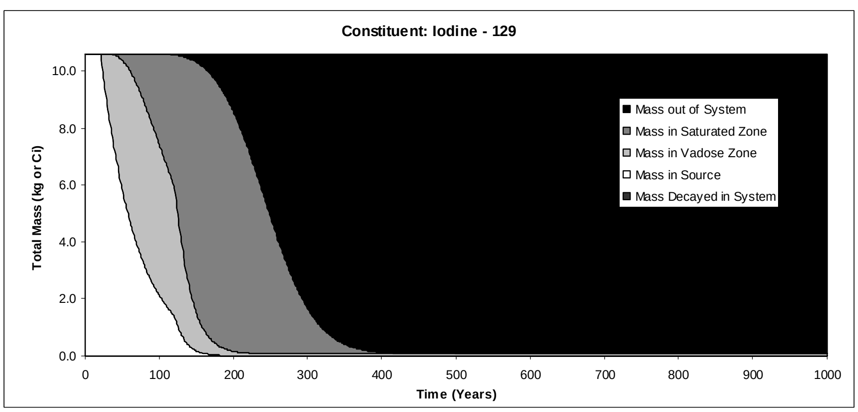
**Figure D-5. Disposition of Total Mass (Activity) for Soil Cover: Sum of All Elements, Full Impact/Late Timing Model Results**




d) Uranium-238

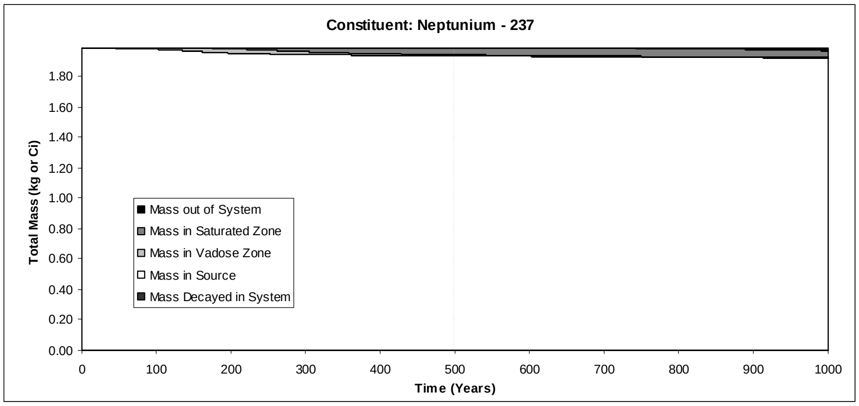



e) Technetium-99

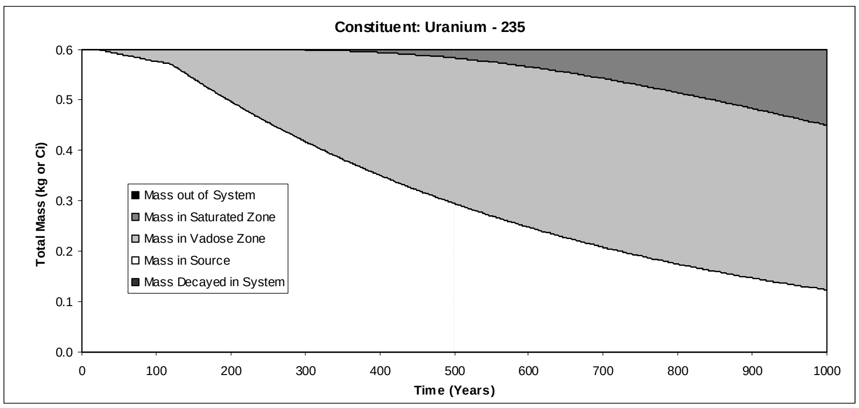



f) Iodine-129

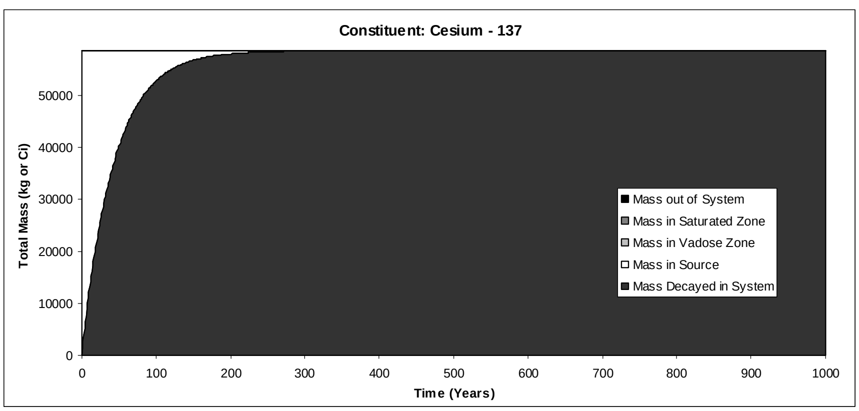
**Figure D-5. (cont't) Disposition of Total Mass (Activity) for Soil Cover: Sum of All Elements, Full Impact/Late Timing Model Results**




g) Neptunium-237

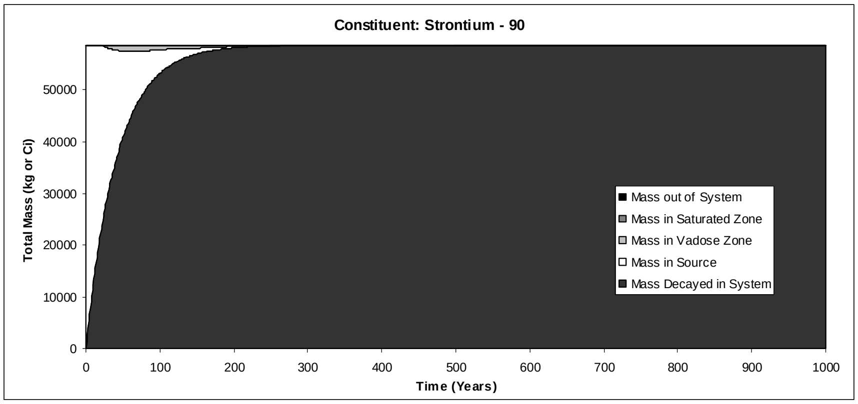



h) Uranium-235

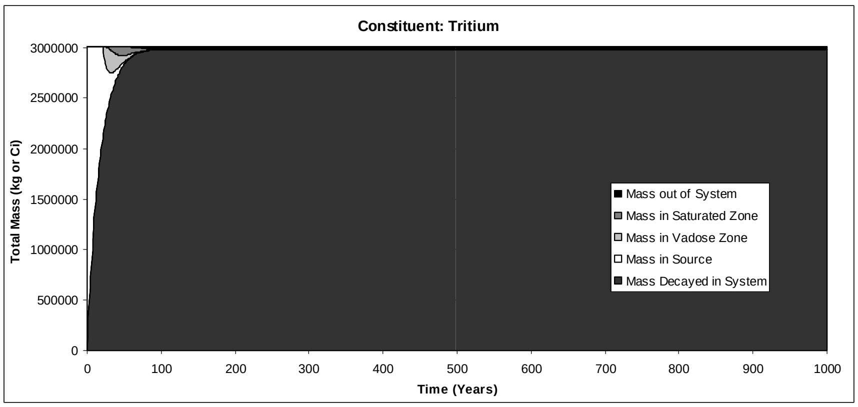



i) Cesium-137

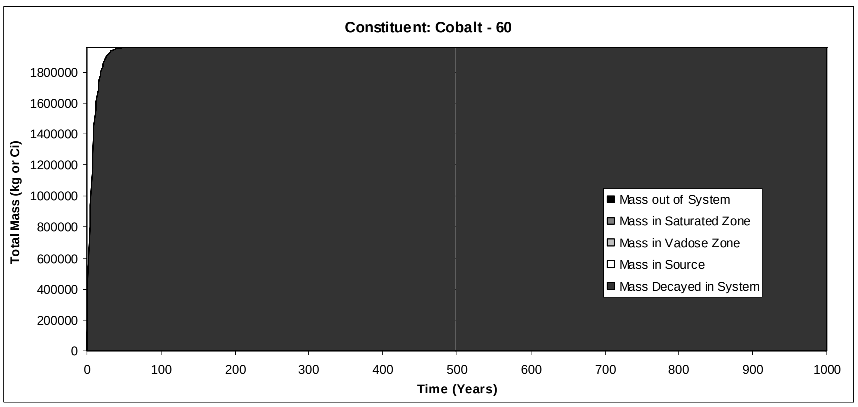
**Figure D-5. (cont't) Disposition of Total Mass (Activity) for Soil Cover: Sum of All Elements, Full Impact/Late Timing Model Results**




j) Strontium-90

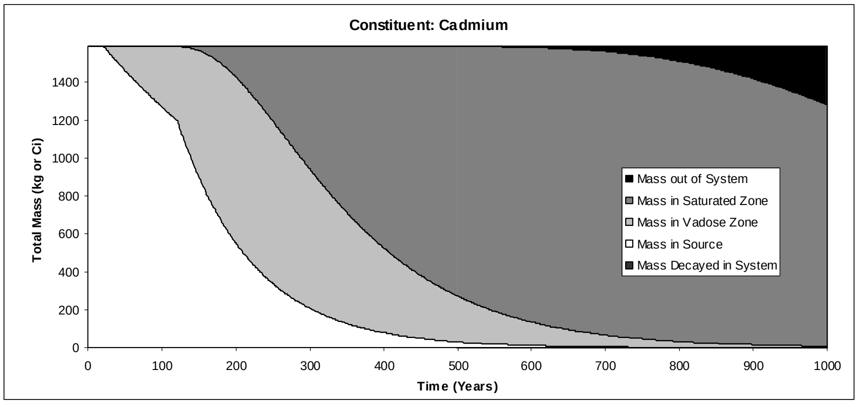



k) Tritium

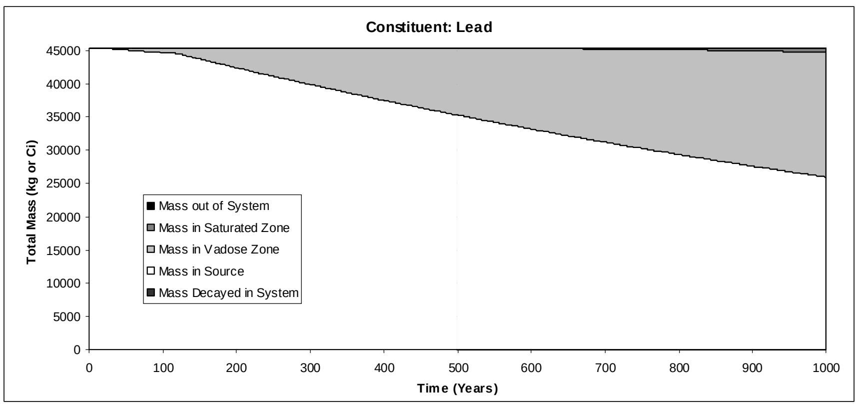



l) Cobalt-60

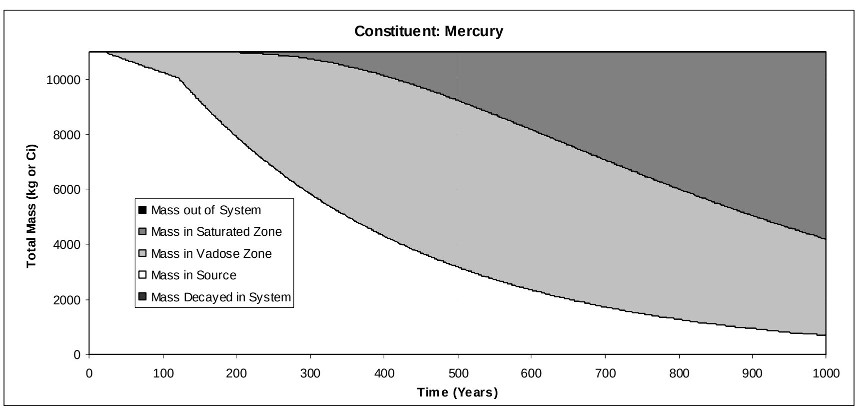
**Figure D-5. (cont't) Disposition of Total Mass (Activity) for Soil Cover: Sum of All Elements, Full Impact/Late Timing Model Results**




m) Cadmium

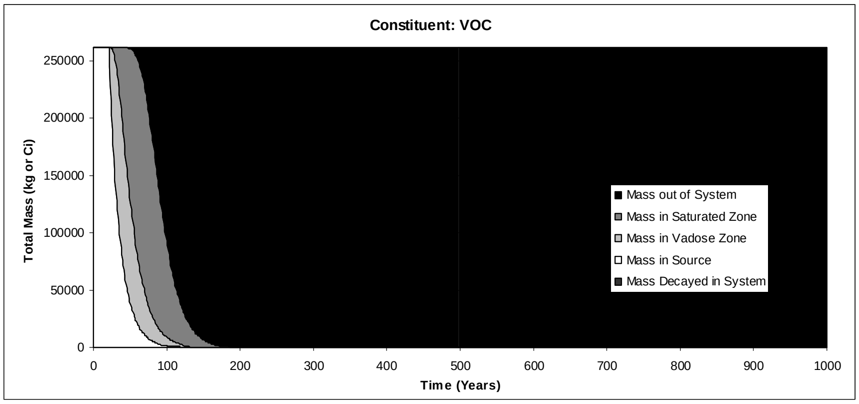



n) Lead



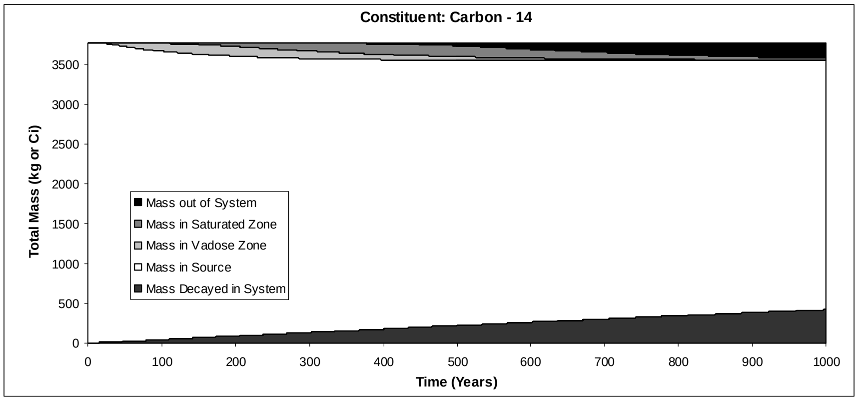

o) Mercury

**Figure D-5. (cont't) Disposition of Total Mass (Activity) for Soil Cover: Sum of All Elements, Full Impact/Late Timing Model Results**

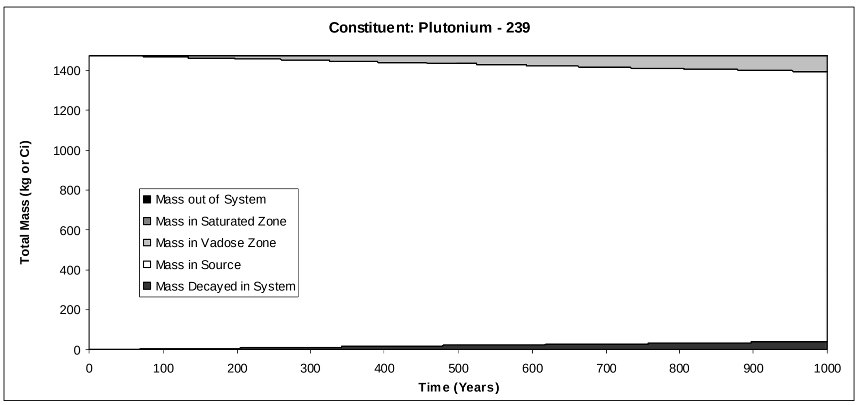



p) VOC

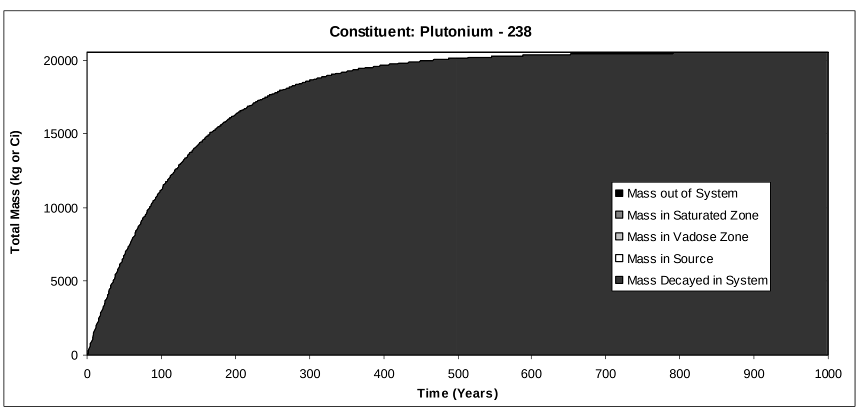
**Figure D-5. (cont't) Disposition of Total Mass (Activity) for Soil Cover: Sum of All Elements, Full Impact/Late Timing Model Results**




