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A computer code system for calculating water flow (unsaturated or saturated), solute transport, and human doses due to the slow release of contaminants from a waste form to an aquifer, well and river, is described. Verification and benchmarking of the codes in the system is also presented

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EXECUTIVE SUMMARY

GPACS is a computer code system which calculates water flow, solute transport, concentrations, and human doses due to the slow release of contaminants from a waste form (in particular grout or glass) through an engineered system and through a vadose zone to an aquifer, well or river. For glass waste forms, the leach rate or release rate of species from glass is an input (or independent) variable for GPACS, not a calculated or dependent variable.

This dual-purpose document is intended to serve as a user's guide and verification/benchmark document for the Grout/Glass Performance Assessment Code System (GPACS). This document is not intended to serve as a complete user's guide, however, as the users will have to have separate documentation for each of the main codes in the system. The document also serves as a verification and benchmark document for GPACS on the Cray computer which was at Hanford, and the IBM and Silicon Graphics workstations in the Scientific and Engineering Computer Center (SECC) at Westinghouse Hanford Company. Also, some elements of a configuration document are included for transitional purposes to a complete software configuration document for the SECC.

Even though the Cray computer was been removed from the Hanford site, the information about GPACS on the Hanford Cray is still presented here because much of the information is generic and applies to any computer system. Also, all of the computer simulations with GPACS for the Grout Performance Assessment (Piepho 1994) were made on the Hanford Cray in 1993.

Even though the GPACS was a product of the Grout Performance Assessment, it can be used for the low-level-waste (LLW) Glass Performance Assessment and many other applications including other low-level-waste (LLW) performance assessments and risk assessments. The main feature of the system is that starting with basic hydrologic data (both unsaturated and saturated media) and waste inventories, several doses to man (drinking-water, irrigated-farm and river) can be calculated as function of time for thousands of years.

Based on all the cases presented, GPACS is adequate (verified) for calculating water flow and contaminant transport in unsaturated-zone sediments and for calculating human doses via the groundwater pathway (both unsaturated and saturated). Both the PORFLOW code and GRTPA code check out very well, on the Cray computer, and IBM and SGI workstations in the SECC, with analytical solutions and benchmarks from other widely-accepted software. However, since the hydrological system is an open system, GPACS can never be completely verified (Oreskes et al, 1994), but only confirmed by realistic test cases. Furthermore, the nonisothermal flow and multiphase flow capability in PORFLOW were not investigated in this study, but do exist. Such capabilities would need to be confirmed before they are used on site, although such testing has been successfully demonstrated elsewhere (Runchal 1994).

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1.0 INTRODUCTION

GPACS is a computer code system which calculates water flow, solute transport,and human doses due to the slow release of contaminants from a waste form (in particular grout or glass) to an aquifer, well and river. For glass waste forms, the leach rate or release rate of species from glass is an input (or independent) variable for GPACS, not a calculated or dependent variable.

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The PORFLOW code (Runchal et al. 1992), which is the main computational engine of GPACS, is described in Section 2.0. The dose post-processing code GRTPA (Rittmann 1993), which calculates the radiological doses and chemical concentrations in the aquifer or river, is described in Section 3.0. The graphics post-processing codes MAKETEC and TECPLOT are briefly described in Section 4.0. The data files, which are used in the GPACS and act as the connection points for the computer codes in the system, are briefly described in Section 5.0. The complete flowchart for GPACS is shown in Figure 5.1 located in Section 5.0. The summary and conclusions are presented in Section 6.0.

2.0 PORFLOW VERSION 2.394gr

2.1 INTRODUCTION

Section 2.0 describes the PORFLOW version 2.394gr code. A brief background, the changes made, the Cray, IBM and SGI configurations, the code custodian and code documentation are all given in Section 2.2. The verification and benchmarking documentation starts in Section 2.3 and the results are given in Sections 2.4 and 2.5. The conclusions are given in Section 2.6.

2.2 DEFINITION OF PORFLOW VERSION 2.394GR

2.2.1 BACKGROUND

Version 2.394gr of the PORFLOW computer code was used for the Hanford Grout Performance Assessment (Kincaid et al. 1993). PORFLOW version 2.394gr was created by Westinghouse Hanford Company (WHC) from the earlier PORFLOW version 2.394 which was released in November, 1991 by Analytic & Computational Research, Inc. (ACRI) in Bel Air, California. PORFLOW was developed by ACRI with support from the United States Department of Energy (DOE). Versions 2.394 and 2.394gr of PORFLOW are licensed non-exclusively to Westinghouse Hanford Company (WHC) by ACRI for use in projects sponsored by the United States government. The source code for PORFLOW version 2.394gr is maintained by WHC on the Hanford Common File Storage (CFS) system. Although this version of the code is maintained within WHC by the code custodian, copies which are provided through ACRI to other government agencies are licensed only by ACRI.

An older version of PORFLOW, version 1.0 (usually denoted as PORFLO-3), has previously been independently verified and benchmark tested by Magnuson et al. (1990). A certification document for version 1.2 of PORFLO-3 was issued in November 1993 (Kline 1993), which was issued after the analyses for this report were completed. However, the results from version 1.2 and version 1.0 of PORFLO-3 are reported to be the same by Kline (1993), and, hence, this report just compares to version 1.0 of PORFLO-3.

The 1.* versions of PORFLOW do not have multiphase flow capability whereas the 2.* versions of PORFLOW do have multiphase flow capability (Piepho et al. 1991). Additional enhancements exist in the 2.* versions, and in particular, in version 2.394gr. The changes and enhancements made to PORLFOW version 2.394 for the Grout PA are described in the next section.

2.2.2 CHANGES AND ENHANCEMENTS

The purpose of this section is to describe the changes made to PORLFOW version 2.394, so that a user can make full use of the enhancements of PORFLOW version 2.394gr, and not misuse it for other problems that differ from grout. However, misuse of version 2.394gr is not likely since one of the design goals of the changes was to allow backward compatibility with version 2.394 (i.e., version 2.394gr should be able to run with version 2.394 input), which was achieved, except for the time-dependent diffusion coefficient capability for a particular zone in version 2.394gr.

2.2.2.1 CONTINUOUS TIME-DEPENDENT DIFFUSION COEFFICIENT

The continuous time-dependent diffusion coefficient change was put in PORFLOW to simulate a disappearing asphalt barrier around the grout vault. As the asphalt barrier gets thinner, the effective diffusion coefficient increases. See Section 2.5.6 for more information. The change to the standard diffusion coefficient (defined on the TRANsport card) is made a) only for ZONE 8, b) only if the EXPO modifier is included on the TRAN card (signaling the use of the Kemper diffusion model), and c) only for times less than 90,000 years (actually 90,000 time units which could be seconds, days, years, etc.), the time assumed for complete asphalt bio-degradation by the Grout PA.

If problems other than grout are run, it would be important to either not use ZONE 8 in the problem definition or not use the EXPO modifier (Kemper diffusion model) with the TRANS card. The Kemper diffusion model is new to PORLFOW, so input files to the PORFLO-3 versions 1.* will not present any incompatibilities in this regard since no EXPO modifier, with the TRAN card, will be found in such older input files. Not using Zone 8 would be the easiest way to avoid a time-vary diffusion coefficient that is monotonically increasing by 6 orders of magnitude for the first 90,000 years.

2.2.2.2 DISCRETE TIME-DEPENDENT CHANGES OF MATERIAL PROPERTIES

Because of the requirement to model degradation changes in the barriers and grout over time (Piepho 1993), material properties can be changed in between SOLV commands with PORFLOW version 2.394gr which eliminates the need to restart a run. The following PORFLOW keywords (only the first four letters are read by PORFLOW and are capitalized here for contrast) can be used to make changes and their order of occurrence can be important:

1. ROCK - Must be located before SOLV, INIT, and TRAN input cards,
2. HYDRaulic - Any order before SOLV card,
3. MULTiphase - Any order before INIT and SOLV cards,
4. TRANsport - Must follow ROCK card and precede SOLV card,
5. INITial H - Must follow ROCK and MULT cards, preceded SOLV card, and only capillary pressure head, H, can be initialized after the start of a run,
6. DISAble FLOW - Any order before SOLV card; turns on pressure equation solver again if it is the second (or even numbered) DISAble card in input file, and it turns the pressure equation solver off if it is an odd-numbered occurrence in the input file,
7. CONVergence - must follow the DISAble FLOW card in order to reset or change convergence criteria. This card appears to be required just to keep the original convergence criteria; i.e., even if none of the original convergence criteria changes.

8. SOLVe - This card should follow all other changes because this card triggers all of the above changes and prints out the updated or changed values, and starts to solve the problem with the new changes.

2.2.2.3 OTHER ENHANCEMENTS

A. Fractional-Release File for GRTPA Code (Dose Post-Processor): The fraction of initial activity of a radionuclide transport group that reaches the aquifer per unit time is calculated in PORFLOW version 2.394gr and stored on local file fort.35. The GRTPA code reads this fractional-release file directly and calculates doses (see Section 3.0 for details of GRTPA code). The local file fort.35 is discussed in Section 5.0.

B. Improved Diagnostic Print-Out: The diagnostic cell print-out for PORFLOW version 2.394gr includes the actual time step value and the cumulative amount of liquid water volume gained or lost for the whole computational domain since the start of the simulation. The water volume gain or loss for the entire modeling domain can be heuristically used as indicator of reaching a steady-state flow solution as the cumulative water volume change becomes constant.

2.2.3 CRAY CONFIGURATION AND CODE CUSTODIAN

Version 2.394gr of PORFLOW was configured on the Hanford Cray on October 18, 1992 by the code custodian. Since that time, no changes have been made to that configured version, which has produced all of the new results in this report and all of the vadose-zone modeling results in the Grout PA (Kincaid et al. 1993, Piepho 1994). Even though the Hanford Cray has been removed from the site, the Cray files are still stored and available at Hanford for use on other Cray computers. The executable file for PORFLOW version 2.394gr is stored on the Hanford Common File Storage (CFS) system in the directory /w94220/grout as por2394gr.e. This executable is dimensioned to model 20,000 internal nodes. The FORTRAN files for this executable are stored on the same CFS directory and are called por2394gr.f, acrlib2394gr.f, porb0.f, and acrcray.f with INCLUDE files param.por, param3.por, and param.sys. To compile and link the executable on a Cray with a UNICOS operating system, the following Cray command is used:

```
cf77 -o por2394gr.e  -Wf"-a static" *.f
```

The acting code custodian of PORFLOW version 2.394gr is Mel Piepho of WHC.

2.2.4 IBM WORKSTATION CONFIGURATION AND CODE CUSTODIAN

Version 2.394gr of PORFLOW was configured on the IBM Workstation, ibml, in the 3200 George Washington Way Building on August 18, 1993 by the code custodian. Since that time, no changes have been made to that configured version. The executable file for PORFLOW version 2.394gr is stored on the IBM (ibml) workstation disk directory /p_ibm/por2.394 as poribmgr.e. This executable is dimensioned to model 20,000 internal nodes. To compile and link the executable, the following IBM compiler command was used:

```
xlf -O3 -qautodbl=dblpad  *.f
```

The acting code custodian of PORFLOW version 2.394gr on the IBM Workstation is Mel Piepho of WHC.

2.2.5 SGI WORKSTATION CONFIGURATION AND CODE CUSTODIAN

PORFLOW version 2.394gr was configured on the SECC SGI Workstations in the 3200 George Washington Way Building on October 25, 1993 by the code custodian. Since that time, no changes have been made to that configured version. The executable is dimensioned to model 20,000 internal nodes. To compile and link the executable, the following SGI compiler command is used:

```
f77 -O3 -r8 -static  *.f
```

The acting code custodian of PORFLOW version 2.394gr on the SGI Workstation is Mel Piepho of WHC.

2.2.6 CODE DOCUMENTATION

The code document that is used for PORFLOW version 2.394gr is entitled "PORFLOW: A Multifluid Multiphase Model for Simulating Flow, Heat Transfer, and Mass Transport in Fractured Porous Media - User's Manual - Version 2.40", (Runchal and Sagar, 1992). With many computer codes, the documentation lags the computer code development. With PORFLOW version 2.394gr, however, the documentation is ahead of the code, but not by much. Basically, version 2.40 was the next version of PORFLOW after version 2.394 with very few differences. The only known differences are the following:

A. PORFLOW version 2.394 and version 2.394gr require a dummy number (real or integer) as a place holder on the BOUNdary card if cell indices are specified on that BOUNdary card. For example, the following BOUNdary card works fine for version 2.40,

```
BOUNdary for P: -3, val=1.0, from (2,3,1) to (5,7,1),
                                 $[vers 2.40]
```

but will not work in versions 2.394 or 2.394gr, which require a dummy value between the boundary value and cell indices on the card, such as

```
BOUNdary for P: -3, val=1.0, dum=0.0, from (2,3,1) to
                     (5,7,1)    $[vers 2.394gr]
```

If the boundary is homogeneous, i.e., no cell indices are specified, then the dummy placeholder is not required.

B. Only UNFOrmatted archive files can be created PORFLOW version 2.394gr, whereas both FORMatted and UNFOrmatted archive files can be created in PORFLOW version 2.40.

C. The EXPO modifier, which turns on the Kemper diffusion model, on the TRANsport card needs only to be specified on the first zone and not for all zones. However, once the EXPO modifier has been used, then other diffusion models cannot be used for any other zone. The documentation for version 2.40 implies that the EXPO modifier can be for each zone or not. In reality, it is an all-or-nothing option (i.e., all zones have it or all zones do not have it) for version 2.394gr. It should also be noted that if the EXPO modifier is present, then the dispersion model, with longitudinal and/or transverse dispersion coefficients cannot be activated for the simulation.

D. The particle tracking capability is not implemented in PORLFOW version 2.394gr; hence, transient travel times cannot be calculated.

E. The DEBUg option is not implemented in PORFLOW version 2.394gr; hence, detailed debug information with this option cannot now be obtained.

The last two deficiencies were not a problem for the Grout PA. Since concentration fluxes to the aquifer were easily calculated over time with version 2.394gr which was more useful information than the travel-time calculation. Furthermore, the steady-state condition for water flow was the dominant feature for the grout problem due to the long times of interest (up to a million years). The steady-state water-travel times were easily determined by the post-processing graphics code, TECPLOT (AMTEC 1992). Concerning the DEBUg option, the code was error-free and detailed information other than the normal output was not needed.

Other differences between PORLFOW version 2.394gr and the version 2.40 documentation may exist, but no other differences have been found yet by the code custodian.

2.3 VERIFICATION AND BENCHMARKING

2.3.1 ACCEPTANCE CRITERIA

One major portion of the PORFLOW Version 2.394gr verification and benchmarking testing will be to demonstrate that it produces the same results as reported in Magnuson et al. (1990). The conclusion of that earlier testing was that PORFLO-3 version 1.0 was a versatile and powerful analysis tool that could be used to:

A. Analyze isothermal fluid flow patterns for saturated and unsaturated conditions,

B. Simulate isothermal mass transport.

This analysis capability encompasses the requirements for the Hanford Grout PA analyses (Piepho 1994). PORFLOW also has the capability to model non-isothermal flow and transport, but this capability was not used for the Grout PA and, therefore, was not tested here. Furthermore, the multiphase capability in PORFLOW was not tested or used in the Grout PA (Piepho 1994).

In addition to the some of the verification (comparison of results with an analytic solution) and benchmark (comparison to other codes) cases that were defined in the Magnuson et al. (1990) report, other verification and benchmark cases representative of the grout modeling were analyzed and compared with analytic solutions or the TRACR3D (Travis 1984)/S301-2 (Farmer 1984) codes.

After the analyses for this report were completed in 1993, documentation (Kline 1993) of version 1.2 of PORFLO-3 was issued. This current document makes no comparison with the version 1.2 results because of the PORFLOW version 2.394gr analyses having been completed prior to the version 1.2 results. However, the version 1.2 results were stated to match the version 1.0 results although no graphical comparisons were presented in the version 1.2 report (Kline 1993). This document assumes that if the version 2.394gr results match the version 1.0 results as shown graphically, then the version 2.394gr results would also match the version 1.2 results.

In summary, the acceptance criteria is based on the following where the comparisons are made by graphical observations of key output:

1. Reproducing the same results as Magnuson et al. (1990),

2. reproducing the same results from analytical solutions of other verification problems, and

3. comparing favorably to other codes such as TRACR3D and S301 on real grout problems that are long running on the Cray.

Since so many options are available in PORLFOW version 2.394gr, it is not practical to test all of them. However, the problems chosen here are representative of many realistic groundwater flow and transport problems, especially the ones required for the Grout PA. Even so, the analyst must still be careful in running such a code so that good input is used and results are consistent with the input.

2.3.2 GENERAL DESCRIPTION OF TEST PROBLEMS

Two sets of test problems were defined for the purpose of verifying and benchmarking PORLFOW version 2.394gr. The purpose of these problems is to show that PORFLOW version 2.394gr can do any problem that previous versions of PORFLOW could do, and to qualify PORLFOW version 2.394gr for Quality Assurance (QA) Impact Level QS. Demonstrated satisfactory performance of PORFLOW version 2.394gr on the following verification and benchmark problems qualify PORFLOW for use on similar problems, but will not qualify PORFLOW other types of problems like multiphase or nonisothermal problems. The verification of computer codes for natural systems is very difficult and can never be perfect (Oreskes et al. 1994). However, showing that the code works for certain types of problems is a necessary step in QA procedures even though it is not sufficient. It is the responsibility of the user to ensure that the simulations are adequate with respect to conservation of mass, etc., and/or engineering/scientific judgement. The problems described here are shown to be solved adequately by PORFLOW version 2.394gr on the Cray, IBM workstation, and SGI workstations in the SECC. The workstation results were only slightly different (less than 0.01%) than the Cray results. This is attributed to the workstations, with their double precision real words, were more accurate than the Cray with single precision.

The first set of test problems consists of four verification problems that have analytical solution to compare against. These problems test the capability of PORFLOW in the following areas (problem identifier/computer filename are in parentheses):

A. Transient unsaturated flow in a one-dimensional vertical column, (vt1)

B. Transient drawdown of pressure head due to pumping a confined aquifer of constant thickness that was fully penetrated by a well, (vt2)

C. Nonuniform infiltration (two-dimensional) into dry homogeneous soil, (warrick)

D. Mass (solute) transport in a two-dimensional groundwater model with a strip source with the grid Peclet number varying three orders of magnitude. (t01, t02, t03)

The second set consists of six benchmark problems that have been compared with other computer code solutions. These problems are representative of the Grout Performance Assessment application and demonstrate the capability of PORFLOW in the following areas (problem identifier/computer file name is in parentheses):

A. Steady state two-dimensional saturated-unsaturated flow, (bt1)

B. Transient two-dimensional unsaturated flow simulating the infiltration of water into a relatively dry, heterogeneous soils, (bt2)

C. Steady-state saturated flow in a porous media with two distinct fractures, (bt3)

D. Transient two-dimensional unsaturated flow on a sloping clay layer embedded within a coarse sandy material with both arithmetic and harmonic averaging. This problem is representative of the required clay cap which overlays the Grout vault demonstrating the water flow through and around the clay cap. (claya and clayh)

E. Mesh refinement impact on the central grout case reported in Whyatt, et al. (1991), which is 2D model in an unsaturated zone with advection and diffusion through the grout vault, (g1mel and g1fine)

F. Grout Performance Assessment (Kincaid et al. 1993) benchmark case, which includes the unsaturated zone, and advective and diffusional release from the grout through a concrete vault (Piepho 1994). (g3bench)

2.3.3 FILE NAMING CONVENTION AND STORAGE

All input, output, and archive files for the test problems are stored on the Hanford Common File Storage (CFS) system in the directory /w94220/porflowqa. The following file designations have been used for each of the verification and benchmark problems:

*.inp
*.out
*.arc

where * denotes the specific problem identifier/computer filename, which are given for each case in parentheses in Sections 2.2, 2.3 and 2.4.

2.4 VERIFICATION CASES AND RESULTS

The verification problems demonstrate the capability of the PORFLOW code to reproduce analytic solutions thus demonstrating the accuracy and stability of the numerical techniques and establishing the operational status of the code.

2.4.1 PHILIPS SOLUTION FOR A VERTICAL COLUMN (vt1)

Magnuson et al. (1990) identify this problem as VT-1. The physical system is a vertical, homogeneous one-dimensional soil column with an initial condition of a uniform pressure head. The pressure head at the upper boundary was a held value corresponding to saturation and the bottom boundary was held constant at the initial pressure head. Transient infiltration of moisture in the vertical direction results from capillary forces and gravity. The model idealization and constitutive equations used are identical to those documented in Magnuson et al. (1990). Figure 2.1 superimposes the results from version 2.394gr of PORFLOW on the results reported by Magnuson et al. (1990). The pressure head plotted versus depth at a time of two hours agrees exactly with the previously reported results. The Picard method of solution with the ADI (Alternating Direction Implicit) method for the inner iterations of the governing equations was employed to produce these results. The results show that PORFLOW does a good job of simulating vertical movement of moisture in a homogeneous, unsaturated soil. Although other methods of solutions are available in PORFLOW, only the Picard/ADI combination of methods were tested in this report. This is because these methods were shown to be the best (most robust, accurate and fast) ones during much informal testing of the code.

2.4.2 THEIS SOLUTION FOR TRANSIENT DRAWDOWN (vt2)

This problem, identified by VT-2 in Magnuson et al. (1990), simulates the transient drawdown of pressure head due to pumping a confined aquifer of constant thickness that was fully penetrated by a well. The initial total pressure head was assumed to be uniform and constant. Figure 2 shows the total head distribution calculated by version 2.394gr of PORFLOW versus the total head distribution calculated by Magnuson et al. (1990). In this case the total hydraulic head is plotted versus the radial distance from the vertical well. The agreement is excellent and demonstrates that PORFLOW adequately solves the governing equations for saturated flow.

FIGURE 2.1 Comparison of Pressure Heads for Case vt1

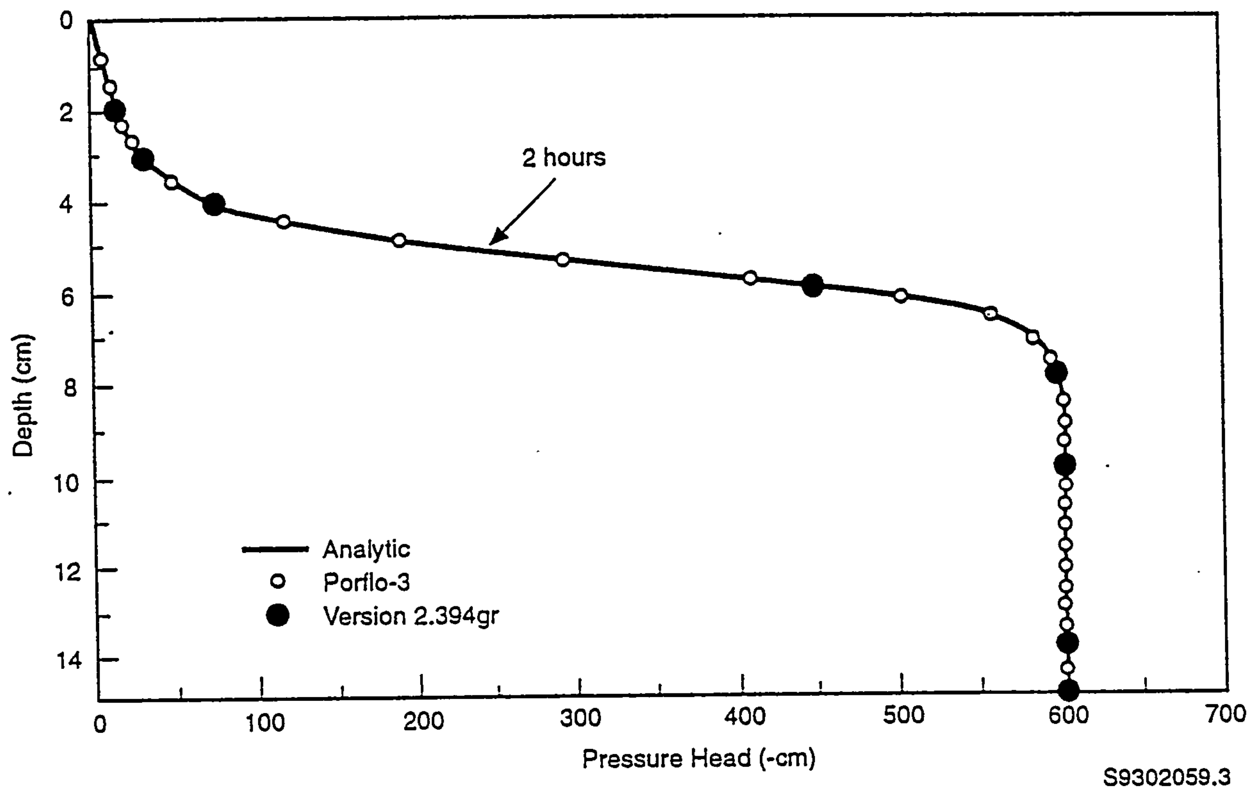
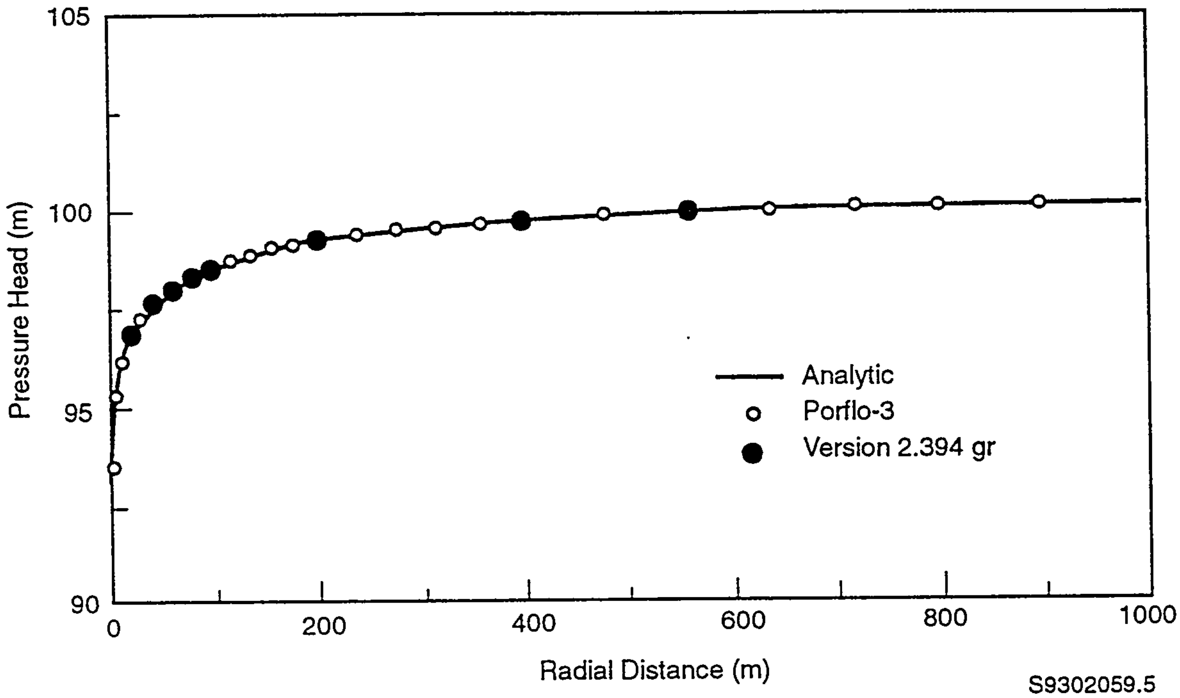


FIGURE 2.2 Comparison of Total Head Profiles for Case vt2



2.4.3 NONUNIFORM INFILTRATION INTO DRY HOMOGENEOUS SOIL (warrick)

This problem, denoted by "warrick", represents the infiltration from a surface strip source into a very dry homogeneous soil. Warrick and Homer (1976) obtained an analytical solution for this problem using the parameters determined for a Panoche soil which is characterized by:

$\theta(h)$ = $(K_o/A)\ \exp(\gamma h)$
θ = volumetric moisture content
h = capillary pressure head
K_o = 0.0694 cm/min
γ = 0.04/cm
A = 0.1388 cm/min
K(h) = $K_o \cdot \exp(\gamma h)$ = Unsaturated conductivity (cm/min)

The model domain is 80 cm wide and 100 cm deep. A nonuniform grid with 31 nodes in the x-direction and 33 nodes in the vertical y-direction has been used to discretize the domain. The coordinates of the nodes (both internal and boundary) in the x-direction were:

-0.5, 0.5, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5, 8.5, 10.5,
12.5, 14.5, 16.5, 18.5, 20.5, 22.5, 24.5, 26.5, 28.5, 30.5,
34.5, 38.5, 42.5, 46.5, 50.5, 54.5, 58.5, 63., 69.0, 76.25,
83.75.

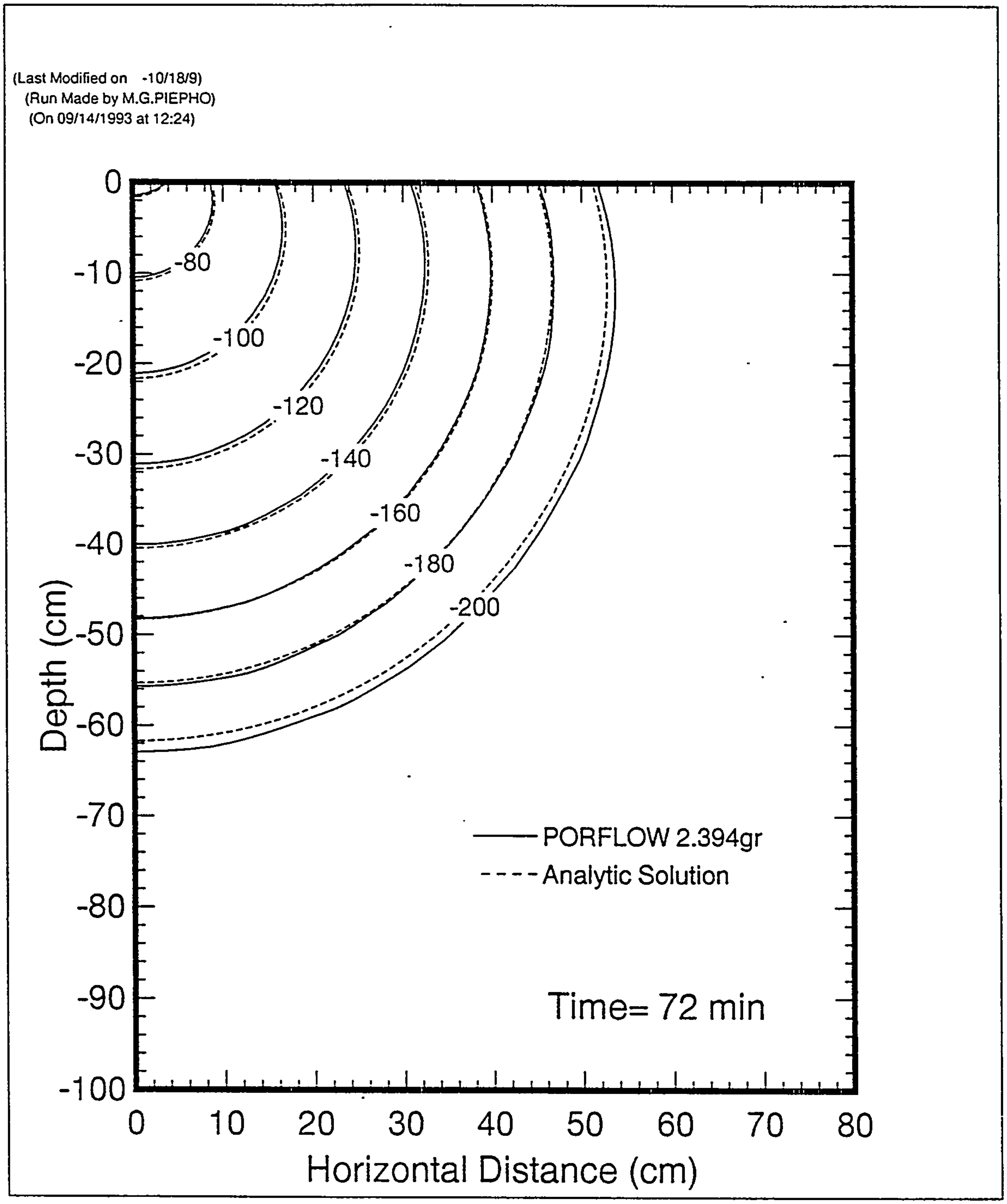
The coordinates of all nodes in the y-direction were the following:

-0.5, 0.5, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5, 8.5, 10.5,
12.5, 14.5, 16.5, 18.5, 20.5, 22.5, 24.5, 26.5, 28.5, 30.5,
34.5, 38.5, 42.5, 46.5, 50.5, 54.5, 58.5, 62.5, 70.5, 78.5,
86.5, 95.25, 104.75.

The length of the strip source was taken as 5 cm and the Darcy flux was 0.0277 cm/min which is equivalent to a volumetric source rate of 200 cm^3/day. The initial pressure head was set equal to -250 cm, and the bottom and right-hand side boundaries were maintained at this initial pressure head. The analytical solution is for an infinitely deep boundary and the initial pressures are at minus infinity. In other words, no water was present in the analytical solution. However, at a pressure head of -250 cm, almost no water (less than 0.01%) is present in the numerical model domains. Concerning the finite depth versus the infinite depth, the calculated pressure heads were obtained at 72 minutes which is before the water front gets close to the bottom boundary at 100 cm. Hence, because of the short simulation time, the finite-depth boundary acts like a boundary at an infinite depth.

Figure 2.3 compares the analytical and the PORFLOW-calculated pressure heads. Good agreement is achieved demonstrating the capability of PORFLOW to solve the nonuniform infiltration problem in unsaturated soil. Since the PORFLOW calculations started a little wetter than the analytic solution, one would expect the PORFLOW water front to travel a little farther.

FIGURE 2.3 Comparison of Pressure Heads for Case warrick



2.4.4 TWO-DIMENSIONAL MASS TRANSPORT MODEL WITH A STRIP SOURCE (t01, t02, t03)

The transport capability of PORFLOW was examined through solution of the problems solved analytically by Cleary & Ungs (1978). These problems are also benchmark problems since the results are also compared to the S301 code by Farmer (1984). These three problems were designed to examine the effect of diffusion and advection on the solution inaccuracy resulting from numerical dispersion. The geometrical problem is a rectangular region defined by $0 \leq x/L \leq 1$ and $0 \leq y/L \leq 0.5$. A uniform velocity field is defined parallel to the x-axis with components $V_x = 10$, $V_y = 0$. The contaminant concentration is defined along the left boundary as 1 for $0 \leq y/L \leq 0.25$ and 0 for $0.25 \leq y/L \leq 0.5$. The other boundaries have zero flux and are defined for all time. The grid Peclet number is defined by

$$P_e = V\frac{\delta L}{\Gamma} \tag{1}$$

where,

V = velocity component
δL = grid interval
Γ = diffusivity.

Case t01 has a Peclet number of 2.222 for which diffusion will be dominant. Case t02 has a Peclet number of 80.0 representing a mixture of advection and diffusion. Case t03 has a Peclet number of 2222. for which advection dominates over diffusion. These variations in Peclet numbers are achieved by varying the diffusion coefficients and keeping the velocity constant at 10 ft/day. However, since PORFLOW does not have heterogeneous diffusion coeffients (i.e., the diffusion coefficient is the same in all directions), the dispersion coefficients (longitudinal and transverse) were used in PORFLOW. This was possible since the velocity is constant in the x-direction and zero in the y-direction. As a result, the dispersion represents the diffusion coefficients as defined by this problem and shown in Table 2.1.

TABLE 2.1 Diffusion Coefficients for Verification Cases t01, t01, t03

Case Identifier	Diffusion Coefficients (Total Dispersion)	
	D_x (ft^2/day)	D_y (ft^2/day)
t01	1.125×10^{-1}	1.25×10^{-2}
t02	3.125×10^{-3}	3.125×10^{-4}
t03	1.125×10^{-4}	1.25×10^{-5}

Figure 2.4 compares the concentrations from the PORFLOW code, S301 code and the analytic solution for the Peclet number = 2.222 at time = 0.08 days. The PORFLOW problem was solved in the transient mode with a constant time increment of 4.0 x 10^{-5} days. For problem t01, diffusion (dispersion) is dominant as both the analytical and numerical solution demonstrate.

Figure 2.5 compares the concentrations where P_e = 80.0. In this case advection is becoming dominant but the numerical codes show tremendous longitudinal numerical dispersion. This inability to control numerical dispersion is a clear warning to keep the grid Peclet number in the range from 2 to 20. Figure 2.6 shows the additional increase in numerical dispersion for the advective dominant transport problems where P_e = 2222.0.