a) Carbon-14

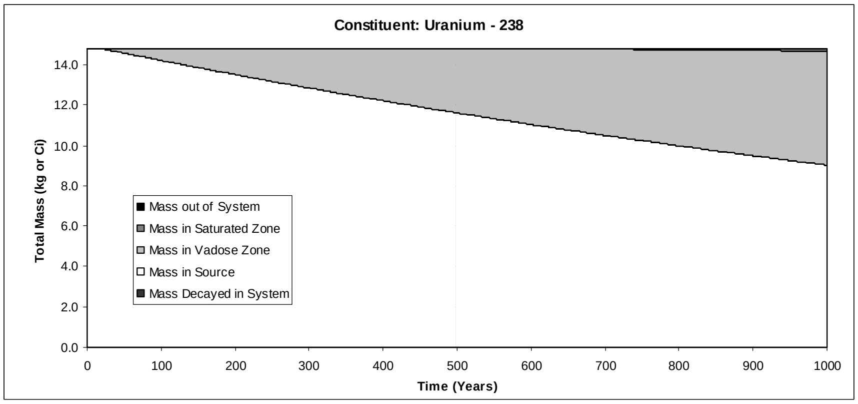



b) Plutonium-239

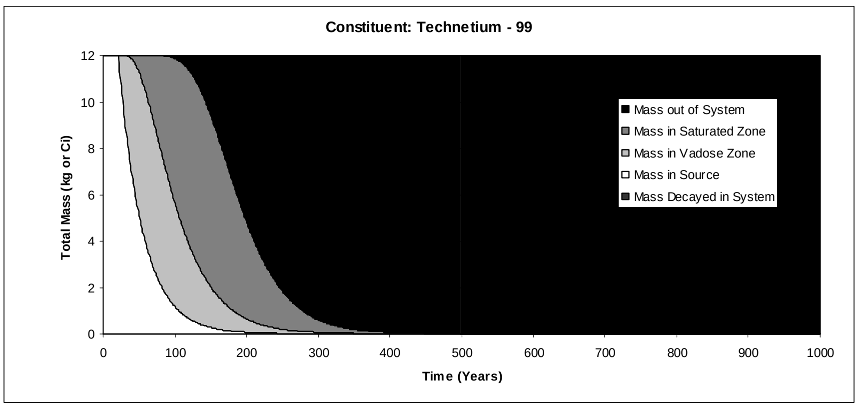



c) Plutonium-238

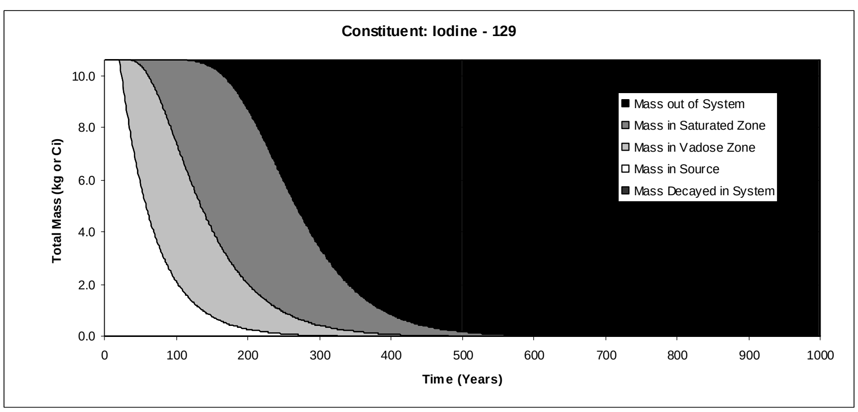
**Figure D-6. Disposition of Total Mass (Activity) for Soil Cover w/ Barrier: Sum of All Elements, Full Impact/Late Timing Model Results**




d) Uranium-238

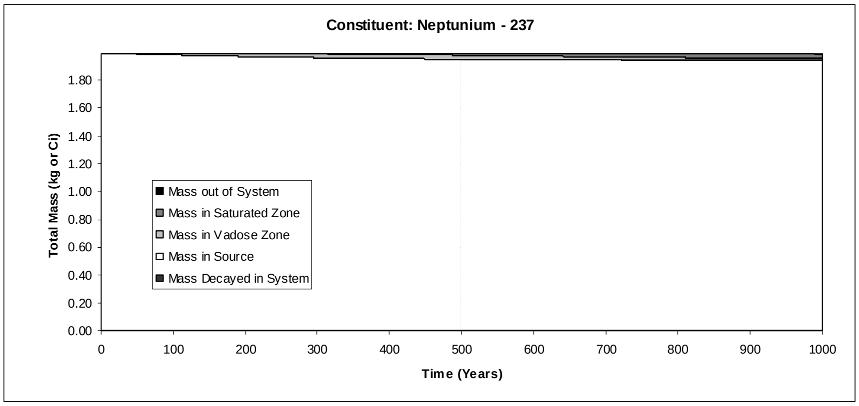



e) Technetium-99

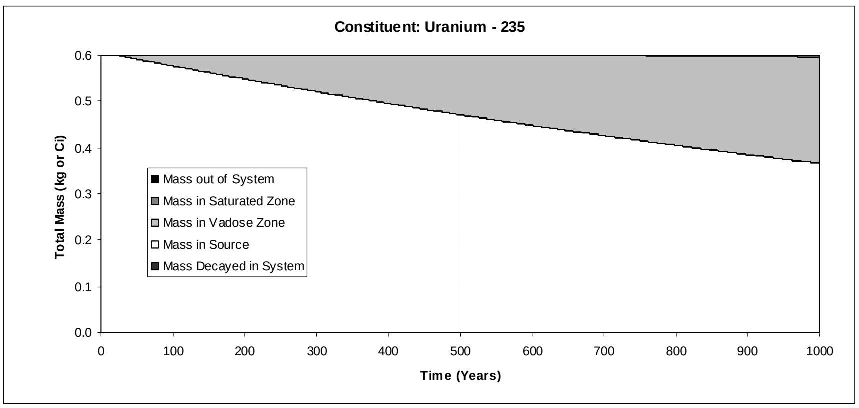



f) Iodine-129

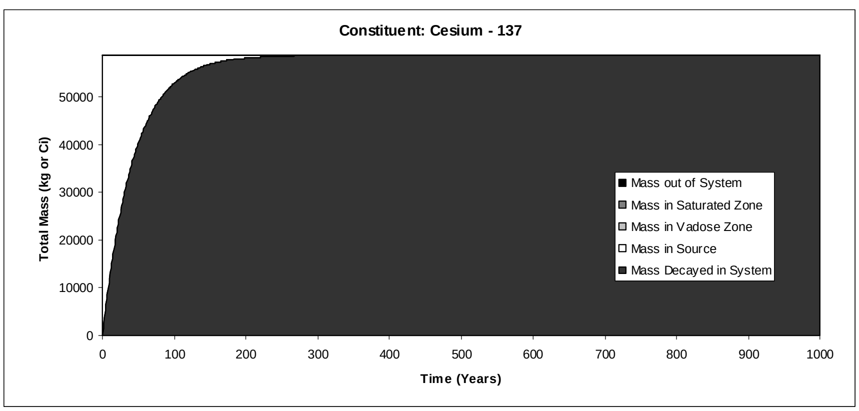
**Figure D-6. (con't) Disposition of Total Mass (Activity) for Soil Cover w/ Barrier: Sum of All Elements, Full Impact/Late Timing Model Results**




g) Neptunium-237

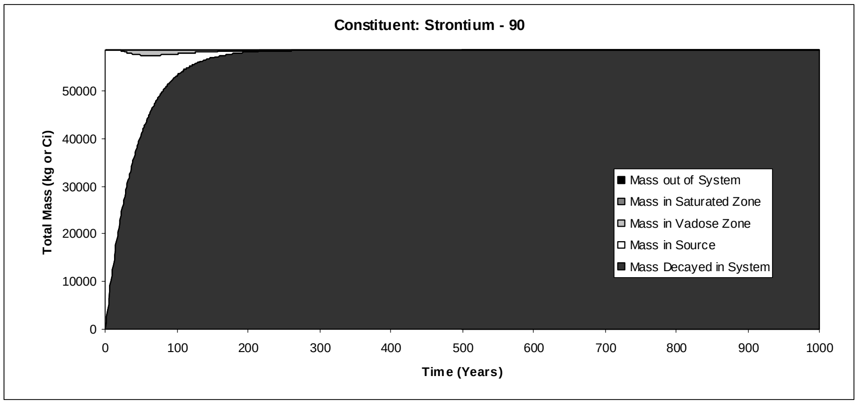



h) Uranium-235

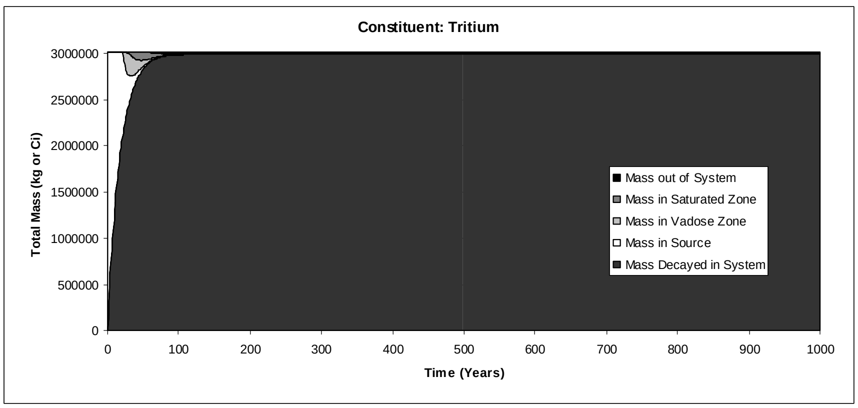



i) Cesium-137

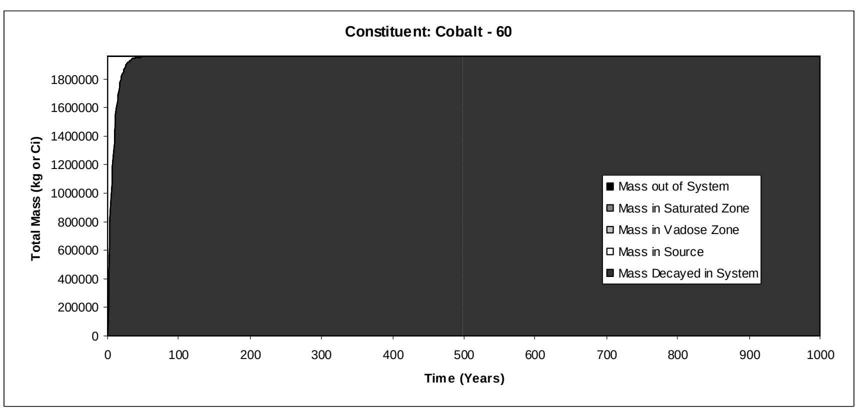
**Figure D-6. (con't) Disposition of Total Mass (Activity) for Soil Cover w/ Barrier: Sum of All Elements, Full Impact/Late Timing Model Results**




j) Strontium-90

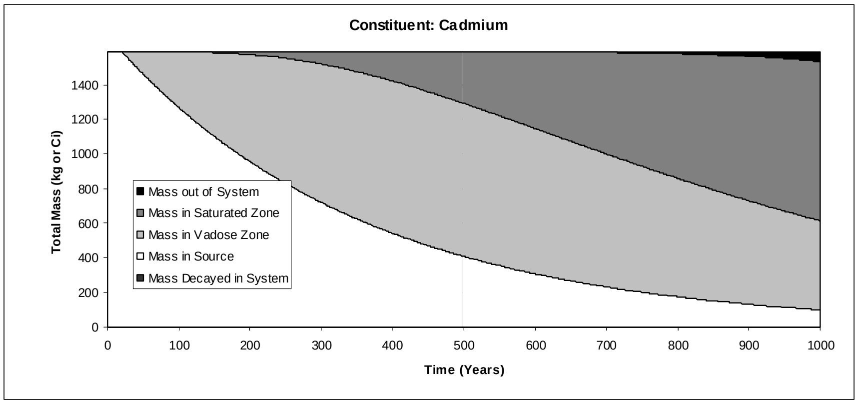



k) Tritium

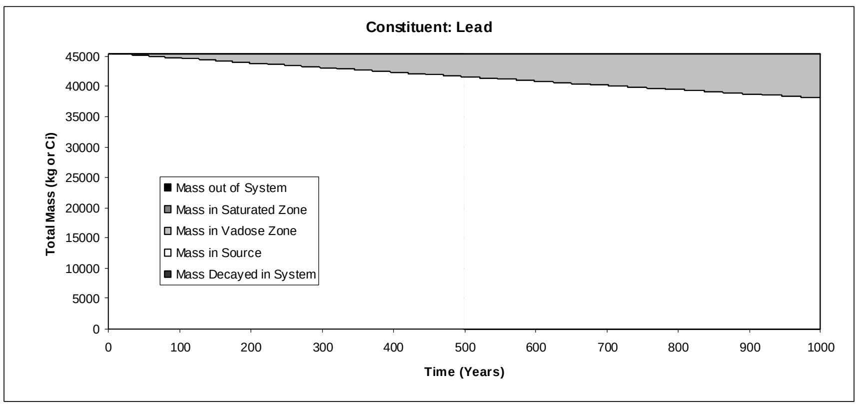



l) Cobalt-60

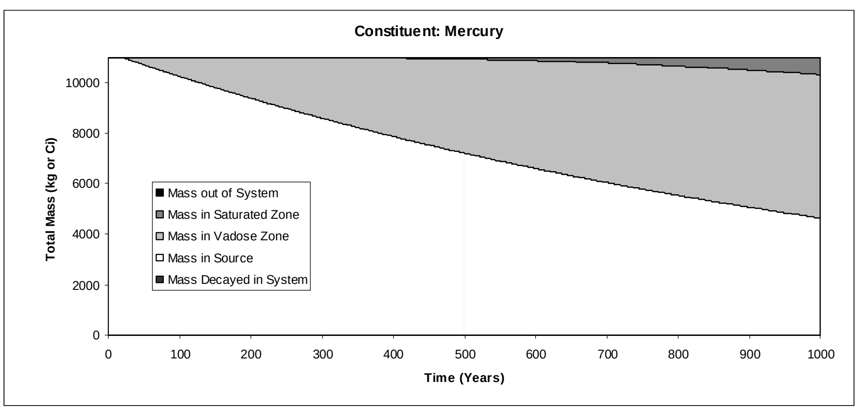
**Figure D-6. (con't) Disposition of Total Mass (Activity) for Soil Cover w/ Barrier: Sum of All Elements, Full Impact/Late Timing Model Results**




m) Cadmium

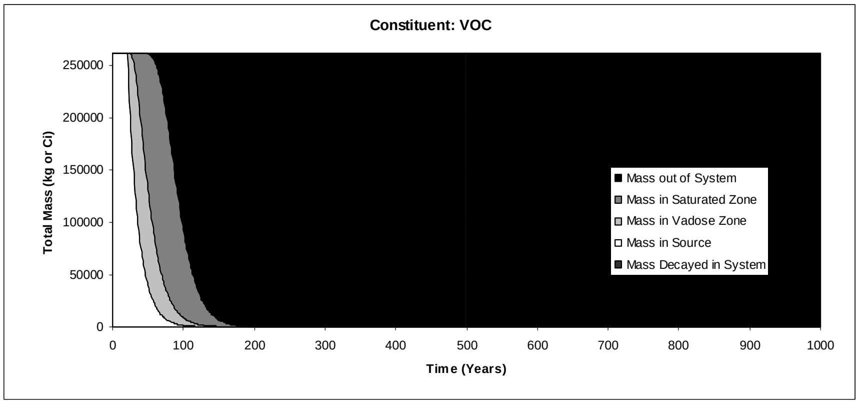



n) Lead



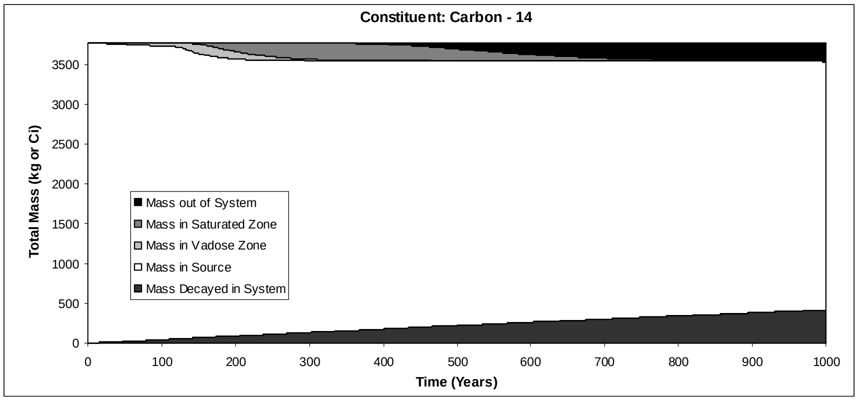

o) Mercury

**Figure D-6. (con't) Disposition of Total Mass (Activity) for Soil Cover w/ Barrier: Sum of All Elements, Full Impact/Late Timing Model Results**

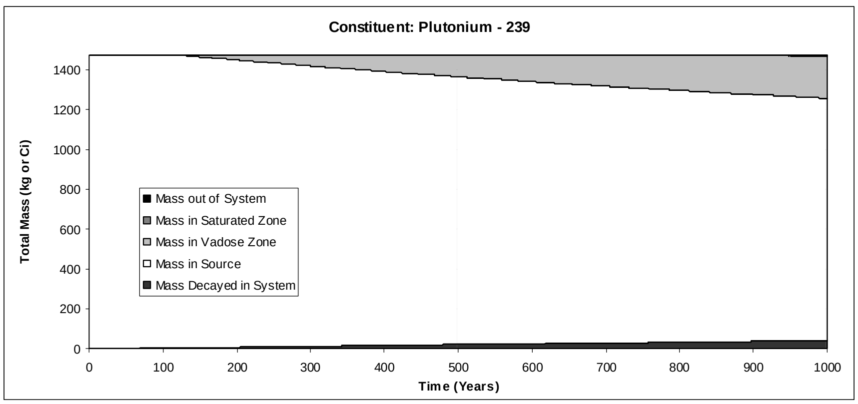



p) VOC

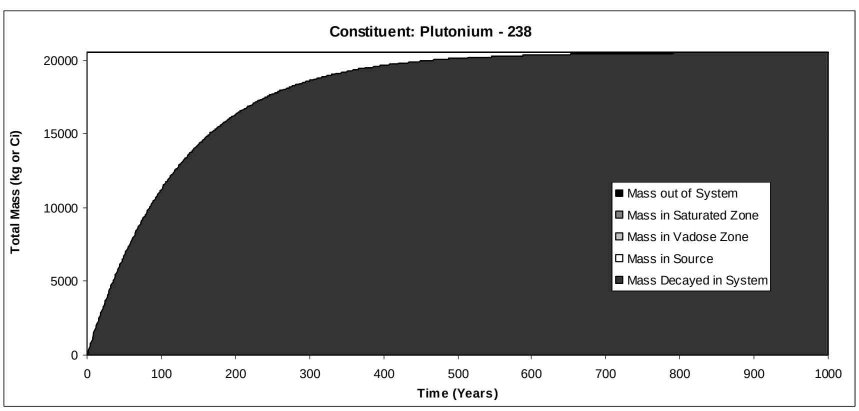
**Figure D-6. (con't) Disposition of Total Mass (Activity) for Soil Cover w/ Barrier: Sum of All Elements, Full Impact/Late Timing Model Results**




a) Carbon-14

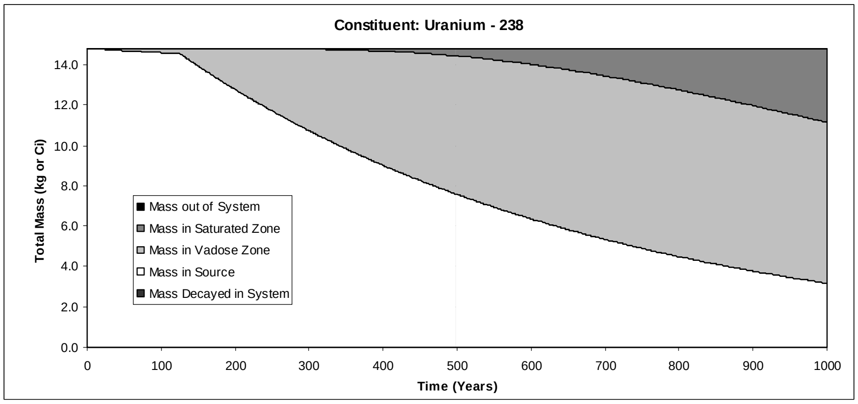



b) Plutonium-239

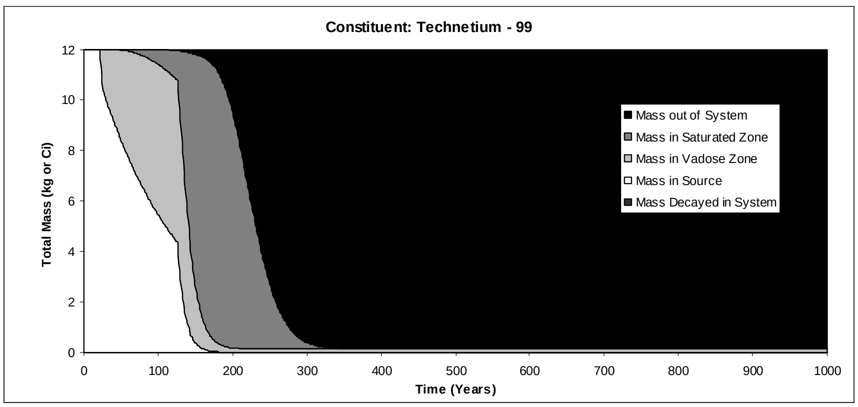



c) Plutonium-238

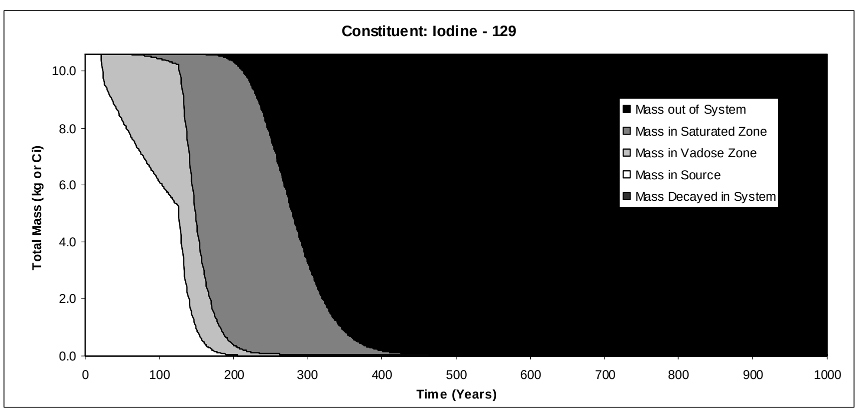
**Figure D-7. Disposition of Total Mass (Activity) for RCRA Clay Cap: Sum of All Elements, Full Impact/Late Timing Model Results**




d) Uranium-238

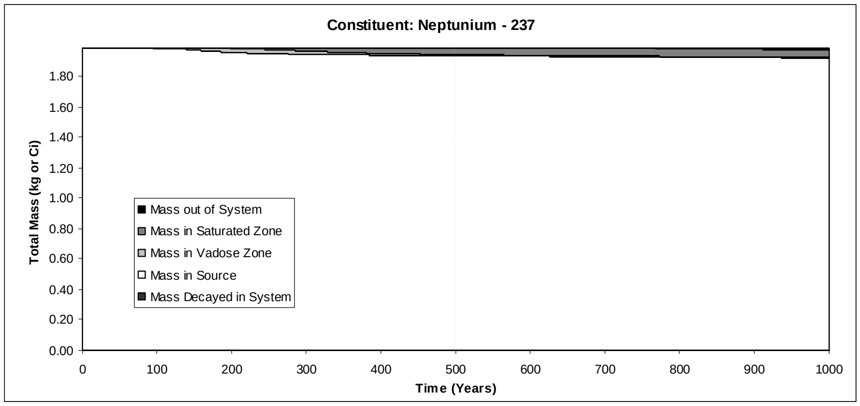



e) Technetium-99

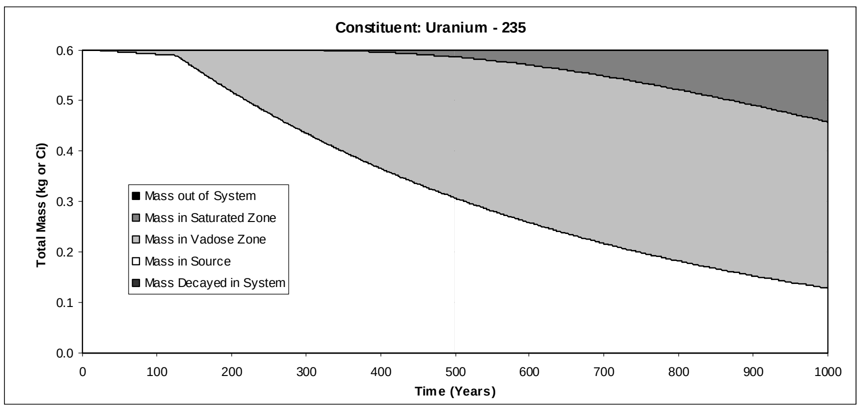



f) Iodine-129

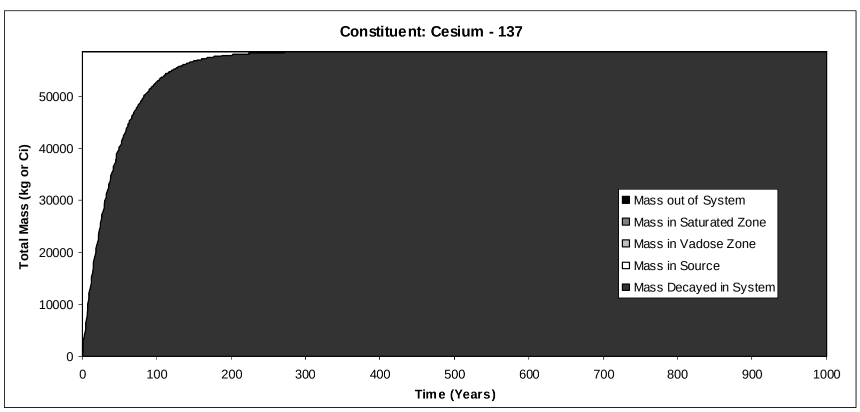
**Figure D-7. (con't) Disposition of Total Mass (Activity) for RCRA Clay Cap: Sum of All Elements, Full Impact/Late Timing Model Results**




g) Neptunium-237

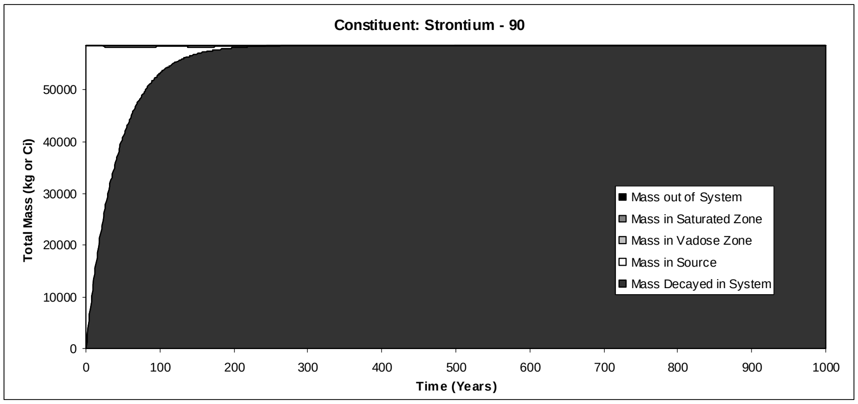



h) Uranium-235

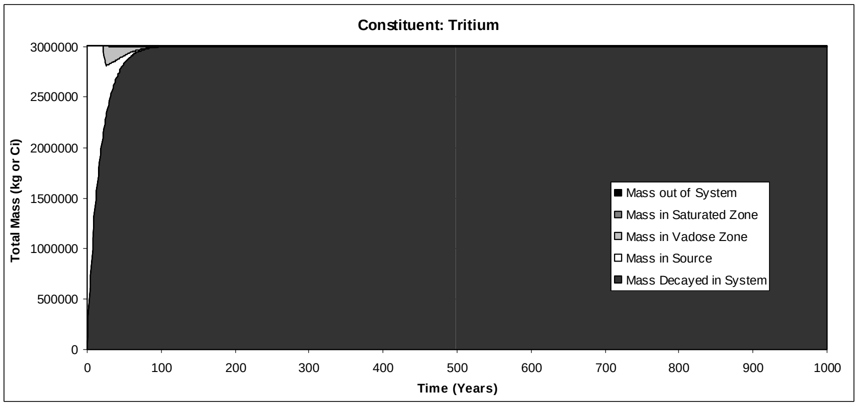



i) Cesium-137

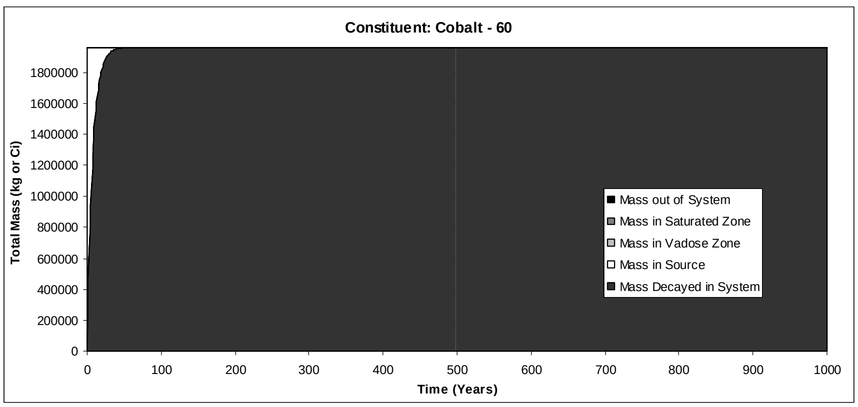
**Figure D-7. (con't) Disposition of Total Mass (Activity) for RCRA Clay Cap: Sum of All Elements, Full Impact/Late Timing Model Results**




j) Strontium-90

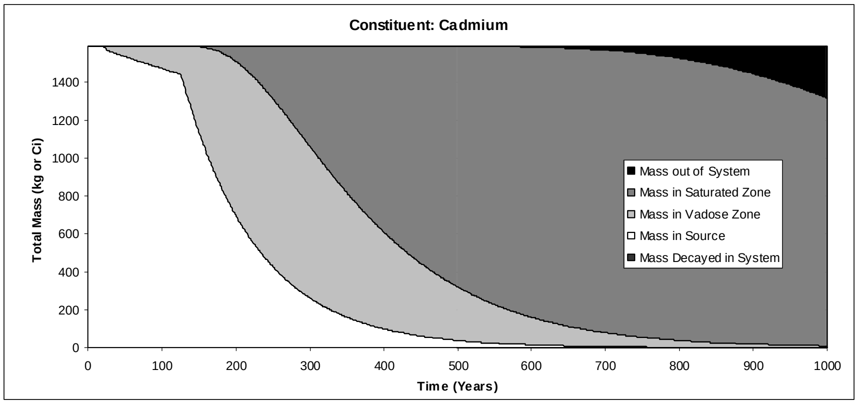



k) Tritium

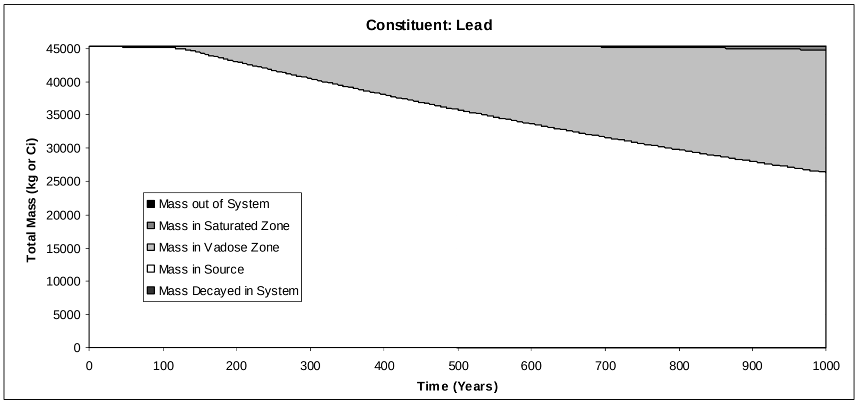



l) Cobalt-60

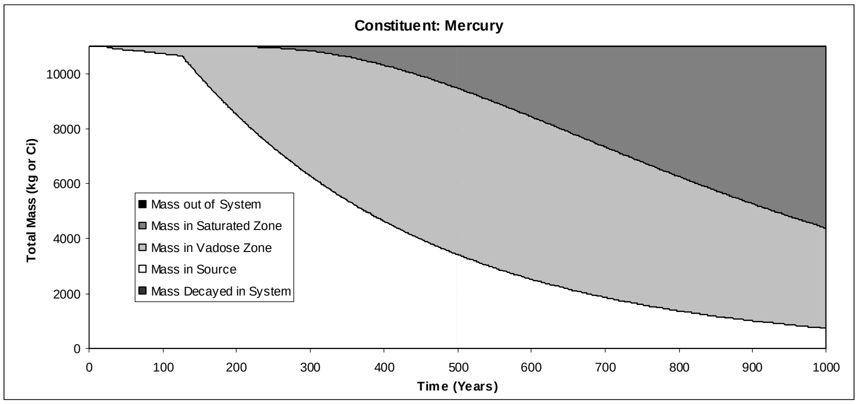
**Figure D-7. (con't) Disposition of Total Mass (Activity) for RCRA Clay Cap: Sum of All Elements, Full Impact/Late Timing Model Results**




m) Cadmium

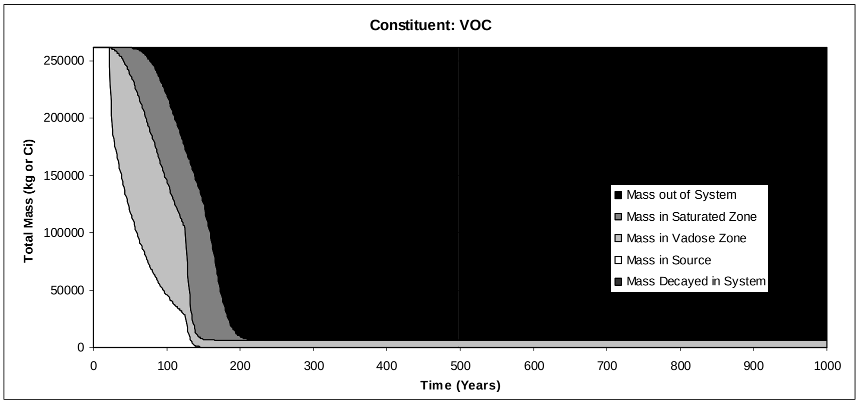



n) Lead



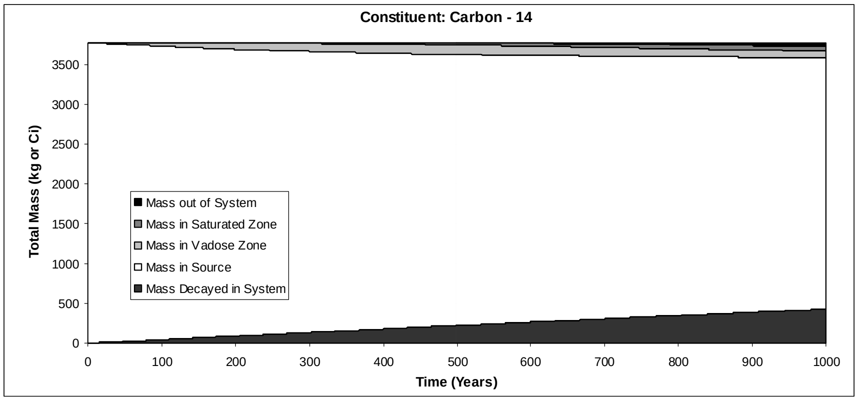

o) Mercury

**Figure D-7. (con't) Disposition of Total Mass (Activity) for RCRA Clay Cap: Sum of All Elements, Full Impact/Late Timing Model Results**