FIGURE 2.4 Concentrations Associated with Diffusion Dominated Transport (Pe=2.222)

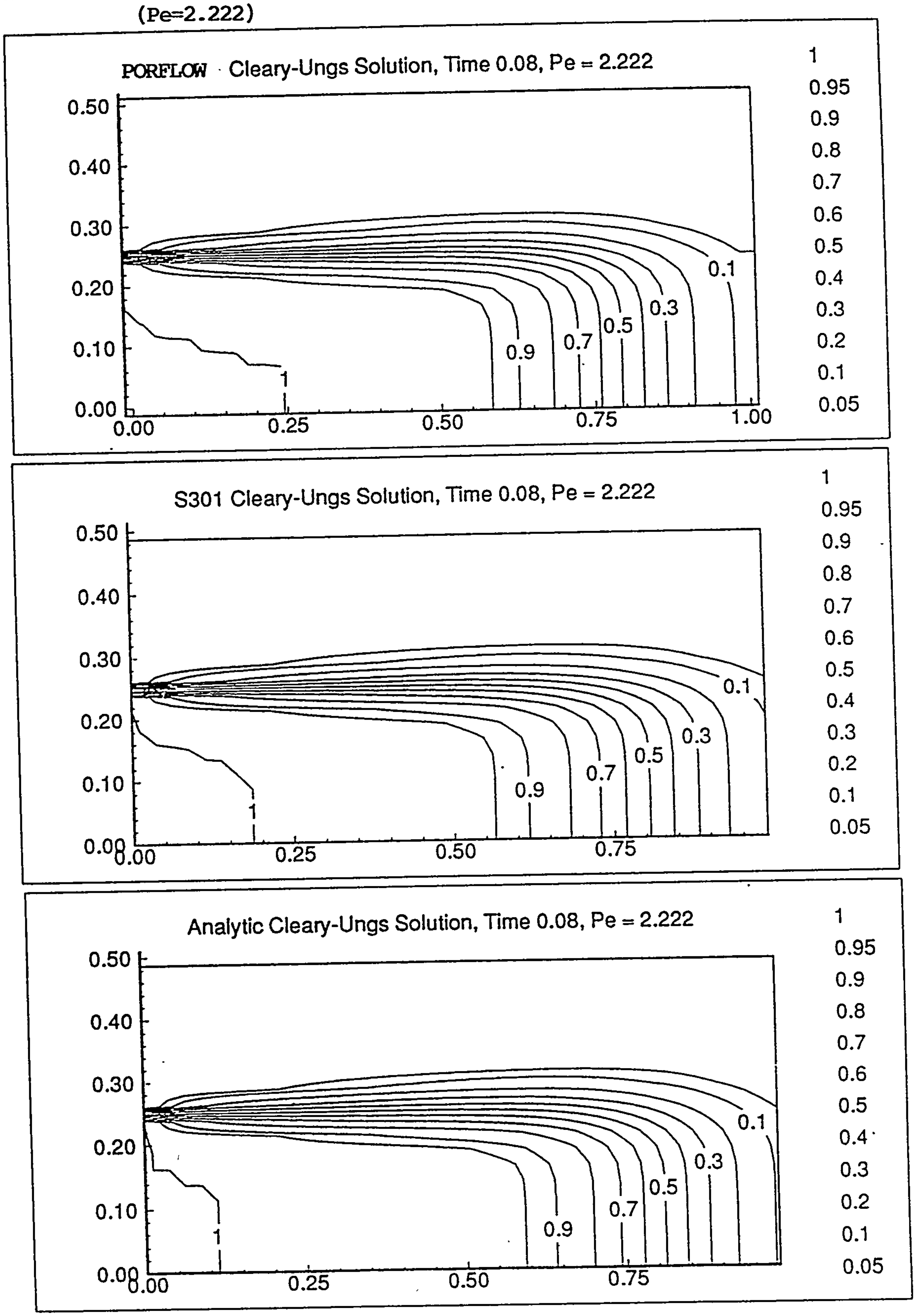


FIGURE 2.5 Concentrations Associated with Slightly Advection Dominated Transport (Pe=80.0)

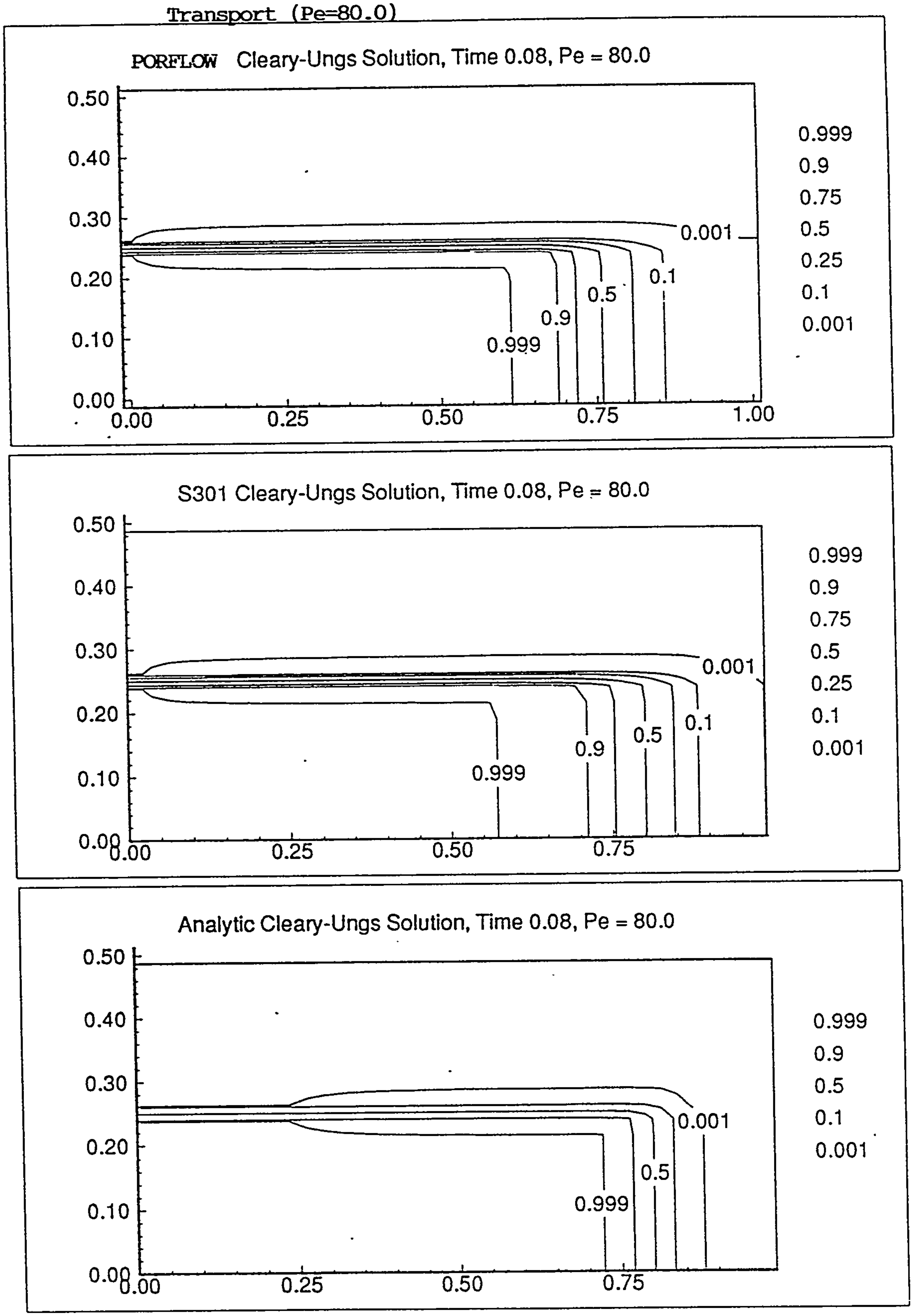
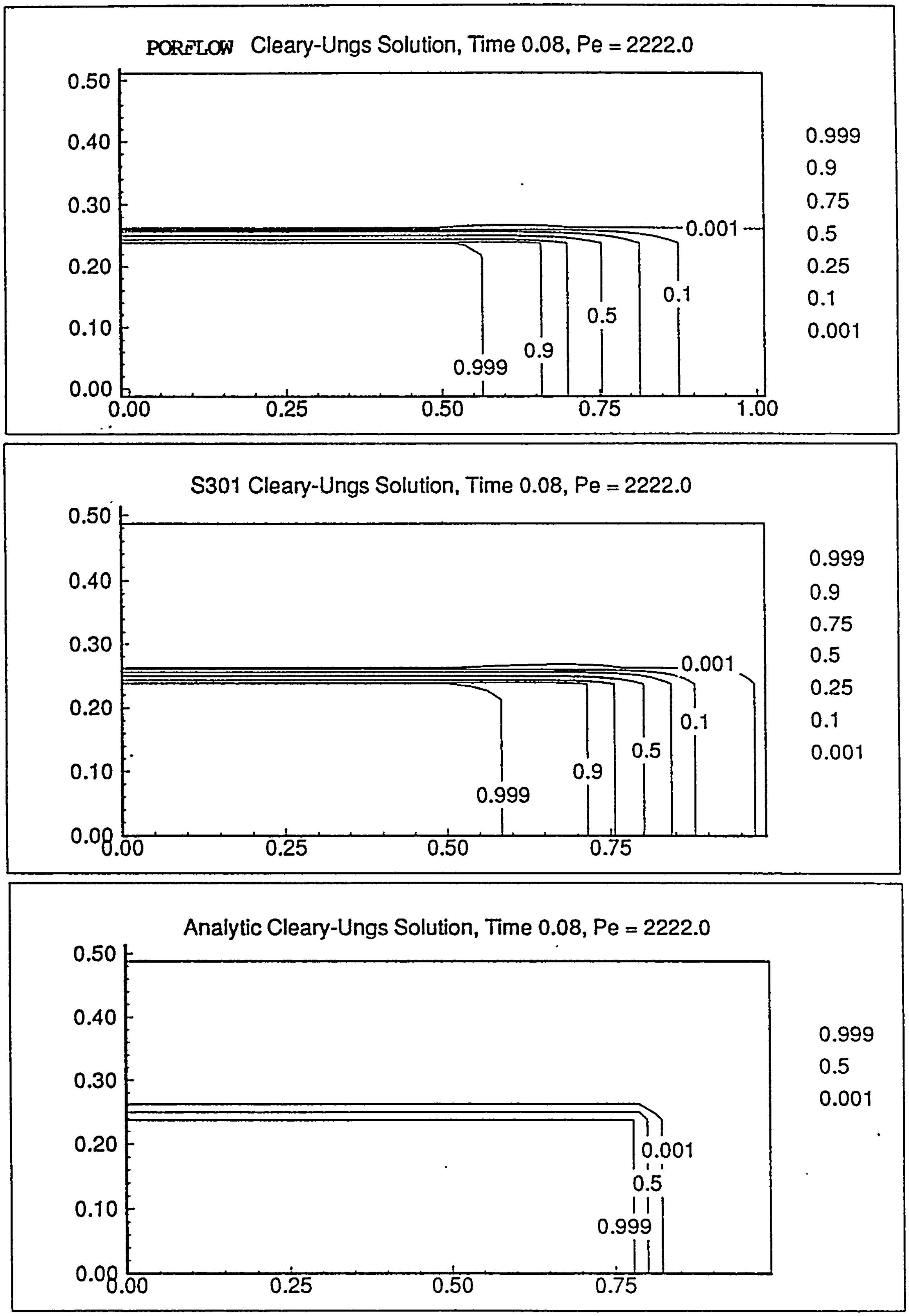


FIGURE 2.6 Concentrations Associated with Advection Dominated Transport (Pe=2222.0)



2.5 BENCHMARK CASES AND RESULTS

The benchmark cases are intended to be more representative of the Grout Performance Assessment application. As a result, no analytical solutions exist and it is necessary to compare the results with other computer codes' numerical results. The value of these benchmarks lie in the demonstration that codes independently developed with alternate solution procedures produce essentially the same numerical results.

2.5.1 TWO-DIMENSIONAL SATURATED-UNSATURATED FLOW (bt1)

This benchmark problem, denoted BT-1 by Magnuson et al. (1990), considers the steady-state movement of moisture for both saturated and unsaturated flow conditions. One should note that the variable S_w in Magnuson's report is really saturation, not moisture content as stated in that report. Figure 2.7 shows the geometry which was modeled. The top surface boundary condition was a flux of 1 m/yr, and a no-flow condition was imposed on the bottom boundary. The boundary conditions for the sides were no-flow above the water table and prescribed head values based on corresponding depth below the water table. An initial pressure head of -10 m was assumed everywhere. Figures 2.8a and 2.8b show the calculated pressure heads from PORFLO-3 Version 1.0 and PORFLOW version 2.394gr, respectively. The contours in common look identical which demonstrates that version 2.394gr is as good as version 1.0 for this case. Figure 2.9 plots the saturation profile at a distance of 30 meters from the left boundary of the domain. The three codes that are shown produce the same results demonstrating that they solve the governing equations for combined saturated-unsaturated flow in a consistent manner.

FIGURE 2.7 Geometry for Case bt1

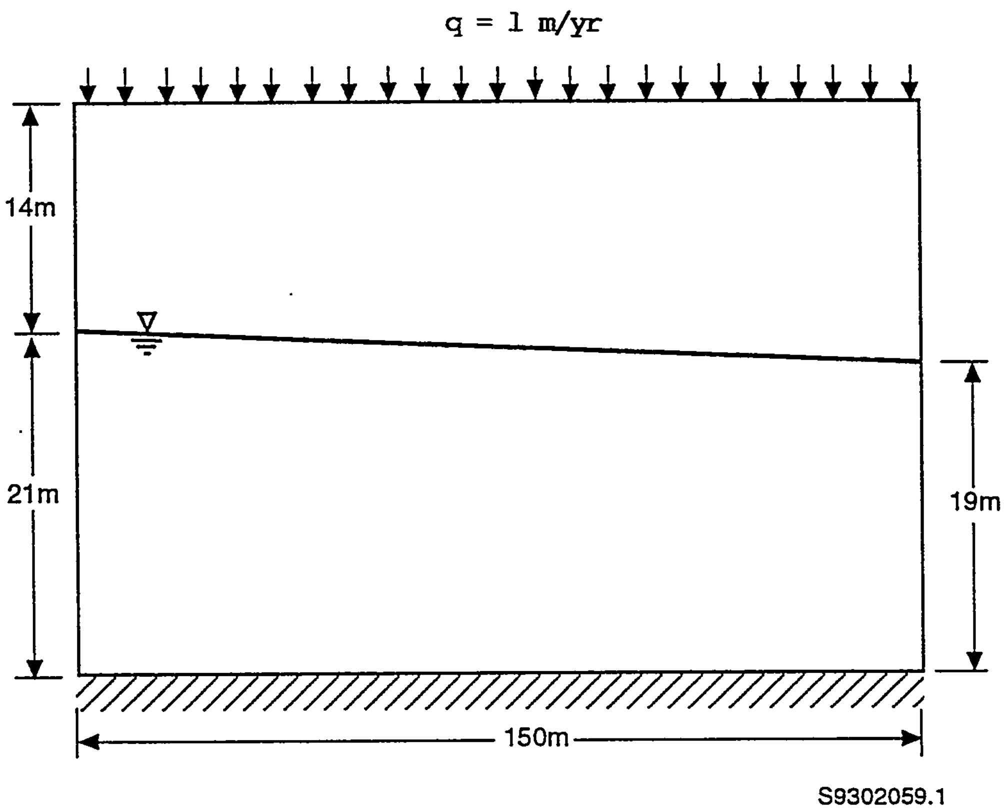


FIGURE 2.8a Pressure Heads from PORFLO-3 for Case bt1

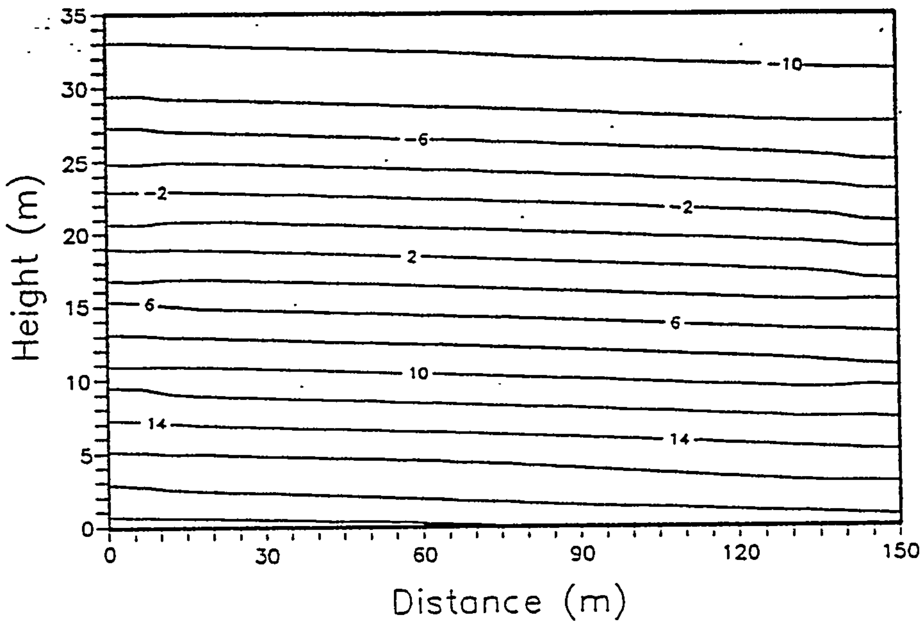


FIGURE 2.8b Pressure Heads from PORFLOW Version 2.394gr for Case bt1

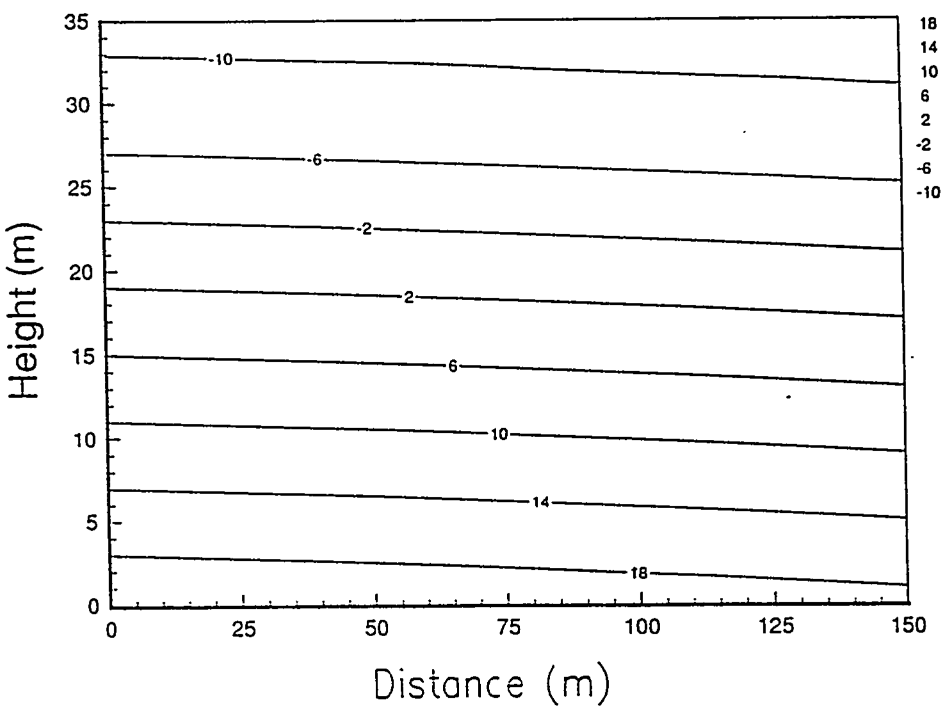
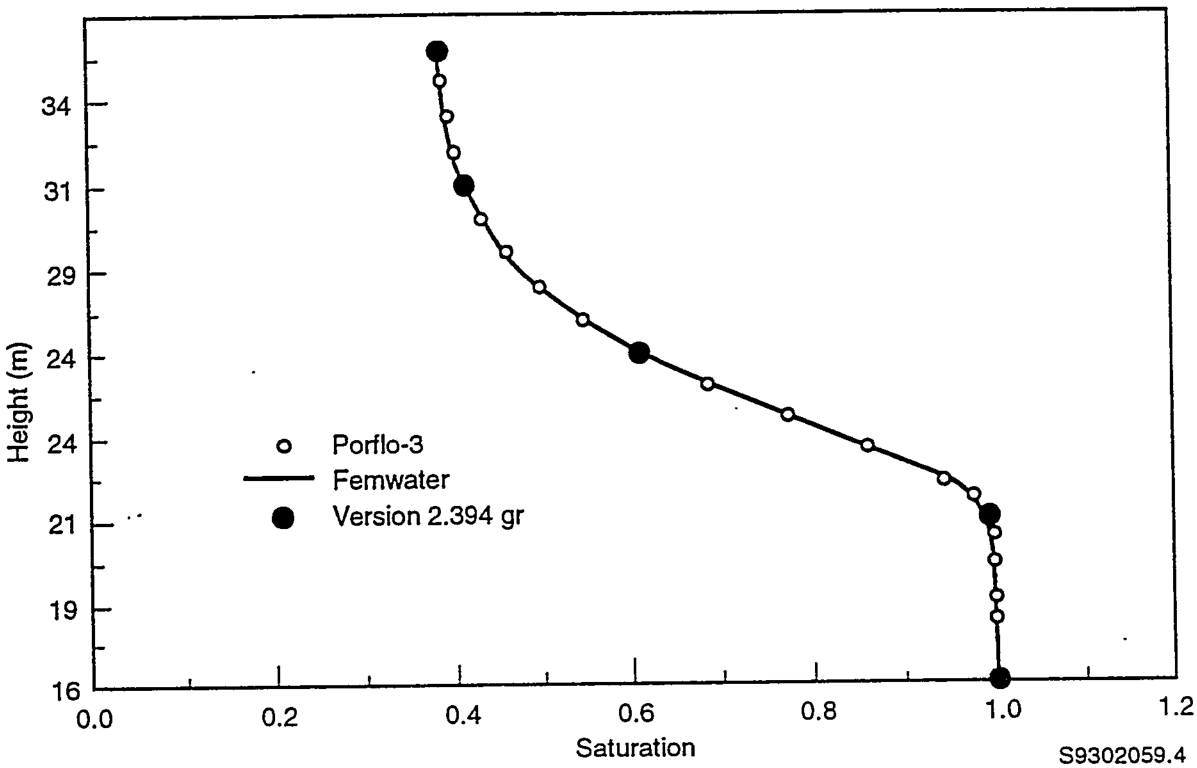


FIGURE 2.9 Comparison of Saturations for Case btl



2.5.2 TWO-DIMENSIONAL UNSATURATED FLOW; JORNADA TEST TRENCH (bt2)

This problem, identified as BT-2 by Magnuson et al. (1990) was, in part, based on the physical setting and soil-hydraulic properties of the Jornada Test Site near Las Cruces, New Mexico. This problem demonstrates the capability of PORFLOW to simulate transient infiltration into an extremely dry heterogeneous soil which is representative of the hydraulic conditions typical of the Hanford Site. Figure 2.10 shows the model domain and the four different physical regions into which the domain is subdivided. A uniform 2 cm/day infiltration rate was used for the area extending 225 cm to the right from the left boundary of the domain. Except for the infiltration zone at the top of the model domain, all boundaries were treated as no-flow. The initial condition was a uniform pressure head of -724 cm for all four zones. The model geometrical idealization and soil properties were identical with those defined in Magnuson et al. (1990).

Figure 2.11 compares the saturations calculated by version 2.394gr of PORFLOW with the saturations reported in Magnuson et al. (1990); note that Figure 2.12 in Magnuson's report shows saturation contours, not moisture content. The PORFLO-3 results show reasonable agreement with the current Version 2.394gr of PORFLOW results. Because of this agreement and the close agreement with the FLASH code (Baca et al. 1992), it can be concluded that PORFLOW solves the governing equation for unsaturated flow in a dry heterogeneous soil as well as the other codes. This typifies the flow conditions expected to exist around the Hanford Grout Facility.

FIGURE 2.10 Geometry for Case bt2

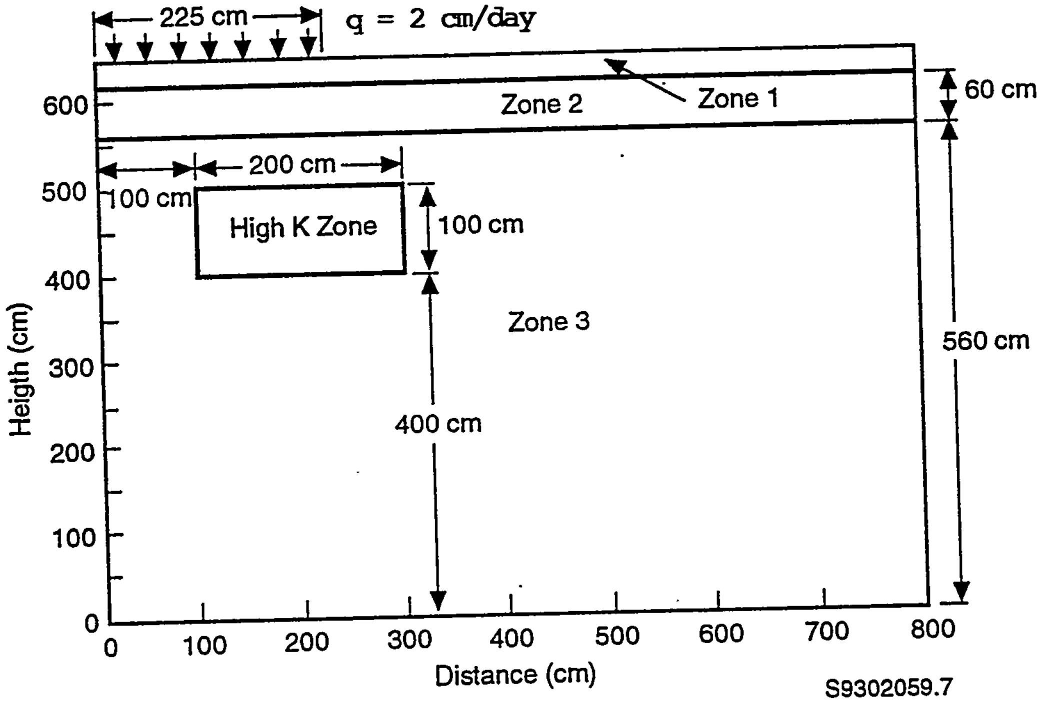
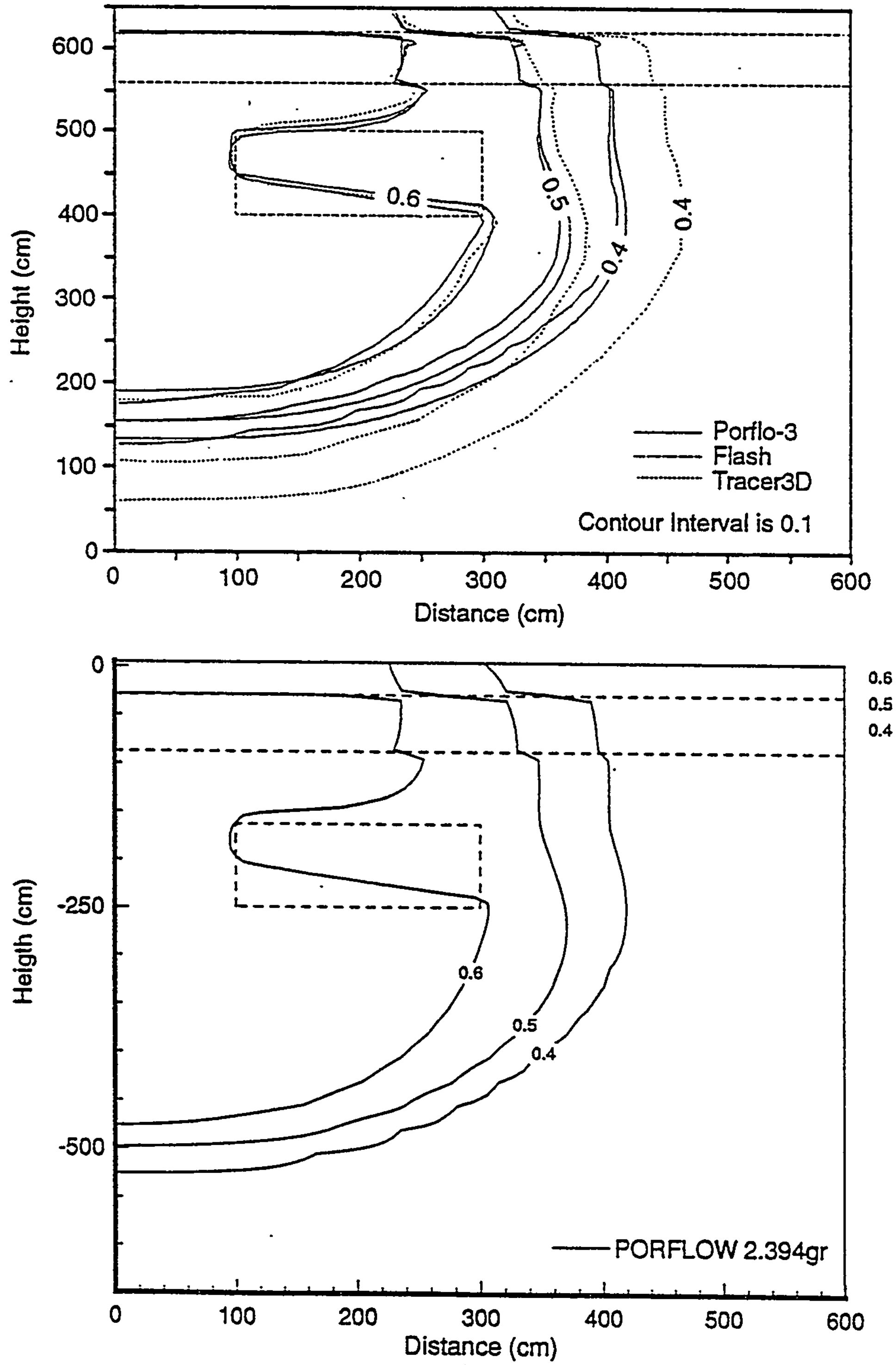


FIGURE 2.11 Comparison of the Saturations for Case bt2



2.5.3 SATURATED FLOW IN A FRACTURED POROUS MEDIA (bt3)

This problem, identified as BT-3 by Magnuson et al. (1990), simulates the steady state saturated flow in a porous domain with two discrete fractures. Figure 2.12 shows the geometry modeled with a unit width in the third dimension. No flow boundaries were specified for the sides and pressure heads of 0.0 cm and 0.2 cm along the bottom and top, respectively. The computational grid was the same as defined by Magnuson et al. (1990). The material properties were the same except for the hydraulic conductivity of 6.0 x 10^2 cm/s. Figure 2.13 compares the calculated pressure heads for PORFLO-3 and FLASH (Baca et al. 1992) in the bottom graph to the pressure heads from PORFLOW version 2.394gr in the top graph. Excellent agreement is achieved between the PORFLO-3 and PORFLOW codes, demonstrating that PORFLOW version 2.394gr simulates saturated flow in a fractured porous media as well as PORFLO-3 version 1.0. The FLASH code results are very similar.

FIGURE 2.12 Geometry for Case bt3

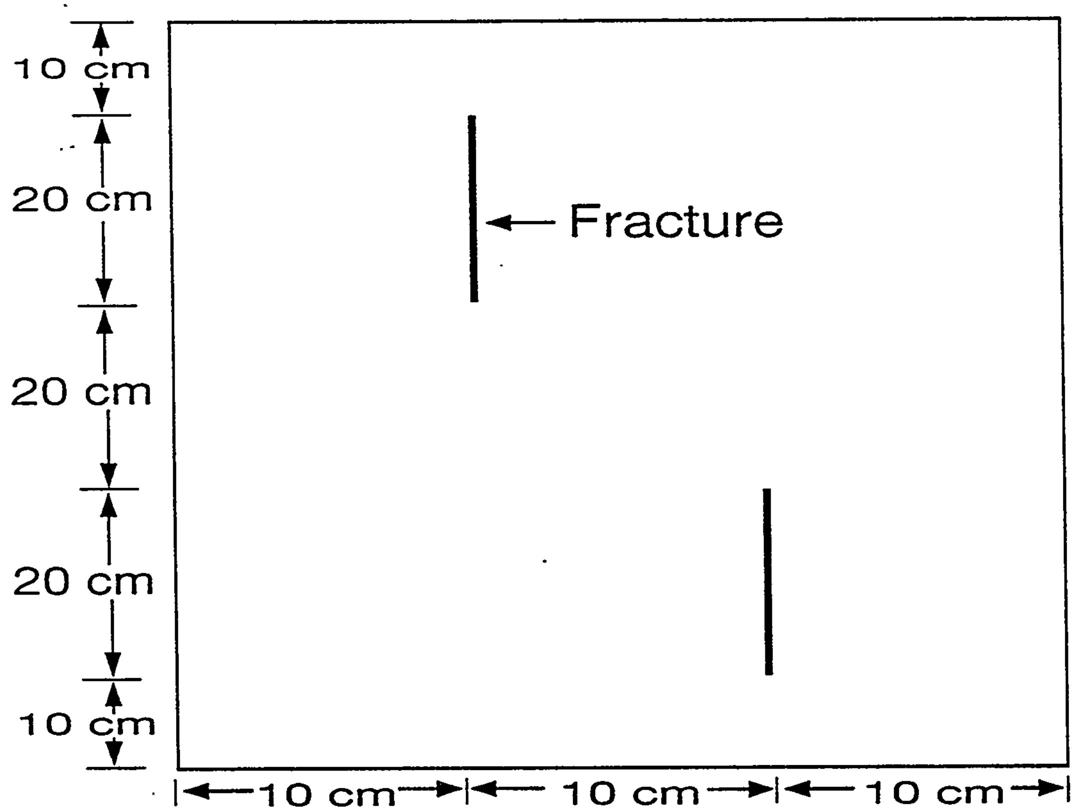
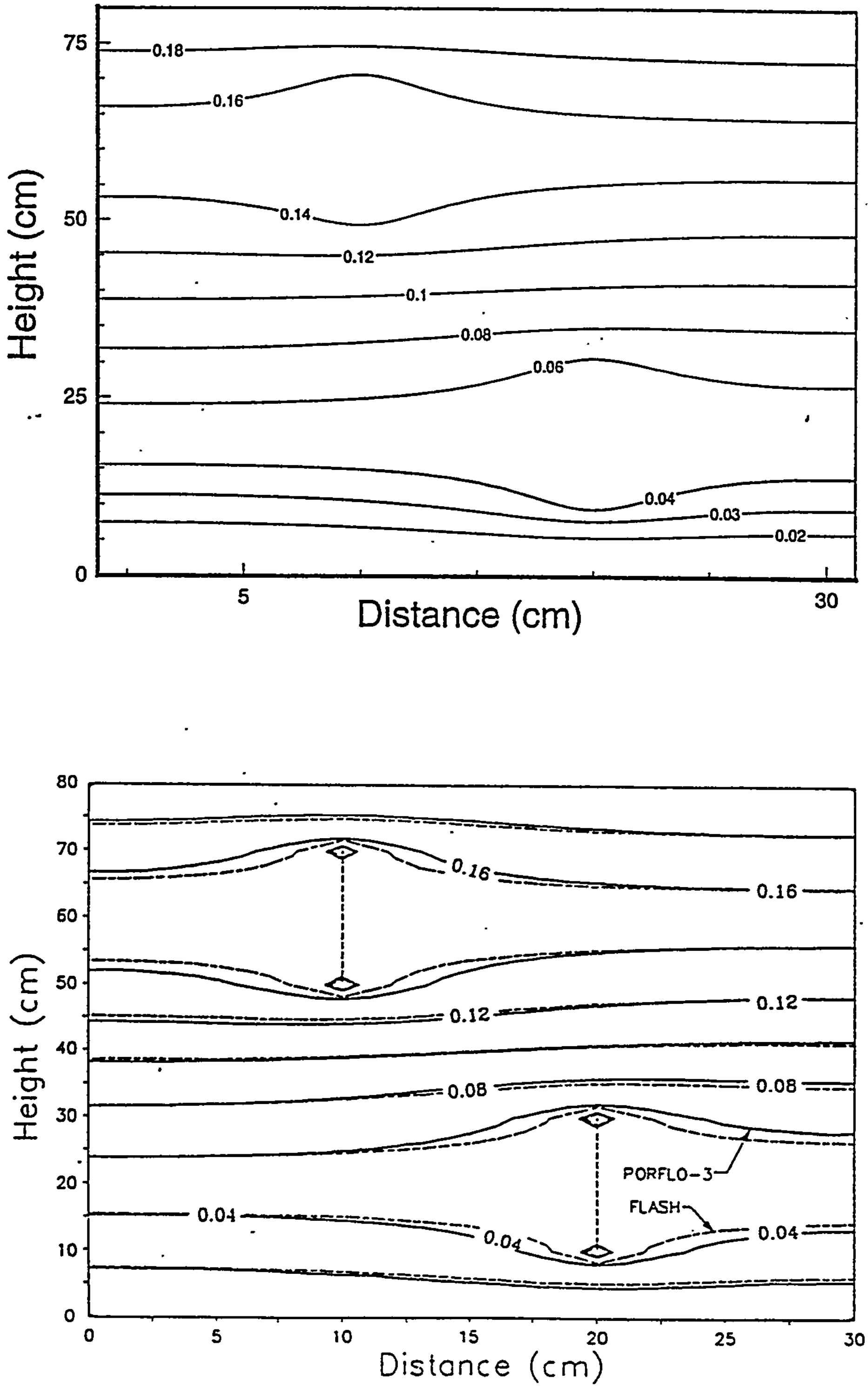


FIGURE 2.13 Comparison of Pressure Heads (top - Version 2.394gr) for Case bt3



2.5.4 SIMPLIFIED CASE MODELING ONLY THE CLAY-CAP OVERLAYING THE GROUT VAULT (claya and clayb)

This benchmark problem was developed as a simplified model of the Hanford Grout Disposal Facility which would permit the direct comparison of TRACR3D and PORFLOW. The problem simulates two-dimensional water flow in a vertical cross-section consisting of a sloping clay layer embedded with no space in a coarse sandy material. This is analogous to the water flow through and around the clay-cap which overlays the Hanford Grout Facility.

Figure 2.14 presents a schematic view of the two-dimensional region to be modeled. A uniform 0.4 m node spacing in the horizontal direction and uniform 0.3 m node spacing in the vertical direction where used. The 7.5% slope of the clay-cap is represented by a series of seven stair steps extending downward from the left edge of the modeled domain. The clay-cap is assumed to be 0.6m thick resulting in a two node representation for the clay-cap.

Two flux planes were specified in order to identify the water passing through the clay-cap and diverted around the clay-cap. The horizontal plane, extending from the left edge of the model domain to the right edge of the clay-cap at a depth of 3.6 m below the surface, was specified to quantify the flux of water passing through the clay-cap. The vertical plane, extending from the surface to a depth of 3.6 m at the right edge of the clay-cap, was specified to quantify the flux of water directed laterally around the clay-cap.

A uniform flux corresponding to a recharge rate of 0.1 cm/yr was specified across the entire upper surface of the modeled domain. The lower boundary was held at a capillary pressure of -481.5 cm, corresponding to a volumetric water content of 0.0406 for the backfill soil. The lateral boundaries were specified as no-flow boundaries. The initial conditions were specified as uniform liquid saturations of 0.266 and 0.924 for the backfill soil and the clay-cap, respectively. The water retention and saturated hydraulic conductivity parameters and characteristic curves that were used to represent the backfill soil and the clay-cap are shown in Figure A.15. These properties were based on the van Genuchten (1978) and Mualam (1976) models.

This benchmark problem was solved with version 2.394gr of PORFLOW and TRACR3D (Travis, 1984) using arithmetic (case claya) and harmonic (case clayh) averaging of the internodal hydraulic conductivities, for a 500-year simulation period. Figure 2.15 shows the instantaneous fluxes passing through the horizontal and vertical flux planes for the two averaging schemes. The two codes demonstrate reasonable agreement in predicting the flux of water that is diverted laterally around the clay-cap compared with that passing directly through the clay-cap (ratio of approximately 1:100). This predictive capability is important when analyzing the Hanford Grout Disposal Facility. It is important to note that the arithmetic averaging scheme produces a larger flux through the horizontal plane; hence, to be conservative, arithmetic averaging was for the Grout PA simulations.