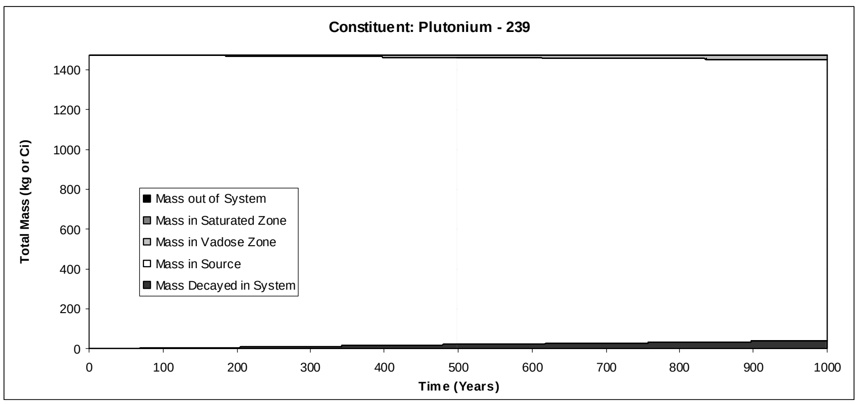



p) VOC

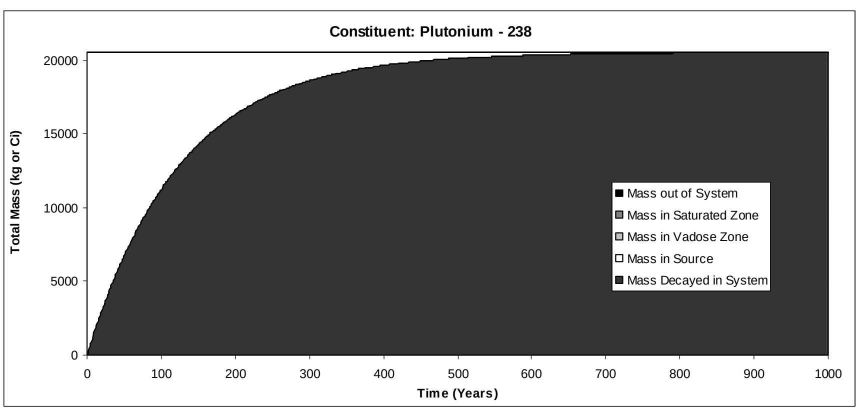
**Figure D-7. (con't) Disposition of Total Mass (Activity) for RCRA Clay Cap: Sum of All Elements, Full Impact/Late Timing Model Results**




a) Carbon-14

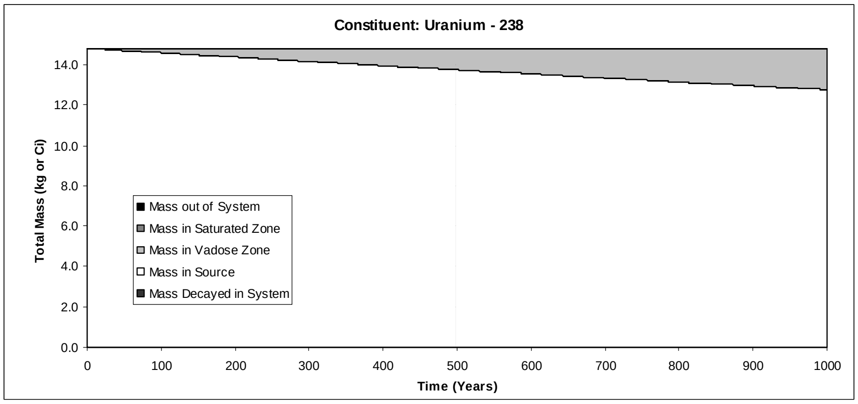



b) Plutonium-239

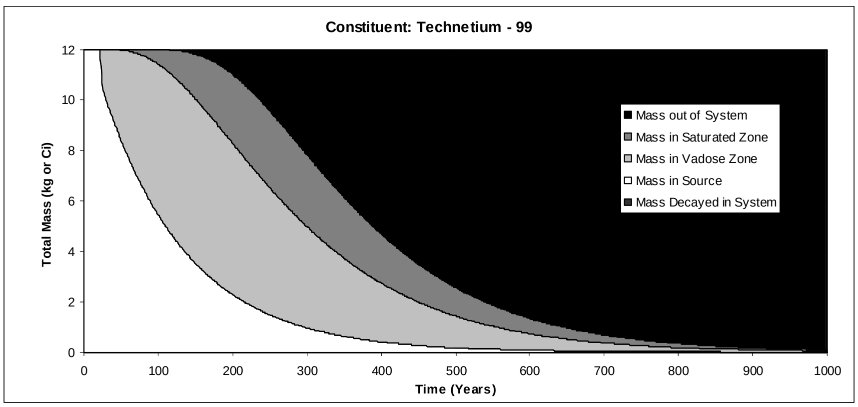



c) Plutonium-238

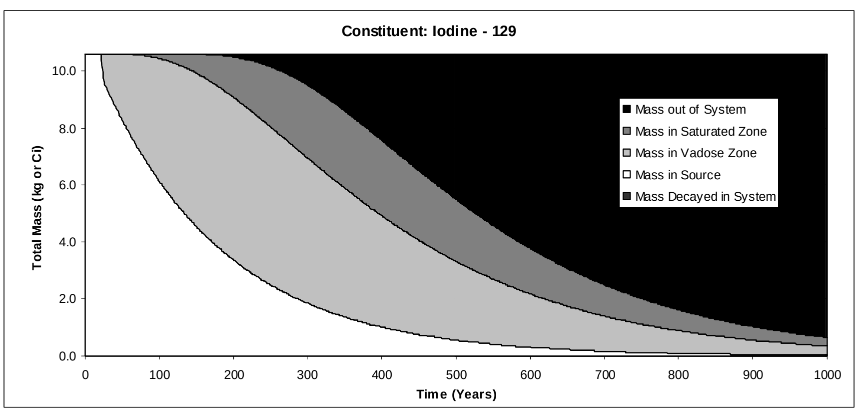
**Figure D-8. Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Sum of All Elements, Full Impact/Late Timing Model Results**




d) Uranium-238

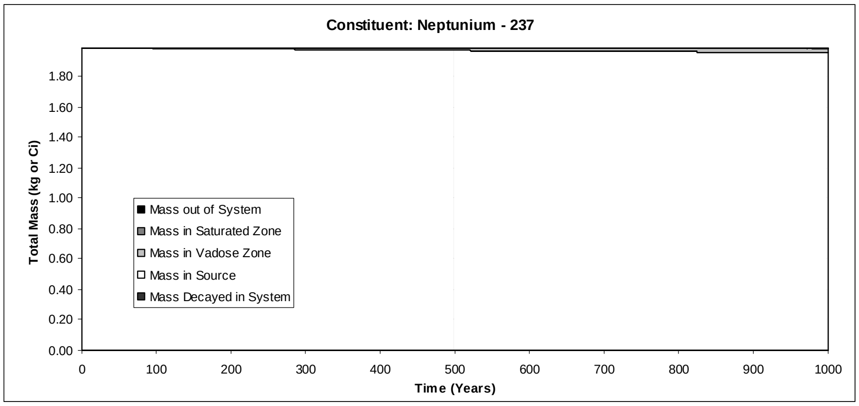



e) Technetium-99

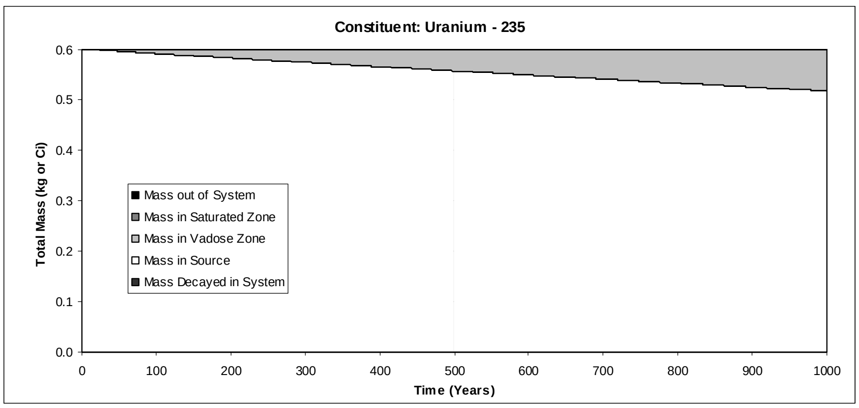



f) Iodine-129

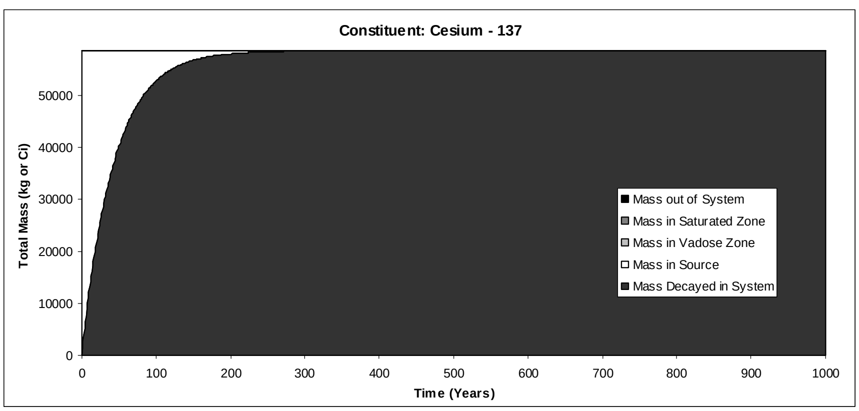
**Figure D-8. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Sum of All Elements, Full Impact/Late Timing Model Results**




g) Neptunium-237

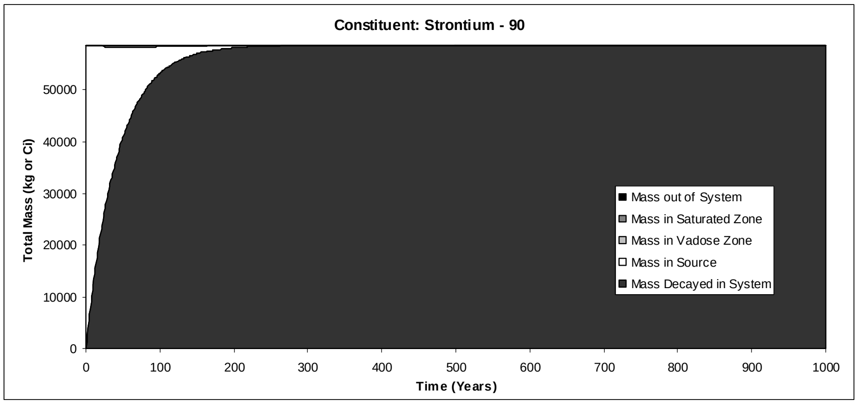



h) Uranium-235

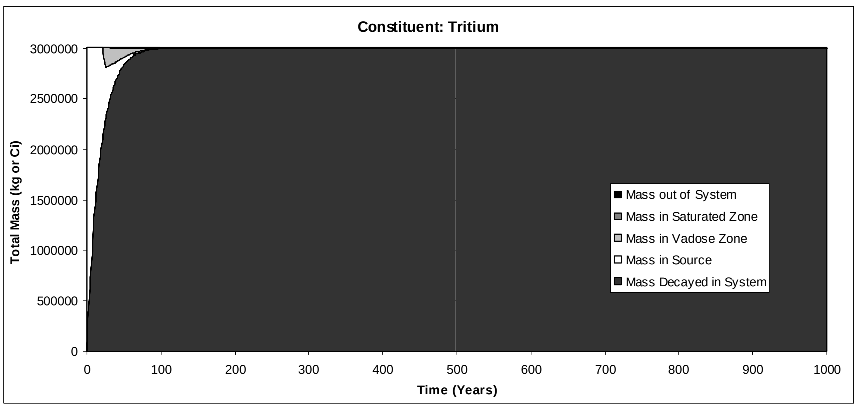



i) Cesium-137

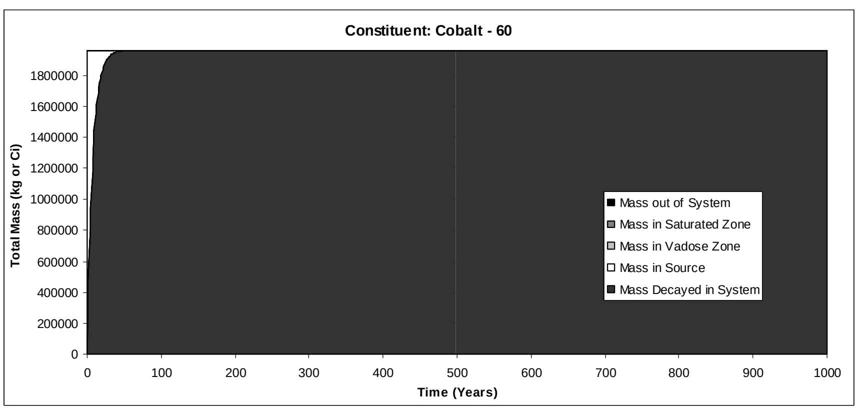
**Figure D-8. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Sum of All Elements, Full Impact/Late Timing Model Results**




j) Strontium-90

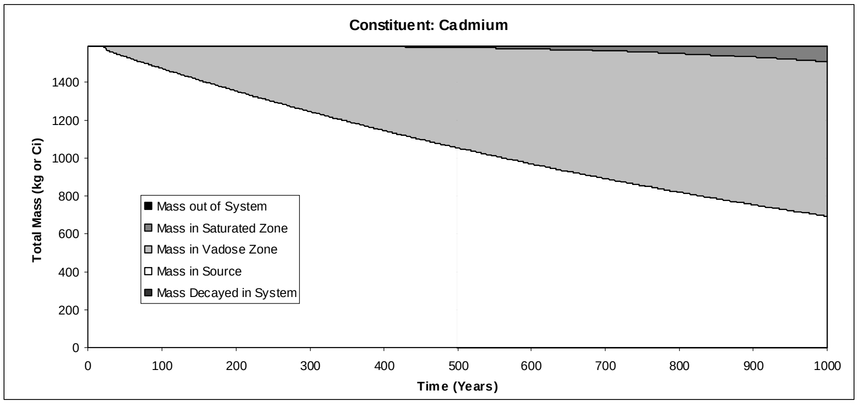



k) Tritium

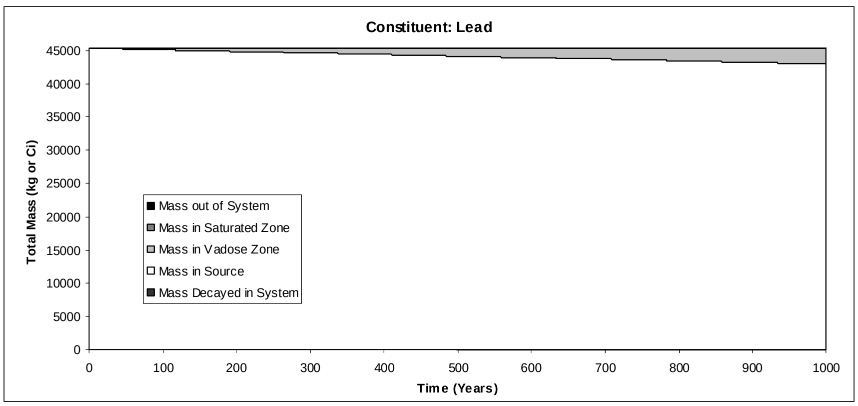



l) Cobalt-60

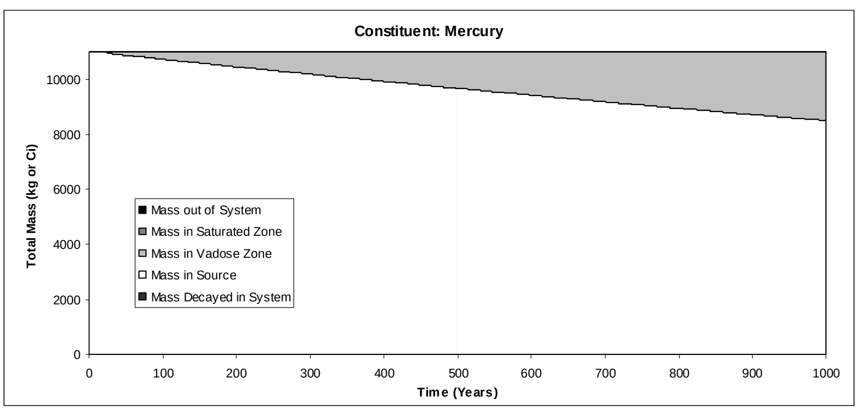
**Figure D-8. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Sum of All Elements, Full Impact/Late Timing Model Results**