FIGURE 2.14 Schematic View of Modeled Cross-Section of Sloping Clay Cap

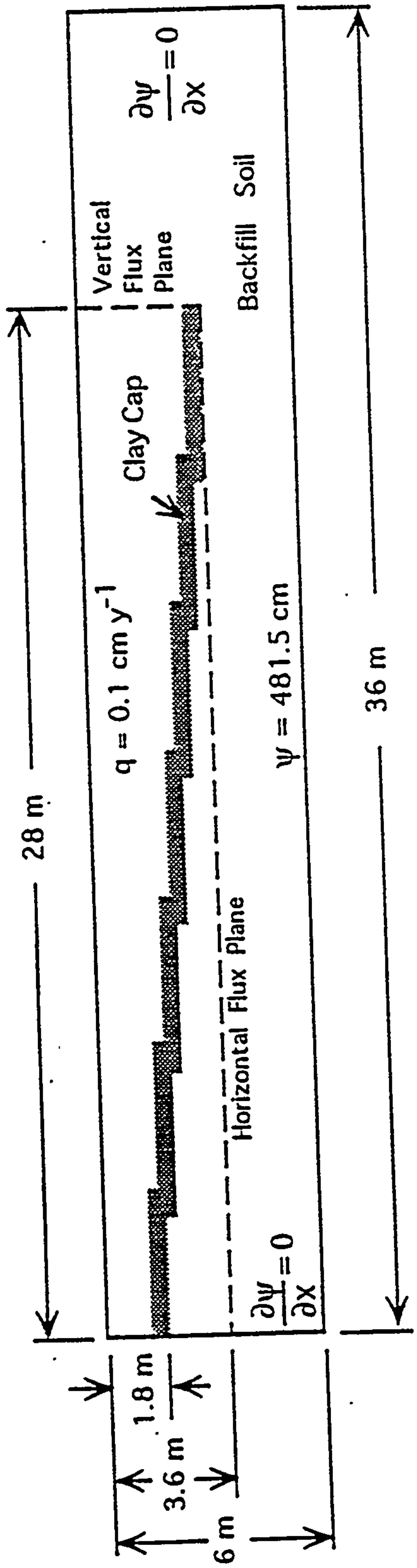


FIGURE 2.15 Water Retention and Conductivity Curves for Backfill Soil and Clay Cap

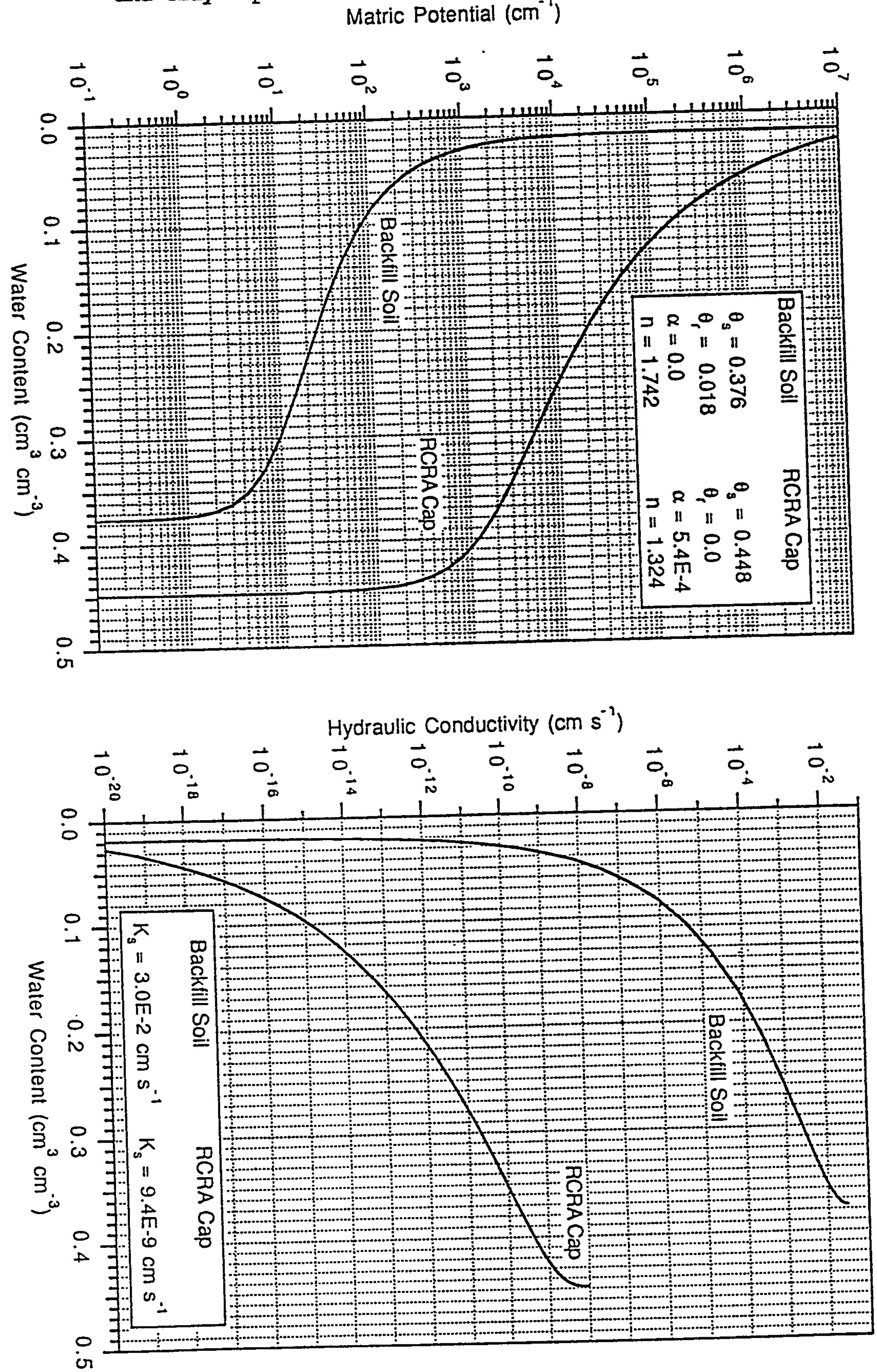
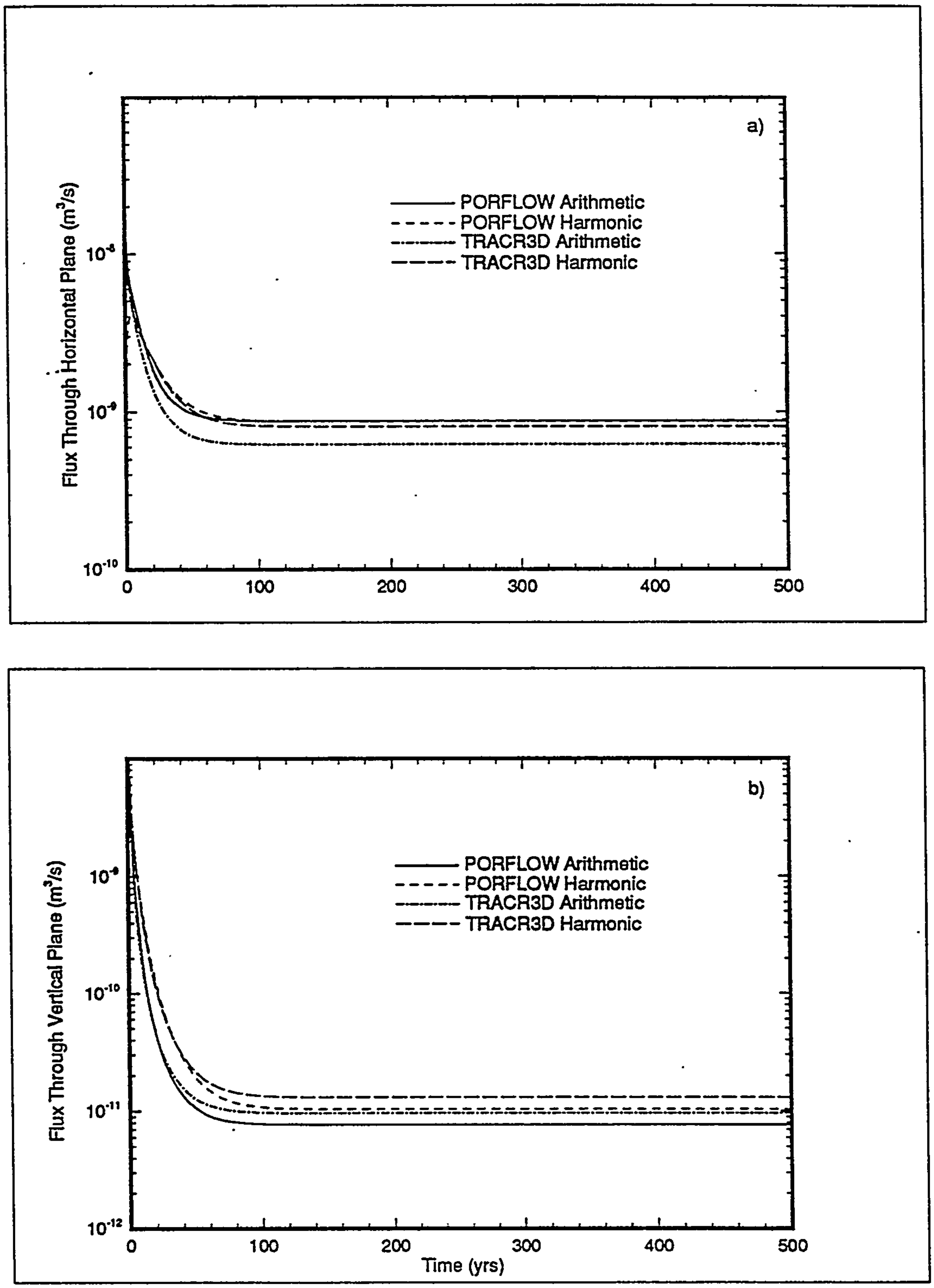


FIGURE 2. Water Retention and Hydraulic Conductivity Curves for Backfill Soil and RCRA Cap

FIGURE 2.16 Comparison of Fluxes Through the Horizontal and Vertical Planes



2.5.5 1991 GROUT PERFORMANCE ASSESSMENT BASE CASE MESH REFINEMENT STUDY (g1mel and g1fine)

Even though this problem is not a true benchmark case, it is of interest to know how accurate and fast PORFLOW is for a real problem with a course grid and a finer grid. Whyatt et al. (1991) presented the results for the Grout Performance Assessment base case for the earlier Grout PA of 1991. This benchmark case was designed to demonstrate the sensitivity of the results to the mesh refinement in the grout vault and barriers regions. Figure 2.17 shows the dimensional details of the grout vault and barriers as they were modeled. Figure 2.18 gives the stratigraphy assumed for the grout disposal site for the 1991 Performance Assessment (Whyatt et al. 1991). In the finite difference model twelve zones were identified to characterize the soil types and the grout vault and barriers:

Zone 1	-	Soil G-1
Zone 2	-	Soil G-2
Zone 3	-	Soil G-3
Zone 4	-	Soil G-4
Zone 5	-	Soil G-5
Zone 6	-	Soil G-6
Zone 7	-	Soil G-7
Zone 8	-	Asphalt Barrier
Zone 9	-	Concrete
Zone 10	-	Grout
Zone 11	-	Gravel
Zone 12	-	Clay-Cap

To investigate the impact of mesh refinement on the numerical results the node spacing for the clay-cap, asphalt barrier, and concrete vault was halved. This mesh refinement increased the total node grid from 92 by 137 to 111 by 167. Since PORFLOW is unable to make transitions in nodal spacing locally, these nodal refinements are required to traverse the entire domain. Thus, this model refinement increases the number of nodes from 12604 to 18537. For this benchmark case the same boundary and initial conditions were used as reported in Whyatt et al. (1991). The case analyzed considered the upper boundary recharge rate to be 0.1 cm/yr.

The flow and transport calculations for this benchmark case were run for 10,000 years. These analyses were performed on the Hanford Cray XMP and the coarse mesh required <u>370</u> cpu minutes to perform the 10,000 year analysis in 5084 steps. The fine mesh required <u>1064</u> cpu minutes in 13987 steps.

The primary area of concern for the Hanford Grout Facility is the transport of the contaminants from the grout to the groundwater. This benchmark case considered zero concentration of contaminants in the cold cap and a unit concentration in the hot grout as shown in Figure 2.18. The purpose of this mesh refinement study was to determine the impact of mesh refinement on the

FIGURE 2.17 Dimensions of Grout Vault and Barriers (Whyatt et al. 1991)

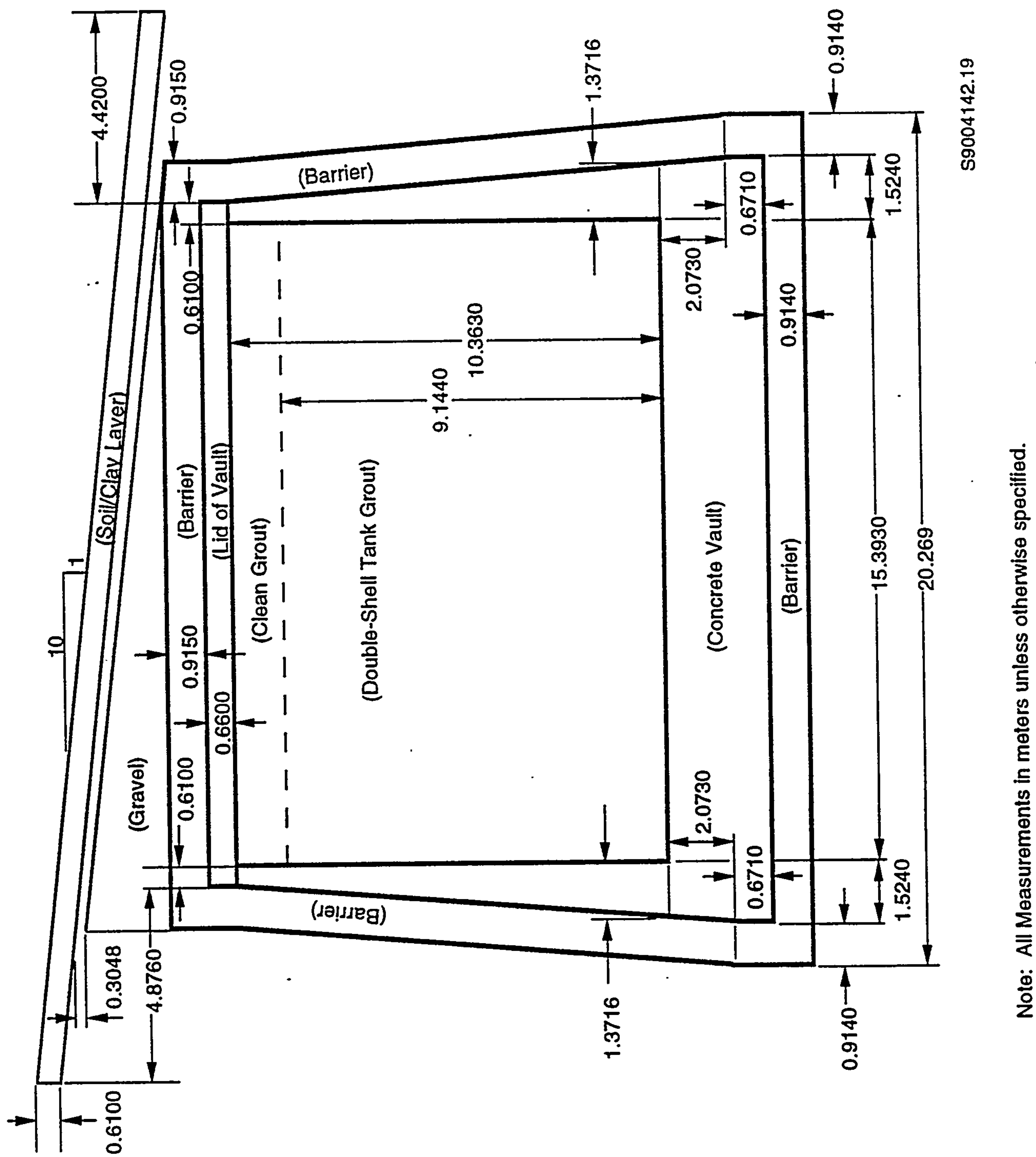
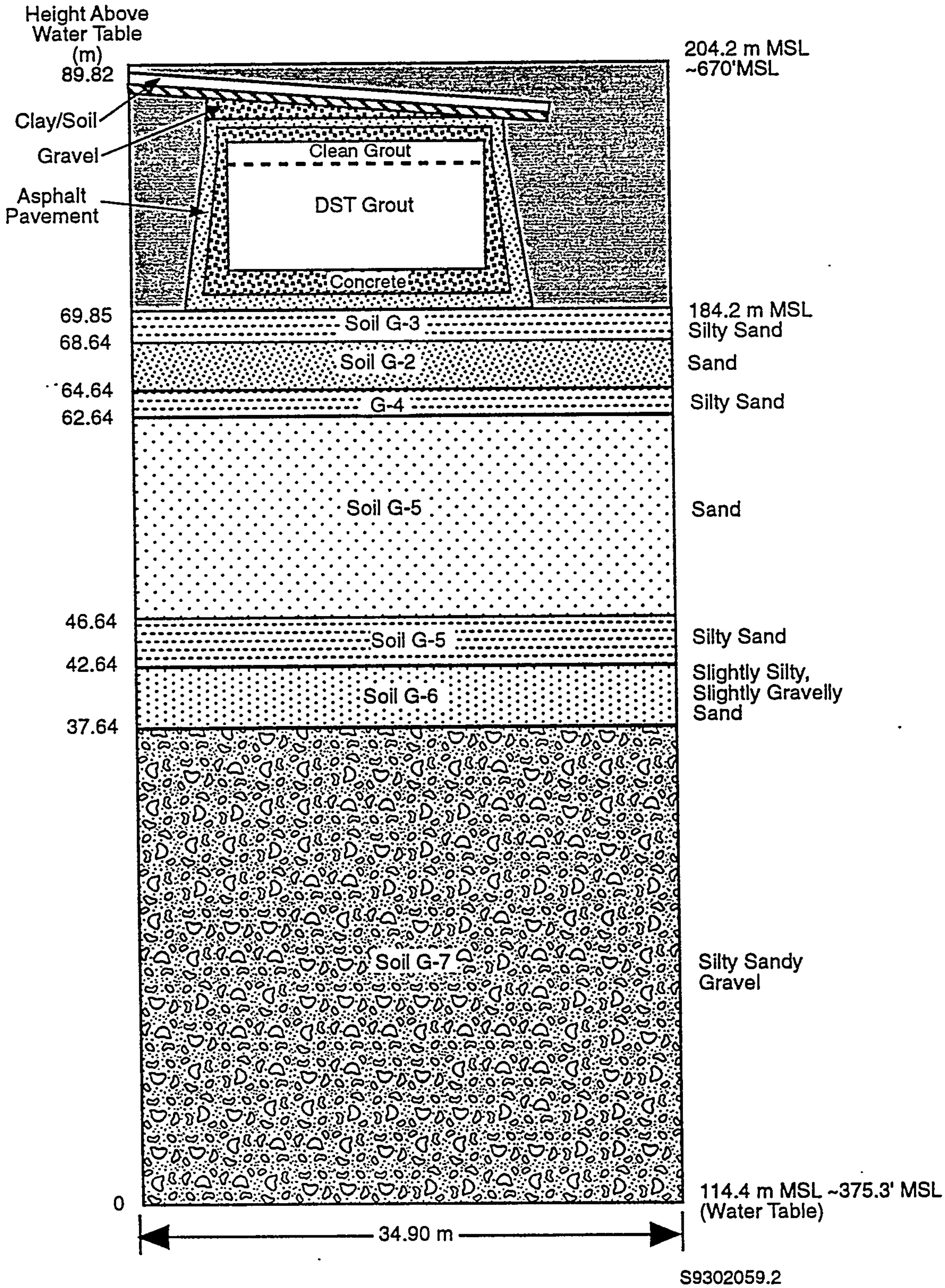


FIGURE 2.18 Stratigraphy of Grout Disposal Facility (Whyatt et al. 1991)



transport of contaminants from the Grout Disposal Facility and the effect of the finer grid on the computer time. As shown in Figures 2.19 and 2.20 the course-mesh concentrations and the finer-mesh concentrations are basically the same. Considering the increased computer time associated with the fine mesh, 1064 minutes versus 370, the potential slight improvement in results does not warrant the additional run time. For the 1993 Grout PA (Kincaid et al. 1993, Piepho 1994), an intermediate mesh size between the course mesh and fine mesh in this problem was used.

Basically, by increasing the number of nodes by 50%, the computer run times tripled using PORFLOW version 2.394gr. The run increased not only due to the increase in the number of nodes, but also due to the smaller size cells causing smaller time steps.

FIGURE 2.19 Concentrations Calculated at 10,000 Years Using a Course Mesh

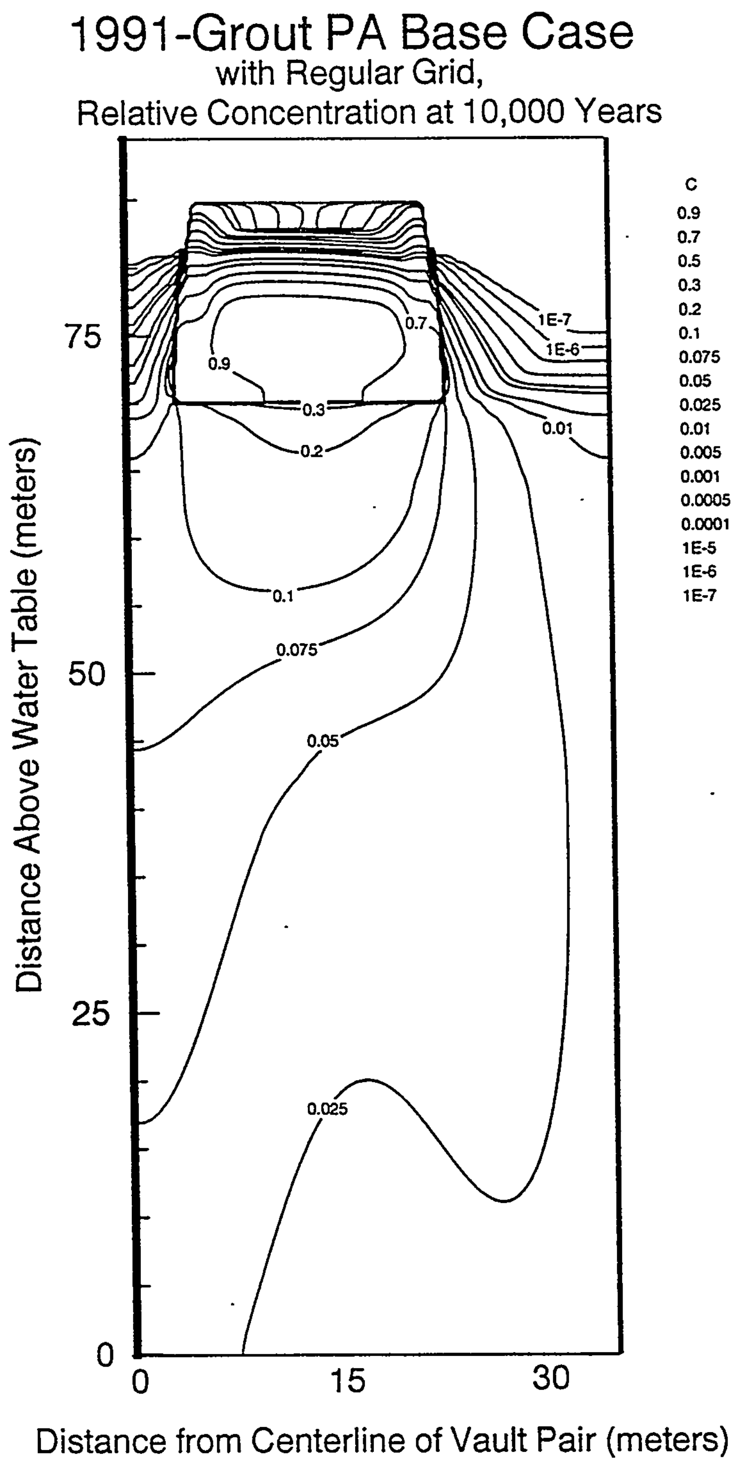
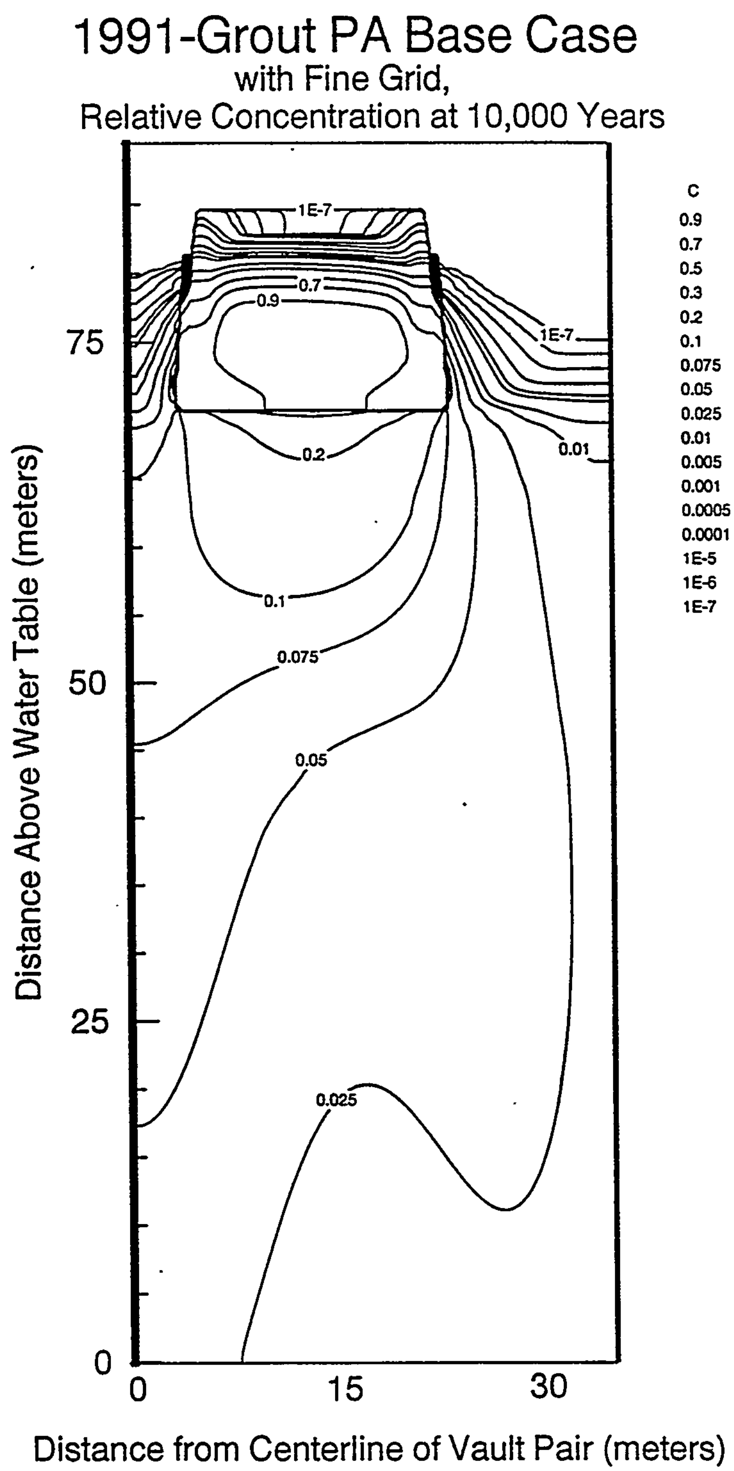


FIGURE 2.20 Concentrations Calculated at 10,000 Years Using a Finer Mesh



2.5.6 1993 GROUT PERFORMANCE ASSESSMENT BENCHMARK CASE (g3bench)

The final benchmark problem was designed to compare results for TRACR3D versus PORFLOW version 2.394gr on the 1993 grout flow and transport model (Piepho 1994). The stratigraphy used for the Hanford Grout Disposal Facility in the Grout PA (Kincaid et al. 1993) is given in Figure 2.21. The finite difference grid used for this problem is given in Figure 2.22. Minimum and maximum node spacings of approximately 0.1 and 1.0 m were used and a minimum of 3 nodes were used to represent the thickness of any given material type. The finite difference grid was designed so that the distance between adjacent nodes does not increase or decrease by more than a factor of 2.

A flux of water corresponding to a recharge rate of 0.1 cm/yr was specified for the upper surface of the modeled domain. A fixed concentration equal to 0.0 was specified for the upper boundary. The lower boundary was held at a pressure head equal to 0.0, corresponding to a water table at atmospheric pressure. A zero concentration gradient boundary condition was specified for the lower boundary. The side boundaries were specified as no flow and zero concentration gradient boundaries based on symmetry.

An initial pressure head of approximately -338 cm was specified for all of the engineered materials and backfill soil. This pressure head corresponds to an assumed volumetric water content of 10% for the backfill soil, which represents the average optimum water content required to obtain 95% compaction. The initial pressure heads in the soils underlying the engineered materials and backfill soil are consistent with a recharge flux of 0.1 cm/yr.

The initial normalized concentrations for the transport simulations were specified as zero everywhere, except for the region labeled hot grout in Figure 2.21. An initial normalized concentration of 1.0 was specified for this region.

FIGURE 2.21 Hanford Grout Disposal Facility Stratigraphy

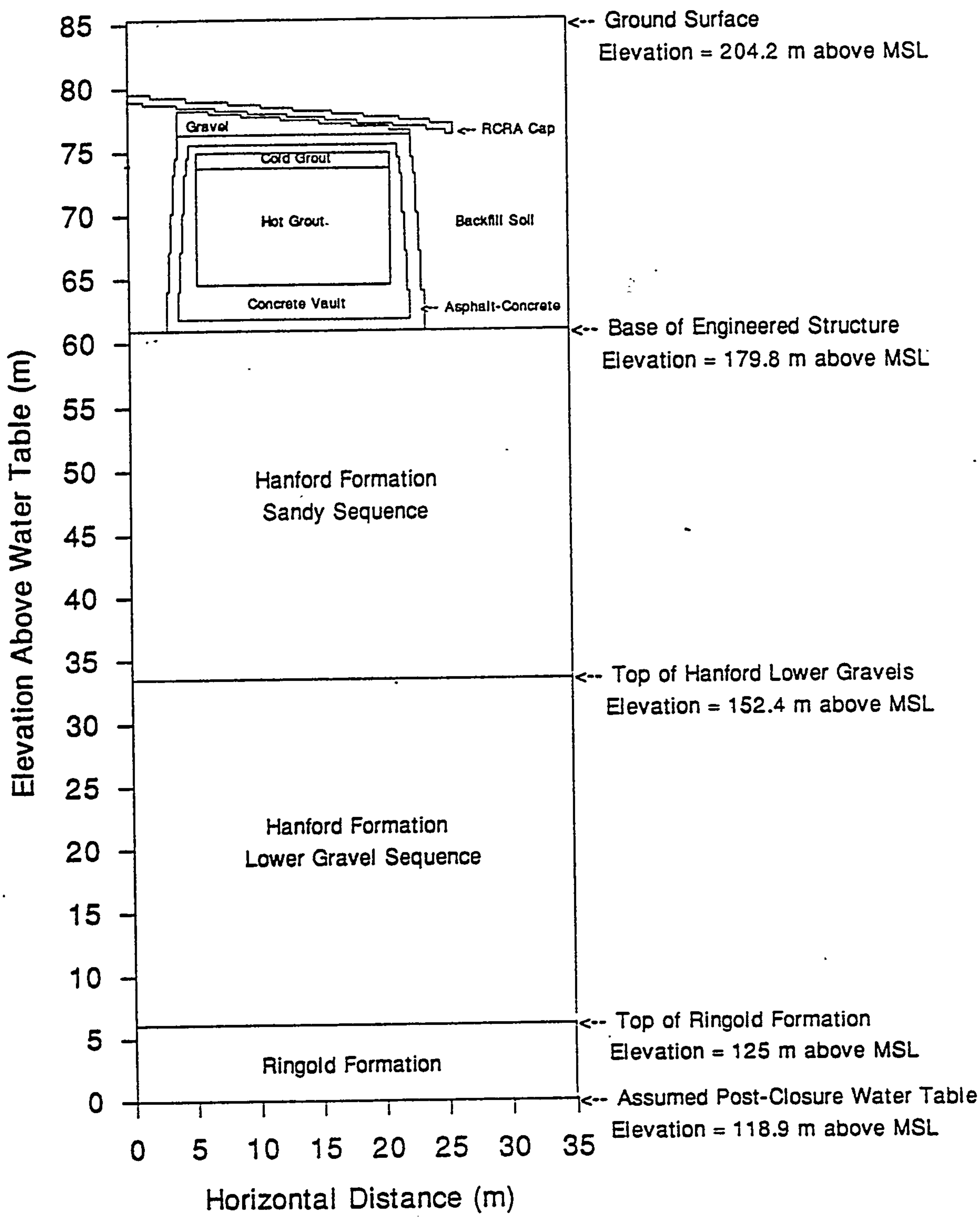
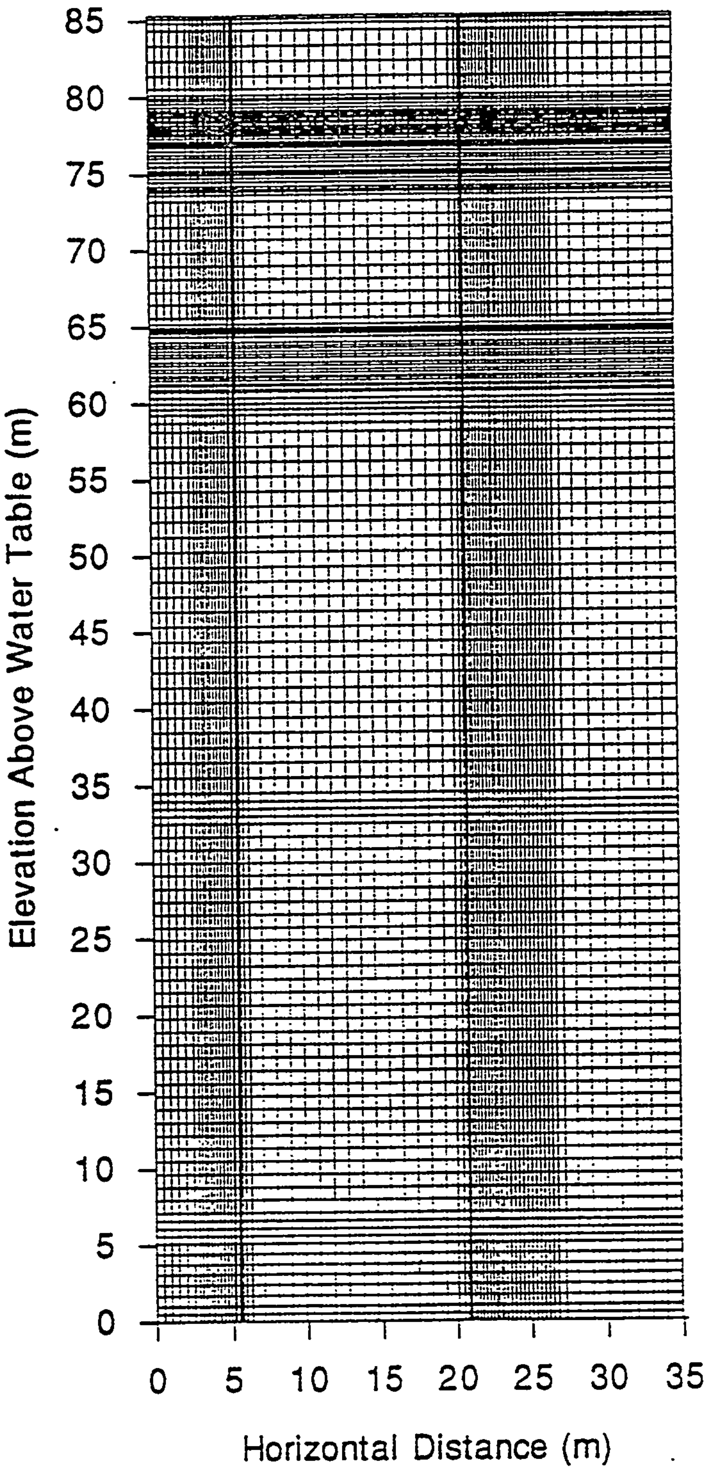


FIGURE 2.22 Finite Difference Grid Used in Grout PA



The material properties used for this benchmark problem for the saturated hydraulic conductivities, van Genuchten model water retention parameters, and bulk densities are listed in the Table 2.3.

TABLE 2.3 1993 Grout PA Benchmark Case Hydraulic Parameters

Hydraulic Parameters for Grout Benchmark Case (1993)					
Material	K_s(cm/s)	θ_s	θ_r	α(cm^{-1})	n
Hanford Formation Sandy Sequence	1.55E-03	0.4203	0.0234	0.1943	1.868
Hanford Formation Gravel sequence	2.73E-04	0.3584	0.0213	0.0290	1.613
Ringold Formation	2.42E-06	0.4982	0.0283	0.0176	1.338
Backfill Soil	3.00E-02	0.3710	0.0450	0.0683	2.080
RCRA Clay Cap	1.00E-07	0.4480	0.0000	5.39E-04	1.324
Gravel	1.85E+00	0.518	0.0140	3.5366	2.661
DSSF Grout	1.47E-08	0.5781	0.0000	1.08E-05	1.650
Concrete	3.75E-10	0.2258	0.0000	7.61E-06	1.393
Asphalt[a] 1	1.00E-20	0.162	0.0000	1.00E-07	2.000
Asphalt[a] 2	3.00E-02	0.202	0.0450	0.0683	2.080
a) Asphalt 1 and 2 refer to the hydraulic parameters assigned to the asphalt at t ≤ 90,000 y and t > 90,000 y, respectively.					

For this benchmark problem it should be noted that the gravel in Figure 2.21 has been replaced with backfill soil.

For simulating contaminant transport, the adsorption behavior of various radioactive species in the different material types was represented using distribution coefficients, K_d (called R_d in Grout PA [Kincaid et al. 1993]), which are defined as

$$K_d = \frac{\textit{amount of radionuclide adsorbed on solid per g solid}}{\textit{amount of radionuclide in solution per ml of solution}} \quad (2)$$

The distribution coefficient is related to the retardation factor, R_f, as

$$R_f = 1 - (\rho_b/e)K_d \tag{3}$$

where ρ_b is the dry bulk density (g/cm^3), and e is the porosity. The retardation factor represents the ratio of the mean water velocity to the mean contaminant velocity in the porous media. The porosity or saturated water content was used to calculate retardation factors, even though most of the materials in the Grout PA simulations are unsaturated, in order to provide a conservative estimate of solute mobilities. Using unsaturated moisture content, as hydrology theory indicates, would increase the retardation.

Three different cases or "bins" were simulated. These bins represent transport properties for different radioactive isotopes. The parameters for Bin 1A conservatively represents species such as ^{129}I and ^{106}Ru. The parameters for bins 2A and 2B conservatively represent species such as ^{99}Tc and ^{94}Nb, respectively. Transport parameter for the different material types and bin numbers that were selected for this benchmark problem are shown in Table 2.4.

TABLE 2.4 1993 Grout PA Benchmark Case Transport Parameters

Retardation Factors and Distribution Coefficients for Grout Benchmark Case				
Bin #	TD_m[a]	Grout K_d	Soil K_d	Species
1A	1.0E-6	0.0	0.0	^{129}I
2A	1.0E-6	2.0	0.0	^{99}Tc
3C	1.0E-6	125	0.0	^{237}Np
2B	1.0E-6	2.0	0.67	^{94}Nb
a) T = 0.04 (tortuosity factor) D_m = 2.5E-5 cm^2/s (molecular diffusion)				

Contaminants are assumed not to be attenuated in the concrete vault or in the asphalt barrier. Therefore, the distribution coefficient and retardation factor for all contaminants in these materials were assigned values of R_d (i.e., K_d) = 0.0 and R_f = 1.0 respectively.

Dispersivities were set equal to zero for all material types in this benchmark problem and in the Grout PA simulations. Effective diffusion coefficients for the different material types were assumed to be a function of volumetric water content following the empirical relationship of (Kemper and van Schaik, 1966)

$$D_e(\theta) = D_m\, a\, exp(b\theta)$$

where a and b are empirical constants. Parameters in the above equation have been estimated from data reported by (Olsen and Kemper, 1965). The values of these parameters that were used for this benchmark problem and for the Grout PA simulations are listed in the Table 2.5.

TABLE 2.5 1993 Grout PA Benchmark Case Effective Diffusion Parameters

Effective Diffusion Coefficients for Grout Benchmark Case			
Material	D_m(cm2/s)	a	b
Hanford Formation Sandy Sequence	2.5E-05	0.005	10
Hanford Formation Gravel Sequence	2.5E-05	0.005	10
Ringold Formation	2.5E-05	0.005	10
Gravel	2.5E-10	1.000	0
Concrete	5.0E-08	1.000	0
RCRA Clay Cap	2.5E-05	0.005	10
Asphalt[a] 1	1.000E-10	1.000	0
Asphalt[a] 2	2.5E-05	0.005	10
a) Asphalt 1 and 2 refer to parameters for t ≤ 90,000 years, and t > 90,000 years. respectively. (See note below regarding time-dependent effective diffusion coefficients.)			

The effective diffusion coefficients that were used to represent the asphalt barrier were also modified as a function of time to approximate the expected degradation of the asphalt. This continuous time-dependency capability of PORLFOW version 2.394gr for the asphalt diffusion coefficient was mentioned briefly in Section 2.2.2. The time-dependent, effective diffusion coefficient, D_t, was assumed to change according to the following equation

$$D_t = D_e \, / \, [1 - (1 - 1.0E\text{-}6) \ (t \, / \, 90000)]$$

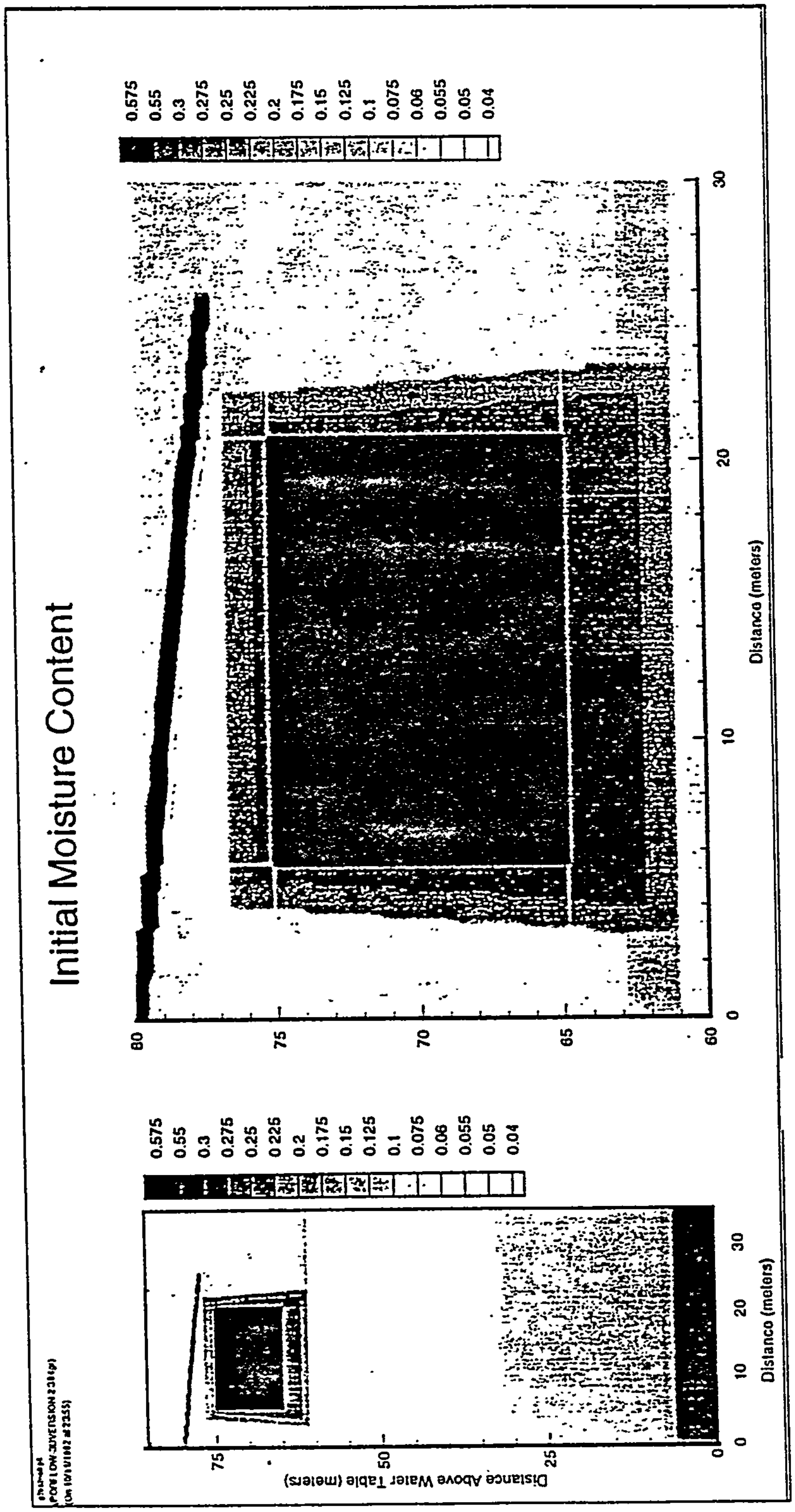
where t is time in years, 90,000 is the number of years of complete asphalt biodegradation, and 1.E-6 is the inverse of the increase of the diffusion coefficient over the 90,000 years. In other words, the 1.E-6 number implies the diffusion coefficient will increase by 6 orders of magnitude (1.E+6) over 90,000 years.

Although the rates of degradation of the asphalt barrier are uncertain, some of the mechanisms that are expected to contribute to the degradation of this material include oxidation, volatilization, polymerization, and biodegradation.

It is also assumed that the concrete vault and asphalt barrier will eventually develop cracks or stress fractures due to seismic events, overburden pressure, etc.

A simplified representation of cracks in the concrete vault and asphalt barrier was developed for the benchmark case (and many sensitivity cases in the Grout PA [Piepho 1994]). A horizontal row of grid blocks in each of the lower corners of the vault, extending outward from the "hot grout" through the concrete vault and asphalt barrier to the backfill soil, was assigned the same flow and transport parameters as the backfill soil to represent hypothetical cracks in the lower corners of the vault and asphalt barrier. A vertical column and horizontal row of grid blocks in each of the upper corners, extending outward from the hot grout through the concrete vault and asphalt barrier, were also assigned the properties of the backfill soil to represent hypothetical cracks in the upper corners of the vault and asphalt barrier. The grid blocks for these cracks are 10 cm in width. These cracks are clearly shown in the initial-moisture-content contour plot in Figure 2.23.