m) Cadmium

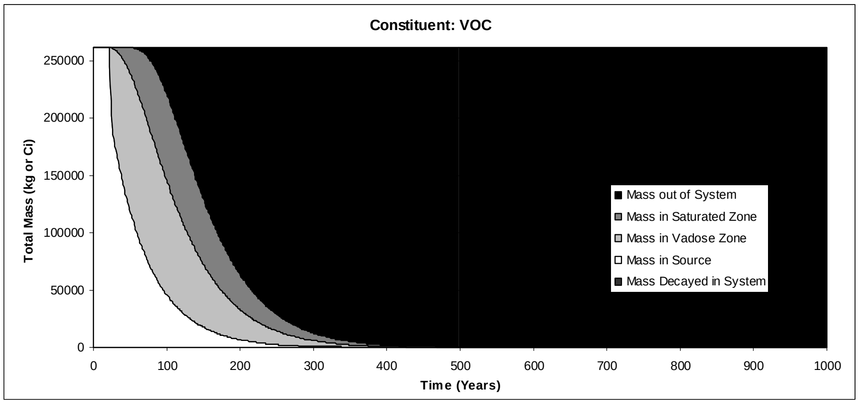



n) Lead



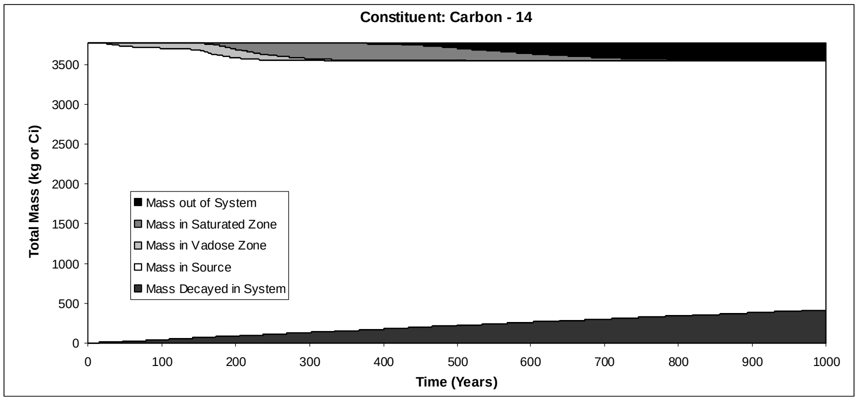

o) Mercury

**Figure D-8. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Sum of All Elements, Full Impact/Late Timing Model Results**

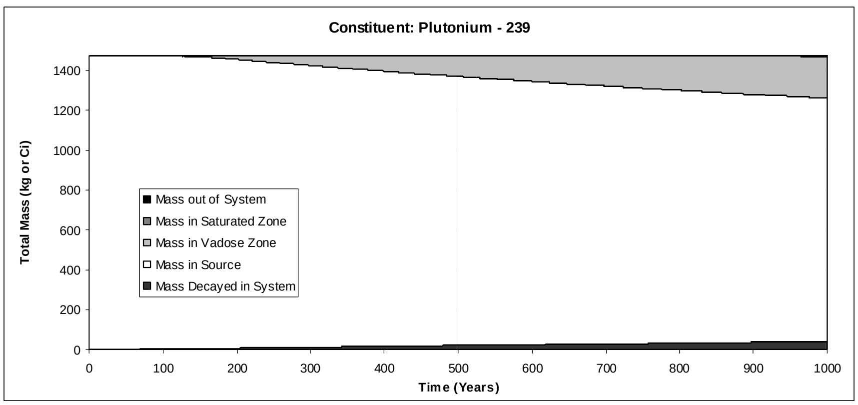



p) VOC

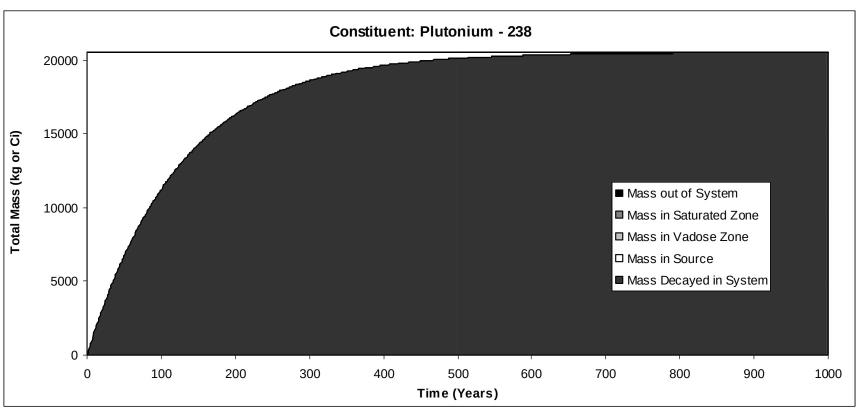
**Figure D-8. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Sum of All Elements, Full Impact/Late Timing Model Results**




a) Carbon-14

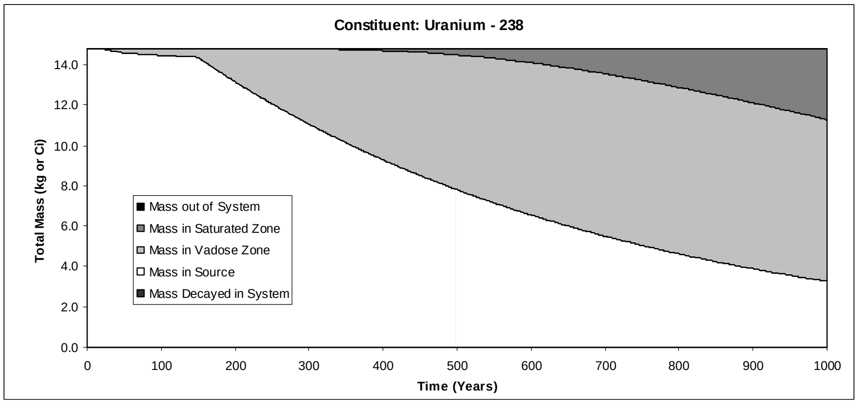



b) Plutonium-239

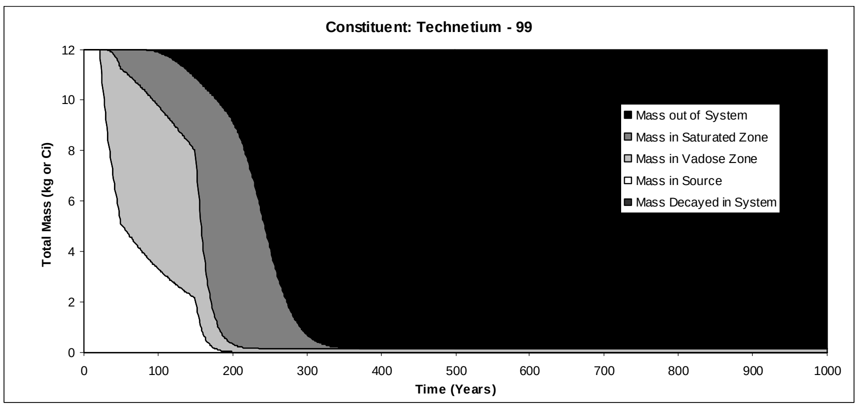



c) Plutonium-238

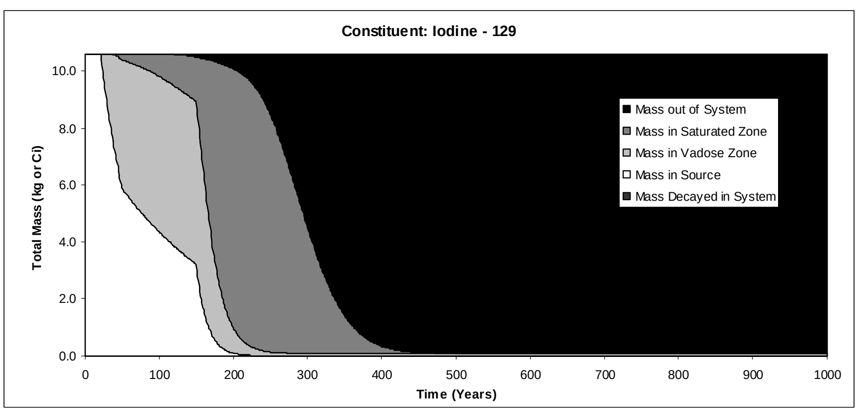
**Figure D-9. Disposition of Total Mass (Activity) for RCRA Clay Cap: Sum of All Elements, Full Impact/Late Timing ("trigger") Model Results**




d) Uranium-238

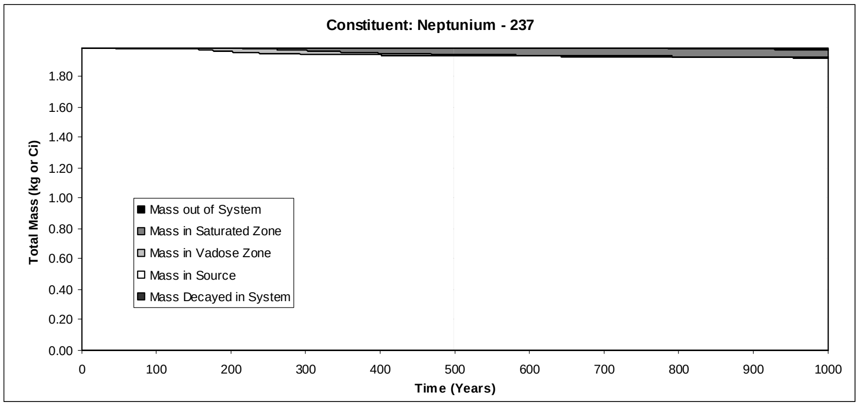



e) Technetium-99

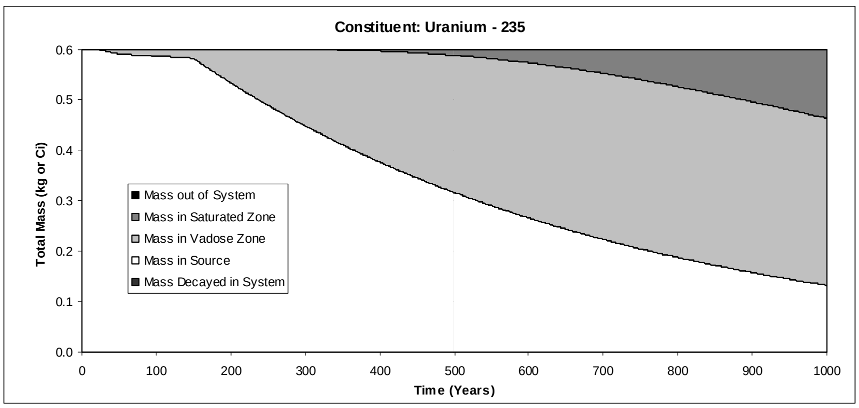



f) Iodine-129

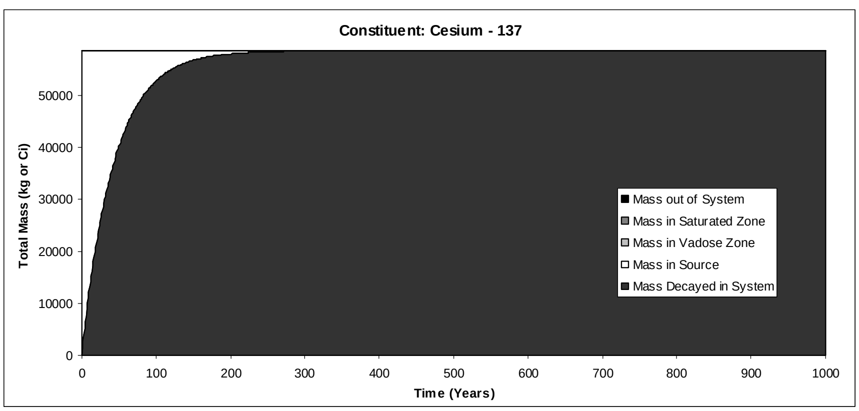
**Figure D-9. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap: Sum of All Elements, Full Impact/Late Timing ("trigger") Model Results**




g) Neptunium-237

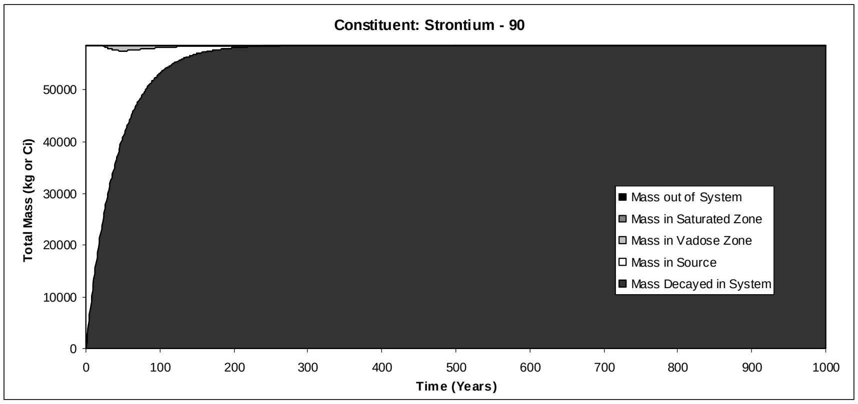



h) Uranium-235

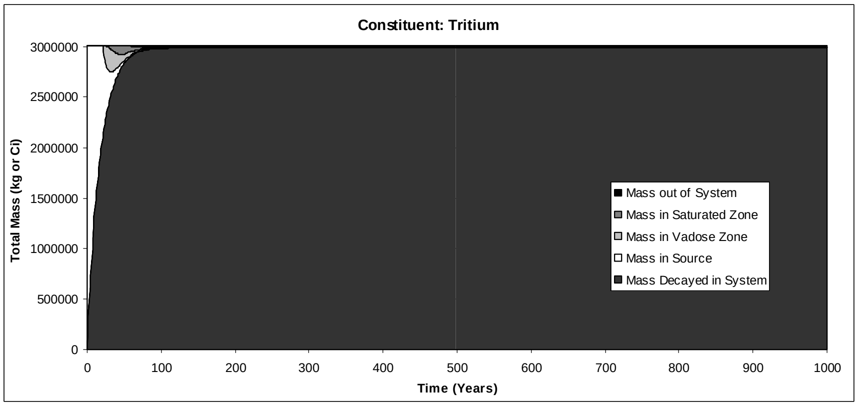



i) Cesium-137

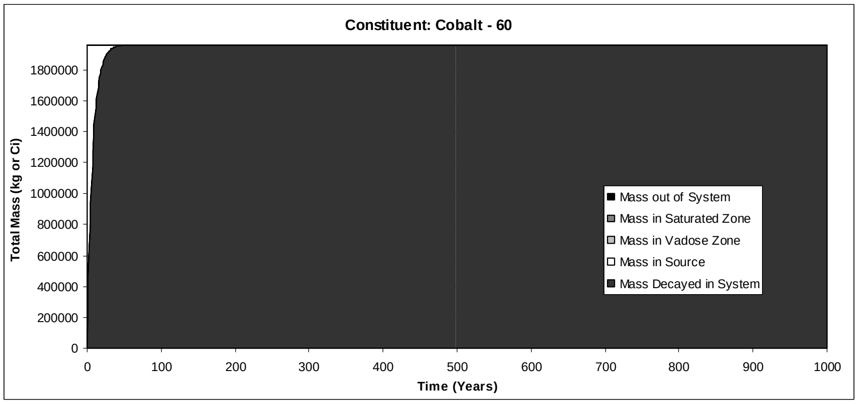
**Figure D-9. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap: Sum of All Elements, Full Impact/Late Timing ("trigger") Model Results**




j) Strontium-90

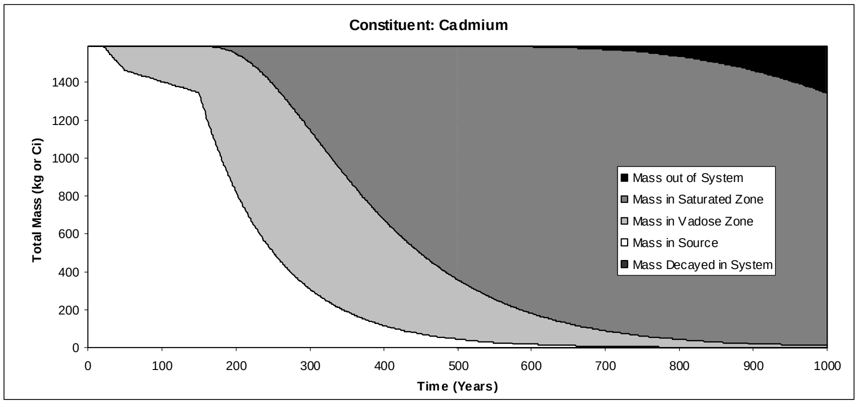



k) Tritium

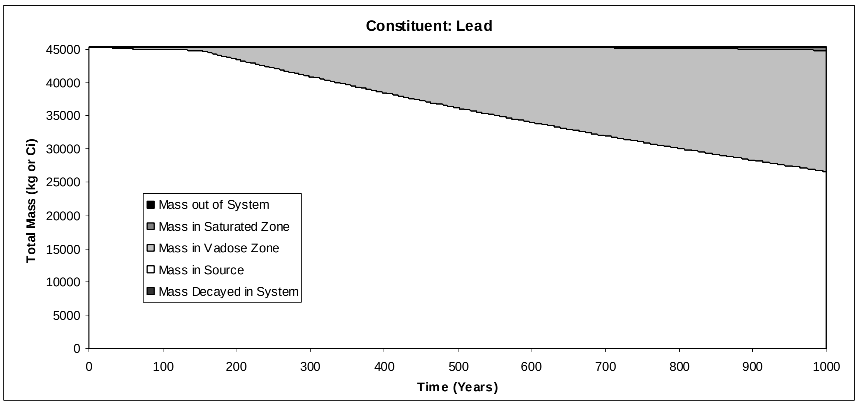



l) Cobalt-60

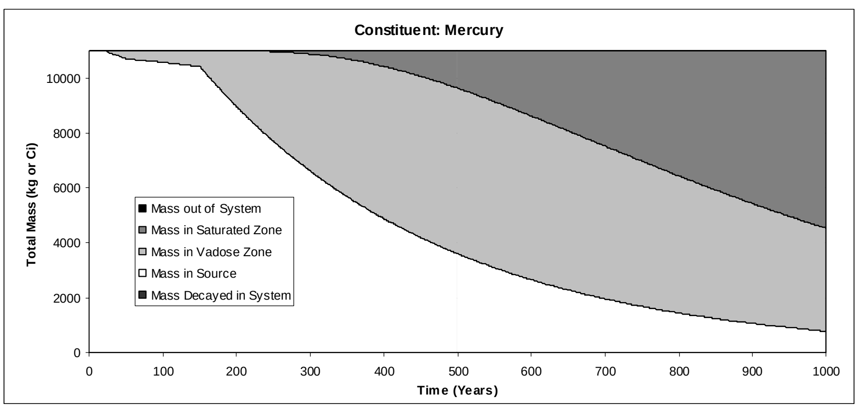
**Figure D-9. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap: Sum of All Elements, Full Impact/Late Timing ("trigger") Model Results**




m) Cadmium

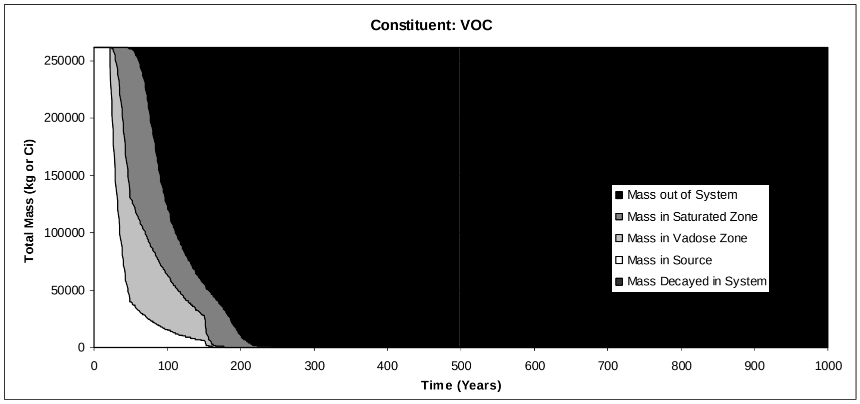



n) Lead



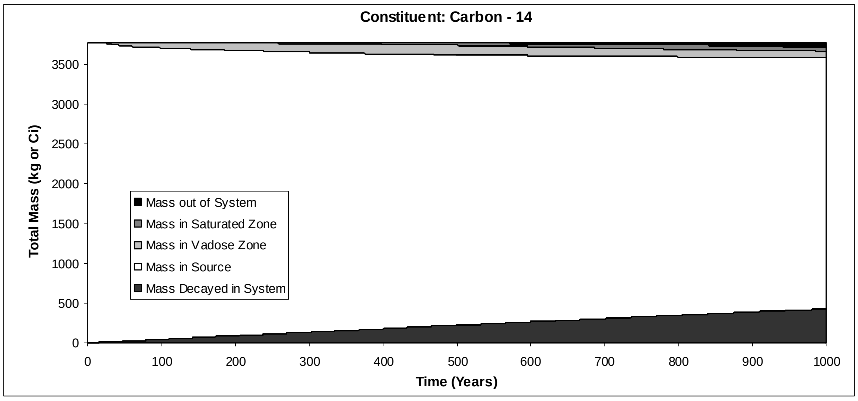

o) Mercury

**Figure D-9. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap: Sum of All Elements, Full Impact/Late Timing ("trigger") Model Results**

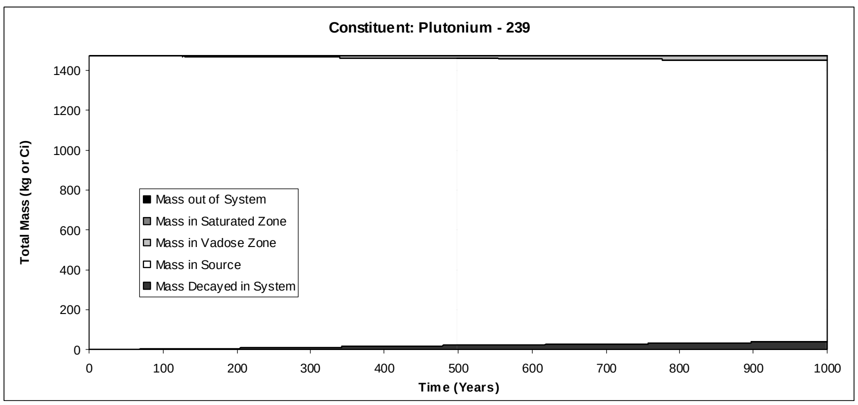



p) VOC

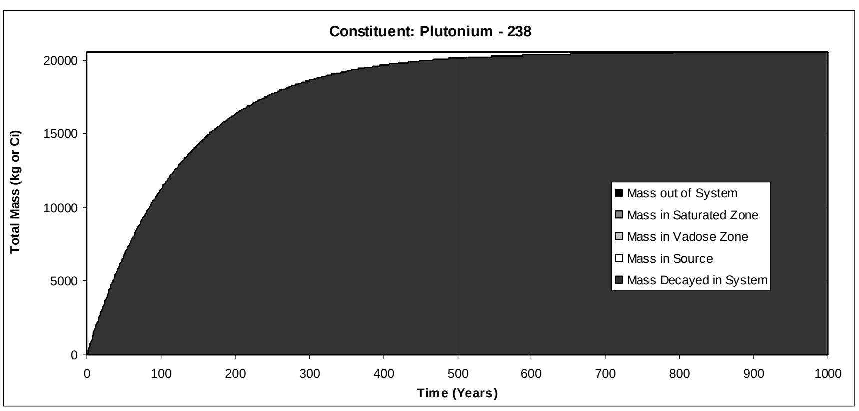
**Figure D-9. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap: Sum of All Elements, Full Impact/Late Timing ("trigger") Model Results**




a) Carbon-14

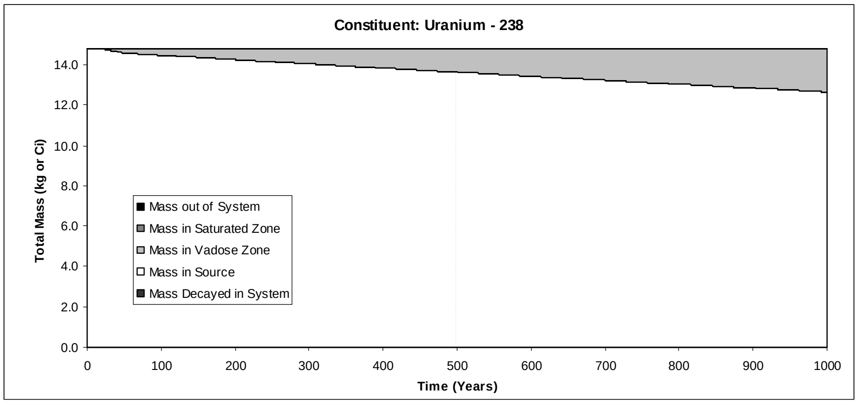



b) Plutonium-239

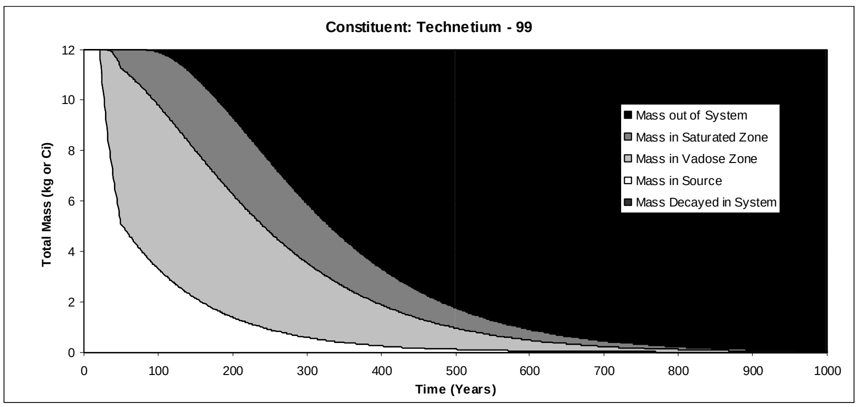



c) Plutonium-238

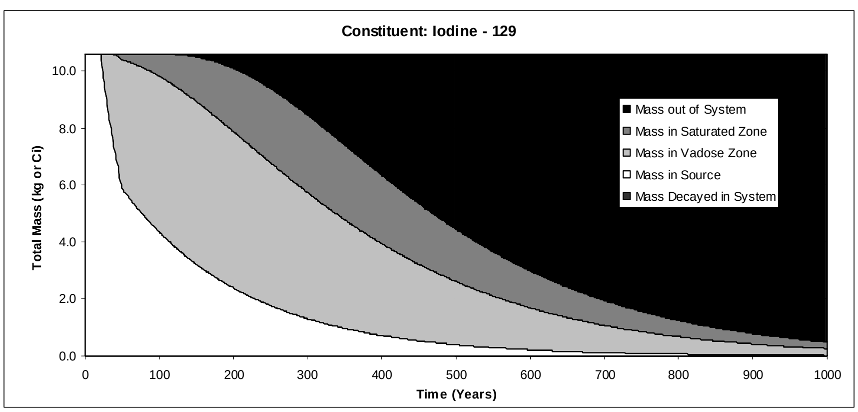
**Figure D-10. Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Sum of All Elements, Full Impact/Late Timing ("trigger") Model Results**




d) Uranium-238

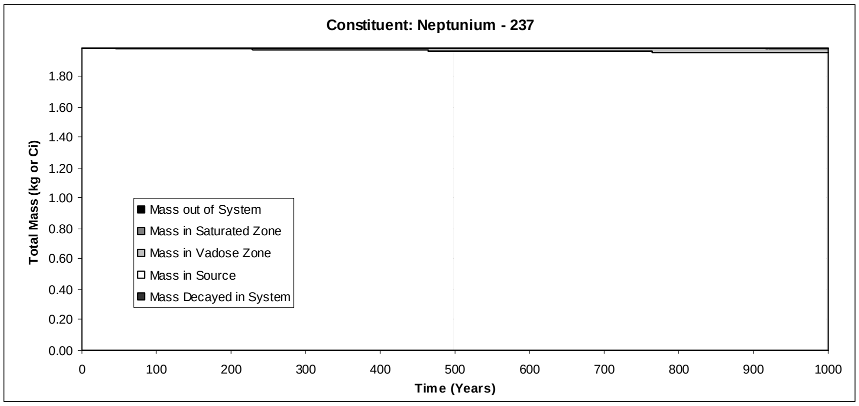



e) Technetium-99

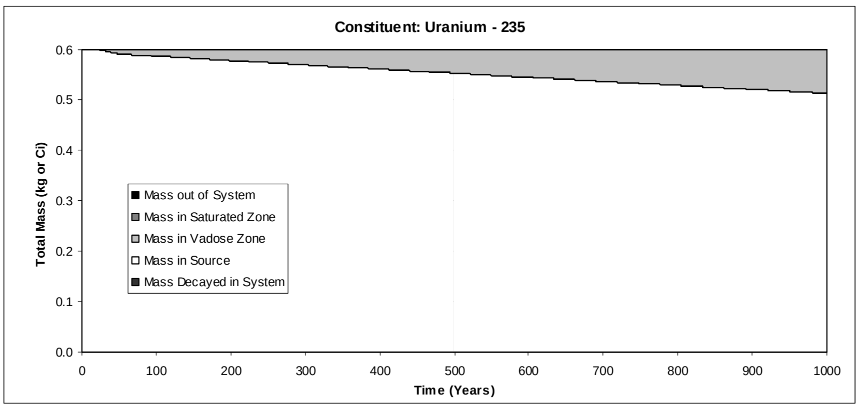



f) Iodine-129

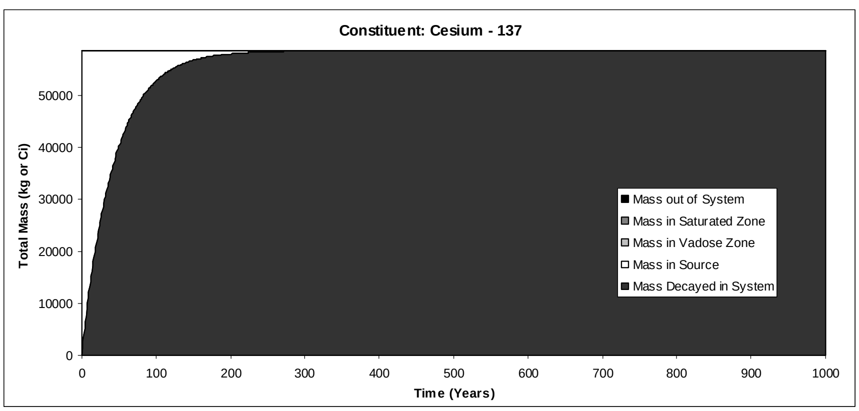
**Figure D-10. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Sum of All Elements, Full Impact/Late Timing ("trigger") Model Results**




g) Neptunium-237

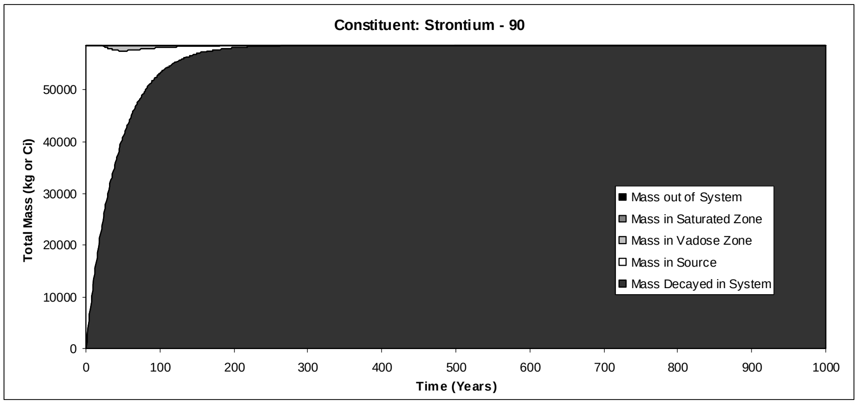



h) Uranium-235

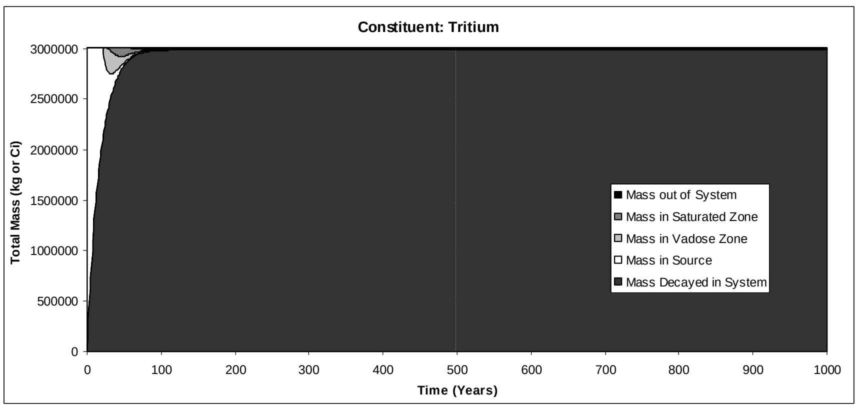



i) Cesium-137

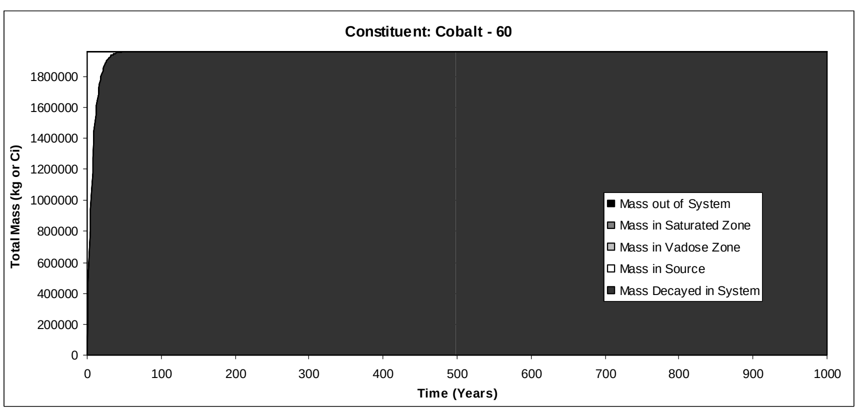
**Figure D-10. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Sum of All Elements, Full Impact/Late Timing ("trigger") Model Results**