FIGURE 2.23 Initial Moisture Content of Grout Disposal Facility



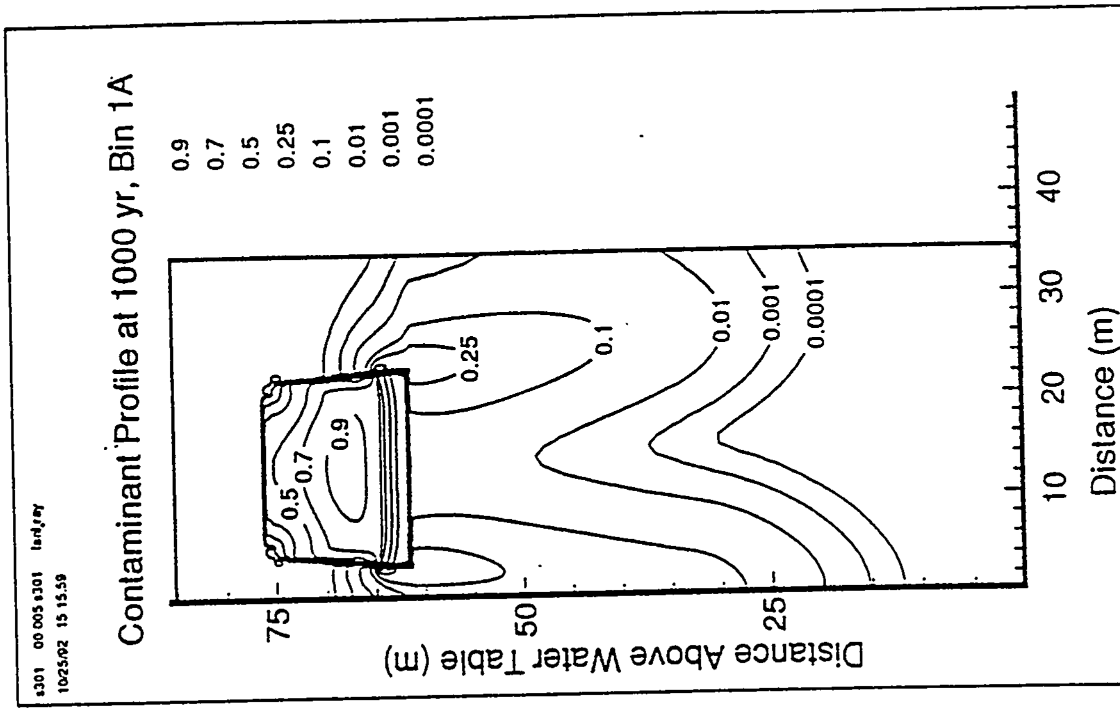
Three different transport cases representing three different bins (1A, 2A, and 2B) were simulated until the outflow concentrations at the lower boundary of the model domain had passed their maximum or peak values. Contour plots of average relative concentration for the Bin 1A simulations at times of 1000 and 10,000 years are shown in Figures 2.24 and 2.25, respectively. These figures show excellent agreement between the results generated by the PORFLOW and TRACR3D/S301 codes. The locations of the cracks are clearly evident and show that the waste inventory is depleted the fastest near the corners of the vault.

Contour plots of relative concentration for the Bin 2A simulations at times of 1000, and 10,000 years are shown in Figures 2.26 and 2.27, respectively. Again, the results generated from PORFLOW and TRACR3D/S301 are very similar.

The results generated from the Bin 2B simulations at times of 1000, and 10,000 years are shown in Figures 2.28 and 2.29, respectively. Considering the complexity of this benchmark problem and differences in numerical solution techniques, the agreement between results generated by the PORFLOW and TRACR3D/S301 codes is considered to be excellent.

Average relative concentrations as a function of time at the water table for the Bin 1A, 2A, and 2B simulations are shown in Figure 2.30. These outflow concentration also show excellent agreement between the PORFLOW and TRACR3D-S301 codes. The bimodal arrival distributions for Bins 2A and 2B reflect the complete degradation of the asphalt-diffusion barrier at a time of 90,000 years. TRACR3D/S301 did not simulate transport bin 3C, which has non-zero retardation in both the grout and soils. Nothing new was expected for that bin since non-zero retardation in the grout and soil was covered by bin 2B.

FIGURE 2.24 Relative Concentrations at 1000 Years for Bin 1A Simulations



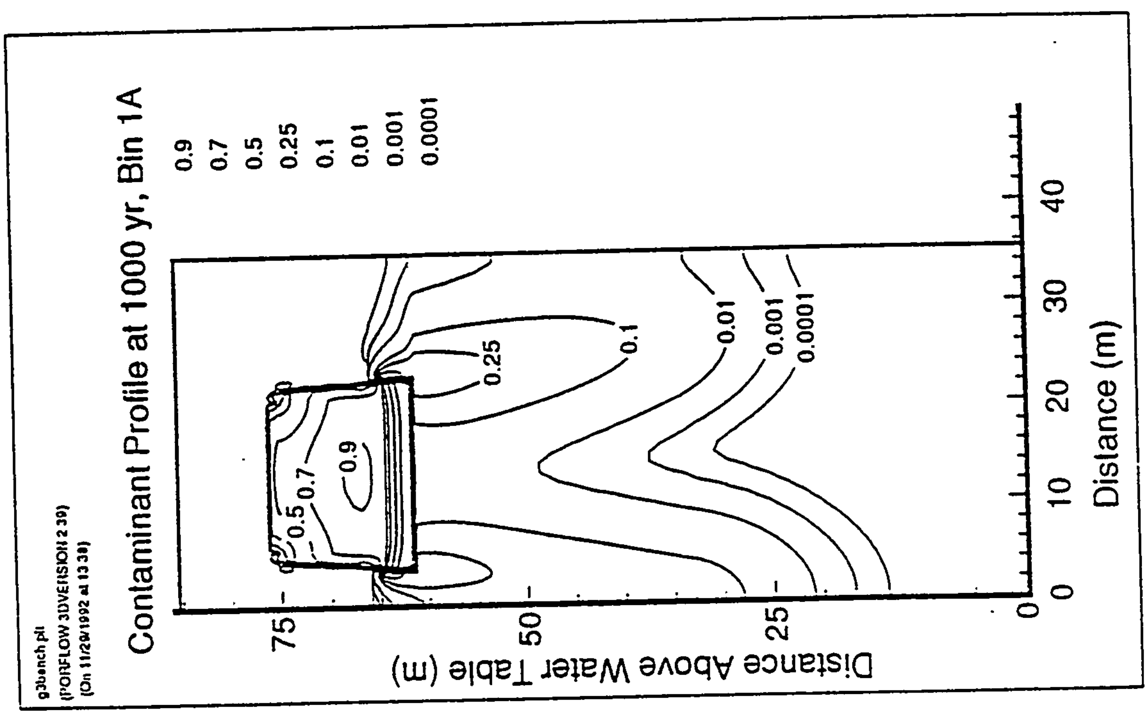
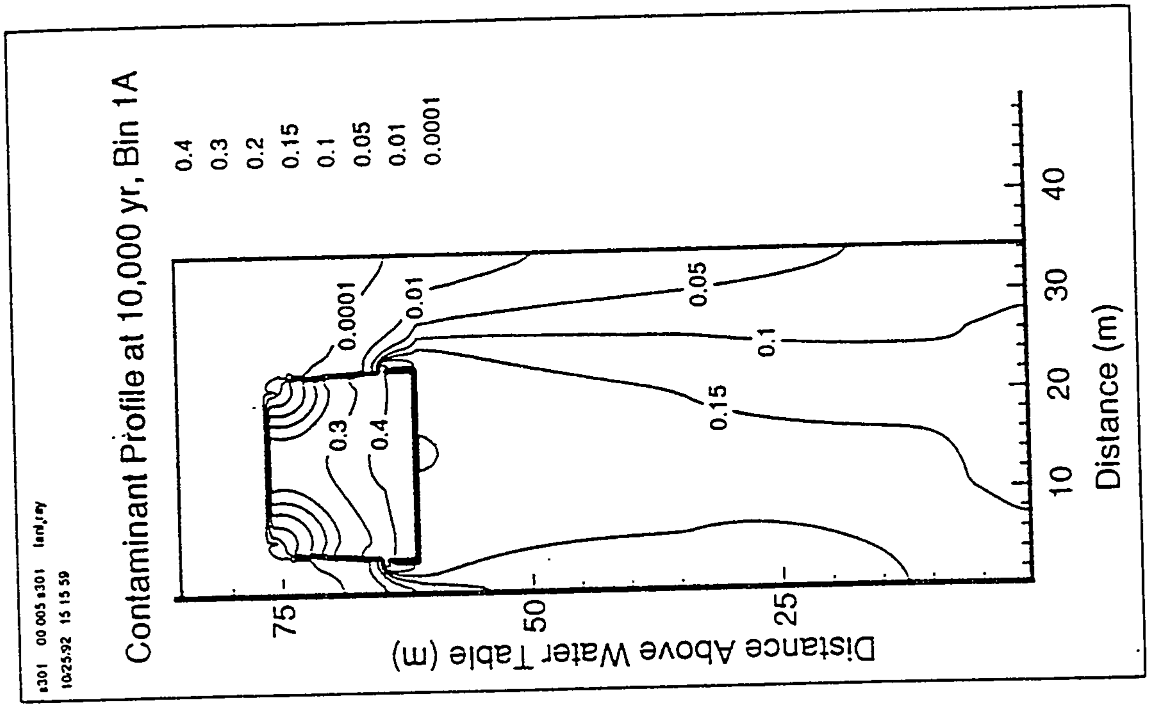


FIGURE 2.25 Relative Concentrations at 10,000 Years for Bin 1A Simulations



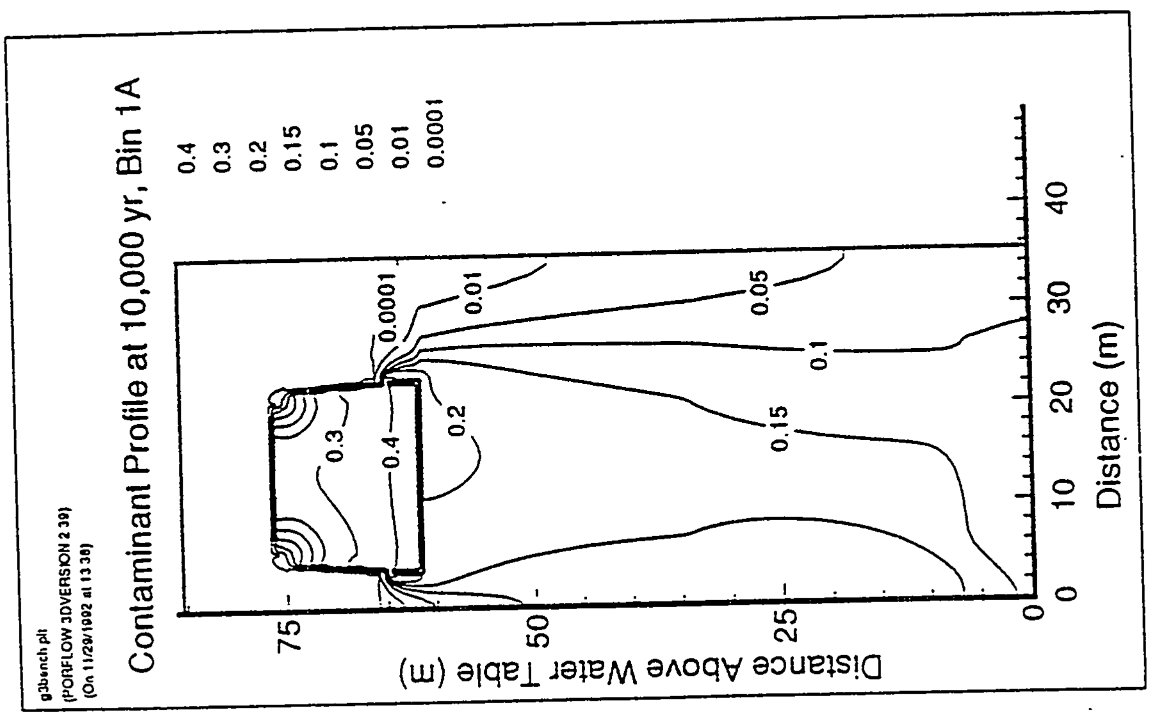
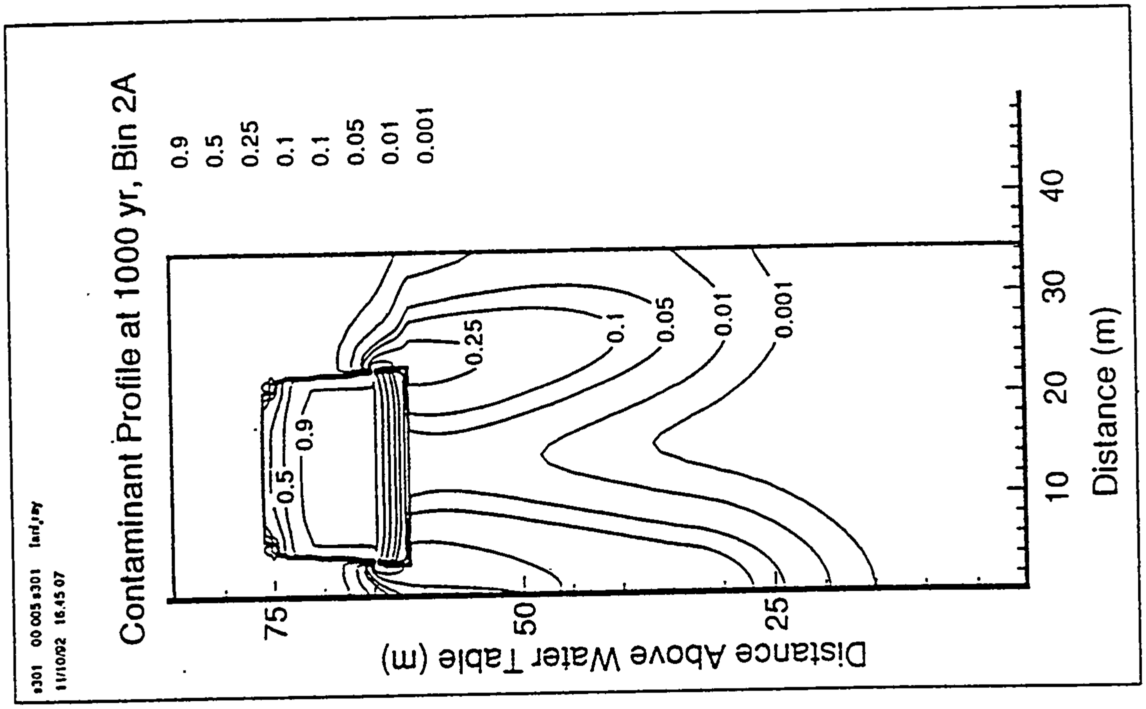


FIGURE 2.26 Relative Concentrations at 1000 Years for Bin 2A Simulations



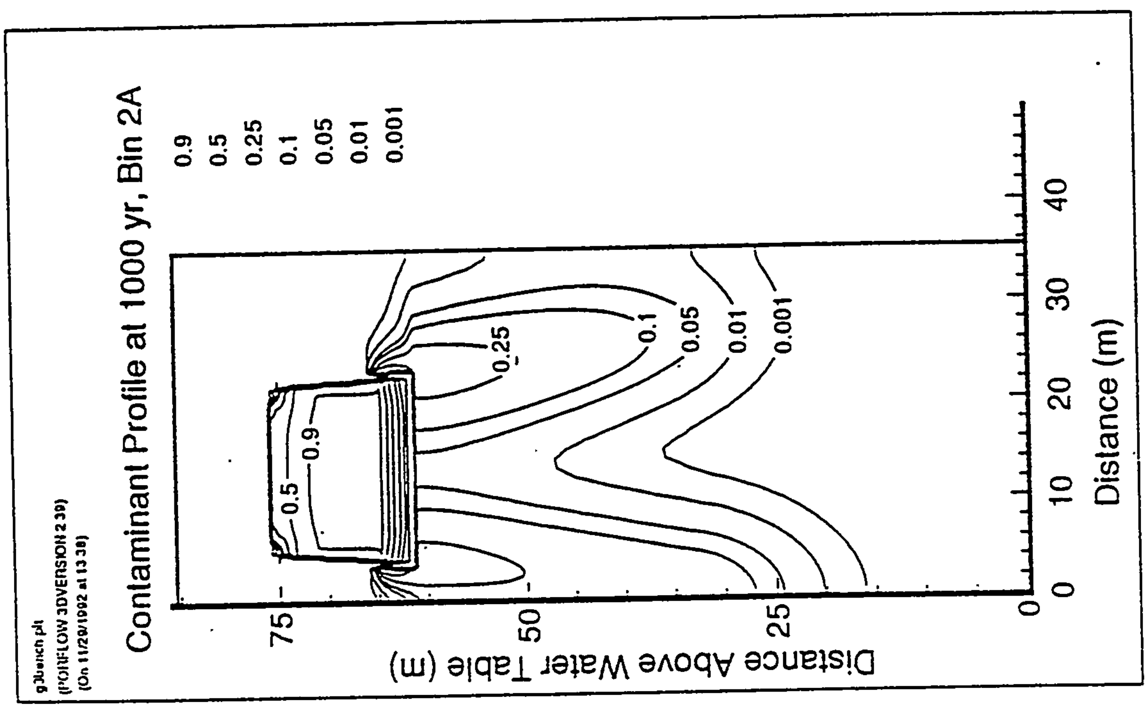
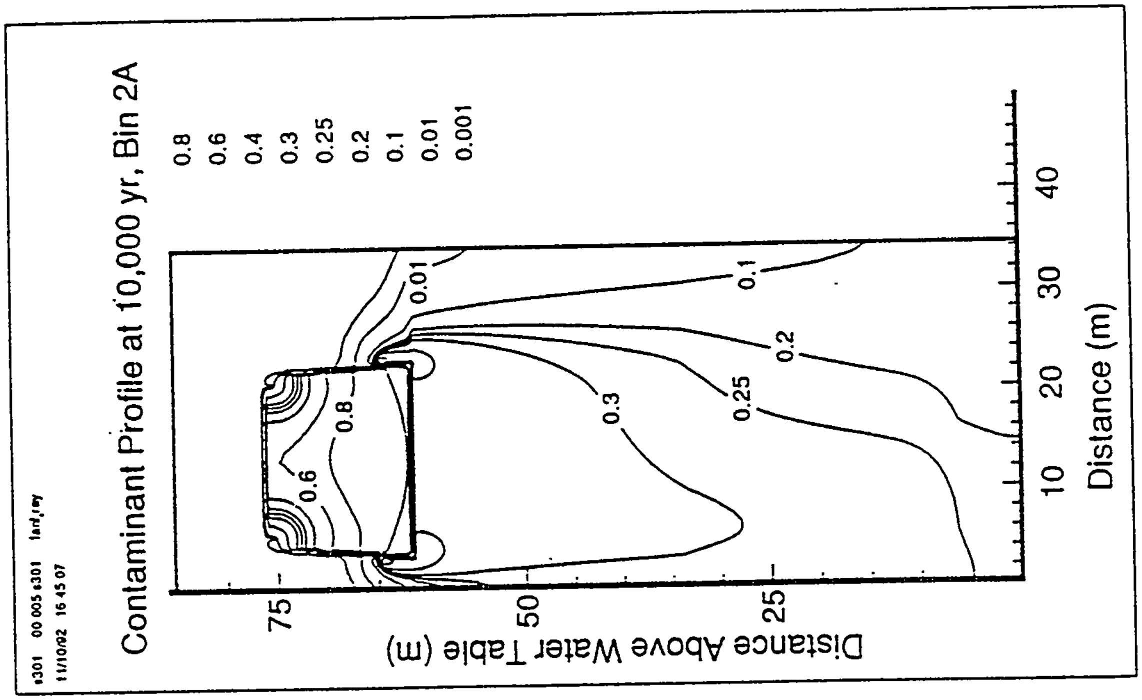


FIGURE 2.27 Relative Concentrations at 10,000 Years for Bin 2A Simulations



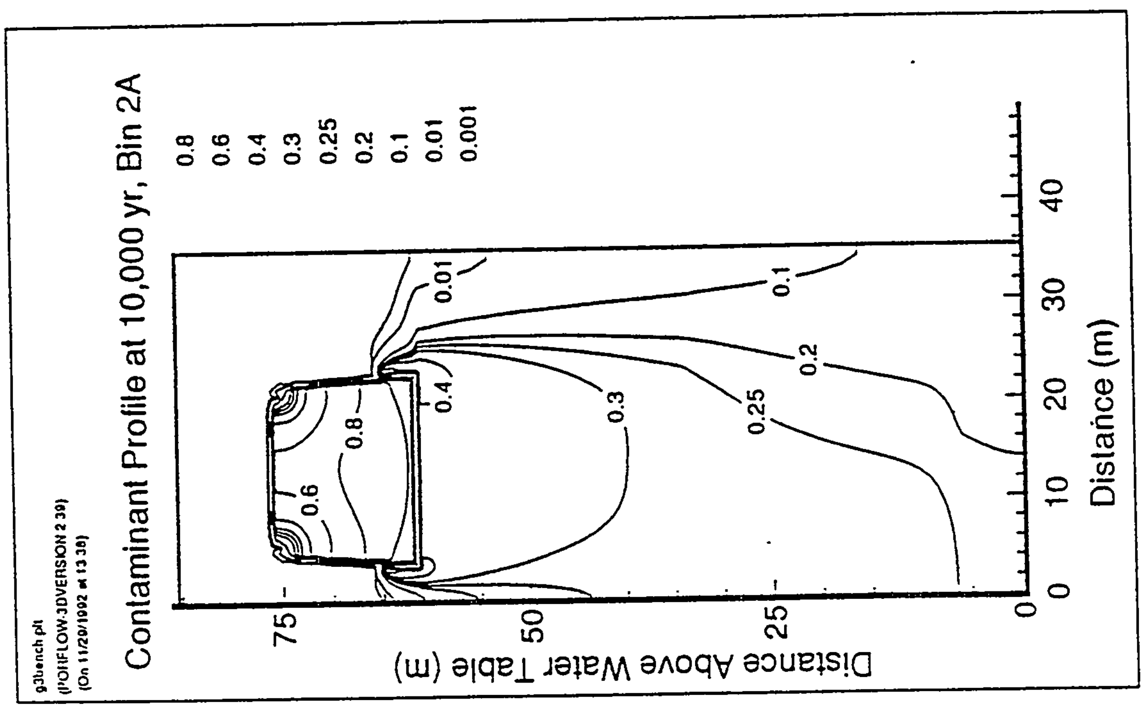
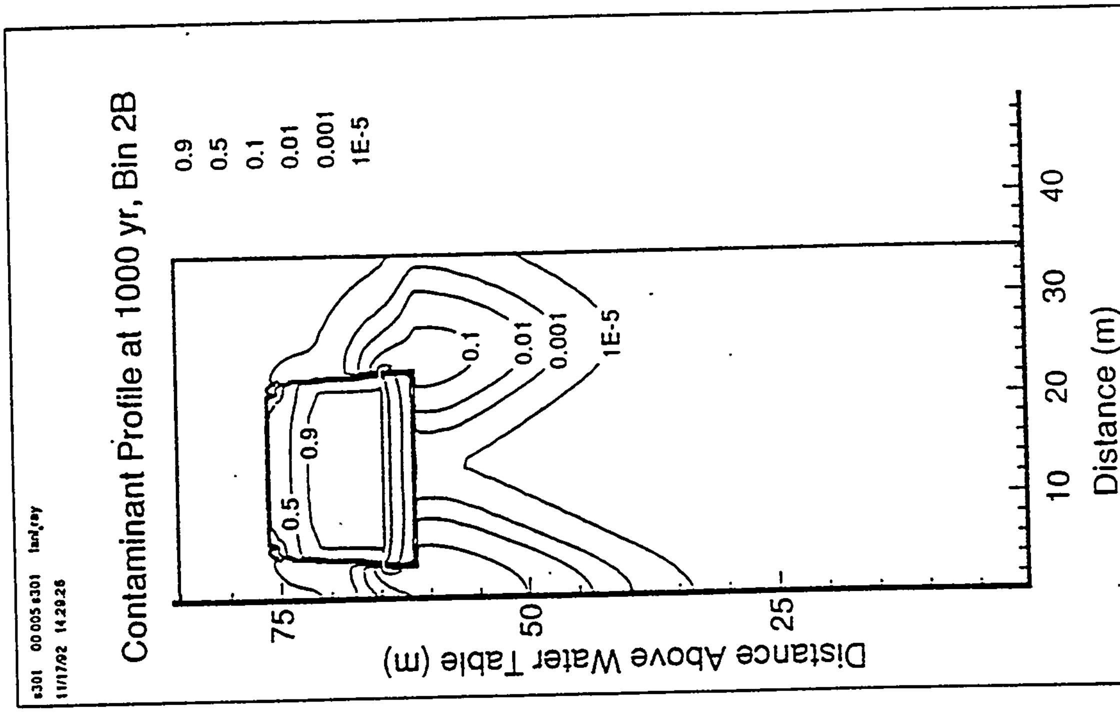


FIGURE 2.28 Relative Concentrations at 1000 Years for Bin 2B Simulations



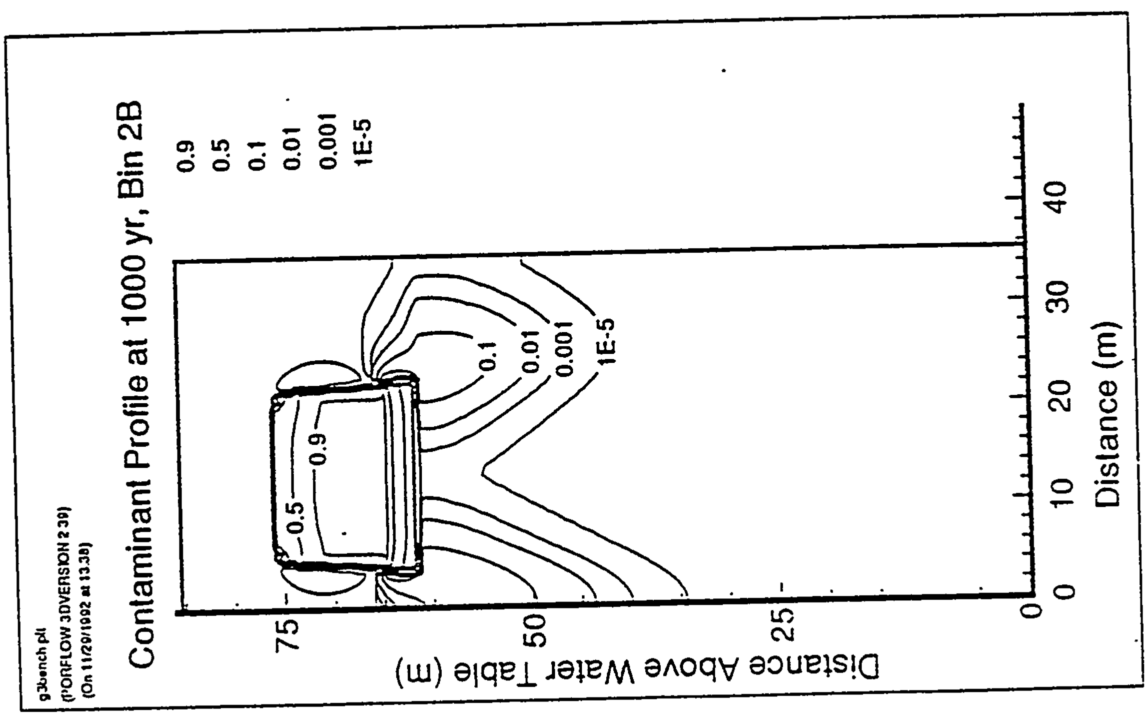
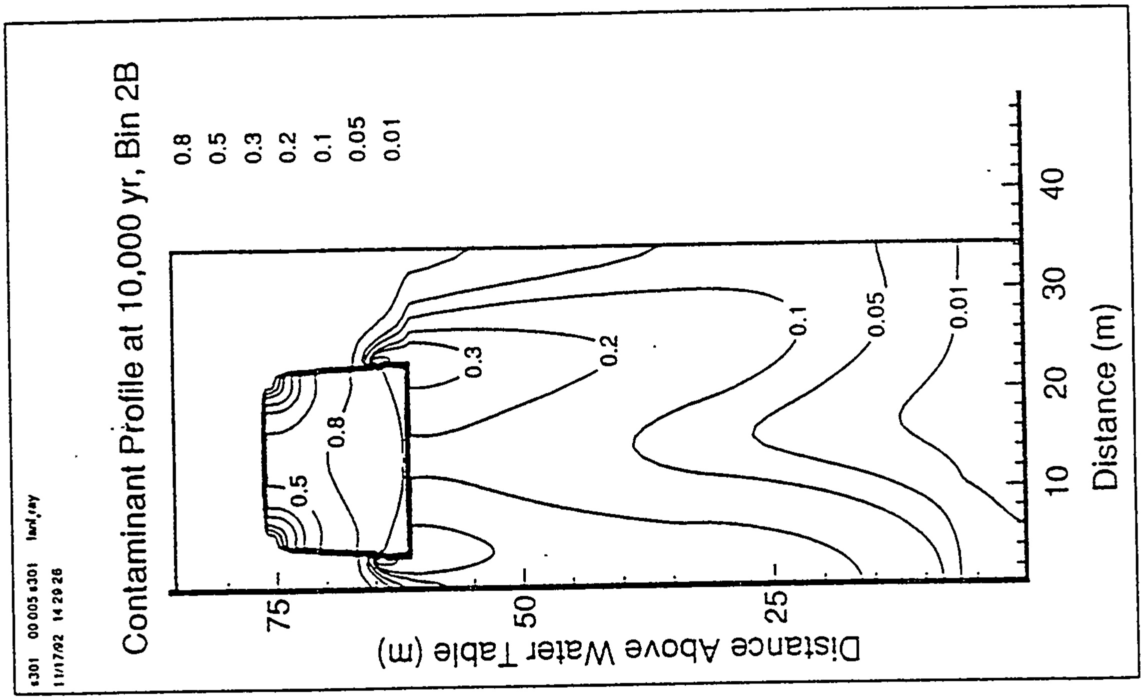


FIGURE 2.29 Relative Concentrations at 10,000 Years for Bin 2B Simulations



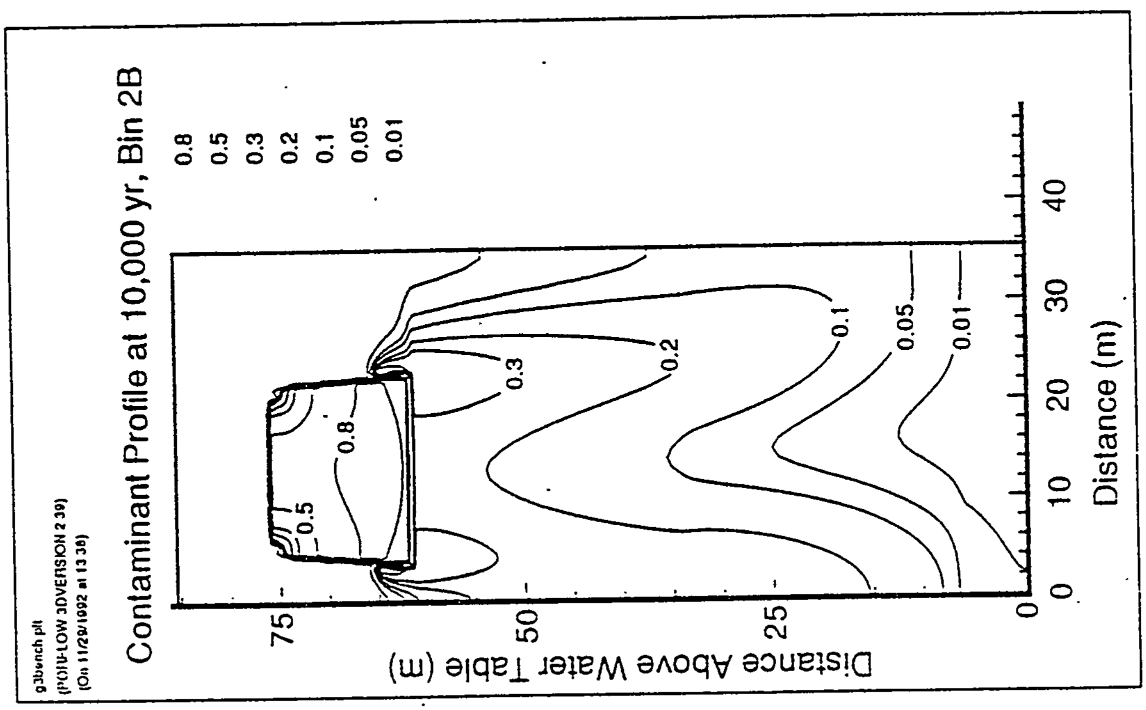
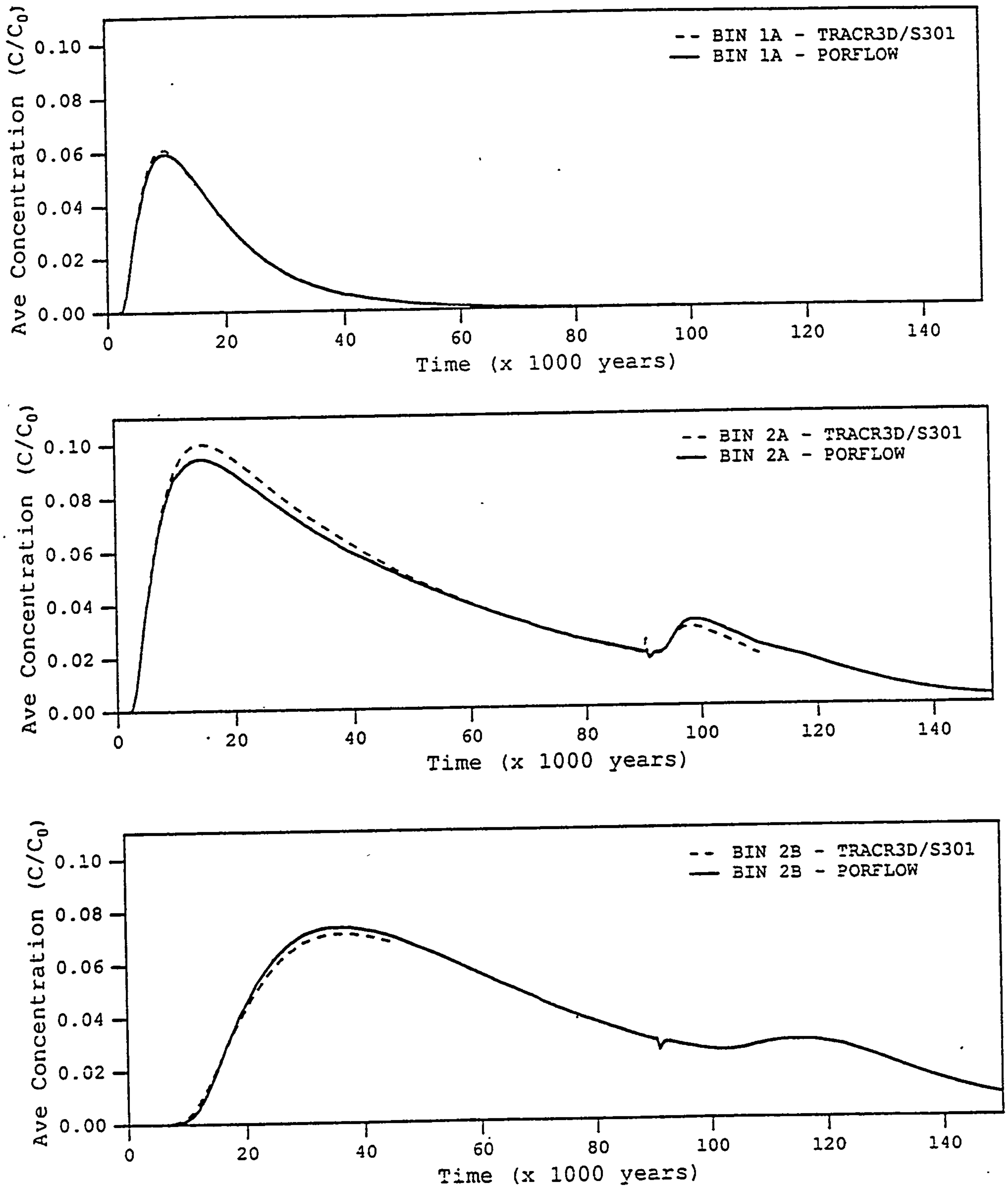


FIGURE 2.30 Average Relative Concentrations at the Water Table Versus Time



3.0 GRTPA VERSION 3.0

3.1 INTRODUCTION

The GRTPA (Grout Performance Assessment) code is a post-processing dose code for the PORFLOW code. The code is defined with the background, configuration, code custodian, and documentation in Section 3.2. The verification of GRTPA is described in Section 3.3, and the benchmarking is described in Section 3.4. The conclusions are presented in Section 3.5.

3.2 DEFINITION OF GRTPA VERSIONS 2.8 and 3.0

3.2.1 BACKGROUND

The GRTPA code (Rittmann 1993) was designed to interface closely with the PORFLOW code so that dose calculations as a function of time could be obtained very quickly after PORFLOW finished running. After the first version (version 1.0) of GRTPA was developed and working, various enhancements were made based on the experience gained from using earlier versions. As a result, GRTPA version 3.0 evolved to a fairly nice user-oriented dose code that handles the radioactive decay of radionuclides and calculates various doses due to contaminated well water and/or contaminated river water.

3.2.2 CRAY CONFIGURATION AND CODE CUSTODIAN

Two versions (2.8 and 3.0) of the GRTPA code are noteworthy. The GRTPA version 2.8 code was configured on the Hanford Cray on September 4, 1993 by the code custodian. That configuration of GRTPA on the Cray produced all of the results in this document.

Version 3.0 of GRTPA is the most recent version and is not implemented on a Cray, but only on the IBM workstations at Hanford and PCs.

The executable file for GRTPA version 2.8 is stored on the Hanford Common File Storage (CFS) system in the directory /w94220/grout as grtpac28.e. The FORTRAN file for this executable is stored on the same CFS directory and is called grtpac28.f with include files grtpa.ca, grtpa.cb, grtpa.cd and grtpa.cp. To compile and link the executable, the following Cray compiler command is used:

```
cf77  grtpac28.f
```

The Cray code custodian of GRTPA version 2.8 is Mel Piepho of WHC.

3.2.3 IBM-WORKSTATION CONFIGURATION AND CODE CUSTODIAN

The GRTPA version 3.0 runs on the IBM workstations in the SECC. The FORTRAN file is called grtpa30ibm.f with include files grtpa.ca, grtpa.cb, grtpa.cd and grtpa.cp. To compile and link the executable, the following IBM compiler command is used:

```
xlf grtpa30ibm.f
```

The IBM code custodian of GRTPA version 3.0 is Mel Piepho of WHC. Paul Rittmann of WHC, was the developer of version 3 of the GRTPA code (Rittmann 1993).

No version of the GRTPA code has been implemented on the SGI or other workstations at Hanford. Since it was developed and runs quickly on PCs, the PCs are expected to serve as adequate backup to the IBM workstations.

3.2.4 CODE DOCUMENTATION

The code documentation for the GRTPA code is entitled "GRTPA - A Program to Calculate Human Dose from PORFLOW Output" (Rittmann 1993).

3.3 VERIFICATION TESTS FOR GRTPA

3.3.1 ACCEPTANCE CRITERIA

The acceptance criteria for satisfactory results from the GRTPA code is quite different than PORFLOW's. The GRTPA code, like most dose codes, does not use a numerical solver since the doses are simple analytic functions which merely need evaluation. In other words, the doses are calculated with just algebraic equations that need evaluation one at a time. Hence, the verification testing, Section 3.3.2, for the GRTPA code consisted of checking the options available to ensure that they are working right. The GRTPA code is benchmarked with the RADDECAY code (RISC 1990) in Section 3.3.3 and the GENII code in Section 3.3.4 (Napier 1988). Since the dose models have so many radionuclides, it is not wise to choose a percentage comparison limit for acceptance criteria. However, for the benchmark comparison of GRTPA and GENII, a percentage difference of doses for each radionuclide of less than ten percent was considered acceptable and a maximum percentage dose difference of five percent for the more important radionuclides was desirable. GRTPA is acceptable if all options are checked out, and the GRTPA important results are close (within 5%) to the results from RADDECAY and GENII codes.

3.3.2 VERIFICATION TESTING

The GRTPA code was tested in such a way to ensure that all anticipated uses of it will not generate erroneous or misleading results. Twenty verification test cases were designed to exercise all logical options in the program. The shell script file that was used on the Cray executes all of the verification test cases and is shown in Table 3.1. In Table 3.1, the "sh" stands for shell, rc.bat is the kernel script file (shown in Table 3.2), the next two fields are input parameters for the rc.bat script, and each column ends with a short descriptive phrase describing the verification test. The first input parameter for the rc.bat script, denotes the GRTPA input test file suffix name, and the second parameter denotes the PORFLOW-generated fractional-release file suffix name. See Table 3.2 for parameter details; the $1 indicates where the first input parameter (shown in Table 3.1 for each test) is substituted, and the $2 indicates where the second input parameter is substituted.

TABLE 3.1 Cray Shell Script File Used for Generating Verification Results

```
sh rc.bat 1 0   checks no -999;  compare with OUT-1.WQ1
sh rc.bat 1 1   identical output with 1 0
sh rc.bat 1 1S  verifies skipping works correctly
sh rc.bat 1 1Z  verifies rejection of zero values
sh rc.bat 1 2E  extra line in second block
sh rc.bat 1 2M  missing line in second block
sh rc.bat 1 3I  incomplete third block
sh rc.bat 1 4   4 blocks, even though only one is needed
sh rc.bat 1 5   5 blocks, identical with 1 4
sh rc.bat 2 6   one chemical, check peak routines on PORFLOW data
sh rc.bat 3 1  no output since 2-4 blocks are needed
sh rc.bat 3 7  many checks, including block additions
sh rc.bat 3X 7 check interpolation using Interp=2
sh rc.bat 3Y 7 check interpolation using Interp=3
sh rc.bat 3Z 7 check interpolation using Interp=4
sh rc.bat 4 7  Am-242m decay chain to compare with RADDECAY
sh rc.bat 5 8  Evaluates multiple peak cases
sh rc.bat 6 7  Checks effect of Ingrowth Ratio
sh rc.bat 7 7  Used in checks of Ingrowth Ratio
sh rc.bat 8 7  Checks combination of block doses
```

TABLE 3.2 Cray rc.bat Shell Script File

```
cp TEST.$1 grtpa.in
cp FORT.$2 fort.35
grtpac28.e
cp grtpa.out out-$1.$2
cp grtpa.por por-$1.$2
cp grtpa.cmb cmb-$1.$2
```

3.4 BENCHMARK CASES

3.4.1 RADDECAY-GRTPA BENCHMARK TEST OF DECAY CHAIN CALCULATIONS

The decay chain Am-242m was selected to verify the correct calculation of radioactive progeny ingrowth. These allow complete testing of all features of the decay algorithms. Three particular features which were verified were the following: (1) the ingrowth of progeny activity, (2) the combination with progeny from other decay chains, and (3) use of the ingrowth weighting factors. In addition, the extra lines of code to compute the Pu-238 branch of the Am-242m chain were also tested.

Additional verifications were indirectly the result of the hand calculations done for other reasons. For Tc-99 and Mo-93, the spreadsheet tool was adequate to verify decay chain calculations.

The RADDECAY program, distributed by the Radiation Shielding Information Center at Oak Ridge National Laboratory (RISC 1990), was used to benchmark the decay calculations performed by GRTPA for Am-242m. The results of these calculations are shown in Tables 3.3 and 3.4 below. RADDECAY does provide more significant figures than GRTPA.

TABLE 3.3 Results from GRTPA for the Am-242m Chain

DK Time	14.6 y	152.0 y	7500.3 y	750,000 y
Am-242m	1.87	1.00	2.80E-15	0.0
Pu-242	8.97E-06	6.96E-05	1.37E-04	3.49E-05
Pu-238	0.174	0.779	5.48E-15	0.0
U-238	1.03E-14	9.15E-13	1.56E-10	8.78E-09
U-234	3.72E-06	2.35E-04	1.01E-03	1.23E-04
Th-230	1.65E-10	1.25E-07	6.35E-05	1.78E-04
Ra-226	2.64E-13	2.21E-09	4.43E-05	1.79E-04
Pb-210	2.24E-14	1.18E-09	4.41E-05	1.79E-04

Comparing Tables 3.3 and 3.4 for Am-242m, there are small differences which are greatest farther down the chain and at small decay times. The percentage differences are shown in Table 3.5. These differences are due to the omission of intermediate steps in the decay chain calculation performed by GRTPA. These nuclides were omitted in GRTPA due to their short halflives. Table 3.6 shows the full decay chain for Am-242m, including all the short lived nuclides. The abbreviation of the decay chains in GRTPA does have a small effect on the resulting concentrations and doses at small decay times. Note that the GRTPA results are always biased toward higher concentrations and doses. Also note that at small decay times, the dose from the progeny is negligible compared with the dose from the parent.

TABLE 3.4 Results from RADDECAY for the Am-242m Chain

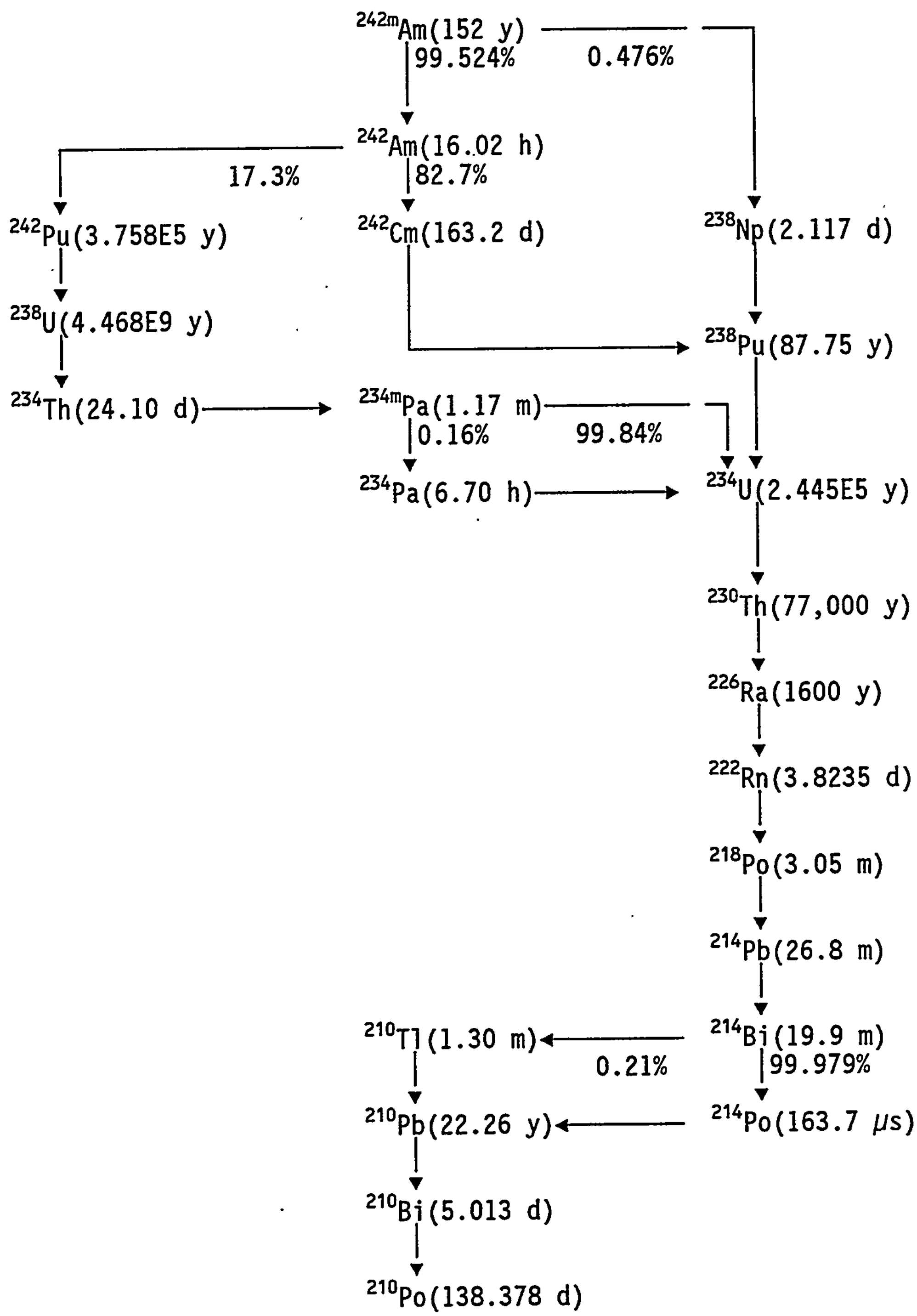
DK Time	14.6 y	152.0 y	7500.3 y	750,000 y
Am-242m	1.8712	1.0000	2.7989E-15	0.0
Am-242	1.8623	0.99525	2.7856E-15	0.0
Cm-242	1.5447	0.82550	2.3105E-15	0.0
Pu-242	8.9695E-06	6.9629E-05	1.3742E-04	3.4937E-05
Pu-238	0.16731	0.77922	5.4975E-15	0.0
Np-238	8.9072E-03	4.7602E-03	1.3323E-17	0.0
U-238	1.0269E-14	9.1507E-13	1.5627E-10	8.7756E-09
Th-234	1.0137E-14	9.1404E-13	1.5627E-10	8.7756E-09
Pa-234m	1.0137E-14	9.1404E-13	1.5627E-10	8.7756E-09
Pa-234	1.6217E-17	1.4624E-15	2.5003E-13	1.4041E-11
U-234	3.4148E-06	2.3343E-04	1.0086E-03	1.2291E-04
Th-230	1.4567E-10	1.2335E-07	6.3537E-05	1.7764E-04
Ra-226	2.2312E-13	2.1794E-09	4.4339E-05	1.7879E-04
Rn-222	2.2217E-13	2.1786E-09	4.4339E-05	1.7879E-04
Po-218	2.2217E-13	2.1786E-09	4.4339E-05	1.7879E-04
Pb-214	2.2212E-13	2.1782E-09	4.4330E-05	1.7875E-04
Bi-214	2.2212E-13	2.1782E-09	4.4330E-05	1.7875E-04
Po-214	2.2207E-13	2.1777E-09	4.4321E-05	1.7871E-04
Pb-210	1.8193E-14	1.1536E-09	4.4054E-05	1.7873E-04
Bi-210	1.8069E-14	1.1530E-09	4.4054E-05	1.7873E-04
Po-210	1.5086E-14	1.1358E-09	4.4049E-05	1.7873E-04

TABLE 3.5 Percent Differences Between GRTPA and RADDECAY for the Am-242m Chain

DK Time	14.6 y	152.0 y	7500.3 y	750,000 y
Am-242m	-0.1	0.0	0.0	
Pu-242	0.0	0.0	-0.3	-0.1
Pu-238	4.0	0.0	-0.3	
U-238	0.3	0.0	-0.2	0.0
U-234	8.9	0.7	0.1	0.1
Th-230	13.3	1.3	-0.1	0.2
Ra-226	18.3	1.4	-0.1	0.1
Pb-210	23.1	2.3	0.1	0.2

Additional tests were done to ensure that the Ingrowth Weighting Factors entered by the user are applied properly. If the nuclide is part of a decay chain, and there are no ancestor nuclides in the block, then the ingrowth factor is ignored. Otherwise, it used to weight the amount of the nuclide which is allowed to grow in from the parent. The GRTPA verification test input file TEST.6 verifies that it is applied correctly. In the GRTPA output for verification test "rc.bat 6 7" (see Table 3.1), the U-234 concentration should be the sum of the U-234 concentration from GRTPA output file OUT-7.7 and half the U-234 concentration shown in OUT-4.7. The verification test input file TEST.8 also verified the use of these factors for Nb-93m.

TABLE 3.6 Decay Chain Schematic for Am-242m



3.4.2 GENII-GRTPA BENCHMARK TEST OF DOSE CALCULATIONS

The PORFLOW/GRTPA output concentrations were the starting point for comparison of irrigated farm doses with the GENII code. Well water concentrations were taken from the GRTPA output for the Grout PA benchmark case (see Section 2.5.6) for each radionuclide. These concentrations were used as input to GENII, and the two sets of doses (one from GENII and one from GRTPA) were compared.

The radionuclide concentrations for this case are shown in Table 3.7.

TABLE 3.7 Groundwater Concentrations (pCi/L) in Irrigation Well

Nuclide	5,000y	10,000y	20,000y	50,000y	90,000y
Se-79	0	0	1.13E-05	4.65E-01	1.35E+00
Nb-94	7.90E-09	1.20E-03	2.41E-02	1.21E-02	1.40E-03
Tc-99	1.51E+03	3.39E+03	3.27E+03	1.65E+03	6.03E+02
Sn-126	0	0	3.70E-05	1.70E+00	5.73E+00
I-129	1.51E+01	2.68E+01	1.41E+01	1.30E+00	4.50E-02
Cs-135	0	0	3.20E-06	1.79E-01	7.87E-01
Np-237	0	0	2.00E-06	1.13E-01	4.96E-01

The main input files, for the GENII version 1.485 code, used in this calculation of irrigated-farm doses are (a) DEFAULT.IN (Grout PA Parameter Values), (b) FTRANS.DAT (Food Transfer Factors, NUREG-5512), and (c) IRRIG.IN (GENII user input) which are attached for reference in Appendix B.

The doses for each radionuclide calculated by GRTPA using GENII internal dose factors and assuming 50-year prior irrigation are shown in Table 3.8. Table 3.9 shows the GENII-calculated doses, using GENII internal dose factors and assuming 50-year prior irrigation. The comparison of the GRTPA and GENII code irrigated-farm doses are shown in Table 3.10 in the form of ratios. These ratios should be near one in order to satisfactorily benchmark the GRTPA dose calculations with the GENII code. The agreement between the two dose calculations is very good as the largest difference is only 4 percent.

TABLE 3.8 GRTPA (GENII DF, 50-yr) - Irrigated Farm Doses, mrem

Nuclide	5,000y	10,000y	20,000y	50,000y	90,000y
Se-79	0	0	1.2E-07	4.9E-03	1.4E-02
Nb-94	5.8E-09	8.6E-04	1.8E-02	8.9E-03	1.0E-03
Tc-99	6.2E+00	1.4E+01	1.3E+01	6.8E+00	2.5E+00
Sn-126	0	0	3.7E-05	1.7E+00	5.6E+00
I-129	4.6E+00	8.1E+00	4.3E+00	4.0E-01	1.4E-02
Cs-135	0	0	3.8E-08	2.1E-03	9.2E-03
Np-237	0	0	7.8E-06	4.3E-01	1.9E+00
Total:	10.8	22	17.7	9.3	10.1

TABLE 3.9 GENII (50-yr) - Irrigated Farm Doses, mrem

Nuclide	5,000y	10,000y	20,000y	50,000y	90,000y
Se-79	0	0	1.2E-07	5.1E-03	1.4E-02
Nb-94	5.8E-09	8.9E-04	1.7E-02	8.9E-03	1.0E-03
Tc-99	6.1E-00	1.4E+01	1.3E+01	6.4E-00	2.4E-00
Sn-126	0	0	3.6E-05	1.7E-00	5.8E-00
I-129	4.5E-00	8.2E-00	4.2E-00	3.9E-01	1.3E-02
Cs-135	0	0	3.7E-08	2.1E-03	9.2E-03
Np-237	0	0	7.6E-06	4.2E-01	1.9E-00
Total:	10.6	22.2	17.8	8.9	10.0

TABLE 3.10 GRTPA (GENII DF, 50-yr) Dose/GENII (50-yr) Dose Ratios

Nuclide	5,000y	10,000y	20,000y	50,000y	90,000y
Se-79			1.00	0.97	1.02
Nb-94	1.00	0.96	1.04	1.00	1.01
Tc-99	1.02	0.99	1.03	1.06	1.03
Sn-126			1.02	0.98	0.97
I-129	1.02	0.99	1.02	1.01	1.05
Cs-135			1.02	1.00	1.00
Np-237			1.03	1.03	1.00
Total:	0.98	1.00	0.98	1.04	1.01

The difference between the GENII internal dose factors and the DOE internal dose factors is also interesting, but not really part of the benchmark. A detailed comparison is made in Rittmann (1993). For this report, using the contaminant concentrations from the PORFLOW benchmark run (shown in Table 3.7), the doses for each radionuclide calculated by GRTPA using internal dose factors from DOE/EH-0071 (DOE dose factors) and assuming 50-year prior irrigation are shown in Table 3.11. The ratios of the irrigated-farm doses calculated by GRTPA using GENII internal dose factors (Table 3.8) and the DOE dose factors (Table 3.11), both assuming 50-year prior irrigation, are shown in Table 3.12. Using the GENII internal dose factors leads to much higher irrigated-farm doses. This is mainly because of the dose factors of two radionuclides (a) Tc-99 which has a 70% higher internal dose factor in GENII than in DOE/EH-0071, and (b) Np-237 which has a 34% higher internal dose factor.

TABLE 3.11 GRTPA (DOE DF, 50yr) - Irrigated Farm Doses, mrem

Nuclide	5,000y	10,000y	20,000y	50,000y	90,000y
Se-79	0	0	1.2E-07	4.9E-03	1.4E-02
Nb-94	5.7E-09	8.4E-04	1.7E-02	8.7E-03	9.9E-04
Tc-99	3.6E+00	8.1E+00	7.8E+00	4.0E+00	1.4E+00
Sn-126	0	0	3.6E-05	1.7E+00	5.6E+00
I-129	5.1E+00	9.1E+00	4.8E+00	4.4E-01	1.5E-02
Cs-135	0	0	3.9E-08	2.2E-03	9.5E-03
Np-237	0	0	5.8E-06	3.2E-01	1.4E+00
Total:	8.78	17.2	12.6	6.4	8.54

TABLE 3.12 GRTPA (GENII DF) Dose/GRTPA (DOE DF) Dose Ratios

Nuclide	5,000y	10,000y	20,000y	50,000y	90,000y
Se-79			1.01	1.01	1.01
Nb-94	1.02	1.02	1.02	1.02	1.02
Tc-99	1.72	1.72	1.72	1.72	1.72
Sn-126			1.01	1.01	1.01
I-129	0.89	0.89	0.89	0.89	0.89
Cs-135			0.97	0.97	0.97
Np-237			1.34	1.34	1.34
Total:	1.23	1.28	1.40	1.45	1.18

One additional comparison is informative for comparisons of the irrigated-farm doses in this report (GRTPA calculated) with the doses in the Grout PA, which were calculated by GENII. For the irrigated-farm doses (not drinking-water doses) in the Grout PA, GENII used GENII dose factors with no prior irrigation assumed. The ratios of the GRTPA irrigated-farm doses using the DOE dose factors with 50-year prior irrigation (Table 3.11) and the GENII irrigated-farm doses with no prior irrigation are shown in Table 3.13. The GENII doses are about 10 to 25% larger, except at very long times, when the Sn-126 is becoming important.

TABLE 3.13 Ratios: GRTPA (DOE DF)/GENII 0-yr

Nuclide	5,000y	10,000y	20,000y	50,000y	90,000y
Se-79			0.99	1.00	1.01
Nb-94	10.88	10.61	10.81	11.00	10.74
Tc-99	0.62	0.62	0.60	0.65	0.63
Sn-126			13.44	13.83	14.00
I-129	1.14	1.11	1.14	1.13	1.17
Cs-135			1.26	1.20	1.25
Np-237			0.78	0.79	0.75
Total:	0.88	0.82	0.74	0.91	1.82

4.0 POST-PROCESSING CODES MAKETEC AND TECPLOT

4.1 INTRODUCTION

Two post-processing codes were used to get the graphical results shown in this report. The MAKETEC code reads the PORFLOW archive file, see Figure 1.1, and creates an ascii file which is processed by the PREPLOT module of the graphics package TECPLOT (Amtec Engineering 1993). The TECPLOT graphics package creates the graphical files for actual printing (color or black & white).

4.2 MAKETEC VERSION 2.394

The program MAKETEC was put together by Mike Connelly for WHC several years ago. Since MAKETEC is menu driven and so easy to use, documentation has never been written for this code. The code merely reads the output variable values from the PORFLOW archive file and puts them into a new file which is compatiable with the graphics code TECPLOT. MAKETEC also linearly interpolates the velocities at the cell edges to obtain velocities at the node location within a computational cell. The choice of output variables and the name of the archive file are determined in the PORFLOW input file (Runchal et al. 1992). The usual output variables of interest are concentrations, velocities, pressure heads, saturation and moisture content, which can vary over time.

4.2.1 CRAY CONFIGURATION AND CODE CUSTODIAN

The Cray executable file for MAKETEC version 2.394 is named maketecf3.e and is stored on CFS in the grout directory. The code custodian for MAKETEC on the Cray is Mel Piepho. To compile MAKETEC on the Cray, the following command was used:

```
cf77 -o maketecf3.e maketecf3.f
```

4.2.2 IBM WORKSTATION CONFIGURATION AND CODE CUSTODIAN

The IBM workstation executable file for MAKETEC is named maketecibm.e. The code custodian for MAKETEC version 2.394 on the SECC IBM workstations is Mel Piepho. To compile MAKETEC on the IBM workstation, the following UNIX command was used:

```
xlf -qautodbl=dblpad -o maketecibm.e maketecibm.f
```

4.2.3 SGI WORKSTATION CONFIGURATION AND CODE CUSTODIAN

The SGI workstation executable file for MAKETEC is named maketecsgi.e. The code custodian for MAKETEC on the SECC SGI workstations is Mel Piepho. To compile MAKETEC on a SGI workstation, the following UNIX command was used with the same source code as that used for the IBM workstation:

```
f77 -r8 -o maketecsgi.e maketecibm.f
```

4.3 TECPLOT VERSION 6.0

TECPLOT is a commercial softare graphics package (AMTEC 1992) that has been used at Westinghouse Hanford Co. for the last few years. The output variable values from PORFLOW are always plotted correctly by TECPLOT whenever checked with the values printed out by PORFLOW. Some verfication of TECPLOT contour capabilities are presented by Kline (1993). TECPLOT exists on the SUN workstations and SGI workstations in the SECC in 3200 George Washington Way building. The code custodian is Don Hammervold of WHC.

5.0 SYSTEM FILES

Each code described in this document has input/output files, most of which come from other codes in the GPAC System. Each file is described in the documentation for each individual code, but since the files form the glue for the entire GPAC System, they are also briefly described here.

PORFLOW code:

A) Input Files

1) fort.15 = local file name for main input file
2) ACR:POR2394gr = file name for initialization of names/variables
   - This file is required to be present in the disk directory where PORFLOW is running.

B) Output Files

1) fort.16 = local file name for main output file
2) fort.35 = local file name containing fractional-release-to-the-aquifer-over-time values; this file is the connection to the GRTPA dose code in GPACS.
3) *.arc = archive file which stores selected data over time; the actual file name and contents are defined in the fort.15 input file. This file is the connection to Maketec code and TECPLOT. The *.arc files exist only as binary files in version 2.394gr of PORFLOW.
4) *.flx = file of selected fluxes over time which are defined in the fort.15 input file. The *.flx files exist only as ASCII files in version 2.394gr.
5) *.his = file of main variable values over time for selected node points which are defined in the fort.15 input file. The *.his files exist only as ASCII files in version 2.394gr of PORFLOW.

GRTPA dose code:

A) Input files

1) grtpa.in = local file name of main input file,
2) fort.35 = local file name of fractional-release data; output file of PORFLOW code.

B) Output Files

1) grtpa.out = local file name of main output file which contains doses/concentrations over time for each radionclide,
2) grtpa.por = local file name of fractional-release data; this file has the same data as the fort.35 file, but in a different format,
3) grtpa.cmb = local file name of combined doses of all radionuclides over time.
4) grtpa.drl = local file name of drilling intruder and gardener doses; this file is only available from version 3.0 of GRTPA code and not from version 2.8,
5) grtpa.rdn = local file name of radon gas release from storage vault; this file is only available from version 3.0 of GRTPA code and not from version 2.8.

These local file names are shown in Table 5.1 which is an example batch run for the Grout PA benchmark case (Piepho 1994). This table shows how one might name their local files for permanent storage purposes. Even though this table is for the Cray computer that was at Hanford, the runstream is easily adapted to the SECC computers as even the CFS system is available to the SECC computers.

TABLE 5.1 CRAY BATCH FILE/RUN STREAM

```
# PORFLOW/GRTPA (GPACS) batch file
cfs get grout/ACR.POR2394gr
cfs get grout/g3bench.inp
cp g3bench.inp fort.15
cfs get grout/por2394gr.e
cfs get grout/grtpac28.e
cp g3bench.inp grtpa.in
por2394gr.e
mv fort.16 g3bench.out
cfs store grout/g3bench.his
cfs store grout/g3bench.arc
cfs store grout/g3bench.flx
cp fort.35 g3bench.sum
grtpac28.e
cp grtpa.por g3bench.por
cp grtpa.cmb g3bench.cmb
cp grtpa.out g3bench.doslg
cfs store grout/g3bench.sum
cfs store grout/g3bench.doslg
cfs store grout/g3bench.rst
cfs store grout/g3bench.out
# end of run
```

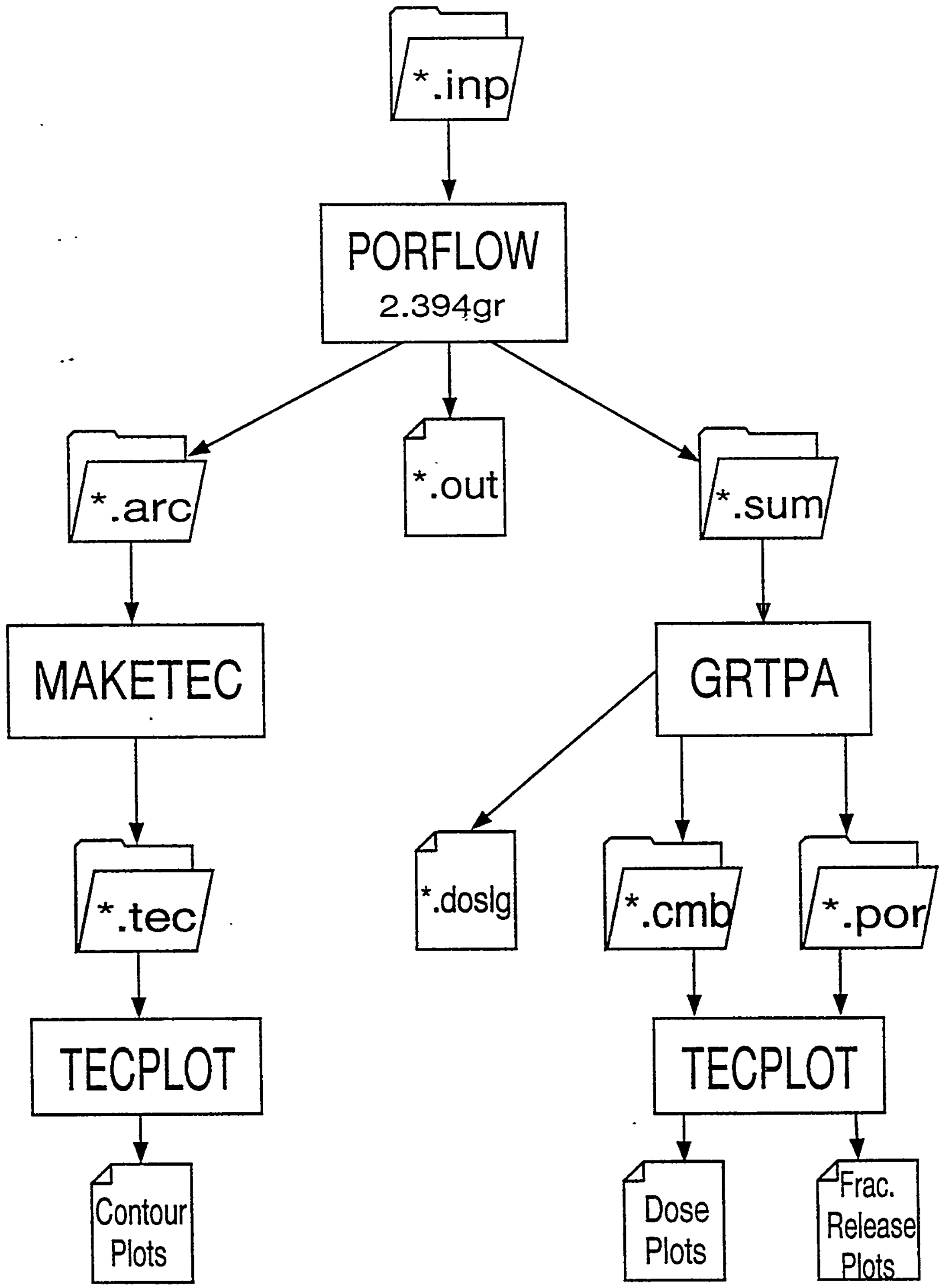
The other codes in GPACS are interactive codes where the files are named by the user. The input and output files are listed here with generic names.

MAKETEC code:
- A) Input Files
  - 1) *.arc = generic archive file name from PORFLOW code,
- B) Output Files
  - 1) *.tec = generic file name for PORFLOW output/TECPLOT graphics,

TECPLOT code:
- A) Input File
  - 1) *.tec = generic file name of PORFLOW output from MAKETEC code,
  - 2) *.cmb = dose file from GRTPA code,
  - 3) *.por = generic release file from GRTPA code,
- B) Output Files
  - 1) Graphic output files are available for many different printers.

The flowchart of the computer codes and the major data files in the Grout/Glass Performance Assessment Codes System (GPACS) is shown in Figure 5.1.

FIGURE 5.1 The Computer Codes and Main Connecting Data Files in GPACS



6.0 CONCLUSIONS

The complete Grout/Glass Performance Assessment Code System (GPACS) was partially described in this document and any potential users will need to get the specific code documents of each code in GPACS in order to make runs. The two main codes of the system are 1) the PORFLOW code (Runchal et al. 1992), and 2) the GRTPA dose code (Rittmann 1993). The Rittmann includes more details on verification and benchmarking with the GENII dose code (Napier et al. 1988). More verification (or confirmation) of PORFLOW is provided in a new PORFLOW document by Runchal (1994).

GPACS is currently implemented on the Scientific and Engineering Computer Center (SECC) at Westinghouse Hanford Company, and a separate configuration document of GPACS on the SECC will be issued.

Based on the test cases presented here, GPACS is qualified to perform unsaturated flow and contaminant transport simulations and to estimate doses (drinking-water, irrigated-farm, and river) to humans via the groundwater pathway (both unsaturated and saturated) for the Hanford site. Some of the dose-factor parameters, such as consumption rates, are site specific and would have to be re-evaluated for use at other sites. The two made codes in GPACS, PORFLOW version 2.394gr and GRTPA versions 2.8 and 3.0, satisfied the acceptance criteria established for each code on the Cray computer, and on the IBM (ibml, ibm2) and SGI (sgil, sgi3) workstations in the Scientific and Engineering Computing Center at Westinghouse Hanford Company. On the other hand, GPACS, or rather PORFLOW, has not been verified in this document for nonisothermal flow or multiphase flow and transport, although these capabilities do exist in PORFLOW.

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APPENDIX A

MODELS AND ASSUMPTIONS IN GRTPA CODE

This appendix describes the formulas and assumptions by which the PORFLOW output is converted into groundwater concentrations and radiation dose. The discussion begins with the three exposure scenarios that are assumed for the code. All three scenarios are calculated during one GRTPA run. Other scenarios can be defined by changing the consumption factors, Section A.2.2, and water flow rates in the aquifer and river, Section A.2.3. All of the mathematical models are contained in section A.2 including the exposure pathways (Section A.2.1), the biosphere models (Sections A.2.4, A.2.5, and A.2.6). The radioactive decay model and the special models for tritium and carbon are described in Section A.2.7. Finally, the effective dose factors with and without prior irrigation are presented in Section A.3.

The GRTPA program uses tables of effective dose factors for each exposure scenario stored in the block data subroutine. The effective dose factors used by GRTPA relate the water concentration coming from the well or river to the eventual dose received by a farmer.

A.1 HUMAN EXPOSURE SCENARIOS

Three exposure scenarios can be calculated in one run with the GRTPA program. These three scenarios, by default, consisted of an individual drinking contaminated water from a well, which is down stream from the grout disposal site, a farmer eating crops irrigated by contaminated well water, consuming contaminated animal produce and drinking water, and another farmer getting irrigation water from the Columbia River, instead of a well, and consuming contaminated fish in addition to the other exposure pathways.

A.1.1 DRINKING-WATER SCENARIO

The well water undergoes none of the treatment that most community water supplies receive. It is assumed to be suitable for human consumption directly from the ground, except for trace amounts of radioactivity. In the farm scenarios, the people are assumed to consume 655 liters of this water in a year. For the drinking water only calculation, the standard consumption rate of 730 liters per year is used. Both of these were used in the Grout PA.

The formula for calculating radionuclide dose from this intake is shown below. Ingestion factors for the radionuclides in GRTPA are listed in Table A.1. Notice that GRTPA allows three options for internal dose factors, (a) GENII, (b) DOE, and (c) EPA. The differences between internal dose-factor collections shown on Table A.1 are less than 30 percent except for eight nuclides: H-3, Co-60, Nb-94, Tc-99, Sn-126, Re-187, Bi-207, and Np-237.

A.1.2 SMALL-IRRIGATED-FARM SCENARIO

It is assumed that the small farm requires irrigation and that all of the water comes from the unconfined aquifer. Since the area of the farm is about two hectare (5 acres), and the applied irrigation is 32.4 inches per year, the volume of water needed annually for the irrigation scenario is 1.6E+07 liters. Since there are only 6 months of irrigation during the year, the actual withdrawal rate is twice this for half the year. Domestic water usage adds an insignificant amount to the above total.

The pathways by which the farmer may be exposed to radiation from the contaminated water are listed below.

- direct ingestion of the contaminated water (655 liters per year)
- ingestion of the vegetables grown in a garden irrigated with contaminated water
- ingestion of meat and milk from animals raised on grass and grains irrigated with the contaminated water. The animals also drink the contaminated water.
- external exposure to soil which becomes contaminated (4383 hr/yr)
- inhalation of radionuclides suspended in the air from the contaminated soil (8766 hr/yr)

The Grout PA includes chicken and egg pathways which have been omitted here since they are very small contributors to total doses. For chemicals the dose is based solely on the drinking water consumption. The accumulation of the chemical in the food chain is not considered.

A.1.3 COLUMBIA RIVER SCENARIO

This scenario uses the same assumptions as the small farm irrigating from a well, except that the irrigation comes from the Columbia River. In addition, the farmer consumes fish taken from the river.

A.2 MATHEMATICAL MODELS

A.2.1 EXPOSURE PATHWAY MODELS

Human exposure to radiation is estimated for both internal and external sources. External sources are outside the body. The only source of external exposure in these scenarios is the contaminated soil. Internal sources of exposure are located inside the body, and get there by being inhaled or ingested. Each of these types of exposure will be discussed separately below. The total dose is the sum of the different types of exposure.

A brief summary of the combinations used in GRTPA is given in Table A.2.

TABLE A.1 Internal and External Dose Factors Available in GRTPA Code

		Ingestion (mrem/pCi)				Inhalation (mrem/pCi)			External[c] mrem/hr per Ci/m²	
Nuclide	f1	GENII	DOE	EPA	Sol	GENII	DOE	EPA	GENII	Redone
H-3	(1.00)	6.1E-08	6.3E-08	6.40E-08	(V)	9.0E-08	6.3E-08	6.40E-08	2.93E-08	3.50E-08
Be-10	(5E-3)	4.7E-06	4.2E-06	4.66E-06	(Y)	3.5E-04	3.5E-04	3.54E-04	3.66E-01	4.34E-01
C-14	(1.00)	2.1E-06	2.1E-06	2.09E-06	(Org)	2.1E-06	2.1E-06	2.09E-06	6.28E-03	7.51E-03
Cl-36	(1.00)	3.0E-06	3.0E-06	3.03E-06	(W)	2.2E-05	2.0E-05	2.19E-05	7.23E-01	8.57E-01
K-40	(1.00)	1.8E-05	1.9E-05	1.86E-05	(D)	1.2E-05	1.2E-05	1.24E-05	4.31E+02	4.87E+02
Co-60	(0.30)	2.7E-05	2.6E-05	2.69E-05	(Y)	2.0E-04	1.5E-04	2.19E-04	6.61E+03	7.51E+03
Ni-59	(0.05)	2.1E-07	2.0E-07	2.10E-07	(D)	1.3E-06	1.3E-06	1.32E-06	1.10E-01	1.32E-01
Ni-63	(0.05)	5.6E-07	5.4E-07	5.77E-07	(D)	3.0E-06	3.0E-06	3.10E-06	1.59E-04	1.91E-04
Se-79	(0.80)	8.4E-06	8.3E-06	8.70E-06	(W)	9.5E-06	8.9E-06	9.84E-06	4.47E-03	5.36E-03
Sr-90	(0.30)	1.3E-04	1.4E-04	1.53E-04	(D)	2.1E-04	2.4E-04	2.47E-04	1.70E+01	1.97E+01
Zr-93	(2E-3)	1.6E-06	1.6E-06	1.66E-06	(D)	3.2E-04	3.2E-04	3.21E-04	1.12E-04	1.34E-04
Nb-93m	(0.01)	5.1E-07	5.3E-07	5.22E-07	(Y)	3.0E-05	2.8E-05	2.92E-05	4.39E-02	5.28E-02
Nb-94	(0.01)	7.3E-06	5.1E-06	7.14E-06	(Y)	3.9E-04	3.3E-04	4.14E-04	4.08E+03	4.66E+03
Mo-93	(0.80)	1.4E-06	1.3E-06	1.35E-06	(Y)	2.8E-05	2.8E-05	2.84E-05	2.12E-01	2.54E-01
Tc-99	(0.80)	2.2E-06	1.3E-06	1.46E-06	(W)	9.0E-06	7.5E-06	8.33E-06	4.22E-02	5.05E-02
Pd-107	(5E-3)	1.5E-07	1.4E-07	1.49E-07	(Y)	1.3E-05	1.3E-05	1.28E-05	3.49E-06	4.17E-06
Cd-113m	(0.05)	1.6E-04	1.5E-04	1.61E-04	(D)	1.5E-03	1.4E-03	1.53E-03	3.60E-01	4.28E-01
Sn-121m	(0.02)	2.2E-06	2.0E-06	2.25E-06	(W)	1.2E-05	9.3E-06	1.19E-05	0	5.16E+00
Sn-126	(0.02)	2.1E-05	1.8E-05	2.11E-05	(W)	1.0E-04	7.5E-05	1.01E-04	5.71E+03	6.56E+03
I-129	(1.00)	2.5E-04	2.8E-04	2.76E-04	(D)	1.5E-04	1.8E-04	1.74E-04	4.64E+00	5.59E+00
Cs-135	(1.00)	6.9E-06	7.1E-06	7.07E-06	(D)	4.5E-06	4.5E-06	4.55E-06	1.22E-02	1.45E-02
Cs-137	(1.00)	4.8E-05	5.0E-05	5.00E-05	(D)	3.0E-05	3.2E-05	3.19E-05	1.58E+03	1.82E+03
Ba-133 a	(0.10)	3.3E-06	3.2E-06	3.40E-06	(D)	7.4E-06	6.9E-06	7.81E-06	9.57E+02	1.10E+03
Sm-147	(3E-4)	1.9E-04	1.8E-04	1.85E-04	(W)	7.5E-02	7.1E-02	7.47E-02	0	0
Sm-151	(3E-4)	3.9E-07	3.4E-07	3.89E-07	(W)	3.0E-05	2.9E-05	3.00E-05	1.63E-03	1.95E-03
Eu-150 a	(1E-3)	6.3E-06	6.2E-06	6.36E-06	(W)	2.7E-04	2.7E-04	2.68E-04	4.38E+03	5.03E+03
Eu-152	(1E-3)	6.5E-06	6.0E-06	6.48E-06	(W)	2.1E-04	2.2E-04	2.21E-04	3.15E+03	3.59E+03
Eu-154	(1E-3)	9.6E-06	9.1E-06	9.55E-06	(W)	2.8E-04	2.6E-04	2.86E-04	3.26E+03	3.73E+03
Gd-152 a	(3E-4)	1.6E-04	1.5E-04	1.62E-04	(D)	2.4E-01	2.4E-01	2.43E-01	0	0
Re-187	(0.80)	1.5E-08	8.3E-09	9.51E-09	(W)	5.9E-08	4.9E-08	5.44E-08	0	0
Pb-210	(0.20)	7.3E-03	6.7E-03	7.27E-03	(D)	2.4E-02	2.1E-02	2.32E-02	3.28E+00	3.88E+00
Bi-207 a	(3E-4)	5.2E-06	4.9E-06	5.48E-06	(D)	1.7E-05	1.4E-05	2.00E-05	4.29E+03	4.93E+03
Po-209 b	(0.10)	2.4E-03	2.0E-03	2.38E-03	(D)	1.2E-02	1.0E-02	1.18E-02	7.78E+00	8.93E+00
Ra-226	(0.20)	9.6E-04	1.1E-03	1.32E-03	(W)	8.2E-03	7.9E-03	8.58E-03	4.92E+03	5.60E+03
Ra-228	(0.20)	8.4E-04	1.2E-03	1.44E-03	(W)	4.4E-03	4.3E-03	4.86E-03	2.67E+03	3.04E+03
Ac-227	(1E-3)	1.4E-02	1.5E-02	1.48E-02	(D)	6.7E+00	6.7E+00	6.72E+00	9.26E+02	1.07E+03
Th-228	(2E-4)	5.8E-04	7.5E-04	8.07E-04	(Y)	3.5E-01	3.1E-01	3.45E-01	4.33E+03	4.88E+03
Th-229	(2E-4)	3.9E-03	3.9E-03	4.03E-03	(W)	2.2E+00	2.0E+00	2.16E+00	7.80E+02	9.03E+02
Th-230	(2E-4)	5.4E-04	5.3E-04	5.48E-04	(W)	3.2E-01	3.2E-01	3.26E-01	3.43E-01	4.10E-01
Th-232	(2E-4)	2.7E-03	2.8E-03	2.73E-03	(W)	1.7E+00	1.6E+00	1.64E+00	1.79E-01	2.13E-01
Pa-231	(1E-3)	1.1E-02	1.1E-02	1.06E-02	(W)	1.3E+00	1.3E+00	1.28E+00	7.82E+01	9.09E+01
U-232	(0.05)	1.3E-03	1.3E-03	1.31E-03	(Y)	6.7E-01	6.7E-01	6.59E-01	2.61E-01	3.11E-01
U-233	(0.05)	2.9E-04	2.7E-04	2.89E-04	(Y)	1.4E-01	1.3E-01	1.35E-01	4.05E-01	4.80E-01
U-234	(0.05)	2.9E-04	2.6E-04	2.83E-04	(Y)	1.3E-01	1.3E-01	1.32E-01	1.58E-01	1.89E-01
U-235	(0.05)	2.7E-04	2.5E-04	2.67E-04	(Y)	1.2E-01	1.2E-01	1.23E-01	2.13E+02	2.52E+02
U-236	(0.05)	2.7E-04	2.5E-04	2.69E-04	(Y)	1.3E-01	1.2E-01	1.25E-01	8.22E-02	9.83E-02
U-238	(0.05)	2.7E-04	2.4E-04	2.68E-04	(Y)	1.2E-01	1.2E-01	1.18E-01	6.32E+01	7.26E+01
Np-237	(1E-3)	5.3E-03	3.9E-03	4.44E-03	(W)	6.4E-01	4.9E-01	5.40E-01	6.16E+02	7.13E+02
Pu-238	(1E-3)	3.2E-03	3.8E-03	3.20E-03	(W)	3.9E-01	4.6E-01	3.92E-01	5.26E-02	6.30E-02
Pu-239	(1E-3)	3.6E-03	4.3E-03	3.54E-03	(W)	4.3E-01	5.1E-01	4.29E-01	1.16E-01	1.12E-01
Pu-240	(1E-3)	3.6E-03	4.3E-03	3.54E-03	(W)	4.3E-01	5.1E-01	4.29E-01	5.23E-02	7.29E-02
Pu-241	(1E-3)	6.8E-05	8.6E-05	6.85E-05	(W)	8.2E-03	1.0E-02	8.25E-03	6.26E-03	1.04E-02
Pu-242	(1E-3)	3.3E-03	4.1E-03	3.36E-03	(W)	4.1E-01	4.8E-01	4.11E-01	4.36E-02	5.24E-02
Pu-244	(1E-3)	3.3E-03	4.0E-03	3.32E-03	(W)	4.0E-01	4.8E-01	4.03E-01	1.02E+03	1.17E+03
Am-241	(1E-3)	3.6E-03	4.5E-03	3.64E-03	(W)	4.4E-01	5.2E-01	4.44E-01	1.19E+01	1.44E+01
Am-242m	(1E-3)	3.6E-03	4.3E-03	3.61E-03	(W)	4.4E-01	5.3E-01	4.40E-01	3.09E+01	3.64E+01
Am-243	(1E-3)	3.6E-03	4.5E-03	3.62E-03	(W)	4.4E-01	5.2E-01	4.40E-01	3.82E+02	4.49E+02
Cm-243	(1E-3)	2.5E-03	2.9E-03	2.51E-03	(W)	3.1E-01	3.5E-01	3.07E-01	2.46E+02	2.90E+02
Cm-244	(1E-3)	2.0E-03	2.3E-03	2.02E-03	(W)	2.5E-01	2.7E-01	2.48E-01	4.25E-02	5.08E-02
Cm-245	(1E-3)	3.7E-03	4.5E-03	3.74E-03	(W)	4.5E-01	5.4E-01	4.55E-01	1.11E+02	1.32E+02
Cm-246	(1E-3)	3.7E-03	4.5E-03	3.70E-03	(W)	4.6E-01	5.4E-01	4.51E-01	3.49E-02	4.19E-02
Cm-247	(1E-3)	3.4E-03	4.1E-03	3.42E-03	(W)	4.2E-01	4.9E-01	4.14E-01	1.13E+03	1.30E+03
Cm-248	(1E-3)	1.4E-02	1.6E-02	1.36E-02	(W)	1.6E+00	1.9E+00	1.65E+00	3.18E-02	3.82E-02

a) GENII values for these nuclides were obtained by averaging the DOE and EPA values.
b) All Po-209 internal dose factors are estimated from Po-210 dose factors.
c) The External Dose Rate Factors are described in more detail in Section A.2.1.3.