j) Strontium-90

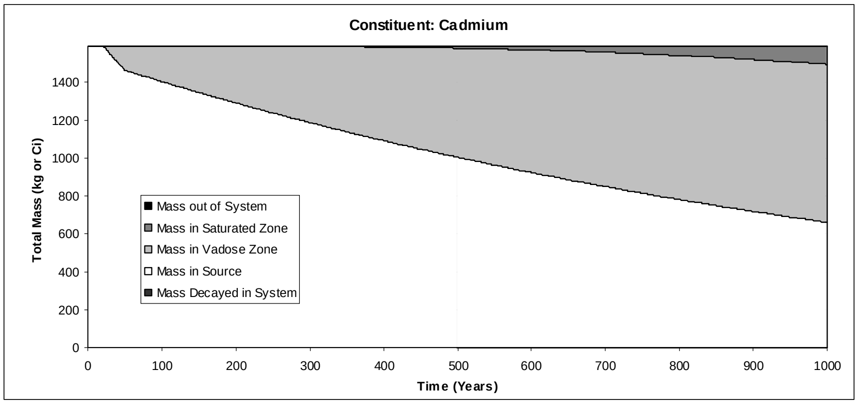



k) Tritium

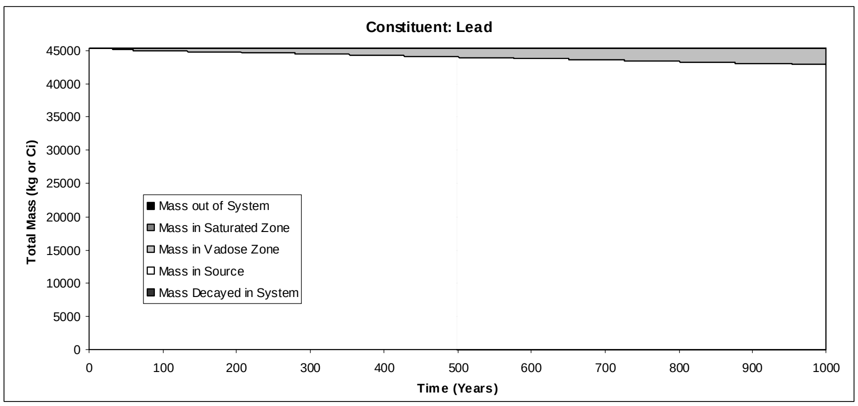



l) Cobalt-60

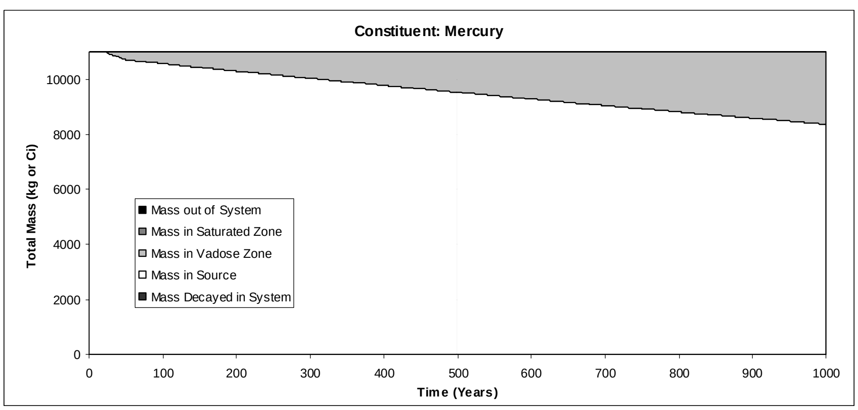
**Figure D-10. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Sum of All Elements, Full Impact/Late Timing ("trigger") Model Results**




m) Cadmium

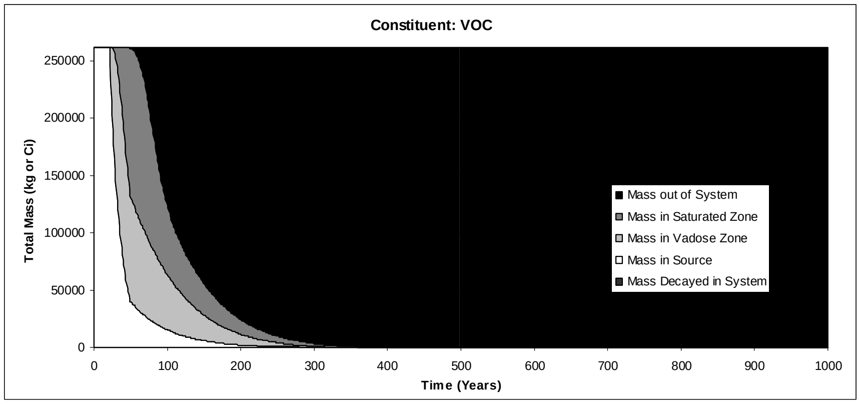



n) Lead




o) Mercury

**Figure D-10. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Sum of All Elements, Full Impact/Late Timing ("trigger") Model Results**




p) VOC

**Figure D-10. (cont't) Disposition of Total Mass (Activity) for RCRA Clay Cap w/ Barrier: Sum of All Elements, Full Impact/Late Timing ("trigger") Model Results**

## Appendix E

### Electronic Files

The electronic files necessary to run the model and view the results are as follows:

**D:\coi_avg_con_by_time\Cd_avg_cons.xls**
**D:\coi_avg_con_by_time\cd_wt_cons.xls**
**D:\coi_avg_con_by_time\coi_01_c14**
**D:\coi_avg_con_by_time\coi_03_pu238**
**D:\coi_avg_con_by_time\coi_04_u238**
**D:\coi_avg_con_by_time\coi_10_sr90**
**D:\coi_avg_con_by_time\coi_11_tritium**
**D:\coi_avg_con_by_time\coi_13_cd**
**D:\coi_avg_con_by_time\coi_14_pb**
**D:\coi_avg_con_by_time\coi_15_hg**
**D:\coi_avg_con_by_time\coi_16_voc**
**D:\coi_avg_con_by_time\h3_avg_cons.xls**
**D:\coi_avg_con_by_time\h3_wt_cons.xls**
**D:\coi_avg_con_by_time\Hg_avg_cons.xls**
**D:\coi_avg_con_by_time\hg_wt_cons.xls**
**D:\coi_avg_con_by_time\Pb_avg_cons.xls**
**D:\coi_avg_con_by_time\Pu238_avg_cons.xls**
**D:\coi_avg_con_by_time\run3_for_entire.bat**
**D:\coi_avg_con_by_time\runall.bat**
**D:\coi_avg_con_by_time\run_stuff_here**
**D:\coi_avg_con_by_time\Sr90_avg_cons.xls**
**D:\coi_avg_con_by_time\U238_avg_cons.xls**
**D:\coi_avg_con_by_time\VOC_avg_cons.xls**
**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_030.csv**
**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_031.csv**
**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_032.csv**
**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_033.csv**
**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_034.csv**
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**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_043.csv**
**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_044.csv**
**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_053_v6.csv**
**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_054_v6.csv**
**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_120.csv**
**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_121.csv**
**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_122.csv**
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**D:\coi_avg_con_by_time\coi_01_c14\sum_cons_01_124.csv**
**D:\coi_avg_con_by_time\coi_03_pu238\sum_cons_03_030.csv**
**D:\coi_avg_con_by_time\coi_03_pu238\sum_cons_03_031.csv**
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**D:\coi_avg_con_by_time\coi_03_pu238\sum_cons_03_044.csv**
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**D:\coi_avg_con_by_time\coi_04_u238\sum_cons_04_043.csv**
**D:\coi_avg_con_by_time\coi_04_u238\sum_cons_04_044.csv**
**D:\coi_avg_con_by_time\coi_04_u238\sum_cons_04_053_v6.csv**
**D:\coi_avg_con_by_time\coi_04_u238\sum_cons_04_054_v6.csv**
**D:\coi_avg_con_by_time\coi_04_u238\sum_cons_04_120.csv**
**D:\coi_avg_con_by_time\coi_04_u238\sum_cons_04_121.csv**
**D:\coi_avg_con_by_time\coi_04_u238\sum_cons_04_122.csv**
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**D:\coi_avg_con_by_time\coi_10_sr90\sum_cons_10_043.csv**
**D:\coi_avg_con_by_time\coi_10_sr90\sum_cons_10_044.csv**
**D:\coi_avg_con_by_time\coi_10_sr90\sum_cons_10_053_v6.csv**
**D:\coi_avg_con_by_time\coi_10_sr90\sum_cons_10_054_v6.csv**
**D:\coi_avg_con_by_time\coi_10_sr90\sum_cons_10_120.csv**
**D:\coi_avg_con_by_time\coi_10_sr90\sum_cons_10_121.csv**
**D:\coi_avg_con_by_time\coi_10_sr90\sum_cons_10_122.csv**
**D:\coi_avg_con_by_time\coi_10_sr90\sum_cons_10_123.csv**
**D:\coi_avg_con_by_time\coi_10_sr90\sum_cons_10_124.csv**
**D:\coi_avg_con_by_time\coi_11_tritium\sum_cons_11_030.csv**
**D:\coi_avg_con_by_time\coi_11_tritium\sum_cons_11_031.csv**
**D:\coi_avg_con_by_time\coi_11_tritium\sum_cons_11_032.csv**
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**D:\coi_avg_con_by_time\coi_11_tritium\sum_cons_11_043.csv**
**D:\coi_avg_con_by_time\coi_11_tritium\sum_cons_11_044.csv**
**D:\coi_avg_con_by_time\coi_11_tritium\sum_cons_11_053_v6.csv**
**D:\coi_avg_con_by_time\coi_11_tritium\sum_cons_11_054_v6.csv**
**D:\coi_avg_con_by_time\coi_11_tritium\sum_cons_11_120.csv**
**D:\coi_avg_con_by_time\coi_11_tritium\sum_cons_11_121.csv**
**D:\coi_avg_con_by_time\coi_11_tritium\sum_cons_11_122.csv**
**D:\coi_avg_con_by_time\coi_11_tritium\sum_cons_11_123.csv**
**D:\coi_avg_con_by_time\coi_11_tritium\sum_cons_11_124.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_030.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_031.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_032.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_033.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_034.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_040.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_041.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_043.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_044.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_053_v6.csv**

**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_054_v6.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_120.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_121.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_122.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_123.csv**
**D:\coi_avg_con_by_time\coi_13_cd\sum_cons_13_124.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_030.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_031.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_032.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_033.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_034.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_040.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_041.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_043.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_044.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_053_v6.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_054_v6.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_120.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_121.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_122.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_123.csv**
**D:\coi_avg_con_by_time\coi_14_pb\sum_cons_14_124.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_030.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_031.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_032.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_033.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_034.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_040.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_041.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_043.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_044.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_053_v6.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_054_v6.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_120.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_121.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_122.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_123.csv**
**D:\coi_avg_con_by_time\coi_15_hg\sum_cons_15_124.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_030.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_031.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_032.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_033.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_034.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_040.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_041.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_043.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_044.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_053_v6.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_054_v6.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_120.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_121.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_122.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_123.csv**
**D:\coi_avg_con_by_time\coi_16_voc\sum_cons_16_124.csv**
**D:\coi_avg_con_by_time\run_stuff_here\elemental.csv**
**D:\coi_avg_con_by_time\run_stuff_here\entire_cons_v1.exe**
**D:\coi_avg_con_by_time\run_stuff_here\run_all_all.bat**
**D:\Subtask0--constant\coi_conc_by_element**
**D:\Subtask0--constant\coi_cum_mass_by_date**
**D:\Subtask0--constant\coi_mass_by_time**
**D:\Subtask0--constant\headers.txt**

**D:\Subtask0--constant\max_elements_by_coi**
**D:\Subtask0--constant\model_files**
**D:\Subtask0--constant\other_executables**
**D:\Subtask0--constant\single_coi_element_by_time**
**D:\Subtask0--constant\coi_conc_by_element\elemsum.120.csv**
**D:\Subtask0--constant\coi_conc_by_element\elemsum.121.csv**
**D:\Subtask0--constant\coi_conc_by_element\elemsum.122.csv**
**D:\Subtask0--constant\coi_conc_by_element\elemsum.123.csv**
**D:\Subtask0--constant\coi_conc_by_element\elemsum.124.csv**
**D:\Subtask0--constant\coi_conc_by_element\elem_sum.exe**
**D:\Subtask0--constant\coi_conc_by_element\lvs_sum.BAT**
**D:\Subtask0--constant\coi_conc_by_element\Mag_comp_120_020.xls**
**D:\Subtask0--constant\coi_conc_by_element\Mag_comp_121_021.xls**
**D:\Subtask0--constant\coi_conc_by_element\Mag_comp_122_022.xls**
**D:\Subtask0--constant\coi_conc_by_element\Mag_comp_123_023.xls**
**D:\Subtask0--constant\coi_conc_by_element\Mag_comp_124_024.xls**
**D:\Subtask0--constant\coi_cum_mass_by_date\date_120.csv**
**D:\Subtask0--constant\coi_mass_by_time\allmass.120.csv**
**D:\Subtask0--constant\coi_mass_by_time\allmass.121.csv**
**D:\Subtask0--constant\coi_mass_by_time\allmass.122.csv**
**D:\Subtask0--constant\coi_mass_by_time\allmass.123.csv**
**D:\Subtask0--constant\coi_mass_by_time\allmass.124.csv**
**D:\Subtask0--constant\coi_mass_by_time\allmass_120.xls**
**D:\Subtask0--constant\coi_mass_by_time\allmass_121.xls**
**D:\Subtask0--constant\coi_mass_by_time\allmass_122.xls**
**D:\Subtask0--constant\coi_mass_by_time\allmass_123.xls**
**D:\Subtask0--constant\coi_mass_by_time\allmass_124.xls**
**D:\Subtask0--constant\max_elements_by_coi\max_elems.bat**
**D:\Subtask0--constant\max_elements_by_coi\max_elems_120.csv**
**D:\Subtask0--constant\max_elements_by_coi\max_elems_121.csv**
**D:\Subtask0--constant\max_elements_by_coi\max_elems_122.csv**
**D:\Subtask0--constant\max_elements_by_coi\max_elems_123.csv**
**D:\Subtask0--constant\max_elements_by_coi\max_elems_124.csv**
**D:\Subtask0--constant\max_elements_by_coi\max_elem_by_coi.exe**
**D:\Subtask0--constant\model_files\120.dat**
**D:\Subtask0--constant\model_files\120.lvs**
**D:\Subtask0--constant\model_files\120.out**
**D:\Subtask0--constant\model_files\121.dat**
**D:\Subtask0--constant\model_files\121.lvs**
**D:\Subtask0--constant\model_files\121.out**
**D:\Subtask0--constant\model_files\122.dat**
**D:\Subtask0--constant\model_files\122.lvs**
**D:\Subtask0--constant\model_files\122.out**
**D:\Subtask0--constant\model_files\123.dat**
**D:\Subtask0--constant\model_files\123.lvs**
**D:\Subtask0--constant\model_files\123.out**
**D:\Subtask0--constant\model_files\124.dat**
**D:\Subtask0--constant\model_files\124.lvs**
**D:\Subtask0--constant\model_files\124.out**
**D:\Subtask0--constant\model_files\lvstran_KEB_v5.exe**
**D:\Subtask0--constant\model_files\lvstran_KEB_v5c.exe**
**D:\Subtask0--constant\model_files\lvs_allrun.bat**
**D:\Subtask0--constant\model_files\Readme.txt**
**D:\Subtask0--constant\other_executables\all_mass.exe**
**D:\Subtask0--constant\other_executables\coc_sum_by_date.exe**
**D:\Subtask0--constant\other_executables\elem_minmax.exe**
**D:\Subtask0--constant\other_executables\lvs_mm.BAT**
**D:\Subtask0--constant\single_coi_element_by_time\cd_120.xls**
**D:\Subtask0--constant\single_coi_element_by_time\cd_124.xls**
**D:\Subtask0--constant\single_coi_element_by_time\cd_7_120.csv**
**D:\Subtask0--constant\single_coi_element_by_time\cd_7_124.csv**