TABLE A.2 Summary of the Effective-Dose-Factors Models Available in GRTPA

Component of Model	GENII DF	DOE DF	NUREG-5512
Internal Dose Factors	GENII	DOE	EPA
External Dose Factors	GENII	GENII	GENII Redo
Concentration Ratios	NUREG-5512	NUREG-5512	NUREG-5512
Consumption Values	Grout PA	Grout PA	NUREG-5512
Other Parameters	GENII	GENII	NUREG-5512

A.2.1.1 INTERNAL EXPOSURE FROM INGESTED ACTIVITY

The ingestion dose is calculated from the ingestion dose factor and the quantity of radioactivity consumed in food and water. The ingestion dose is calculated using the general equation below.

$$H_{ing} = (Q_w^h C_w + \sum_p Q_p^h C_p + C_{wr} B_{fish} Q_{fish}) D_{ing}$$

where,

H_{ing} = ingestion dose, in mrem.

Q_w^h = amount of drinking water consumed by the human, in liters per year.

Q_p^h = amount of produce type p the human consumes each year, in kilograms (or liters for milk) per year. Values are listed in Table A.3. Note that p refers to meat and milk as well as vegetables.

C_p = radionuclide concentration in plant or animal type p at the time it is consumed by the human, in curies per kilogram (or curies per liter for milk). Includes an insignificant amount of decay during holdup prior to consumption.

D_{ing} = internal dose factor for ingestion, in mrem per picocurie ingested.

C_{wr} = water concentration from the Columbia River, in curies per liter (Ci/L). These units are chosen to avoid unit conversions in the produce formulas, but pCi/L are actually used in GRTPA.

B_{fish} = bioaccumulation factor in fish, i.e., the ratio of the concentration in the edible parts of the fish to the water concentration in which the fish lives. Units are liters per kilogram.

Q_{fish} = quantity of fish consumed annually, in kilograms.

TABLE A.3 Human Food Consumption (kilograms per year)

Type of Produce		GENII defaults Average	Maximum	Grout PA	NUREG-5512
Leafy	(leafy)	15	30	4.1	11
Other	(protected)	140	220	13.8	51
Fruit	(exposed + misc)	64	330	7.0	46
Cereal	(grain)	72	80	0.0	69
Fish		6.9	40	10.0	10
Meat	(beef & pork)	70	80	22.0	59
Milk		230	270	50.8	100

The concentration of radionuclides in fish are simply the product of the water concentration and the bioaccumulation factor for that element in fish. Values used by GENII and the NUREG are given in Table A.4.

The ingestion dose to the person catching and eating the fish is the product of the annual fish consumption, the nuclide concentration in the fish, and the ingestion dose factor for the nuclide. The selected human intake rate for fish is given on Table A.3.

TABLE A.4 Transfer Factors from NUREG/CR-5512

Name	Dry Plant/Soil Conc Ratio (B_p) Leafy	Root	Fruit	Grain	Beef day/kg (F_b)	Milk day/L (F_m)	Fish (B_f)	Leaching per yr (λ_s)	Distr ml/g (K_d)
H							1	2.5	0
BE	1.0E-2	1.5E-3	1.5E-3	1.5E-3	1.0E-3	9.0E-7	2	2.77E-3	240
C	7.0E-1	7.0E-1	7.0E-1	7.0E-1	4.9E-2	1.1E-2	4600	9.57E-2	6.7
CL	70	70	70	70	8.0E-2	1.5E-2	50	3.39E-1	1.7
K	1.0	5.5E-1	5.5E-1	5.5E-1	2.0E-2	7.0E-3	1000	3.65E-2	18
CO	8.1E-2	4.0E-2	7.0E-3	3.7E-3	2.0E-2	2.0E-3	330	1.11E-2	60
NI	2.8E-1	6.0E-2	6.0E-2	3.0E-2	6.0E-3	1.0E-3	100	1.67E-3	400
SE	2.5E-2	2.5E-2	2.5E-2	2.5E-2	1.5E-2	4.0E-3	170	4.75E-3	140
SR	1.6	8.1E-1	1.7E-1	1.3E-1	3.0E-4	1.5E-3	50	4.37E-2	15
Y	1.5E-2	6.0E-3	6.0E-3	6.0E-3	3.0E-4	2.0E-5	25	3.50E-3	190
ZR	2.0E-3	5.0E-4	5.0E-4	5.0E-4	5.5E-3	3.0E-5	200	1.15E-3	580
NB	2.0E-2	5.0E-3	5.0E-3	5.0E-3	2.5E-1	2.0E-2	200	4.16E-3	160
MO	2.5E-1	6.0E-2	6.0E-2	6.0E-2	6.0E-3	1.5E-3	10	6.49E-2	10
TC	44	1.1	1.5	7.3E-1	8.5E-3	1.0E-2	15	1.82	0.1
PD	1.5E-1	4.0E-2	4.0E-2	4.0E-2	4.0E-3	1.0E-2	10	1.28E-2	52
CD	5.5E-1	1.5E-1	1.5E-1	1.5E-1	5.5E-4	1.0E-3	200	1.66E-2	40
IN	4.0E-3	4.0E-4	4.0E-4	4.0E-4	8.0E-3	1.0E-4	100000	1.71E-3	390
SN	3.0E-2	6.0E-3	6.0E-3	6.0E-3	8.0E-2	1.0E-3	3000	5.12E-3	130
SB	1.3E-4	5.6E-4	8.0E-5	3.0E-2	1.0E-3	1.0E-4	200	1.47E-2	45
TE	2.5E-2	4.0E-3	4.0E-3	4.0E-3	1.5E-2	2.0E-4	400	4.75E-3	140
I	3.4E-3	5.0E-2	5.0E-2	5.0E-2	7.0E-3	1.0E-2	500	5.26E-1	1
CS	1.3E-1	4.9E-2	2.2E-1	2.6E-2	2.0E-2	7.0E-3	2000	2.47E-3	270
BA	1.5E-1	1.5E-2	1.5E-2	1.5E-2	1.5E-4	3.5E-4	200	1.28E-2	52
SM	1.0E-2	4.0E-3	4.0E-3	4.0E-3	5.0E-3	2.0E-5	25	2.77E-3	240
EU	1.0E-2	4.0E-3	4.0E-3	4.0E-3	5.0E-3	2.0E-5	25	2.77E-3	240
GD	1.0E-2	4.0E-3	4.0E-3	4.0E-3	3.5E-3	2.0E-5	25	2.77E-3	240
RE	1.5	3.5E-1	3.5E-1	3.5E-1	8.0E-3	1.5E-3	120	4.67E-2	14
PB	5.8E-3	3.2E-3	9.0E-3	4.7E-3	3.0E-4	2.5E-4	100	2.47E-3	270
BI	3.5E-2	5.0E-3	5.0E-3	5.0E-3	4.0E-4	5.0E-4	15	5.54E-3	120
PO	2.5E-3	9.0E-3	4.0E-4	4.0E-4	3.0E-4	3.5E-4	500	4.44E-3	150
RN	0.0	0.0	0.0	0.0	0.0	0.0	1	2.5	0
FR		(none given)					2000		
RA	7.5E-2	3.2E-3	6.1E-3	1.2E-3	2.5E-4	4.5E-4	70	1.33E-3	500
AC	3.5E-3	3.5E-4	3.5E-4	3.5E-4	2.5E-5	2.0E-5	25	1.59E-3	420
TH	6.6E-3	1.2E-4	8.5E-5	3.4E-5	6.0E-6	5.0E-6	100	2.08E-4	3200
PA	2.5E-3	2.5E-4	2.5E-4	2.5E-4	1.0E-5	5.0E-6	11	1.31E-3	510
U	1.7E-2	1.4E-2	4.0E-3	1.3E-3	2.0E-4	6.0E-4	50	4.37E-2	15
NP	1.3E-2	9.4E-3	1.0E-2	2.7E-3	5.5E-5	5.0E-6	250	1.27E-1	5
PU	3.9E-4	2.0E-4	4.5E-5	2.6E-5	5.0E-7	1.0E-7	250	1.21E-3	550
AM	5.8E-4	4.1E-4	2.5E-4	5.9E-5	3.5E-6	4.0E-7	250	3.51E-4	1900
CM	3.0E-4	2.4E-4	1.5E-5	2.1E-5	3.5E-6	2.0E-5	250	1.67E-4	4000

Note: Animal fresh forage and stored hay are treated as leafy vegetables.

A.2.1.2 INTERNAL EXPOSURE FROM INHALED ACTIVITY

The activity inhaled in the course of a year depends on the volume of air inhaled during the year, as well as the average air concentration. The average air concentration is estimated from an average mass loading in the air. The material in the air is assumed to have the same concentration as the soil. Thus the equation for human dose from inhaled activity is shown below.

$$H_{inh} = M_a \, V_a \, D_{inh} \, W_p^i \, \{1 - Exp[-(\lambda_s+\lambda_r)T_h]\}/(\lambda_s+\lambda_r)$$

where,

H_{inh} = inhalation dose, in mrem.

M_a = average mass concentration in the air during the year, in kilograms per cubic meter. The value assumed for the inhalation dose calculation is 1E-07 kg/m^3.

V_a = daily average breathing rate, in cubic meters per hour. In the GENII model this is 0.972 cubic meters per hour. In the Grout PA model, this is 0.959 cubic meters per hour. Finally, in the NUREG-5512 model, the assumed value is 0.95 cubic meters per hour, the daily average in ICRP 23 (Reference Man).

D_{inh} = internal dose factor for inhalation, in mrem per picocurie inhaled.

W_p^i = soil concentration due to irrigation, in curies per kilogram of soil.

T_h = inhalation time, in hours. This is the number of hours per year that the individual is breathing the average air concentration. The value assumed is 8766 hours per year.

A.2.1.3 EXTERNAL EXPOSURE

The external dose from soil contamination depends on the nuclide, the contamination level and the exposure time. The assumed exposure time for external dose accumulation is 4380 hours.

The GENII program calculates external dose from surface contamination using unit dose factors computed by the EXTDF program. The EXTDF program uses parts of the ISOSHLD program to calculate dose equivalent rates from external sources for user entered geometry data. Values from the GENII library (GRDF.DAT) are shown in Table A.1. These values have been converted from the SI units to mrem/hr per Ci/m².

$$H_{ext} = \rho \; d \; D_{ext} \, W_p^i \, \{1 - Exp[-(\lambda_s+\lambda_r)T_e]\}/(\lambda_s+\lambda_r)$$

where,

H_{ext} = external dose, in mrem.

ρ = bulk density of the soil, in grams per cubic centimeter. Surface soil density is assumed to be 1.5 g/cc.

d = thickness of soil from which nuclides migrate, in centimeters. Assumed to be 15 cm.

T_e = annual average time exposed to the external radiation, 4383 hours.

D_{ext} = external dose rate factor from GENII, in mrem/hr per Ci/m^2.

The GENII external dose factors were recomputed using soil properties, instead of concrete properties, which includes a density of 1.5 g/cm^3, and a slightly improved photon production library. The results of this recalculation are shown in the last column of Table A.1. All dose factors increased by about 15 percent, except Sn-121m, which had been zero previously.

A.2.2 CONSUMPTION VALUES

The calculation of human intakes of radioactivity from the ingestion of food grown on the farm uses transport models found in the GENII program (Napier et al. 1988) which were developed from NRC Regulatory Guide 1.109 (USNRC 1977). However, there are different collections of parameters for the uptake of nuclides by plants and animals, and human dietary consumption rates. Therefore three distinct sets of scenario dose factors were chosen for incorporation into GRTPA. The first two sets use assumptions found in the current revision to the Grout PA (Kincaid et al, 1993). These two models differ only in the internal dose factors used. The DOE model uses the DOE internal dose factors, while the GENII model uses the dose factors provided with the GENII program. The third effective-dose-factor model uses the methods contained in NUREG/CR-5512.

The food consumption rates are shown in Table A.3. The GENII default values shown on this table were not used in the GRTPA effective-dose-factor models, but are shown for comparison purposes. The GRTPA code used the Grout PA consumption values for the GENII and DOE effective-dose-factor models, and the NUREG-5512 consumption values for the NUREG-5512 effective-dose-factor model.

The "Grout PA" column in Table A.3 includes factors which adjust the annual consumption rates for the amount of contaminated produce actually consumed by the individual. For fruit the fraction is 0.20, while for leafy vegetables, grains and other vegetables, the fraction produced locally is 0.25. For milk the fraction is 0.46, while for meat this fraction is 0.44. The "NUREG-5512" column does not include these factors. For the third dose factor model, only two fractions were used, 0.25 for vegetables and 0.5 for animal products (milk and meat).

Note that these locally produced fractions were not used in the river-scenario effective dose factors like they were in the well-water irrigated-farm scenario dose factors. For the river doses, the person was assumed to grow 100 percent of the vegetables, milk and meat they consume locally.

The radionuclide concentrations in the food were determined from the food chain models described below. The first section deals with the accumulation of activity in the soil. The second section describes the transfer of activity from the soil to the plants. This happens in three ways, root uptake, rain splash, and direct deposition. The third section describes the accumulation of activity in milk and meat. The fourth section summarizes the way human doses are computed. The hand calculations were verified by comparison with GENII Version 1.485 computations.

A.2.3 WELL-WATER AND RIVER-WATER CONCENTRATIONS

The PORFLOW program computes the normalized contaminant flux into the groundwater as a function of time. The GRTPA program reads these PORFLOW output tables and computes groundwater concentrations for the particular nuclides and chemicals of concern. The water concentration at the well head onsite is determined by the initial amount of contaminant in the grout vaults, the PORFLOW flux rates, the aquifer flow rate, and the aquifer retardation factor. Average water concentrations projected for the Columbia River also use the annual average river flow rate.

The user supplies information needed to compute the total amount of contaminant which is free to migrate from the grout initially. In particular, the user supplies the nuclide or chemical concentration, the volume contaminated, and the retardation factor for release from the grout. The total free amount is the product of the concentration and volume divided by the retardation factor.

$$\text{Free Amount} = \frac{\text{Grout Conc} * \text{Grout Volume}}{\text{Grout Retardation Factor}}$$

The groundwater concentration apart from radioactive decay is the concentration ratios read from the PORFLOW output file times the total free amount divided by the aquifer flow rate. This is shown in the equation below.

$$\text{Groundwater Conc} = \frac{\text{PORFLOW Conc Ratios} * \text{Free Amount}}{\text{Aquifer Flow Rate}}$$

Two aquifer flow rates must be provided as input to the GRTPA program. The first is the flow rate assuming the well is only used for a domestic water supply. The second aquifer flow rate is for a well which is also used to irrigate a small farm. The larger amount drawn from the aquifer will dilute the groundwater concentration. GRTPA allows the user to include this effect through the use of separate aquifer flow rates for the two exposure scenarios.

In GRTPA, the amount of a contaminant extracted from the aquifer is based on the usage values given in the current revision to the Grout PA, and NUREG/CR-5512 (Kennedy and Strenge, 1992). The non-farming household is assumed to use 91,250 liters annually for drinking and other domestic uses. The farming scenario needs are based on the area irrigated. It is assumed that the total irrigated area is 2 hectare (5 acres), with an annual irrigation water application of 32.4 inches (equivalent to a pumping rate of 45 m^3/day), the Grout PA value. Thus, the irrigated farm uses 1.6×10^7 liters of water annually. This large removal rate results in increased dilution of the groundwater. The aquifer flow rate, for the irrigated farm, used in the Grout PA was 2.9054×10^7 liters/yr which is larger than the pumping rate since the irrigation well is not expected to capture the entire plume.

The contaminant concentration in the Columbia River depends on both the aquifer flow rate and the river flow rate. The drinking water aquifer flow rate is used, since this is closer to the undisturbed aquifer flow rate. The equation used in GRTPA to calculate river concentrations is shown below.

$$\text{River Conc} = \frac{\text{PORFLOW Conc Ratios} * \text{Free Amount}}{\text{Drinking Water Aquifer Flow Rate} + \text{River Flow Rate}}$$

A.2.4 SOIL CONTAMINATION MODEL

The soil concentration decreases with time due to leaching and radioactive decay. Leaching is the process by which radioactive materials migrate from the surface layer of soil into deeper layers below. The driving force behind the leaching process is the application of water to the soil. Leaching is treated as a removal rate constant giving the fraction of the material in the surface layer which is removed per unit of time. It is calculated using the equation shown below.

$$\lambda_s = \frac{P + I - E}{\theta\, d\, (1 + \rho/\theta\, K_d)}$$

where,

λ_s = annual average soil leaching coefficient, fraction removed from a soil layer of thickness "d" per year.

P = total precipitation, in centimeters per year.

I = total irrigation, in centimeters per year.

E = total evapo-transpiration, in centimeters per year.

d = thickness of soil from which nuclides migrate, in centimeters. Assumed to be 15 cm.

ρ = bulk density of the soil, in grams per cubic centimeter. Surface soil density is assumed to be 1.5 g/cc.

θ = volumetric water content of the surface soil, milliliters of water per cubic centimeter of soil. A value of 0.4 ml/cc is assumed.

K_d = distribution coefficient in surface soil for an element, in milliliters per gram.

Values for the leaching parameter are found in the GENII data file named FTRANS.DAT. The values for the radionuclides considered in GRTPA are listed in Table A.4. They are taken from NUREG/CR-5512. The following assumptions were used to relate the λ_s and K_d values: ρ = 1.5 g/cc; θ = 0.4 ml/cc; d = 15 cm; and P+I-E = 15 cm/yr.

In the irrigation situation, the activity accumulates on the plants and in the soil differently. For accumulation on plants by direct deposition, the rate of deposition determines the final concentration in the plants. For determining the soil concentration, which determines the root uptake, inhalation and external doses, the total activity remaining in the surface layer at the end of the year is all that matters. These differences are included in the equations below.

The rate of addition of contamination to the soil is given by the equation shown below. The conversion factor from inches of water applied to the soil to units of liters applied per square meter is shown in the equation.

$$D_p = C_w \, I_p \, (25.4 \text{ L/m}^2\text{/inch}) \, / \, F_i$$

where,

D_p = activity deposition rate due to irrigation of soils growing plant type p, in curies per square meter per year (Ci/yr/m²).

C_w = irrigation water concentration from ground water or the Columbia River, in curies per liter (Ci/L). These units are chosen to avoid unit conversions in the formulas, but pCi/L are actually used in GRTPA.

I_p = inches of irrigation water applied each year to plant type p (values are shown on Tables A.5 and A.6.

F_i = fraction of the year that irrigation water is applied. The value 0.5 is used since the irrigation takes place 6 months per year.

The soil concentration in the irrigation model increases due to the application of water, but the increase is offset by the removal of contaminants by leaching and radioactive decay. The function used to represent this is shown in the equation below. The soil concentration has units of Ci/kg. At the end of the irrigation period, the soil concentration is given by the equation below.

$$W_p^i = \frac{F_i \, D_p \, (1 - \mathrm{Exp}[-(\lambda_s + \lambda_r)T])}{\rho \, d \, (\lambda_s + \lambda_r)}$$

where,

W_p^i = soil concentration due to irrigation, in curies per kilogram of soil.

λ_r = radioactive decay constant, namely, the natural logarithm of 2 divided by the radioactive decay halflife in years.

T = soil leaching time, in years. For GRTPA, the activity was assumed to accumulate in the soil for 50 years. In the GENII program, this time is set to one year internally.

Note that the soil concentration from irrigation depends on the plant type because the amount of irrigation water varies with plant type. Neither the GENII software nor the hand calculated dose factors for GRTPA generate separate leaching factors for each plant type. The main reason for this is that leaching has little effect on the final doses.

Note that the soil concentration from irrigation depends on the plant type because the amount of irrigation water varies with plant type. Neither GENII nor the spreadsheet generate separate leaching factors for each plant type. The main reason for this is that leaching has little effect on the final doses.

The GENII software also considers reduction in the soil concentration due to uptake in plants and their subsequent harvest. This is a smaller effect which was not included in the spreadsheet calculations for the GRTPA program.

TABLE A.5 Dietary Parameters Used in GENII Version 1.485

Type, p	T_v	K_p^f	Y_p	R_p	F_p^{f}*	I_p	T_p^f	T_p^h
Plants Consumed by Humans								
Leafy	1.0	2.9	2.0	0.10	0.440	32.4	90	1
Other	0.1	3.6	2.0	0.25	0.765	32.4	90	5
Fruit	0.1	3.6	3.0	0.18	0.791	32.4	90	5
Grain	0.1	2.9	0.8	0.18	0.341	0.0	90	180
Plants Consumed Beef Cattle								
Forage	1.0	2.9	1.0	0.20	0.440	32.4	45	100
Stored[2]	0.1	2.9	0.8	0.18	0.341	32.4	90	180
Plants Consumed Milk Cows								
Forage	1.0	2.9	1.5	0.20	0.581	32.4	45	0
Stored[2]	0.1	2.9	1.0	0.20	0.440	32.4	90	100

*The values shown were calculated. For direct deposition of nuclides on plants by irrigation water, the interception fraction (F_p^f) is 0.25 for all plant types.

[2]In GENII, the stored feed model uses the translocation factor (T_v) and soil-to-plant concentration ratio (B_p) for grain.

TABLE A.6 Dietary Parameters from NUREG/CR-5512

Type, p	T_v	K_p^f	Y_p	R_p	F_p^{f}*	I_p	T_p^f	T_p^h
Plants Consumed by Humans								
Leafy Veget.	1.0	2.9	2.0	0.20	0.687	30	45	1
Other Veget.	0.1	3.6	4.0	0.25	0.945	30	90	14
Fruit	0.1	3.6	2.0	0.18	0.648	30	90	14
Grain	0.1	2.9	1.0	0.91	0.929	0	90	14
Plants Consumed Beef Cattle								
Fresh Forage	1.0	2.9	1.0	0.22	0.616	30	30	0
Stored hay	1.0	2.9	1.0	0.22	0.616	30	45	0
Stored grain	0.1	2.9	1.0	0.91	0.929	30	90	0
Plants Consumed Milk Cows								
Fresh Forage	1.0	2.9	1.5	0.22	0.616	30	30	0
Stored hay	1.0	2.9	1.5	0.22	0.616	30	45	0
Stored grain	0.1	2.9	1.5	0.91	0.929	30	90	0

*The values shown were calculated. For direct deposition of nuclides on plants by irrigation water, the interception fraction (F_p^f) is 0.25 for all plant types.

A.2.5 CONTAMINANT CONCENTRATION IN VEGETABLES

The calculation of radionuclide concentrations in living plants uses three main routes, (1) root uptake, (2) resuspension to leaves (also called "rain splash"), and (3) direct deposition of irrigation water on foliage. Each of these will be considered separately below. The three uptake routes are then combined to get the total concentration in the vegetables.

GENII includes the effects of radioactive decay between the time a plant type is harvested and when it is consumed. This time period is called the holdup time. It enters the equations for plant concentration as shown below.

$$C_p = (C_p^d + C_p^f + C_p^r)\ \mathrm{Exp}(-\lambda_r\ T_p^h)$$

where,

C_p = radionuclide concentration in plant type p at the time it is consumed, in curies per kilogram.

C_p^d = concentration of a radionuclide in plant type p due to direct deposition of irrigation water. The units for C_p^d are Ci/kg.

C_p^r = concentration of a radionuclide in plant type p due to absorption from the soil through the roots. The units for C_p^r are Ci/kg.

C_p^f = concentration of a radionuclide in plant type p due to foliar deposition from soil resuspension. The units for C_p^f are Ci/kg.

T_p^h = holdup time, i.e. the time between harvest and consumption of plant type p, in days.

It was not necessary to include the effects of holdup due to the long half-lives of the important nuclides. However, for a few nuclides, the production of daughter activity leads to a small increase in certain doses. Since this effect is small, the calculation of holdup was not included in the spreadsheet.

A.2.5.1 ROOT UPTAKE INTO EDIBLE PORTIONS

Root uptake is calculated through a concentration ratio. Only one source is used for the numbers, NUREG/CR-5512, which is extensively documented. These ratios are listed in Table A.4.

Since the concentration ratios are based on dry weights, a dry-to-wet ratio must be applied when calculating the plant concentrations from root uptake. These dry-to-wet ratios are listed below in Tables A.5 and A.6.

The plant concentration due to root uptake into the various types of vegetation is described with the equation shown below. There are four main plant types consumed by humans: leafy vegetables, other vegetables, fruit, and grain. There are also three plant types consumed by animals: fresh forage (grass) and stored feed (hay and grain). Hay is treated as a leafy vegetable.

$$C_p^r = R_p \, B_p \, W_p^i$$

where,

R_p = dry to wet ratio for plant type p.

B_p = soil to plant concentration ratio, as Ci/kg dry weight of vegetables to Ci/kg of soil. See Table A.4 for values.

W_p^i = soil concentration due to irrigation, in curies per kilogram of soil.

A.2.5.2 RESUSPENSION OF SURFACE SOIL TO FOLIAGE (RAIN SPLASH)

The GENII software and the NUREG/CR-5512 differ on the method used to determine the nuclide concentration in plants due to rain splash. The NUREG takes the simple approach of using an effective concentration ratio which is independent of nuclide identity. The GENII software uses the method shown below. This is the method used in all cases to generate food pathway dose factors for GRTPA.

The resuspension of dust by wind, or water drops splashing soil onto the foliage leads to some contamination of the edible portion of the plant. The concentration of the radionuclide in the plant is approximated by the equation shown below.

$$C_p^f = \frac{W_p^i \, R^a \, \rho \, d \, V_d \, T_v \, F_p^f \, \{ \, 1 - \mathrm{Exp}[-(\lambda_w + \lambda_r) T_p^f] \, \}}{Y_p \, (\lambda_w + \lambda_r) \, (1 \text{ day}/86400 \text{ sec})}$$

where,

R^a = resuspension factor, i.e. the ratio of the air concentration to the surface contamination causing it. In GENII this is used to calculate the rain splash onto plants, and has the value 1E-9 per meter.

V_d = diffusion attachment speed, or ground deposition speed, in meters per second. The value 0.001 m/s is assumed for every nuclide.

T_v = translocation factor, i.e. the fraction of what deposits on the foliage that ends up in the edible portions of the plant.

F_p^f = interception fraction for plant type p. The fraction of what falls to the earth that lands on the plant.

Y_p = yield of crop type p, in kilograms per square meter (wet weight). Also called the standing biomass.

λ_w = weathering removal coefficient, 0.0495105 per day, or 18.0713 per year, which corresponds to a 14 day half time.

λ_r = radioactive decay constant, namely, the natural logarithm of 2 divided by the radioactive decay halflife in days.

T_p^f = exposure time of the plant type p to the airborne contamination depositing on the foliage, in days (also called growing period).

The weathering process removes contaminants from the outer surfaces of the plants due to the action of wind and water. In GENII the interception fractions are computed from the standing biomass using the equation shown below.

$$F_p^f = 1 - \mathrm{Exp}(-K_p^f\, Y_p\, R_p)$$

where,

K_p^f = constant used to relate the standing biomass (dry) and the interception fraction for plant type p, in square meters per kilogram.

Values for K_p^f, Y_p, R_p, T_v, and T_p^f are shown in Tables A.5 and A.6.

A.2.5.3 DIRECT DEPOSITION OF IRRIGATION WATER ON FOLIAGE

The previous two avenues by which contamination reaches the edible portions of the plants apply only to activity which is present in the soil. This section discusses direct deposition of contaminants in irrigation water onto the foliage. The concentration in the edible portion of the plants due to direct deposition on foliage is given in the equation below.

$$C_p^d = \frac{D_p\, T_v\, F_p^f \{\, 1 - \mathrm{Exp}[-(\lambda_w + \lambda_r)T_p^f] \,\}}{Y_p\, (\lambda_w + \lambda_r)\ (365\ \text{days}/1\ \text{year})}$$

where,

F_p^f = interception fraction for plant type p. The fraction of what falls to the earth that lands on the plant. The value 0.25 is used for all plant types.

The plant concentration due to direct deposition depends on the rate at which water is applied. In the previous two pathways, root uptake and rain splash, the determining factor is the total amount of water (and thus activity) applied to the soil.

A.2.6 CONTAMINANT CONCENTRATION IN ANIMALS

Radionuclide concentrations in animal products (meat and milk) are derived from two sources, drinking water and feed. In GENII, the cattle used for milk production and meat production are considered separately. Each has its own dietary parameters. These were listed on Tables A.7 and A.8. The nuclide concentrations in drinking water and feed determine the meat or milk concentration through a concentration ratio. These concentration ratios were listed in Table A.6. The equation relating feed and water concentrations to the eventual concentration in meat and milk is shown below.

$$C_q = F_q \left[Q_f^q C_f^q + Q_h^q C_h^q + Q_g^q C_g^q + Q_w^q C_w\right]$$

where,

C_q = radionuclide concentration in beef or milk (q), in curies per kilogram.

F_q = ratio of the equilibrium concentration of a nuclide in the animal product (beef or milk) to the daily intake by cattle. For beef the units are Ci/kg(beef) per Ci/day, while for milk the units are Ci/L(milk) per Ci/day. See Table A.3 for values.

Q_f^q = amount of fresh forage consumed by beef or milk cattle on an average day, in kilograms per day. See Table A.7 for values.

C_f^q = radionuclide concentration in fresh forage (grass) the cattle eat, in curies per kilogram. This includes the decay during holdup.

Q_h^q = amount of stored hay consumed by beef or milk cattle on an average day, in kilograms per day. See Table A.7 for values.

C_h^q = radionuclide concentration in stored hay the cattle eat, in curies per kilogram. This includes the decay during holdup.

Q_g^q = amount of stored grain consumed by beef or milk cattle on an average day, in kilograms per day. See Table A.7 for values.

C_g^q = radionuclide concentration in stored grain the cattle eat, in curies per kilogram. This includes the decay during holdup.

Q_w^q = amount of drinking water consumed by cattle, in liters per day. See Table A.7 for values.

TABLE A.7 Quantities Consumed by Cattle

	Grout PA Beef	Grout PA Milk	NUREG/CR-5512 Beef	NUREG/CR-5512 Milk	Units
Water	50	60	50	60	L/day
Fresh Forage	51	41.25	27	36	kg/day
Stored Hay	0	0	14	29	kg/day
Stored Grain	17	13.75	3	2	kg/day
Total Feed	68	55	44	67	kg/day

A.2.7 RADIOACTIVE DECAY AND SPECIAL RADIONUCLIDE SUBMODELS

A.2.7.1 RADIOACTIVE DECAY AND THE INGROWTH OF PROGENY

Radioactive decay is incorporated using the usual decay equations. Fundamental inputs to the decay equations are the halflives and branching ratios. The values (Kocher 1981) used in GRTPA are listed in Table A.8. Certain nuclides are assumed to be in equilibrium with short-lived progeny nuclides. The half-lives of all progeny nuclides are less than 1 year. The equilibrium amounts of the progeny are shown in parentheses if they are not equal to 1. Dose factors for the progeny nuclides are weighted by the equilibrium amount and added to the dose factors for the parent nuclides.

The activity of any nuclide decreases exponentially with time according to the equation shown below. A_0 is the initial activity, and t is the decay time.

$$A = A_0 e^{-\lambda t}$$

The decay time is computed from the aquifer travel time entered by the user, and the aquifer retardation factor computed from other data supplied by the user. The formula shown below is used to compute travel times. Note that all four variables are assigned values by the user.

$$t = T_p + T_{aq}(1 + \rho/\theta\ K_d)$$

where,

t = total travel time from the grout to the well, or the river. (In the program listing, this is called the retarded time.)

T_p = travel time as output from PORFLOW.

T_{aq} = average water travel time in the aquifer from where the contaminants enter the aquifer to where they enter the well or the river.

ρ = bulk density of the soil, in grams per cubic centimeter.

θ = volumetric water content of soil, milliliters of water per cubic centimeter of soil.

K_d = distribution coefficient in soil for an element, in milliliters per gram.

TABLE A.8 Radionuclides Available in the GRTPA Code

Nuclide	Halflife years	Progeny Combined with Parent for Dose Calculations
H-3	12.28	
Be-10	1.60E+06	
C-14	5730	
Cl-36	301,000	
K-40	1.277E+09	
Co-60	5.271	
Ni-59	75,000	
Ni-63	100.1	
Se-79	65,000	
Sr-90	28.6	Y-90
Zr-93	1.53E+06	
Nb-93m	14.6	
Nb-94	20,300	
Mo-93	3500	
Tc-99	213,000	
Pd-107	6.50E+06	
Cd-113m	13.7	
Sn-121m	55	Sn-121 (0.778)
Sn-126	100,000	Sb-126m, Sb-126 (0.14)
I-129	1.57E+07	
Cs-135	2.30E+06	
Cs-137	30.17	Ba-137m (0.946)
Ba-133	10.5	
Sm-147	1.06E+11	
Sm-151	90	
Eu-150	36	
Eu-152	13.6	
Eu-154	8.8	
Gd-152	1.10E+14	
Re-187	4.7E+10	
Pb-210	22.26	Bi-210, Po-210
Bi-207	33.4	
Po-209	102	
Ra-226	1600	Rn-222, Po-218, Pb-214, Bi-214, Po-214
Ra-228	5.75	Ac-228
Ac-227	21.773	Th-227 (0.9862), Fr-223 (0.0138), Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Tl-207 (0.99727), Po-211 (0.00273)
Th-228	1.9132	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212 (0.6407), Tl-208 (0.3593)
Th-229	7340	Ra-225, Ac-225, Fr-221, At-217, Bi213, Po-213, Tl-209
Th-230	77,000	
Th-232	1.405E+10	
Pa-231	32,764	
U-232	72	
U-233	159,200	
U-234	244,500	
U-235	7.038E+08	Th-231
U-236	2.34E+07	
U-238	4.468E+09	Th-234, Pa-234m, Pa-234 (0.0016)
Np-237	2.14E+06	Pa-233
Pu-238	86.75	
Pu-239	24,131	
Pu-240	6569	
Pu-241	14.4	U-237 (2.45E-05)
Pu-242	375,800	
Pu-244	8.26E+07	U-240, Np-240m, Np-240 (0.0011)
Am-241	432.2	
Am-242m	152	Am-242 (0.99524), Cm-242 (0.827), Np-238 (0.00476)
Am-243	7380	Np-239
Cm-243	28.5	
Cm-244	18.11	
Cm-245	8500	
Cm-246	4750	
Cm-247	1.56E+07	Pu-243
Cm-248	339,000	
Chemical	6.93E+21	(set to a large number to eliminate decay effects)

Some nuclides decay to nuclides which are also radioactive. The activity of the progeny at the nth step in a decay chain is computed using the equations shown below.

$$A_n = A_{10}\left(\prod_{k=1}^{n-1} B_{k,k+1}\right)\left(\prod_{k=2}^{n} \lambda_k\right) DK_n$$

where

$$DK_n = \sum_{k=1}^{n} \frac{e^{-\lambda_k t}}{PD_{1,k,n}}$$

$$PD_{1,k,n} = \prod_{\substack{i=1 \\ i \neq k}}^{n} (\lambda_i - \lambda_k)$$

A_{10} is the initial activity of the first member of the chain. A_n is the activity of the "nth" member of the chain, where n is 2 or more. Initially, the A_n are assumed to be zero. The λ_i are the decay constants for each nuclide. The $B_{k,k+1}$ are the branching ratios for the k to k+1 nuclide decay step. For convenience in writing the denominator, the product of decay constant differences is defined as $PD_{1,k,n}$.

At small decay times, the above decay equation begins to show numerical errors due to the finite size of real numbers in a computer. To compensate for this, the "First Improvement" described in WHC-SA-1282-FP (Rittmann, 1991) was used to improve the numeric precision of the results. This improvement uses the following form for DK_n.

$$DK_n = \sum_{k=1}^{n} \frac{e^{-\lambda_k t} - 1}{PD_{1,k,n}}$$

The advantage of this form is that the function $(e^{-x}-1)$ can be restated readily as a power series as shown below. This polynomial can be evaluated in two ways, as shown below for the case of n=5.

$$\frac{e^{-x} - 1}{-x} = \sum_{k=0}^{n} \frac{(-x)^k}{(k+1)!}$$

$$\frac{e^{-x} - 1}{-x} = 1 - \frac{x}{2} + \frac{x^2}{3!} - \frac{x^3}{4!} + \frac{x^4}{5!} - \frac{x^5}{6!}$$

$$= 1 - \frac{x}{2}\left(1 - \frac{x}{3}\left(1 - \frac{x}{4}\left(1 - \frac{x}{5}\left(1 - \frac{x}{6}\right)\right)\right)\right)$$

The number of terms actually used in the polynomial determines the accuracy of the computed result. A limit is reached when the last term in the polynomial is so small it can no longer be represented in the mantissa used by the computer. The value of this smallest useable number (relative to 1) is one-half raised to a power corresponding to the number of bits in the mantissa. Note that it must be assumed that the computer is able to compute values of the function (e^{-x}-1) to the limit of machine precision; i.e., x is not too small. For a kth order polynomial, the value of x which puts the last term at the mantissa limit is shown in the equation below.

$$x = \left[(k+1)!\ 2^{-bits}\right]^{\frac{1}{k}}$$

This value of x is used to decide whether to use the polynomial expansion or the exponential. At values of x smaller than the above, the polynomial is computed.