**D:\Subtask0--constant\single_coi_element_by_time\ext_coc4.exe**
**D:\Subtask0--constant\single_coi_element_by_time\h3_11_120.csv**
**D:\Subtask0--constant\single_coi_element_by_time\h3_11_124.csv**
**D:\Subtask0--constant\single_coi_element_by_time\h3_120.xls**
**D:\Subtask0--constant\single_coi_element_by_time\h3_124.xls**
**D:\Subtask0--constant\single_coi_element_by_time\hg_120.xls**
**D:\Subtask0--constant\single_coi_element_by_time\hg_124.xls**
**D:\Subtask0--constant\single_coi_element_by_time\hg_7_120.csv**
**D:\Subtask0--constant\single_coi_element_by_time\hg_7_124.csv**
**D:\Subtask0--constant\single_coi_element_by_time\lvs_con.BAT**
**D:\Subtask1--variable\coi_conc_by_element**
**D:\Subtask1--variable\coi_cum_mass_by_date**
**D:\Subtask1--variable\coi_mass_by_time**
**D:\Subtask1--variable\coi_maxmin_mass_by_element**
**D:\Subtask1--variable\max_elements_by_coi**
**D:\Subtask1--variable\model_files**
**D:\Subtask1--variable\single_coi_element_by_time**
**D:\Subtask1--variable\coi_conc_by_element\elemsum.030.csv**
**D:\Subtask1--variable\coi_conc_by_element\elemsum.031.csv**
**D:\Subtask1--variable\coi_conc_by_element\elemsum.032.csv**
**D:\Subtask1--variable\coi_conc_by_element\elemsum.033.csv**
**D:\Subtask1--variable\coi_conc_by_element\elemsum.034.csv**
**D:\Subtask1--variable\coi_conc_by_element\elem_sum.exe**
**D:\Subtask1--variable\coi_conc_by_element\lvs_sum.BAT**
**D:\Subtask1--variable\coi_conc_by_element\Mag_comp_030_120.xls**
**D:\Subtask1--variable\coi_conc_by_element\Mag_comp_031_121.xls**
**D:\Subtask1--variable\coi_conc_by_element\Mag_comp_032_122.xls**
**D:\Subtask1--variable\coi_conc_by_element\Mag_comp_033_123.xls**
**D:\Subtask1--variable\coi_conc_by_element\Mag_comp_034_124.xls**
**D:\Subtask1--variable\coi_cum_mass_by_date\coc_sum_by_date.exe**
**D:\Subtask1--variable\coi_cum_mass_by_date\date_030.csv**
**D:\Subtask1--variable\coi_cum_mass_by_date\date_031.csv**
**D:\Subtask1--variable\coi_cum_mass_by_date\date_033.csv**
**D:\Subtask1--variable\coi_cum_mass_by_date\date_034.csv**
**D:\Subtask1--variable\coi_mass_by_time\allmass.030.csv**
**D:\Subtask1--variable\coi_mass_by_time\allmass.031.csv**
**D:\Subtask1--variable\coi_mass_by_time\allmass.032.csv**
**D:\Subtask1--variable\coi_mass_by_time\allmass.033.csv**
**D:\Subtask1--variable\coi_mass_by_time\allmass.034.csv**
**D:\Subtask1--variable\coi_mass_by_time\allmass_030.xls**
**D:\Subtask1--variable\coi_mass_by_time\allmass_031.xls**
**D:\Subtask1--variable\coi_mass_by_time\allmass_032.xls**
**D:\Subtask1--variable\coi_mass_by_time\allmass_033.xls**
**D:\Subtask1--variable\coi_mass_by_time\allmass_034.xls**
**D:\Subtask1--variable\coi_mass_by_time\all_mass.exe**
**D:\Subtask1--variable\coi_maxmin_mass_by_element\elem_minmax.exe**
**D:\Subtask1--variable\coi_maxmin_mass_by_element\elem_mm.030.csv**
**D:\Subtask1--variable\coi_maxmin_mass_by_element\elem_mm.031.csv**
**D:\Subtask1--variable\coi_maxmin_mass_by_element\elem_mm.032.csv**
**D:\Subtask1--variable\coi_maxmin_mass_by_element\elem_mm.033.csv**
**D:\Subtask1--variable\coi_maxmin_mass_by_element\elem_mm.034.csv**
**D:\Subtask1--variable\coi_maxmin_mass_by_element\lvs_mm.BAT**
**D:\Subtask1--variable\max_elements_by_coi\max_elems.bat**
**D:\Subtask1--variable\max_elements_by_coi\max_elems_030.csv**
**D:\Subtask1--variable\max_elements_by_coi\max_elems_031.csv**
**D:\Subtask1--variable\max_elements_by_coi\max_elems_032.csv**
**D:\Subtask1--variable\max_elements_by_coi\max_elems_033.csv**
**D:\Subtask1--variable\max_elements_by_coi\max_elems_034.csv**
**D:\Subtask1--variable\max_elements_by_coi\max_elem_by_coi.exe**
**D:\Subtask1--variable\model_files\030.dat**
**D:\Subtask1--variable\model_files\030.lvs**

**D:\Subtask1--variable\model_files\030.out**
**D:\Subtask1--variable\model_files\031.dat**
**D:\Subtask1--variable\model_files\031.lvs**
**D:\Subtask1--variable\model_files\031.out**
**D:\Subtask1--variable\model_files\032.dat**
**D:\Subtask1--variable\model_files\032.lvs**
**D:\Subtask1--variable\model_files\032.out**
**D:\Subtask1--variable\model_files\033.dat**
**D:\Subtask1--variable\model_files\033.lvs**
**D:\Subtask1--variable\model_files\033.out**
**D:\Subtask1--variable\model_files\034.dat**
**D:\Subtask1--variable\model_files\034.lvs**
**D:\Subtask1--variable\model_files\034.out**
**D:\Subtask1--variable\model_files\lvstran_KEB_v5.exe**
**D:\Subtask1--variable\model_files\lvs_allrun.bat**
**D:\Subtask1--variable\model_files\Readme.txt**
**D:\Subtask1--variable\single_coi_element_by_time\cd030.XLS**
**D:\Subtask1--variable\single_coi_element_by_time\cd034.XLS**
**D:\Subtask1--variable\single_coi_element_by_time\cd_54_034.csv**
**D:\Subtask1--variable\single_coi_element_by_time\cd_7_030.csv**
**D:\Subtask1--variable\single_coi_element_by_time\ext_coc4.exe**
**D:\Subtask1--variable\single_coi_element_by_time\h3_030.xls**
**D:\Subtask1--variable\single_coi_element_by_time\h3_034.xls**
**D:\Subtask1--variable\single_coi_element_by_time\h3_11_030.csv**
**D:\Subtask1--variable\single_coi_element_by_time\h3_11_034.csv**
**D:\Subtask1--variable\single_coi_element_by_time\hg_030.xls**
**D:\Subtask1--variable\single_coi_element_by_time\hg_034.xls**
**D:\Subtask1--variable\single_coi_element_by_time\hg_7_030.csv**
**D:\Subtask1--variable\single_coi_element_by_time\hg_7_034.csv**
**D:\Subtask2--delayed\coi_conc_by_element**
**D:\Subtask2--delayed\coi_cum_mass_by_date**
**D:\Subtask2--delayed\coi_mass_by_time**
**D:\Subtask2--delayed\max_elements_by_coi**
**D:\Subtask2--delayed\model_files**
**D:\Subtask2--delayed\single_coi_element_by_time**
**D:\Subtask2--delayed\coi_conc_by_element\elemsum_040.csv**
**D:\Subtask2--delayed\coi_conc_by_element\elemsum_041.csv**
**D:\Subtask2--delayed\coi_conc_by_element\elemsum_043.csv**
**D:\Subtask2--delayed\coi_conc_by_element\elemsum_044.csv**
**D:\Subtask2--delayed\coi_conc_by_element\elem_sum.exe**
**D:\Subtask2--delayed\coi_conc_by_element\Mag_comp_040_030.xls**
**D:\Subtask2--delayed\coi_conc_by_element\Mag_comp_040_120.xls**
**D:\Subtask2--delayed\coi_conc_by_element\Mag_comp_041_031.xls**
**D:\Subtask2--delayed\coi_conc_by_element\Mag_comp_041_121.xls**
**D:\Subtask2--delayed\coi_conc_by_element\Mag_comp_043_033.xls**
**D:\Subtask2--delayed\coi_conc_by_element\Mag_comp_043_123.xls**
**D:\Subtask2--delayed\coi_conc_by_element\Mag_comp_044_034.xls**
**D:\Subtask2--delayed\coi_conc_by_element\Mag_comp_044_124.xls**
**D:\Subtask2--delayed\coi_cum_mass_by_date\coc_sum_by_date.exe**
**D:\Subtask2--delayed\coi_cum_mass_by_date\date_040.csv**
**D:\Subtask2--delayed\coi_cum_mass_by_date\date_041.csv**
**D:\Subtask2--delayed\coi_cum_mass_by_date\date_043.csv**
**D:\Subtask2--delayed\coi_cum_mass_by_date\date_044.csv**
**D:\Subtask2--delayed\coi_mass_by_time\allmass.040.csv**
**D:\Subtask2--delayed\coi_mass_by_time\allmass.041.csv**
**D:\Subtask2--delayed\coi_mass_by_time\allmass.044.csv**
**D:\Subtask2--delayed\coi_mass_by_time\allmass_040.xls**
**D:\Subtask2--delayed\coi_mass_by_time\allmass_041.xls**
**D:\Subtask2--delayed\coi_mass_by_time\allmass_043.csv**
**D:\Subtask2--delayed\coi_mass_by_time\allmass_043.xls**
**D:\Subtask2--delayed\coi_mass_by_time\allmass_044.xls**

**D:\Subtask2--delayed\coi_mass_by_time\all_mass.exe**
**D:\Subtask2--delayed\max_elements_by_coi\max_elems.bat**
**D:\Subtask2--delayed\max_elements_by_coi\max_elems_040.csv**
**D:\Subtask2--delayed\max_elements_by_coi\max_elems_040_v5.csv**
**D:\Subtask2--delayed\max_elements_by_coi\max_elems_041.csv**
**D:\Subtask2--delayed\max_elements_by_coi\max_elems_043.csv**
**D:\Subtask2--delayed\max_elements_by_coi\max_elems_044.csv**
**D:\Subtask2--delayed\max_elements_by_coi\max_elem_by_coi.exe**
**D:\Subtask2--delayed\model_files\040.dat**
**D:\Subtask2--delayed\model_files\040.lvs**
**D:\Subtask2--delayed\model_files\040.out**
**D:\Subtask2--delayed\model_files\040_v5.lvs**
**D:\Subtask2--delayed\model_files\040_v5.out**
**D:\Subtask2--delayed\model_files\041.dat**
**D:\Subtask2--delayed\model_files\041.lvs**
**D:\Subtask2--delayed\model_files\041.out**
**D:\Subtask2--delayed\model_files\043.dat**
**D:\Subtask2--delayed\model_files\043.lvs**
**D:\Subtask2--delayed\model_files\043.out**
**D:\Subtask2--delayed\model_files\044.dat**
**D:\Subtask2--delayed\model_files\044.lvs**
**D:\Subtask2--delayed\model_files\044.out**
**D:\Subtask2--delayed\model_files\lvstran_KEB_v5.exe**
**D:\Subtask2--delayed\model_files\lvstran_KEB_v6.exe**
**D:\Subtask2--delayed\model_files\lvs_allrun.bat**
**D:\Subtask2--delayed\model_files\Readme.txt**
**D:\Subtask2--delayed\single_coi_element_by_time\cd_040.xls**
**D:\Subtask2--delayed\single_coi_element_by_time\cd_044.xls**
**D:\Subtask2--delayed\single_coi_element_by_time\cd_7_040.csv**
**D:\Subtask2--delayed\single_coi_element_by_time\cd_7_044.csv**
**D:\Subtask2--delayed\single_coi_element_by_time\ext_coc4.exe**
**D:\Subtask2--delayed\single_coi_element_by_time\h3_040.xls**
**D:\Subtask2--delayed\single_coi_element_by_time\h3_044.xls**
**D:\Subtask2--delayed\single_coi_element_by_time\h3_11_040.csv**
**D:\Subtask2--delayed\single_coi_element_by_time\h3_11_5.csv**
**D:\Subtask2--delayed\single_coi_element_by_time\h3_11_6.csv**
**D:\Subtask2--delayed\single_coi_element_by_time\h3_15_044.csv**
**D:\Subtask2--delayed\single_coi_element_by_time\hg_040.xls**
**D:\Subtask2--delayed\single_coi_element_by_time\hg_044.xls**
**D:\Subtask2--delayed\single_coi_element_by_time\hg_7_040.csv**
**D:\Subtask2--delayed\single_coi_element_by_time\hg_7_044.csv**
**D:\Subtask3--trigger\coi_conc_by_element**
**D:\Subtask3--trigger\coi_cum_mass_by_date**
**D:\Subtask3--trigger\coi_mass_by_time**
**D:\Subtask3--trigger\max_elements_by_coi**
**D:\Subtask3--trigger\model_files**
**D:\Subtask3--trigger\model_trigger_determ_files**
**D:\Subtask3--trigger\single_coi_element_by_time**
**D:\Subtask3--trigger\coi_conc_by_element\elemsum.050_v7.csv**
**D:\Subtask3--trigger\coi_conc_by_element\elemsum.053_v6.csv**
**D:\Subtask3--trigger\coi_conc_by_element\elemsum.053_v7.csv**
**D:\Subtask3--trigger\coi_conc_by_element\elemsum.054_v6.csv**
**D:\Subtask3--trigger\coi_conc_by_element\elemsum.054_v7.csv**
**D:\Subtask3--trigger\coi_conc_by_element\elem_sum.exe**
**D:\Subtask3--trigger\coi_conc_by_element\Mag_comp_053_v6_040.xls**
**D:\Subtask3--trigger\coi_conc_by_element\Mag_comp_053_v6_043.xls**
**D:\Subtask3--trigger\coi_conc_by_element\Mag_comp_054_v6_040.xls**
**D:\Subtask3--trigger\coi_conc_by_element\Mag_comp_054_v6_044.xls**
**D:\Subtask3--trigger\coi_cum_mass_by_date\coc_sum_by_date.exe**
**D:\Subtask3--trigger\coi_cum_mass_by_date\date_053.csv**
**D:\Subtask3--trigger\coi_cum_mass_by_date\date_054.csv**

**D:\Subtask3--trigger\coi_mass_by_time\allmass.054_v6.csv**
**D:\Subtask3--trigger\coi_mass_by_time\allmass_053.xls**
**D:\Subtask3--trigger\coi_mass_by_time\allmass_053_v6.csv**
**D:\Subtask3--trigger\coi_mass_by_time\allmass_054.xls**
**D:\Subtask3--trigger\coi_mass_by_time\all_mass.exe**
**D:\Subtask3--trigger\max_elements_by_coi\max_elems.bat**
**D:\Subtask3--trigger\max_elements_by_coi\max_elems_053_v6.csv**
**D:\Subtask3--trigger\max_elements_by_coi\max_elems_054_v6.csv**
**D:\Subtask3--trigger\max_elements_by_coi\max_elem_by_coi.exe**
**D:\Subtask3--trigger\model_files\053.dat**
**D:\Subtask3--trigger\model_files\053_v6.lvs**
**D:\Subtask3--trigger\model_files\053_v6.out**
**D:\Subtask3--trigger\model_files\054.dat**
**D:\Subtask3--trigger\model_files\054_v6.lvs**
**D:\Subtask3--trigger\model_files\054_v6.out**
**D:\Subtask3--trigger\model_files\lvstran_KEB_v6.exe**
**D:\Subtask3--trigger\model_files\lvs_allrun.bat**
**D:\Subtask3--trigger\model_files\Readme.txt**
**D:\Subtask3--trigger\model_trigger_determ_files\050.dat**
**D:\Subtask3--trigger\model_trigger_determ_files\050_v7.lvs**
**D:\Subtask3--trigger\model_trigger_determ_files\050_v7.out**
**D:\Subtask3--trigger\model_trigger_determ_files\053_v7.lvs**
**D:\Subtask3--trigger\model_trigger_determ_files\053_v7.out**
**D:\Subtask3--trigger\model_trigger_determ_files\054_v7.lvs**
**D:\Subtask3--trigger\model_trigger_determ_files\054_v7.out**
**D:\Subtask3--trigger\model_trigger_determ_files\lvstran_KEB_v7.exe**
**D:\Subtask3--trigger\model_trigger_determ_files\trigger_summary.txt**
**D:\Subtask3--trigger\single_coi_element_by_time\c14_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\c14_51_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\cd_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\cd_54_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\co60_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\co60_7_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\cs137_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\cs137_7_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\ext_coc4.exe**
**D:\Subtask3--trigger\single_coi_element_by_time\h3_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\h3_11_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\hg_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\hg_7_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\i129_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\i129_51_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\lvs_con.BAT**
**D:\Subtask3--trigger\single_coi_element_by_time\np237_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\np237_13_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\pb_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\pb_7_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\pu238_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\pu238_23_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\pu239_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\pu239_23_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\sr90_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\sr90_7_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\tc99_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\tc99_9_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\u235_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\u235_23_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\u238_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\u238_7_054.csv**
**D:\Subtask3--trigger\single_coi_element_by_time\voc_054.xls**
**D:\Subtask3--trigger\single_coi_element_by_time\voc_54_054.csv**