In GRTPA, the subroutine which evaluates the exponential (DXPN) uses a variable length polynomial to simplify the estimates. The transition from exponential to polynomial was based on a polynomial of the fifth order. For the 8-byte real variables used on office personal computers, the mantissa length is 53 bits and the transition x is 0.003 with a smallest digit of 2.0E-16. For the 8-byte real variables used on the Hanford Cray computer, the mantissa length is 48 bits and the transition x is 0.006 with a smallest digit of 7.0E-15. The value for the smallest digit is used in the subroutine to decide when to terminate the calculated series. Each term in the sum is computed and compared with the smallest digit. The transition x is chosen to limit the power series to fifth order.

The decay chains used by GRTPA are shown in Table A.9. The short-lived nuclides shown on Table A.8 are not listed, but are always assumed to be present in equilibrium amounts.

TABLE A.9 Radioactive Decay Chains Calculated by GRTPA

$^{93}Mo \longrightarrow {}^{93m}Nb \longleftarrow {}^{93}Zr$

$^{245}Cm \longrightarrow {}^{241}Pu \longrightarrow {}^{241}Am \longrightarrow {}^{237}Np \longrightarrow {}^{233}U \longrightarrow {}^{229}Th$

$^{247}Cm \longrightarrow {}^{243}Am \longrightarrow {}^{239}Pu \longrightarrow {}^{235}U \longrightarrow {}^{231}Pa \longrightarrow {}^{227}Ac$

$^{243}Cm \longrightarrow {}^{239}Pu$

$^{246}Cm \longrightarrow {}^{242}Pu \longrightarrow {}^{238}U \longrightarrow {}^{234}U \longrightarrow {}^{230}Th \longrightarrow {}^{226}Ra \longrightarrow {}^{210}Pb$

$^{242m}Am \xrightarrow{.17218} {}^{242}Pu$

$^{242m}Am \xrightarrow{.82782} {}^{238}Pu \longrightarrow {}^{234}U$

$^{248}Cm \xrightarrow{.917} {}^{244}Pu \longrightarrow {}^{240}Pu \longrightarrow {}^{236}U \longrightarrow {}^{232}Th \longrightarrow {}^{228}Ra \longrightarrow {}^{228}Th$

$^{244}Cm \longrightarrow {}^{240}Pu$

$^{232}U \longrightarrow {}^{228}Th$

To account for soil transport mechanisms which may physically separate different elements in a decay series, the relative amounts of any of the progeny nuclides may be adjusted by means of the Ingrowth Weighting Factors. Normally, the ingrowth weighting factors have the value 1.0 to indicate the progeny amounts are only affected by radioactive decay. Ingrowth weights which differ from 1.0 mean that some additional natural process may be acting to change the amount of the progeny from what would be expected by simple radioactive decay. For example, consider ^{241}Am in the grout matrix. Suppose some natural process was acting to reduce the aquifer concentration of ^{237}Np by a factor of 10. However, the next nuclide in the chain, ^{233}U was not affected by this process. Its concentration would be just what would be computed from the standard decay equations. Furthermore, the amount of ^{229}Th is reduced by a factor of 100 from what it would be from natural radioactive decay. The weighting factors which would be entered in the GRTPA input file would be the following:

Am-241	1.0
Np-237	0.1
U-233	1.0
Th-229	0.01

Note that the weighting factors only apply to the nuclide they accompany. Other nuclides further down the chain are not affected.

Five of the nuclides shown in Table 3 are not found in the GENII library. The GENII dose factors for Ba-133, Eu-150, Gd-152, and Bi-207 were computed by averaging the values from the EPA and DOE. Dose factors for the fifth nuclide, Po-209, are not found in any dose factor collection.

Dose factors for Po-209 were computed by comparison with Po-210. Corrections were made for the energy of the alpha particles emitted, and the decay halflife using the equation shown below.

$$\text{Dose Factor} \propto \frac{E\alpha}{\lambda_{eff}} \left[1 - e^{(-\lambda_{eff} * T_d)} \right]$$

where,

$E\alpha$ = total alpha energy per decay. For Po-209 this is 4.882 Mev per decay, while for Po-210 this is 5.3045 Mev per decay.

λ_{eff} = effective removal constant, which combines both the biological elimination and the radioactive decay of the nuclide.

T_d = dose commitment period used in the dose factor collections shown in Table 3, namely, 50 years.

The biological removal halftime for polonium is 50 days (ICRP 30). The decay halflife of Po-209 is 102 year, thus its λ_{eff} is 0.01388 per day. The decay halflife of Po-210 is 138 days, thus its λ_{eff} is 0.01889 per day. Since these are so large, the dose integration term in brackets is always 1. The ratio of Po-209 to Po-210 internal dose factors is shown below. This ratio was applied to the Po-210 inhalation and ingestion dose factors to arrive at the Po-209 internal dose factors.

$$\frac{\text{Po-209 Dose Factor}}{\text{Po-210 Dose Factor}} = \frac{4.882 \text{ Mev} * 0.01889 \text{ per day}}{5.3045 \text{ Mev} * 0.01388 \text{ per day}} = 1.252$$

A.2.7.2 SPECIAL MODELS FOR TRITIUM AND CARBON

The concentrations of tritium (^3H) in food crops, beef and milk are calculated using a specific activity model based on the concentration of tritium in the irrigation water. This same concentration is assumed to exist in the water present in all food items, since the plants and animals obtain nearly all their water from the contaminated source.

The soil concentration of tritium due to irrigation is based on the assumption that all of the soil moisture is contaminated at the same level as the water.

The concentration of tritium in the air is calculated from the soil contamination, just as it is for all the nuclides. The formula for soil concentration of tritium is shown below.

$$W = \theta_w C_w$$

where,

θ_w = moisture content of soil assumed for the tritium model, in liters per kilogram of soil. Both GENII and the NUREG use the value 0.1 L/kg for this parameter.

The plants derive nearly all of their water from the irrigation applied, thus the tritium concentration in the plant water is the same as the ground water. Since the feed given the cattle as well as the water are contaminated with tritium, all of the water in the animal will have the same tritium concentration as the ground water. Using this simple assumption, the tritium concentration in plants, cows and milk could be calculated from the equation shown below.

$$C_p = F_p^w C_w$$

where,

F_p^w = fraction of water in produce type p, where p refers to meat and milk as well as vegetables. The dry to wet ratio (R_p) can be calculated from this since $R_p = 1 - F_p^w$.

Actually, both GENII and the NUREG considers the organically bound hydrogen in the produce and the animals to be contaminated as well as the water. The specific activity model actually requires that the concentration of tritium in the hydrogen in the water be reproduced throughout the food product. Thus, in GENII, an effective water fraction is added to the actual water fraction, and this is used to calculate results. The adjusted water fraction is shown below. Values for these parameters are shown in Table A.10. Values from NUREG/CR-5512 are also shown for comparison. Note that this table shows water fractions which differ from Tables A.5 and A.6. The values shown on Table 10 are only used in the tritium model.

$$F_p^{w2} = F_p^w + (1 - F_p^w)\, F_p^H \times 9$$

where,

F_p^{w2} = effective water fraction in produce type p, where p refers to meat and milk as well as vegetables. This water fraction includes hydrogen which is not in the form of water. It is used in place of F_p^w.

F_p^H = fraction of hydrogen in the dry produce. The scale factor of 9 converts this to an effective water fraction. The NUREG supplies values of hydrogen fractions in the wet produce, so these parameters are converted into F_p^{W2} values simply by multiplication by 9.

TABLE A.10 Dietary Parameters Used in the Tritium and Carbon-14 Models

Type, p	GENII Tritium & Carbon Models F_p^W	F_p^H	F_p^{W2}	C_p^C	NUREG/CR-5512 F_p^{W2}	C_p^C
Leafy	0.80	0.0625	0.9125	0.09	0.90	0.09
Other	0.80	0.0625	0.9125	0.09	0.90	0.09
Fruit	0.80	0.0625	0.9125	0.09	0.90	0.09
Grain	0.12	0.0625	0.6150	0.4	0.612	0.4
Beef	0.60	0.094	0.9384	0.24	0.90	0.24
Milk	0.88	0.083	0.9696	0.07	0.99	0.07

In GENII, the concentrations of ^{14}C in food crops, beef and milk are calculated using a specific activity model based on the concentration of ^{14}C in the soil. In GENII, the plants are assumed to obtain 90 percent of their carbon from the air, and 10 percent from the soil. The ratio of the ^{14}C concentration in plants to the concentration of carbon in the soil is assumed to be the same in all plant types.

However, based on recent data for ^{14}C uptake in plants (Shepard, 1991), ^{14}C will be treated like the other nuclides described earlier. The specific activity model used by GENII on plants is not used here. Parameters found in NUREG-5512 are applied. The soil leaching coefficient is 0.0957 per year based on a Kd of 6.7 ml/g, as well as the other soil parameters discussed earlier. The concentration ratio for all plant types is assumed to be 0.7, on a dry-weight basis.

Continuing with the NUREG-5512 model for C-14, the transfer of C-14 into beef and milk are computed using a specific activity model. The concentration of ^{14}C in animal products (beef and milk) is computed using the equation shown below. This equation gives the ratio of ^{14}C activity consumed by the cow, to total carbon consumed by the cow. In the specific activity model, this ratio also holds for the carbon in the cow.

$$\frac{C_q^{C14}}{C_q^C} = \frac{Q_f^q C_f^q + Q_h^q C_h^q + Q_g^q C_g^q + Q_w^q C_w}{Q_f^q C_f^C + Q_h^q C_h^C + Q_g^q C_g^C + Q_w^q C_w^C}$$

where,

C_q^{C14} = concentration of ^{14}C in animal product q (beef or milk) consumed by the human, in Ci/kg.

C_q^c = concentration of carbon in animal product q consumed by the human, in kg carbon per kilogram (wet) of animal product q (beef or milk).

C_p^c = concentration of carbon in animal feed type p, in kg carbon per kilogram (wet) of plant. In this equation p refers to fresh forage, stored hay, stored grain, and drinking water. The carbon concentration of drinking water is small enough that it can be ignored.

Using the specific equation above, the effective transfer factor (F_q^{C14}) for the cattle can be computed from the parameters given. The diet-to-animal product transfer factor is the ratio of the equilibrium ^{14}C concentration in the cow to the daily intake of activity.

$$F_q^{C14} = \frac{C_q^c}{Q_f^q\ C_f^c \ + \ Q_h^q\ C_h^c \ + \ Q_g^q\ C_g^c \ + \ Q_w^q\ C_w^c}$$

The effective diet-to-animal transfer factors for ^{14}C was computed from pathway parameters already described. The computed F values for ^{14}C are shown in Table A.6.

A.3 EFFECTIVE DOSE FACTORS

Using the parameters and models, the dose from a unit concentration of a radionuclide in water used for irrigation and drinking was computed using a spreadsheet. Effective dose factors for two of GRTPA's models, GENII and DOE internal dose factors, are shown in Tables A.11 and A.12. All pathways are listed for each of the two internal-dose-factor models used by GRTPA. The pathway with the greatest dose contribution is also identified in the last two columns. If the maximum pathway for the "River" dose factors was the same as the maximum pathway for the "Well" dose factors, then the "River" column was left blank.

The effective dose factors for pathways from the well water and river water are computed differently because of the different produce consumption values assumed for each scenario. The produce columns, veggie, beef and milk, include the consumption fractions described in Section A.2.1.1 (under Grout PA column in Table A.3, which are for the well-water scenario. The effective dose factors for the river-water scenario include higher consumption rates; four times the Veggie column, two times the beef and milk columns. In other words, the maximally-exposed individual living along the river is assumed to consume four times as many contaminated vegetables and twice as much contaminated beef and milk as the maximally-exposed individual living on the small-irrigated farm near a well.

The equation used by GRTPA to compute doses from the effective dose factors and from radionuclide concentrations in irrigation water derived from the PORFLOW output is shown below.

Irrigation Dose = Water Concentration * Effective Dose Factor

A.3.1 EFFECTIVE DOSE FACTORS WITH PRIOR IRRIGATION

The effective dose factors in Tables A.11 and A.12 assume there has been 50 years of prior irrigation of the soil. The effective dose factors were calculated with the Grout PA assumptions (consumption and scenario assumptions) and GENII internal dose factors for Table A.11 and DOE internal dose factors in Table A.12. Effective dose factors with no prior irrigation are listed in Section A.3.2.

TABLE A.11 GRTPA Effective Dose Factors Using GENII Internal Dose Factors
(Units are mrem/yr per pCi/L)

	Dose (mrem/yr) for Water Concentration of 1 pCi/L							Total Doses (EDE)		Max. Pathway	
Nuclide	Inhale	Extern	Veggie	Beef	Milk	Water	Fish	Well	River	Well	River
H-3	2.3E-11	8.7E-15	1.4E-06	1.3E-06	3.0E-06	4.0E-05	6.1E-07	4.58E-05	5.48E-05	Water	
Be-10	5.2E-05	6.3E-05	3.2E-04	1.2E-04	1.4E-07	3.1E-03	9.4E-05	3.62E-03	4.80E-03	Water	
C-14	6.7E-08	2.3E-07	4.2E-04	1.4E-03	6.7E-04	1.4E-03	9.5E-02	3.86E-03	1.02E-01	Beef	Fish
Cl-36	2.0E-07	7.7E-06	1.2E-02	5.8E-02	2.0E-02	1.9E-03	1.5E-03	9.10E-02	2.05E-01	Beef	
K-40	8.6E-07	3.6E-02	5.8E-03	1.7E-02	9.1E-03	1.2E-02	1.8E-01	7.93E-02	3.01E-01	Extern	Fish
Co-60	4.4E-06	1.7E-01	1.9E-03	1.3E-02	1.7E-03	1.7E-02	8.7E-02	2.02E-01	3.10E-01	Extern	
Ni-59	1.9E-07	1.9E-05	2.8E-05	4.5E-05	1.1E-05	1.3E-04	2.1E-04	2.38E-04	5.84E-04	Water	Fish
Ni-63	3.9E-07	2.4E-08	7.2E-05	1.2E-04	2.8E-05	3.7E-04	5.6E-04	5.87E-04	1.51E-03	Water	Fish
Se-79	1.3E-06	7.3E-07	7.4E-04	3.3E-03	1.1E-03	5.5E-03	1.4E-02	1.06E-02	3.14E-02	Water	Fish
Sr-90	9.4E-06	8.7E-04	3.4E-02	1.7E-03	1.3E-02	8.6E-02	6.6E-02	1.37E-01	3.20E-01	Water	Veggie
Zr-93	5.1E-05	4.7E-06	1.1E-04	3.3E-04	1.5E-05	1.1E-03	3.3E-03	1.58E-03	5.51E-03	Water	Fish
Nb-93m	1.7E-06	2.8E-06	3.5E-05	3.2E-03	3.2E-04	3.3E-04	1.0E-03	3.85E-03	8.45E-03	Beef	
Nb-94	5.6E-05	6.8E-01	5.3E-04	4.6E-02	4.8E-03	4.8E-03	1.5E-02	7.32E-01	7.99E-01	Extern	
Mo-93	2.4E-06	1.3E-05	1.2E-04	2.9E-04	8.4E-05	9.0E-04	1.4E-04	1.41E-03	2.28E-03	Water	
Tc-99	1.5E-08	8.4E-08	2.6E-04	8.5E-04	1.5E-03	1.5E-03	3.3E-04	4.09E-03	7.57E-03	Milk	
Pd-107	1.5E-06	4.7E-10	1.5E-05	1.8E-05	6.1E-05	9.8E-05	1.5E-05	1.94E-04	3.33E-04	Water	Milk
Cd-113m	6.9E-05	1.9E-05	1.9E-02	2.8E-03	7.2E-03	1.1E-01	3.3E-01	1.36E-01	5.29E-01	Water	Fish
Sn-121m	1.2E-06	0.0E+00	1.6E-04	4.5E-03	7.3E-05	1.5E-03	6.7E-02	6.24E-03	7.79E-02	Beef	Fish
Sn-126	1.4E-05	9.2E-01	1.5E-03	4.4E-02	7.0E-04	1.4E-02	6.3E-01	9.85E-01	1.66E+00	Extern	
I-129	8.9E-07	3.2E-05	1.7E-02	4.3E-02	7.8E-02	1.6E-01	1.3E+00	3.03E-01	1.73E+00	Water	Fish
Cs-135	6.7E-07	2.1E-06	1.1E-03	4.1E-03	2.0E-03	4.5E-03	1.4E-01	1.17E-02	1.58E-01	Water	Fish
Cs-137	2.7E-06	1.6E-01	5.7E-03	2.7E-02	1.3E-02	3.1E-02	9.6E-01	2.40E-01	1.25E+00	Extern	Fish
Ba-133	2.9E-07	4.3E-02	2.4E-04	1.3E-05	4.0E-05	2.2E-03	6.6E-03	4.55E-02	5.29E-02	Extern	
Sm-147	1.1E-02	0.0E+00	1.3E-02	2.4E-02	1.2E-04	1.2E-01	4.7E-02	1.71E-01	2.81E-01	Water	
Sm-151	3.7E-06	2.3E-07	2.7E-05	4.9E-05	2.5E-07	2.5E-04	9.7E-05	3.34E-04	5.62E-04	Water	
Eu-150	2.6E-05	4.8E-01	4.4E-04	7.9E-04	4.0E-06	4.1E-03	1.6E-03	4.90E-01	4.93E-01	Extern	
Eu-152	1.1E-05	2.0E-01	4.4E-04	8.0E-04	4.1E-06	4.2E-03	1.6E-03	2.03E-01	2.07E-01	Extern	
Eu-154	1.0E-05	1.4E-01	6.5E-04	1.2E-03	6.0E-06	6.3E-03	2.4E-03	1.50E-01	1.56E-01	Extern	
Gd-152	3.6E-02	0.0E+00	1.1E-02	1.4E-02	1.0E-04	1.0E-01	3.9E-02	1.63E-01	2.49E-01	Water	
Re-187	3.5E-09	0.0E+00	3.3E-06	5.8E-06	1.7E-06	9.5E-06	1.7E-05	2.04E-05	5.53E-05	Water	Fish
Pb-210	1.8E-03	2.9E-04	5.1E-01	5.5E-02	5.8E-02	4.8E+00	5.3E+00	5.41E+00	1.23E+01	Water	Fish
Bi-207	1.5E-06	4.3E-01	3.7E-04	5.3E-05	8.5E-05	3.4E-03	7.8E-04	4.39E-01	4.41E-01	Extern	
Po-209	1.5E-03	1.1E-03	1.7E-01	1.8E-02	2.6E-02	1.6E+00	1.2E+01	1.79E+00	1.44E+01	Water	Fish
Ra-226	3.0E-03	8.7E-01	8.9E-02	7.4E-03	1.7E-02	6.3E-01	6.7E-01	1.61E+00	2.57E+00	Extern	
Ra-228	9.0E-03	2.1E-01	5.8E-02	5.3E-03	1.2E-02	5.5E-01	5.9E-01	8.43E-01	1.62E+00	Water	Fish
Ac-227	5.1E-01	8.2E-02	9.7E-01	8.9E-03	9.0E-03	9.4E+00	3.6E+00	1.10E+01	1.75E+01	Water	
Th-228	3.0E-03	4.3E-02	3.9E-02	8.6E-05	9.1E-05	3.8E-01	6.8E-01	4.64E-01	1.26E+00	Water	Fish
Th-229	3.4E-01	1.4E-01	2.6E-01	5.8E-04	6.1E-04	2.5E+00	3.9E+00	3.27E+00	7.90E+00	Water	Fish
Th-230	5.1E-02	9.7E-03	3.7E-02	9.2E-05	1.2E-04	3.5E-01	5.4E-01	4.50E-01	1.10E+00	Water	Fish
Th-232	3.0E-01	1.0E+00	1.9E-01	1.1E-03	2.6E-03	1.8E+00	2.7E+00	3.32E+00	6.64E+00	Water	Fish
Pa-231	7.1E-01	9.6E-02	7.2E-01	2.7E-03	1.8E-03	6.9E+00	1.2E+00	8.48E+00	1.18E+01	Water	
U-232	5.5E-02	2.7E-01	9.3E-02	6.6E-03	2.5E-02	8.6E-01	6.6E-01	1.31E+00	2.27E+00	Water	
U-233	9.0E-03	2.1E-04	2.1E-02	1.5E-03	5.5E-03	1.9E-01	1.5E-01	2.27E-01	4.41E-01	Water	
U-234	8.5E-03	1.2E-05	2.0E-02	1.4E-03	5.4E-03	1.9E-01	1.4E-01	2.22E-01	4.33E-01	Water	
U-235	8.1E-03	1.6E-02	1.9E-02	1.3E-03	5.1E-03	1.8E-01	1.3E-01	2.25E-01	4.23E-01	Water	
U-236	8.0E-03	6.1E-06	1.9E-02	1.4E-03	5.2E-03	1.8E-01	1.4E-01	2.11E-01	4.10E-01	Water	
U-238	7.5E-03	4.7E-03	1.9E-02	1.4E-03	5.2E-03	1.8E-01	1.4E-01	2.16E-01	4.17E-01	Water	
Np-237	1.6E-02	1.8E-02	3.6E-01	7.2E-03	8.3E-04	3.4E+00	1.3E+01	3.84E+00	1.81E+01	Water	Fish
Pu-238	5.0E-02	7.7E-06	2.2E-01	4.0E-05	1.0E-05	2.1E+00	8.0E+00	2.37E+00	1.10E+01	Water	Fish
Pu-239	6.7E-02	2.1E-05	2.4E-01	4.4E-05	1.1E-05	2.3E+00	8.9E+00	2.65E+00	1.23E+01	Water	Fish
Pu-240	6.7E-02	9.3E-06	2.4E-01	4.4E-05	1.1E-05	2.3E+00	8.9E+00	2.64E+00	1.23E+01	Water	Fish
Pu-241	1.9E-03	4.4E-05	4.6E-03	9.8E-07	2.3E-07	4.5E-02	1.7E-01	5.11E-02	2.35E-01	Water	Fish
Pu-242	6.2E-02	7.8E-06	2.2E-01	4.1E-05	1.0E-05	2.2E+00	8.3E+00	2.45E+00	1.14E+01	Water	Fish
Pu-244	6.2E-02	1.8E-01	2.2E-01	4.1E-05	1.0E-05	2.2E+00	8.3E+00	2.64E+00	1.16E+01	Water	Fish
Am-241	6.7E-02	2.1E-03	2.4E-01	3.1E-04	4.6E-05	2.4E+00	9.1E+00	2.69E+00	1.25E+01	Water	Fish
Am-242m	6.9E-02	5.0E-03	2.4E-01	3.1E-04	4.5E-05	2.3E+00	8.9E+00	2.65E+00	1.23E+01	Water	Fish
Am-243	6.9E-02	6.9E-02	2.4E-01	3.1E-04	4.6E-05	2.4E+00	9.1E+00	2.76E+00	1.26E+01	Water	Fish
Cm-243	2.8E-02	2.6E-02	1.7E-01	2.2E-04	1.6E-03	1.6E+00	6.3E+00	1.87E+00	8.65E+00	Water	Fish
Cm-244	1.7E-02	3.4E-06	1.3E-01	1.7E-04	1.3E-03	1.3E+00	5.0E+00	1.47E+00	6.90E+00	Water	Fish
Cm-245	7.3E-02	2.0E-02	2.5E-01	3.2E-04	2.3E-03	2.4E+00	9.3E+00	2.77E+00	1.28E+01	Water	Fish
Cm-246	7.2E-02	6.4E-06	2.5E-01	3.2E-04	2.3E-03	2.4E+00	9.4E+00	2.78E+00	1.29E+01	Water	Fish
Cm-247	6.6E-02	2.1E-01	2.3E-01	3.0E-04	2.2E-03	2.3E+00	8.6E+00	2.76E+00	1.21E+01	Water	Fish
Cm-248	2.6E-01	5.8E-06	9.1E-01	1.2E-03	8.5E-03	8.8E+00	3.4E+01	1.00E+01	4.65E+01	Water	Fish

Note: These dose factors are calculated for 50 years of prior irrigation.

TABLE A.12 GRTPA Effective Dose Factors Using DOE Internal Dose Factors
(Units are mrem/yr per pCi/L)

	Dose (mrem/yr) for Water Concentration of 1 pCi/L							Total Doses (EDE)		Max. Pathway	
Nuclide	Inhale	Extern	Veggie	Beef	Milk	Water	Fish	Well	River	Well	River
H-3	1.6E-11	8.7E-15	1.4E-06	1.3E-06	3.1E-06	4.1E-05	6.3E-07	4.71E-05	5.65E-05	Water	
Be-10	5.1E-05	6.3E-05	2.9E-04	1.1E-04	1.2E-07	2.8E-03	8.4E-05	3.26E-03	4.32E-03	Water	
C-14	6.7E-08	2.3E-07	4.3E-04	1.4E-03	6.8E-04	1.4E-03	9.7E-02	3.92E-03	1.04E-01	Beef	Fish
Cl-36	1.8E-07	7.7E-06	1.2E-02	5.9E-02	2.0E-02	2.0E-03	1.5E-03	9.26E-02	2.08E-01	Beef	
K-40	8.5E-07	3.6E-02	6.1E-03	1.8E-02	9.7E-03	1.2E-02	1.9E-01	8.20E-02	3.18E-01	Extern	Fish
Co-60	3.2E-06	1.7E-01	1.9E-03	1.3E-02	1.7E-03	1.7E-02	8.6E-02	2.01E-01	3.07E-01	Extern	
Ni-59	2.0E-07	1.9E-05	2.8E-05	4.4E-05	1.1E-05	1.3E-04	2.0E-04	2.33E-04	5.70E-04	Water	Fish
Ni-63	3.8E-07	2.4E-08	6.9E-05	1.1E-04	2.7E-05	3.5E-04	5.4E-04	5.62E-04	1.45E-03	Water	Fish
Se-79	1.2E-06	7.3E-07	7.3E-04	3.2E-03	1.1E-03	5.4E-03	1.4E-02	1.05E-02	3.12E-02	Water	Fish
Sr-90	1.0E-05	8.7E-04	3.6E-02	1.8E-03	1.4E-02	9.2E-02	7.0E-02	1.45E-01	3.40E-01	Water	Veggie
Zr-93	5.1E-05	4.7E-06	1.1E-04	3.3E-04	1.6E-05	1.0E-03	3.2E-03	1.56E-03	5.43E-03	Water	Fish
Nb-93m	1.5E-06	2.8E-06	3.7E-05	3.3E-03	3.4E-04	3.5E-04	1.1E-03	4.05E-03	8.87E-03	Beef	
Nb-94	4.7E-05	6.8E-01	3.7E-04	3.3E-02	3.3E-03	3.3E-03	1.0E-02	7.15E-01	7.63E-01	Extern	
Mo-93	2.2E-06	1.3E-05	1.2E-04	2.8E-04	8.0E-05	8.5E-04	1.3E-04	1.34E-03	2.18E-03	Water	
Tc-99	1.3E-08	8.4E-08	1.5E-04	4.9E-04	8.9E-04	8.5E-04	2.0E-04	2.39E-03	4.41E-03	Milk	
Pd-107	1.5E-06	4.7E-10	1.4E-05	1.7E-05	5.7E-05	9.2E-05	1.4E-05	1.81E-04	3.11E-04	Water	Milk
Cd-113m	6.2E-05	1.9E-05	1.7E-02	2.6E-03	6.7E-03	9.8E-02	3.0E-01	1.25E-01	4.87E-01	Water	Fish
Sn-121m	9.6E-07	0.0E+00	1.4E-04	4.1E-03	6.6E-05	1.3E-03	6.0E-02	5.59E-03	6.99E-02	Beef	Fish
Sn-126	1.0E-05	9.2E-01	1.4E-03	3.8E-02	6.1E-04	1.2E-02	5.5E-01	9.77E-01	1.57E+00	Extern	
I-129	1.1E-06	3.2E-05	1.9E-02	4.9E-02	8.8E-02	1.8E-01	1.4E+00	3.39E-01	1.93E+00	Water	Fish
Cs-135	6.6E-07	2.1E-06	1.1E-03	4.3E-03	2.1E-03	4.7E-03	1.4E-01	1.21E-02	1.64E-01	Water	Fish
Cs-137	2.8E-06	1.6E-01	6.0E-03	2.8E-02	1.3E-02	3.3E-02	1.0E+00	2.43E-01	1.30E+00	Extern	Fish
Ba-133	2.6E-07	4.3E-02	2.3E-04	1.3E-05	3.8E-05	2.1E-03	6.4E-03	4.54E-02	5.26E-02	Extern	
Sm-147	1.0E-02	0.0E+00	1.3E-02	2.3E-02	1.2E-04	1.2E-01	4.5E-02	1.64E-01	2.70E-01	Water	
Sm-151	3.5E-06	2.3E-07	2.4E-05	4.3E-05	2.2E-07	2.2E-04	8.5E-05	2.93E-04	4.93E-04	Water	
Eu-150	2.5E-05	4.8E-01	4.3E-04	7.8E-04	3.9E-06	4.1E-03	1.6E-03	4.89E-01	4.93E-01	Extern	
Eu-152	1.2E-05	2.0E-01	4.1E-04	7.5E-04	3.8E-06	3.9E-03	1.5E-03	2.03E-01	2.06E-01	Extern	
Eu-154	9.6E-06	1.4E-01	6.2E-04	1.1E-03	5.7E-06	6.0E-03	2.3E-03	1.50E-01	1.55E-01	Extern	
Gd-152	3.5E-02	0.0E+00	1.1E-02	1.3E-02	9.6E-05	9.8E-02	3.8E-02	1.57E-01	2.40E-01	Water	
Re-187	2.9E-09	0.0E+00	1.9E-06	3.3E-06	9.8E-07	5.4E-06	1.0E-05	1.17E-05	3.16E-05	Water	Fish
Pb-210	1.6E-03	2.9E-04	4.6E-01	5.0E-02	5.3E-02	4.4E+00	4.9E+00	4.96E+00	1.13E+01	Water	Fish
Bi-207	1.2E-06	4.3E-01	3.5E-04	5.0E-05	8.0E-05	3.2E-03	7.4E-04	4.39E-01	4.41E-01	Extern	
Po-209	1.2E-03	1.1E-03	1.4E-01	1.5E-02	2.2E-02	1.3E+00	1.0E+01	1.49E+00	1.20E+01	Water	Fish
Ra-226	2.7E-03	8.7E-01	9.8E-02	8.3E-03	1.9E-02	7.2E-01	7.7E-01	1.72E+00	2.81E+00	Extern	
Ra-228	6.5E-03	2.1E-01	8.2E-02	7.6E-03	1.7E-02	7.9E-01	8.4E-01	1.11E+00	2.22E+00	Water	Fish
Ac-227	5.1E-01	8.2E-02	9.8E-01	9.0E-03	9.2E-03	9.6E+00	3.6E+00	1.11E+01	1.78E+01	Water	
Th-228	2.1E-03	4.3E-02	5.0E-02	1.1E-04	1.2E-04	4.9E-01	8.8E-01	5.88E-01	1.62E+00	Water	Fish
Th-229	3.1E-01	1.4E-01	2.6E-01	5.9E-04	6.2E-04	2.6E+00	3.9E+00	3.28E+00	7.98E+00	Water	Fish
Th-230	5.0E-02	9.7E-03	3.6E-02	9.2E-05	1.2E-04	3.5E-01	5.3E-01	4.43E-01	1.08E+00	Water	Fish
Th-232	2.8E-01	1.0E+00	2.0E-01	1.4E-03	3.6E-03	1.8E+00	2.8E+00	3.34E+00	6.74E+00	Water	Fish
Pa-231	7.1E-01	9.6E-02	7.5E-01	2.8E-03	1.8E-03	7.2E+00	1.2E+00	8.76E+00	1.22E+01	Water	
U-232	5.0E-02	2.7E-01	9.2E-02	6.5E-03	2.5E-02	8.5E-01	6.5E-01	1.29E+00	2.25E+00	Water	
U-233	8.6E-03	2.1E-04	1.9E-02	1.4E-03	5.2E-03	1.8E-01	1.4E-01	2.11E-01	4.11E-01	Water	
U-234	8.2E-03	1.2E-05	1.9E-02	1.3E-03	5.0E-03	1.7E-01	1.3E-01	2.03E-01	3.95E-01	Water	
U-235	7.7E-03	1.6E-02	1.8E-02	1.3E-03	4.8E-03	1.6E-01	1.3E-01	2.11E-01	3.96E-01	Water	
U-236	7.5E-03	6.1E-06	1.8E-02	1.3E-03	4.8E-03	1.6E-01	1.3E-01	1.95E-01	3.80E-01	Water	
U-238	7.5E-03	4.7E-03	1.7E-02	1.2E-03	4.6E-03	1.6E-01	1.2E-01	1.95E-01	3.74E-01	Water	
Np-237	1.2E-02	1.8E-02	2.7E-01	5.3E-03	6.1E-04	2.6E+00	9.8E+00	2.86E+00	1.34E+01	Water	Fish
Pu-238	5.8E-02	7.7E-06	2.6E-01	4.7E-05	1.2E-05	2.5E+00	9.5E+00	2.80E+00	1.31E+01	Water	Fish
Pu-239	7.7E-02	2.1E-05	2.9E-01	5.3E-05	1.3E-05	2.8E+00	1.1E+01	3.18E+00	1.48E+01	Water	Fish
Pu-240	7.7E-02	9.3E-06	2.9E-01	5.3E-05	1.3E-05	2.8E+00	1.1E+01	3.18E+00	1.48E+01	Water	Fish
Pu-241	2.2E-03	4.4E-05	5.8E-03	1.2E-06	2.9E-07	5.6E-02	2.2E-01	6.44E-02	2.97E-01	Water	Fish
Pu-242	7.3E-02	7.8E-06	2.8E-01	5.1E-05	1.3E-05	2.7E+00	1.0E+01	3.03E+00	1.41E+01	Water	Fish
Pu-244	7.3E-02	1.8E-01	2.7E-01	5.0E-05	1.3E-05	2.6E+00	1.0E+01	3.14E+00	1.40E+01	Water	Fish
Am-241	7.8E-02	2.1E-03	3.0E-01	3.9E-04	5.6E-05	2.9E+00	1.1E+01	3.33E+00	1.55E+01	Water	Fish
Am-242m	8.4E-02	5.0E-03	2.9E-01	3.7E-04	5.4E-05	2.8E+00	1.1E+01	3.19E+00	1.48E+01	Water	Fish
Am-243	8.1E-02	6.9E-02	3.0E-01	3.9E-04	5.6E-05	2.9E+00	1.1E+01	3.40E+00	1.56E+01	Water	Fish
Cm-243	3.1E-02	2.6E-02	1.9E-01	2.5E-04	1.8E-03	1.9E+00	7.3E+00	2.15E+00	9.99E+00	Water	Fish
Cm-244	1.9E-02	3.4E-06	1.5E-01	2.0E-04	1.4E-03	1.5E+00	5.8E+00	1.68E+00	7.90E+00	Water	Fish
Cm-245	8.7E-02	2.0E-02	3.0E-01	3.9E-04	2.8E-03	2.9E+00	1.1E+01	3.36E+00	1.55E+01	Water	Fish
Cm-246	8.4E-02	6.4E-06	3.0E-01	3.9E-04	2.8E-03	2.9E+00	1.1E+01	3.34E+00	1.55E+01	Water	Fish
Cm-247	7.7E-02	2.1E-01	2.8E-01	3.6E-04	2.6E-03	2.7E+00	1.0E+01	3.25E+00	1.43E+01	Water	Fish
Cm-248	3.0E-01	5.8E-06	1.1E+00	1.4E-03	1.0E-02	1.0E+01	4.0E+01	1.19E+01	5.51E+01	Water	Fish

Note: These dose factors are calculated for 50 years of prior irrigation.

A.3.2 EFFECTIVE DOSE FACTORS WITHOUT PRIOR IRRIGATION

Tables A.11 and A.12 provide effective dose factors assuming the land is irrigated for 50 years prior to the year in which the individual's dose is computed. The water concentration of each nuclide does not change with the no-prior irrigation assumption. Radioactive decay and leaching are the only processes acting to remove activity from the surface layer of soil. Note that the vegetable, beef, and milk pathway doses have been adjusted for the consumption rates in the irrigated farm scenario. The total river dose factors use larger consumption rates.

For comparison purposes, Tables A.13 and A.14 provide effective dose factors assuming the land is first irrigated in the year of interest; i.e., no prior irrigation. The actual comparison of effective dose factors (EDFs) is made by using ratios of the 50-year values and the 0-year values. Values which are within 25 percent of each other are not shown on the comparison ratio Tables A.15 and A.16.

It is apparent that for most nuclides the ratios are less than 50, which indicates that an equilibrium occurs. Longer periods (than 50 years) of prior irrigation will have no effect on the resulting doses. The few cases where the dose increases by more than a factor of 50 are due to the ingrowth of progeny nuclides.

TABLE A.13 GRTPA Effective Dose Factors with no Prior Irrigation using GENII Internal Dose Factors and Grout PA Assumptions

(Units are mrem/yr per pCi/L)

Nuclide	Dose (mrem/yr) for Water Concentration of 1 pCi/L Inhale	Extern	Veggie	Beef	Milk	Water	Fish	Total Doses (EDE) Well	River	Max. Pathway Well	River
H-3	2.3E-11	8.7E-15	1.4E-06	1.3E-06	3.0E-06	4.0E-05	6.1E-07	4.58E-05	5.48E-05	Water	
Be-10	1.1E-06	1.3E-06	3.1E-04	1.2E-04	1.3E-07	3.1E-03	9.4E-05	3.50E-03	4.65E-03	Water	
C-14	6.2E-09	2.2E-08	1.6E-04	1.1E-03	5.1E-04	1.4E-03	9.5E-02	3.14E-03	1.00E-01	Water	Fish
Cl-36	5.8E-08	2.2E-06	3.5E-03	2.1E-02	6.6E-03	1.9E-03	1.5E-03	3.28E-02	7.22E-02	Beef	
K-40	3.6E-08	1.5E-03	1.4E-03	9.2E-03	4.1E-03	1.2E-02	1.8E-01	2.80E-02	2.24E-01	Water	Fish
Co-60	5.8E-07	2.2E-02	1.8E-03	1.3E-02	1.7E-03	1.7E-02	8.7E-02	5.62E-02	1.64E-01	Extern	Fish
Ni-59	4.0E-09	4.0E-07	1.4E-05	3.1E-05	6.5E-06	1.3E-04	2.1E-04	1.86E-04	4.70E-04	Water	Fish
Ni-63	9.4E-09	5.7E-10	3.9E-05	8.4E-05	1.8E-05	3.7E-04	5.6E-04	5.10E-04	1.29E-03	Water	Fish
Se-79	3.0E-08	1.6E-08	5.6E-04	3.1E-03	1.0E-03	5.5E-03	1.4E-02	1.02E-02	3.02E-02	Water	Fish
Sr-90	6.4E-07	5.9E-05	1.1E-02	1.0E-03	6.7E-03	8.6E-02	6.6E-02	1.05E-01	2.10E-01	Water	
Zr-93	9.8E-07	4.1E-09	1.1E-04	2.6E-04	5.1E-06	1.1E-03	3.3E-03	1.44E-03	5.29E-03	Water	Fish
Nb-93m	9.1E-08	1.5E-07	3.4E-05	3.1E-03	3.2E-04	3.3E-04	1.0E-03	3.80E-03	8.35E-03	Beef	
Nb-94	1.2E-06	1.5E-02	4.9E-04	4.5E-02	4.5E-03	4.8E-03	1.5E-02	6.94E-02	1.35E-01	Beef	
Mo-93	8.8E-08	7.4E-07	9.4E-05	2.4E-04	6.9E-05	9.0E-04	1.4E-04	1.30E-03	2.02E-03	Water	
Tc-99	1.3E-08	7.0E-08	2.4E-04	7.9E-04	1.4E-03	1.5E-03	3.3E-04	3.88E-03	7.11E-03	Water	Milk
Pd-107	4.0E-08	1.3E-11	1.0E-05	1.5E-05	4.7E-05	9.8E-05	1.5E-05	1.71E-04	2.78E-04	Water	
Cd-113m	4.6E-06	1.3E-06	1.1E-02	2.3E-03	5.2E-03	1.1E-01	3.3E-01	1.26E-01	4.94E-01	Water	Fish
Sn-121m	3.6E-08	0.0E+00	1.5E-04	4.4E-03	6.9E-05	1.5E-03	6.7E-02	6.07E-03	7.76E-02	Beef	Fish
Sn-126	3.1E-07	2.1E-02	1.4E-03	4.2E-02	6.6E-04	1.4E-02	6.3E-01	7.80E-02	7.54E-01	Beef	Fish
I-129	3.7E-07	1.3E-05	1.7E-02	4.3E-02	7.8E-02	1.6E-01	1.3E+00	3.02E-01	1.72E+00	Water	Fish
Cs-135	1.4E-08	4.4E-08	4.7E-04	3.4E-03	1.5E-03	4.5E-03	1.4E-01	9.88E-03	1.53E-01	Water	Fish
Cs-137	9.2E-08	5.6E-03	3.3E-03	2.4E-02	1.1E-02	3.1E-02	9.6E-01	7.47E-02	1.08E+00	Water	Fish
Ba-133	2.2E-08	3.3E-03	2.2E-04	1.2E-05	3.6E-05	2.2E-03	6.6E-03	5.75E-03	1.31E-02	Extern	Fish
Sm-147	2.3E-04	0.0E+00	1.3E-02	2.3E-02	1.2E-04	1.2E-01	4.7E-02	1.59E-01	2.66E-01	Water	
Sm-151	9.3E-08	5.8E-09	2.6E-05	4.8E-05	2.4E-07	2.5E-04	9.7E-05	3.28E-04	5.52E-04	Water	
Eu-150	8.3E-07	1.6E-02	4.2E-04	7.8E-04	3.9E-06	4.1E-03	1.6E-03	2.09E-02	2.46E-02	Extern	
Eu-152	6.4E-07	1.1E-02	4.3E-04	8.0E-04	4.0E-06	4.2E-03	1.6E-03	1.65E-02	2.03E-02	Extern	
Eu-154	8.2E-07	1.1E-02	6.4E-04	1.2E-03	6.0E-06	6.3E-03	2.4E-03	1.94E-02	2.49E-02	Extern	
Gd-152	7.5E-04	0.0E+00	1.0E-02	1.4E-02	9.8E-05	1.0E-01	3.9E-02	1.27E-01	2.11E-01	Water	
Re-187	1.8E-10	0.0E+00	1.1E-06	3.0E-06	7.3E-07	9.5E-06	1.7E-05	1.43E-05	3.88E-05	Water	Fish
Pb-210	7.2E-05	1.2E-05	4.9E-01	5.4E-02	5.7E-02	4.8E+00	5.3E+00	5.39E+00	1.23E+01	Water	Fish
Bi-207	5.2E-08	1.5E-02	3.5E-04	5.1E-05	8.1E-05	3.4E-03	7.8E-04	1.92E-02	2.11E-02	Extern	
Po-209	3.7E-05	2.8E-05	1.6E-01	1.8E-02	2.6E-02	1.6E+00	1.2E+01	1.78E+00	1.43E+01	Water	Fish
Ra-226	2.7E-05	1.8E-02	6.4E-02	6.3E-03	1.4E-02	6.3E-01	6.7E-01	7.28E-01	1.61E+00	Water	Fish
Ra-228	1.8E-04	1.1E-02	5.7E-02	5.2E-03	1.2E-02	5.5E-01	5.9E-01	6.38E-01	1.41E+00	Water	Fish
Ac-227	2.1E-02	3.3E-03	9.6E-01	8.9E-03	9.0E-03	9.4E+00	3.6E+00	1.04E+01	1.70E+01	Water	
Th-228	9.1E-04	1.3E-02	3.9E-02	8.6E-05	9.1E-05	3.8E-01	6.8E-01	4.32E-01	1.23E+00	Water	Fish
Th-229	6.7E-03	2.8E-03	2.6E-01	5.7E-04	6.0E-04	2.5E+00	3.9E+00	2.79E+00	7.42E+00	Water	Fish
Th-230	1.0E-03	5.1E-06	3.6E-02	8.0E-05	8.6E-05	3.5E-01	5.4E-01	3.90E-01	1.04E+00	Water	Fish
Th-232	5.1E-03	6.6E-04	1.8E-01	5.5E-04	7.6E-04	1.8E+00	2.7E+00	1.99E+00	5.28E+00	Water	Fish
Pa-231	4.3E-03	3.3E-04	7.1E-01	2.7E-03	1.7E-03	6.9E+00	1.2E+00	7.66E+00	1.10E+01	Water	
U-232	2.2E-03	2.5E-03	8.8E-02	6.5E-03	2.5E-02	8.6E-01	6.6E-01	9.82E-01	1.93E+00	Water	
U-233	4.1E-04	1.6E-06	1.9E-02	1.4E-03	5.4E-03	1.9E-01	1.5E-01	2.17E-01	4.27E-01	Water	
U-234	4.1E-04	5.6E-07	1.9E-02	1.4E-03	5.3E-03	1.9E-01	1.4E-01	2.13E-01	4.20E-01	Water	
U-235	3.8E-04	7.5E-04	1.8E-02	1.3E-03	5.0E-03	1.8E-01	1.3E-01	2.01E-01	3.95E-01	Water	
U-236	3.8E-04	2.9E-07	1.8E-02	1.3E-03	5.1E-03	1.8E-01	1.4E-01	2.02E-01	3.98E-01	Water	
U-238	3.6E-04	2.2E-04	1.8E-02	1.3E-03	5.1E-03	1.8E-01	1.4E-01	2.03E-01	4.01E-01	Water	
Np-237	1.9E-03	2.1E-03	3.5E-01	7.1E-03	8.2E-04	3.4E+00	1.3E+01	3.80E+00	1.80E+01	Water	Fish
Pu-238	1.2E-03	1.9E-07	2.2E-01	4.0E-05	1.0E-05	2.1E+00	8.0E+00	2.32E+00	1.10E+01	Water	Fish
Pu-239	1.4E-03	4.2E-07	2.4E-01	4.4E-05	1.1E-05	2.3E+00	8.9E+00	2.58E+00	1.22E+01	Water	Fish
Pu-240	1.3E-03	1.9E-07	2.4E-01	4.4E-05	1.1E-05	2.3E+00	8.9E+00	2.57E+00	1.22E+01	Water	Fish
Pu-241	2.6E-05	5.6E-08	4.6E-03	9.6E-07	2.3E-07	4.5E-02	1.7E-01	4.92E-02	2.33E-01	Water	Fish
Pu-242	1.3E-03	1.6E-07	2.2E-01	4.1E-05	1.0E-05	2.2E+00	8.3E+00	2.39E+00	1.13E+01	Water	Fish
Pu-244	1.3E-03	3.7E-03	2.2E-01	4.1E-05	1.0E-05	2.2E+00	8.3E+00	2.40E+00	1.14E+01	Water	Fish
Am-241	1.4E-03	4.3E-05	2.4E-01	3.1E-04	4.5E-05	2.4E+00	9.1E+00	2.62E+00	1.24E+01	Water	Fish
Am-242m	1.4E-03	1.1E-04	2.4E-01	3.1E-04	4.5E-05	2.3E+00	8.9E+00	2.58E+00	1.22E+01	Water	Fish
Am-243	1.4E-03	1.4E-03	2.4E-01	3.1E-04	4.5E-05	2.4E+00	9.1E+00	2.62E+00	1.24E+01	Water	Fish
Cm-243	9.5E-04	8.8E-04	1.7E-01	2.2E-04	1.6E-03	1.6E+00	6.3E+00	1.82E+00	8.60E+00	Water	Fish
Cm-244	7.6E-04	1.5E-07	1.3E-01	1.7E-04	1.3E-03	1.3E+00	5.0E+00	1.45E+00	6.88E+00	Water	Fish
Cm-245	1.4E-03	4.0E-04	2.5E-01	3.2E-04	2.3E-03	2.4E+00	9.3E+00	2.68E+00	1.27E+01	Water	Fish
Cm-246	1.4E-03	1.3E-07	2.5E-01	3.2E-04	2.3E-03	2.4E+00	9.4E+00	2.70E+00	1.28E+01	Water	Fish
Cm-247	1.3E-03	4.1E-03	2.3E-01	3.0E-04	2.2E-03	2.3E+00	8.6E+00	2.49E+00	1.18E+01	Water	Fish
Cm-248	5.1E-03	1.1E-07	9.0E-01	1.2E-03	8.4E-03	8.8E+00	3.4E+01	9.76E+00	4.62E+01	Water	Fish

TABLE A.14 GRTPA Effective Dose Factors with no Prior Irrigation using DOE Internal Dose Factors and Grout PA Assumptions

(Units are mrem/yr per pCi/L)

	Dose (mrem/yr) for Water Concentration of 1 pCi/L							Total Doses (EDE)		Max. Pathway	
Nuclide	Inhale	Extern	Veggie	Beef	Milk	Water	Fish	Well	River	Well	River
H-3	1.6E-11	8.7E-15	1.4E-06	1.3E-06	3.1E-06	4.1E-05	6.3E-07	4.71E-05	5.65E-05	Water	
Be-10	1.1E-06	1.3E-06	2.8E-04	1.0E-04	1.2E-07	2.8E-03	8.4E-05	3.14E-03	4.17E-03	Water	
C-14	6.2E-09	2.2E-08	1.7E-04	1.1E-03	5.2E-04	1.4E-03	9.7E-02	3.18E-03	1.02E-01	Water	Fish
Cl-36	5.2E-08	2.2E-06	3.6E-03	2.1E-02	6.7E-03	2.0E-03	1.5E-03	3.34E-02	7.34E-02	Beef	
K-40	3.6E-08	1.5E-03	1.5E-03	9.8E-03	4.4E-03	1.2E-02	1.9E-01	2.96E-02	2.38E-01	Water	Fish
Co-60	4.3E-07	2.2E-02	1.8E-03	1.3E-02	1.6E-03	1.7E-02	8.6E-02	5.55E-02	1.61E-01	Extern	Fish
Ni-59	4.0E-09	4.0E-07	1.4E-05	3.0E-05	6.3E-06	1.3E-04	2.0E-04	1.81E-04	4.59E-04	Water	Fish
Ni-63	9.2E-09	5.7E-10	3.7E-05	8.1E-05	1.7E-05	3.5E-04	5.4E-04	4.89E-04	1.24E-03	Water	Fish
Se-79	2.7E-08	1.6E-08	5.6E-04	3.1E-03	1.0E-03	5.4E-03	1.4E-02	1.01E-02	3.00E-02	Water	Fish
Sr-90	7.1E-07	5.9E-05	1.1E-02	1.1E-03	7.1E-03	9.2E-02	7.0E-02	1.11E-01	2.23E-01	Water	
Zr-93	9.9E-07	4.1E-09	1.1E-04	2.5E-04	5.2E-06	1.0E-03	3.2E-03	1.42E-03	5.20E-03	Water	Fish
Nb-93m	8.4E-08	1.5E-07	3.6E-05	3.3E-03	3.3E-04	3.5E-04	1.1E-03	3.99E-03	8.77E-03	Beef	
Nb-94	1.0E-06	1.5E-02	3.4E-04	3.2E-02	3.2E-03	3.3E-03	1.0E-02	5.31E-02	9.91E-02	Beef	
Mo-93	8.5E-08	7.4E-07	8.9E-05	2.3E-04	6.5E-05	8.5E-04	1.3E-04	1.24E-03	1.93E-03	Water	
Tc-99	1.1E-08	7.0E-08	1.4E-04	4.6E-04	8.1E-04	8.5E-04	2.0E-04	2.26E-03	4.14E-03	Water	Milk
Pd-107	4.0E-08	1.3E-11	9.5E-06	1.4E-05	4.4E-05	9.2E-05	1.4E-05	1.59E-04	2.60E-04	Water	
Cd-113m	4.2E-06	1.3E-06	1.1E-02	2.1E-03	4.8E-03	9.8E-02	3.0E-01	1.16E-01	4.54E-01	Water	Fish
Sn-121m	2.8E-08	0.0E+00	1.3E-04	3.9E-03	6.2E-05	1.3E-03	6.0E-02	5.44E-03	6.96E-02	Beef	Fish
Sn-126	2.3E-07	2.1E-02	1.2E-03	3.6E-02	5.7E-04	1.2E-02	5.5E-01	7.07E-02	6.61E-01	Beef	Fish
I-129	4.3E-07	1.3E-05	1.9E-02	4.8E-02	8.8E-02	1.8E-01	1.4E+00	3.38E-01	1.93E+00	Water	Fish
Cs-135	1.4E-08	4.4E-08	4.9E-04	3.5E-03	1.6E-03	4.7E-03	1.4E-01	1.02E-02	1.59E-01	Water	Fish
Cs-137	9.7E-08	5.6E-03	3.4E-03	2.5E-02	1.1E-02	3.3E-02	1.0E+00	7.77E-02	1.12E+00	Water	Fish
Ba-133	2.0E-08	3.3E-03	2.2E-04	1.2E-05	3.5E-05	2.1E-03	6.4E-03	5.68E-03	1.28E-02	Extern	Fish
Sm-147	2.2E-04	0.0E+00	1.2E-02	2.2E-02	1.1E-04	1.2E-01	4.5E-02	1.53E-01	2.56E-01	Water	
Sm-151	8.9E-08	5.8E-09	2.3E-05	4.2E-05	2.1E-07	2.2E-04	8.5E-05	2.88E-04	4.84E-04	Water	
Eu-150	8.2E-07	1.6E-02	4.2E-04	7.7E-04	3.9E-06	4.1E-03	1.6E-03	2.09E-02	2.44E-02	Extern	
Eu-152	6.6E-07	1.1E-02	4.0E-04	7.4E-04	3.8E-06	3.9E-03	1.5E-03	1.61E-02	1.96E-02	Extern	
Eu-154	7.7E-07	1.1E-02	6.1E-04	1.1E-03	5.7E-06	6.0E-03	2.3E-03	1.90E-02	2.42E-02	Extern	
Gd-152	7.4E-04	0.0E+00	1.0E-02	1.3E-02	9.4E-05	9.8E-02	3.8E-02	1.22E-01	2.03E-01	Water	
Re-187	1.5E-10	0.0E+00	6.2E-07	1.7E-06	4.2E-07	5.4E-06	1.0E-05	8.21E-06	2.22E-05	Water	Fish
Pb-210	6.4E-05	1.2E-05	4.5E-01	5.0E-02	5.2E-02	4.4E+00	4.9E+00	4.94E+00	1.13E+01	Water	Fish
Bi-207	4.2E-08	1.5E-02	3.3E-04	4.9E-05	7.7E-05	3.2E-03	7.4E-04	1.89E-02	2.08E-02	Extern	
Po-209	3.1E-05	2.8E-05	1.3E-01	1.5E-02	2.2E-02	1.3E+00	1.0E+01	1.48E+00	1.19E+01	Water	Fish
Ra-226	2.5E-05	1.8E-02	7.4E-02	7.2E-03	1.6E-02	7.2E-01	7.7E-01	8.35E-01	1.85E+00	Water	Fish
Ra-228	1.3E-04	1.1E-02	8.1E-02	7.4E-03	1.7E-02	7.9E-01	8.4E-01	9.03E-01	2.01E+00	Water	Fish
Ac-227	2.0E-02	3.3E-03	9.8E-01	9.0E-03	9.1E-03	9.6E+00	3.6E+00	1.06E+01	1.72E+01	Water	
Th-228	6.5E-04	1.3E-02	5.0E-02	1.1E-04	1.2E-04	4.9E-01	8.8E-01	5.57E-01	1.59E+00	Water	Fish
Th-229	6.2E-03	2.8E-03	2.6E-01	5.8E-04	6.1E-04	2.6E+00	3.9E+00	2.83E+00	7.52E+00	Water	Fish
Th-230	9.8E-04	5.1E-06	3.6E-02	7.9E-05	8.4E-05	3.5E-01	5.3E-01	3.84E-01	1.02E+00	Water	Fish
Th-232	4.9E-03	6.6E-04	1.9E-01	6.2E-04	9.1E-04	1.8E+00	2.8E+00	2.03E+00	5.39E+00	Water	Fish
Pa-231	4.3E-03	3.3E-04	7.4E-01	2.8E-03	1.8E-03	7.2E+00	1.2E+00	7.95E+00	1.14E+01	Water	
U-232	2.1E-03	2.5E-03	8.7E-02	6.4E-03	2.4E-02	8.5E-01	6.5E-01	9.74E-01	1.92E+00	Water	
U-233	3.9E-04	1.6E-06	1.8E-02	1.3E-03	5.1E-03	1.8E-01	1.4E-01	2.02E-01	3.98E-01	Water	
U-234	3.9E-04	5.6E-07	1.7E-02	1.3E-03	4.9E-03	1.7E-01	1.3E-01	1.94E-01	3.83E-01	Water	
U-235	3.6E-04	7.5E-04	1.7E-02	1.2E-03	4.7E-03	1.6E-01	1.3E-01	1.88E-01	3.69E-01	Water	
U-236	3.6E-04	2.9E-07	1.7E-02	1.2E-03	4.7E-03	1.6E-01	1.3E-01	1.87E-01	3.68E-01	Water	
U-238	3.6E-04	2.2E-04	1.6E-02	1.2E-03	4.6E-03	1.6E-01	1.2E-01	1.82E-01	3.58E-01	Water	
Np-237	1.4E-03	2.1E-03	2.6E-01	5.3E-03	6.1E-04	2.6E+00	9.8E+00	2.83E+00	1.34E+01	Water	Fish
Pu-238	1.4E-03	1.9E-07	2.5E-01	4.7E-05	1.2E-05	2.5E+00	9.5E+00	2.75E+00	1.30E+01	Water	Fish
Pu-239	1.6E-03	4.2E-07	2.9E-01	5.3E-05	1.3E-05	2.8E+00	1.1E+01	3.11E+00	1.47E+01	Water	Fish
Pu-240	1.6E-03	1.9E-07	2.9E-01	5.3E-05	1.3E-05	2.8E+00	1.1E+01	3.11E+00	1.47E+01	Water	Fish
Pu-241	3.1E-05	5.6E-08	5.8E-03	1.2E-06	2.9E-07	5.6E-02	2.2E-01	6.21E-02	2.94E-01	Water	Fish
Pu-242	1.5E-03	1.6E-07	2.7E-01	5.1E-05	1.3E-05	2.7E+00	1.0E+01	2.96E+00	1.40E+01	Water	Fish
Pu-244	1.5E-03	3.7E-03	2.7E-01	4.9E-05	1.3E-05	2.6E+00	1.0E+01	2.89E+00	1.37E+01	Water	Fish
Am-241	1.6E-03	4.3E-05	3.0E-01	3.9E-04	5.6E-05	2.9E+00	1.1E+01	3.25E+00	1.54E+01	Water	Fish
Am-242m	1.6E-03	1.1E-04	2.9E-01	3.7E-04	5.4E-05	2.8E+00	1.1E+01	3.10E+00	1.47E+01	Water	Fish
Am-243	1.6E-03	1.4E-03	3.0E-01	3.9E-04	5.6E-05	2.9E+00	1.1E+01	3.25E+00	1.54E+01	Water	Fish
Cm-243	1.1E-03	8.8E-04	1.9E-01	2.5E-04	1.8E-03	1.9E+00	7.3E+00	2.10E+00	9.93E+00	Water	Fish
Cm-244	8.1E-04	1.5E-07	1.5E-01	2.0E-04	1.4E-03	1.5E+00	5.8E+00	1.66E+00	7.88E+00	Water	Fish
Cm-245	1.7E-03	4.0E-04	3.0E-01	3.9E-04	2.8E-03	2.9E+00	1.1E+01	3.25E+00	1.54E+01	Water	Fish
Cm-246	1.7E-03	1.3E-07	3.0E-01	3.9E-04	2.8E-03	2.9E+00	1.1E+01	3.25E+00	1.54E+01	Water	Fish
Cm-247	1.5E-03	4.1E-03	2.7E-01	3.5E-04	2.6E-03	2.7E+00	1.0E+01	2.97E+00	1.40E+01	Water	Fish
Cm-248	5.8E-03	1.1E-07	1.1E+00	1.4E-03	1.0E-02	1.0E+01	4.0E+01	1.16E+01	5.48E+01	Water	Fish

TABLE A.15 Ratios of 50-Year EDFs to No-Prior EDFs using GENII Internal Dose Factors and Grout PA Assumptions
(Ratios less than 1.25 are not shown.)

Nuclide	Ratios of Individual Pathway Doses					Ratio of Total	
	Inhale	Extern	Veggie	Beef	Milk	Well	River
H-3							
Be-10	47.6	47.6					
C-14	10.9	10.9	2.6	1.3	1.3		
Cl-36	3.5	3.5	3.3	2.8	3.0	2.8	2.8
K-40	23.6	23.6	4.1	1.8	2.2	2.8	1.3
Co-60	7.5	7.5				3.6	1.9
Ni-59	48.9	48.9	2.0	1.5	1.7	1.3	
Ni-63	41.5	41.5	1.9	1.4	1.6		
Se-79	45.4	45.4	1.3				
Sr-90	14.8	14.8	3.2	1.7	2.0	1.3	1.5
Zr-93	52.3	1152.1		1.3	3.0		
Nb-93m	18.4	18.4					
Nb-94	46.0	46.0				10.6	5.9
Mo-93	26.8	17.6	1.3				
Tc-99							
Pd-107	37.7	37.7	1.5		1.3		
Cd-113m	14.9	14.9	1.7	1.3	1.4		
Sn-121m	33.9						
Sn-126	45.0	45.0				12.6	2.2
I-129	2.4	2.4					
Cs-135	48.0	48.0	2.3		1.3		
Cs-137	28.9	28.9	1.7			3.2	
Ba-133	13.0	13.0				7.9	4.0
Sm-147	47.6						
Sm-151	39.7	39.7					
Eu-150	31.0	31.0				23.4	20.1
Eu-152	17.9	17.9				12.3	10.2
Eu-154	12.6	12.6				7.7	6.3
Gd-152	47.6					1.3	
Re-187	19.9		3.0	1.9	2.3	1.4	1.4
Pb-210	24.8	24.8					
Bi-207	28.5	28.5				22.9	20.9
Po-209	39.0	39.0					
Ra-226	112.1	48.8	1.4			2.2	1.6
Ra-228	49.7	18.0				1.3	
Ac-227	24.9	24.9					
Th-228	3.3	3.3					
Th-229	50.6	50.6					
Th-230	50.8	1916.7			1.4		
Th-232	59.1	1548.7		2.0	3.5	1.7	1.3
Pa-231	164.4	287.6					
U-232	25.1	109.3				1.3	
U-233	21.9	137.6					
U-234	20.9	20.9					
U-235	21.4	20.9					
U-236	20.9	20.9					
U-238	20.9	20.9					
Np-237	8.4	8.4					
Pu-238	41.0	41.0					
Pu-239	49.5	49.5					
Pu-240	49.4	49.4					
Pu-241	72.1	786.1					
Pu-242	49.5	49.5					
Pu-244	49.6	49.5					
Am-241	48.6	48.6					
Am-242m	51.2	45.2					
Am-243	50.5	50.4					
Cm-243	29.5	29.5					
Cm-244	22.9	22.9					
Cm-245	52.2	50.8					
Cm-246	50.6	50.6					
Cm-247	50.9	50.8					
Cm-248	50.8	50.8					

TABLE A.16 Ratios of 50-Year EDFs to No-prior EDFs using DOE Internal Dose Factors and Grout PA Assumptions

(Ratios less than 1.25 are not shown.)

	Ratios of Individual Pathway Doses					Ratio of Total	
Nuclide	Inhale	Extern	Veggie	Beef	Milk	Well	River
H-3							
Be-10	47.6	47.6					
C-14	10.9	10.9	2.6	1.3	1.3		
Cl-36	3.5	3.5	3.3	2.8	3.0	2.8	2.8
K-40	23.6	23.6	4.1	1.8	2.2	2.8	1.3
Co-60	7.5	7.5				3.6	1.9
Ni-59	48.9	48.9	2.0	1.5	1.7	1.3	
Ni-63	41.5	41.5	1.9	1.4	1.6		
Se-79	45.4	45.4	1.3				
Sr-90	14.8	14.8	3.2	1.7	2.0	1.3	1.5
Zr-93	52.1	1152.1		1.3	3.1		
Nb-93m	18.4	18.4					
Nb-94	46.0	46.0				13.5	7.7
Mo-93	26.2	17.6	1.3				
Tc-99							
Pd-107	37.7	37.7	1.5		1.3		
Cd-113m	14.9	14.9	1.7	1.3	1.4		
Sn-121m	33.9						
Sn-126	45.0	45.0				13.8	2.4
I-129	2.4	2.4					
Cs-135	48.0	48.0	2.3		1.3		
Cs-137	28.9	28.9	1.7			3.1	
Ba-133	13.0	13.0				8.0	4.1
Sm-147	47.6						
Sm-151	39.7	39.7					
Eu-150	31.0	31.0				23.4	20.2
Eu-152	17.9	17.9				12.6	10.5
Eu-154	12.6	12.6				7.9	6.4
Gd-152	47.6					1.3	
Re-187	19.9		3.0	1.9	2.3	1.4	1.4
Pb-210	24.8	24.8					
Bi-207	28.5	28.5				23.1	21.2
Po-209	39.0	39.0					
Ra-226	108.3	48.8	1.3			2.1	1.5
Ra-228	48.8	18.0					
Ac-227	24.9	24.9					
Th-228	3.3	3.3					
Th-229	50.6	50.6					
Th-230	50.8	1916.7			1.4		
Th-232	57.0	1548.7		2.3	3.9	1.6	1.3
Pa-231	163.5	287.6					
U-232	23.3	109.3				1.3	
U-233	21.9	137.6					
U-234	20.9	20.9					
U-235	21.4	20.9					
U-236	20.9	20.9					
U-238	20.9	20.9					
Np-237	8.4	8.4					
Pu-238	41.0	41.0					
Pu-239	49.5	49.5					
Pu-240	49.4	49.4					
Pu-241	70.1	786.1					
Pu-242	49.5	49.5					
Pu-244	49.6	49.5					
Am-241	48.6	48.6					
Am-242m	50.9	45.2					
Am-243	50.5	50.4					
Cm-243	29.5	29.5					
Cm-244	22.9	22.9					
Cm-245	52.2	50.8					
Cm-246	50.6	50.6					
Cm-247	50.9	50.8					
Cm-248	50.8	50.8					

APPENDIX B

INPUT FILES FOR GENII CODE FOR GRTPA BENCHMARK

TABLE B.1 GENII Data File with Default Parameters - DEFAULT.IN

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Grout PA Parameter Values (14-Sep-93 PDR)

INVENTORY PARAMETERS-------------------------------------------------------------
0.037, 3.7E4, 3.7E7, 3.7E10, 1.0          NVU     Source input conversion
1.0, 0.15, 224.0                          SVU     Soil source conversion
ENVIRONMENTAL PARAMETERS---------------------------------------------------------
0.008                                     ABSHUM  Absolute humidity (kg/m3)
2                                         PRCNTI  Air dispersion conserv. flag
0.001                                     DPVRES  Deposition vel./resuspension
1.0E-9                                    LEAFRS  Leaf resuspension factor
2.0,2.0,3.0, 6*1.0, 1.5                 * BIOMAS  BIOMA2 Biomass (kg/m2)
0.25                                      DEPFR2  Interception frac./irrigate
15.0                                      SURCM   Depth of surface soil (cm)
224.0                                     SLDN    Surface soil density (kg/m2)
1.5E3                                     SSLDN   Soil density (kg/m3)
True                                      HARVST  Harvest removal considered?
100.0                                   * SOLING  Soil ingested (mg/da)
14.0                                      WTIM    Weathering time (da)
1.0, 0.1, 0.1, 0.1                        TRANS   Translocation, plants
0.1, 0.1, 0.1, 0.1, 1.0, 1.0              TRANSA  Translocation, animal food
68.0, 0.12, 55.0, 0.12, 68.0, 55.0        CONSUM  Animal Consumption (kg/da)
50.0, 0.3, 60., 0.3                       DWATER  Animal drinking water (L/da)
0.0, 0.8, 1.0, 0.8                        FRACUT  Acute fresh forage by season
0.2, 0.3, 0.5, 1.0                        SHORWI  Shore width factors
0.02                                      INGWAT  Swim water ingested (L/hr)
25295.0                                   TCWS    H2O/sed. transfer (L/m2/yr)
0.4,  5.0, 4.0                            YELDBT  BIOT: Veg. prod. (kg/m2/yr)
9.41E-4, 2*7.48E-4                        TOTEXC  BIOT: Excavation (m2/m3-yr)
1.0, 0.81, 0.19, 0.02, 0.008, 0.002,      EXCAV   BIOT: Frac. soil brought to
1.0, 0.9, 0.096, 0.006, 0.0005, 0.0005,           surface from within the
1.0, 0.9, 0.096, 0.006, 0.0005, 0.0005            waste by animal excavation
270.0                                     RINH    Chronic breathing (cm3/sec)
330.0                                     RINHA   Acute breathing (cm3/sec)
10                                        NDIST   Number of distances
805.0, 2414.0, 4023.0, 5632.0, 7241.0,
12068.0, 24135.0, 40255.0, 56315.0,
72405.0                                   X       JF/chi/Q/pop grid dist. (m)
0.1, 0.25, 6*0.18, 2*0.2                  DRYFAC, DRYFA2 dry/wet ratio
METABOLIC PARAMETERS-------------------------------------------------------------
0.5, 50.0, 500.0                                      XDIV
0.5,  0.5,  0.95, 0.05,  0.8, 0.0, 0.0,  0.2, 0.0,    ADJ
0.1,  0.9,  0.5,  0.5,  0.15, 0.4, 0.4, 0.05, 0.0,
0.01, 0.99, 0.01, 0.99, 0.05, 0.4, 0.4, 0.135, 0.015

DOSE PARAMETERS------------------------------------------------------------------
0.25, 0.15, 0.12, 0.12, 0.03, 0.03, 5*0.06            WT   Weighting factors
2.0                                                   SI2I Semi-infinite/inf
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TABLE B.2 GENII Data File with Concentration Ratios - FTRANS.DAT

Food Transfer Factors, NUREG-5512 (2/5/93 PDR) by atomic number

Element	Dep Spd m/sec	Soil-to-Plant Conc Ratios Leafy	Root	Fruit	Grain	Beef day/kg	Poultry day/kg	Milk day/L	Egg day/kg	Leaching Factor	Kd	Atomic Number
H	0	0	0	0	0	0	0	0	0	2.50E+0	0	1
BE	0.0008	0.01	0.0015	0.0015	0.0015	0.001	0.4	9E-07	0.02	2.77E-3	240	4
C	0	0.7	0.7	0.7	0.7	0	0	0	0	9.57E-2	6.7	6
N	0.0008	30	30	30	30	0.075	0.1	0.025	0.8	2.50E+0		7
F	0.0008	0.06	0.006	0.006	0.006	0.15	0.01	0.001	2	7.64E-3	87	9
NA	0.0008	0.075	0.055	0.055	0.055	0.055	0.01	0.035	0.2	8.74E-3	76	11
MG	0.0008	1	0.55	0.55	0.55	0.005	0.03	0.004	1.6	2.50E+0		12
SI	0.0008	0.35	0.07	0.07	0.07	4E-05	0.2	2E-05	0.8	2.50E+0		14
P	0.0008	3.5	3.5	3.5	3.5	0.055	0.19	0.015	10	7.27E-2	8.9	15
S	0.0008	1.5	1.5	1.5	1.5	0.1	0.9	0.015	7	4.67E-2	14	16
CL	0.0008	70	70	70	70	0.08	0.03	0.015	2	3.39E-1	1.7	17
AR	0	0	0	0	0	0	0	0	0	2.50E+0		18
K	0.0008	1	0.55	0.55	0.55	0.02	0.4	0.007	0.7	3.65E-2	18	19
CA	0.0008	3.5	0.35	0.35	0.35	0.0007	0.044	0.01	0.44	7.27E-2	8.9	20
SC	0.0008	0.006	0.001	0.001	0.001	0.015	0.004	5E-06	0.003	2.15E-3	310	21
CR	0.0008	0.0075	0.0045	0.0045	0.0045	0.0055	0.2	0.0015	0.8	2.20E-2	30	24
MN	0.0008	0.56	0.15	0.05	0.29	0.0004	0.05	0.00035	0.065	1.33E-2	50	25
FE	0.0008	0.004	0.001	0.001	0.001	0.02	1.5	0.00025	1.3	4.16E-3	160	26
CO	0.0008	0.081	0.04	0.007	0.0037	0.02	0.5	0.002	0.1	1.11E-2	60	27
NI	0.0008	0.28	0.06	0.06	0.03	0.006	0.001	0.001	0.1	1.67E-3	400	28
CU	0.0008	0.4	0.25	0.25	0.25	0.01	0.51	0.0015	0.49	2.20E-2	30	29
ZN	0.0008	1.4	0.59	0.9	1.3	0.1	6.5	0.01	2.6	3.33E-3	200	30
GA	0.0008	0.004	0.0004	0.0004	0.0004	0.0005	0.3	5E-05	0.8	2.50E+0		31
AS	0.0008	0.04	0.006	0.006	0.006	0.002	0.83	6E-05	0.8	6.05E-3	110	33
SE	0.0008	0.025	0.025	0.025	0.025	0.015	8.5	0.004	9.3	4.75E-3	140	34
BR	0.01	1.5	1.5	1.5	1.5	0.025	0.004	0.02	1.6	4.67E-2	14	35
KR	0	0	0	0	0	0	0	0	0	2.50E+0	0	36
RB	0.0008	0.15	0.07	0.07	0.07	0.015	2	0.01	3	1.28E-2	52	37
SR	0.0008	1.6	0.81	0.17	0.13	0.0003	0.035	0.0015	0.3	4.37E-2	15	38
Y	0.0008	0.015	0.006	0.006	0.006	0.0003	0.01	2E-05	0.002	3.50E-3	190	39
ZR	0.0008	0.002	0.0005	0.0005	0.0005	0.0055	6.4E-05	3E-05	0.00019	1.15E-3	580	40
NB	0.0008	0.02	0.005	0.005	0.005	0.25	0.00031	0.02	0.0013	4.16E-3	160	41
MO	0.0008	0.25	0.06	0.06	0.06	0.006	0.19	0.0015	0.78	6.49E-2	10	42
TC	0.0008	44	1.1	1.5	0.73	0.0085	0.03	0.01	3	1.82E+0	0.1	43
RU	0.0008	0.52	0.02	0.02	0.005	0.002	0.007	6E-07	0.006	1.21E-2	55	44
RH	0.0008	0.15	0.04	0.04	0.04	0.002	0.5	0.01	0.1	1.28E-2	52	45
PD	0.0008	0.15	0.04	0.04	0.04	0.004	0.0003	0.01	0.004	1.28E-2	52	46
AG	0.0008	0.00027	0.0013	0.0008	0.1	0.003	0.5	0.02	0.5	7.39E-3	90	47
CD	0.0008	0.55	0.15	0.15	0.15	0.00055	0.84	0.001	0.1	1.66E-2	40	48
IN	0.0008	0.004	0.0004	0.0004	0.0004	0.008	0.3	0.0001	0.8	1.71E-3	390	49
SN	0.0008	0.03	0.006	0.006	0.006	0.08	0.2	0.001	0.8	5.12E-3	130	50
SB	0.0008	0.00013	0.00056	8E-05	0.03	0.001	0.006	0.0001	0.07	1.47E-2	45	51
TE	0.0008	0.025	0.004	0.004	0.004	0.015	0.085	0.0002	5.2	4.75E-3	140	52
I	0.01	0.0034	0.05	0.05	0.05	0.007	0.018	0.01	2.8	5.26E-1	1	53
XE	0	0	0	0	0	0	0	0	0	2.50E+0	0	54
CS	0.0008	0.13	0.049	0.22	0.026	0.02	4.4	0.007	0.49	2.47E-3	270	55
BA	0.0008	0.15	0.015	0.015	0.015	0.00015	0.00081	0.00035	1.5	1.28E-2	52	56
LA	0.0008	0.00057	0.00064	0.004	0.004	0.0003	0.1	2E-05	0.009	5.55E-4	1200	57
CE	0.0008	0.01	0.004	0.004	0.004	0.00075	0.01	2E-05	0.005	1.33E-3	500	58
PR	0.0008	0.01	0.004	0.004	0.004	0.0003	0.03	2E-05	0.005	2.77E-3	240	59
ND	0.0008	0.01	0.004	0.004	0.004	0.0003	0.004	2E-05	0.0002	2.77E-3	240	60
PM	0.0008	0.01	0.004	0.004	0.004	0.005	0.002	2E-05	0.02	2.77E-3	240	61
SM	0.0008	0.01	0.004	0.004	0.004	0.005	0.004	2E-05	0.007	2.77E-3	240	62
EU	0.0008	0.01	0.004	0.004	0.004	0.005	0.004	2E-05	0.007	2.77E-3	240	63
GD	0.0008	0.01	0.004	0.004	0.004	0.0035	0.004	2E-05	0.007	2.77E-3	240	64
TB	0.0008	0.01	0.004	0.004	0.004	0.0045	0.004	2E-05	0.007	2.77E-3	240	65
DY	0.0008	0.01	0.004	0.004	0.004	0.0055	0.004	2E-05	0.007	2.50E+0		66
HO	0.0008	0.01	0.004	0.004	0.004	0.0045	0.004	2E-05	0.007	2.77E-3	240	67
ER	0.0008	0.01	0.004	0.004	0.004	0.004	0.004	2E-05	0.007	2.50E+0		68
HF	0.0008	0.0035	0.00085	0.00085	0.00085	0.001	6E-05	5E-06	0.0002	2.50E+0		72
TA	0.0008	0.01	0.0025	0.0025	0.0025	0.0006	0.0003	3E-06	0.001	2.50E+0		73
W	0.0008	0.045	0.01	0.01	0.01	0.045	0.2	0.0003	0.8	6.65E-3	100	74
RE	0.0008	1.5	0.35	0.35	0.35	0.008	0.04	0.0015	0.4	4.67E-2	14	75
OS	0.0008	0.015	0.0035	0.0035	0.0035	0.4	0.1	0.005	0.09	3.50E-3	190	76
IR	0.0008	0.055	0.015	0.015	0.015	0.0015	0.5	2E-06	0.1	7.30E-3	91	77

TABLE B.2 Continued

AU	0.0008	0.4	0.1	0.1	0.1	0.008	0.5	5.5E-06	0.5	2.20E-2	30	79
HG	0.0008	0.9	0.2	0.2	0.2	0.25	0.011	0.00045	0.2	3.46E-2	19	80
TL	0.0008	0.004	0.0004	0.0004	0.0004	0.04	0.3	0.002	0.8	1.71E-3	390	81
PB	0.0008	0.0058	0.0032	0.009	0.0047	0.0003	0.2	0.00025	0.8	2.47E-3	270	82
BI	0.0008	0.035	0.005	0.005	0.005	0.0004	0.1	0.0005	0.8	5.54E-3	120	83
PO	0.0008	0.0025	0.009	0.0004	0.0004	0.0003	0.9	0.00035	7	4.44E-3	150	84
RN	0	0	0	0	0	0	0	0	0	2.50E+0	0	86
RA	0.0008	0.075	0.0032	0.0061	0.0012	0.00025	0.03	0.00045	2E-05	1.33E-3	500	88
AC	0.0008	0.0035	0.00035	0.00035	0.00035	2.5E-05	0.004	2E-05	0.002	1.59E-3	420	89
TH	0.0008	0.0066	0.00012	8.5E-05	3.4E-05	6E-06	0.004	5E-06	0.002	2.08E-4	3200	90
PA	0.0008	0.0025	0.00025	0.00025	0.00025	1E-05	0.004	5E-06	0.002	1.31E-3	510	91
U	0.0008	0.017	0.014	0.004	0.0013	0.0002	1.2	0.0006	0.99	4.37E-2	15	92
NP	0.0008	0.013	0.0094	0.01	0.0027	5.5E-05	0.004	5E-06	0.002	1.27E-1	5	93
PU	0.0008	0.00039	0.0002	4.5E-05	2.6E-05	5E-07	0.00015	1E-07	0.008	1.21E-3	550	94
AM	0.0008	0.00058	0.00041	0.00025	5.9E-05	3.5E-06	0.0002	4E-07	0.009	3.51E-4	1900	95
CM	0.0008	0.0003	0.00024	1.5E-05	2.1E-05	3.5E-06	0.004	2E-05	0.002	1.67E-4	4000	96
CF	0.0008	0.01	0.01	0.01	0.01	0.005	0.004	7.5E-07	0.002	1.31E-3	510	98

TABLE B.3 GENII Input Data File - Irrigated Farm Scenario

```
########################## Program GENII Input File ########### 8 Jul 88 ####
Title: All Pathways from Ground Water
      \IRRIG.IN          .                        Created on 09-14-1993 at 17:39
OPTIONS======================== Default ===================================
T    Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F    Population dose?         (Individual)                release, single site
F    Acute release?             (Chronic)     FAR-FIELD:  wide-scale release,
     Maximum Individual data set used                     multiple sites
                              Complete                                Complete
TRANSPORT OPTIONS=========== Section    EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport                 1      F  Finite plume, external        5
F  Surface Water Transport       2      F  Infinite plume, external      5
F  Biotic Transport (near-field) 3,4    T  Ground, external              5
F  Waste Form Degradation (near) 3,4    F  Recreation, external          5
                                        T  Inhalation uptake             5,6
REPORT OPTIONS=======================   T  Drinking water ingestion      7,8
T  Report AEDE only                     F  Aquatic foods ingestion       7,8
F  Report by radionuclide               T  Terrestrial foods ingestion   7,9
T  Report by exposure pathway           T  Animal product ingestion      7,10
F  Debug report on screen               T  Inadvertent soil ingestion

INVENTORY ####################################################################

 1   Inventory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 0   Surface soil source units (1- m2  2- m3  3- kg).
     Equilibrium question goes here

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally      |
     --------|-----------------------|---------------------------------------|
     Release |       Surface Buried  |       Surface Deep    Ground  Surface|
     Radio-  |Air    Water   Waste   |Air    Soil    Soil    Water   Water  |
     nuclide |/yr    /yr     /m3     |/m3    /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     CO60                                                    1.0E+00

     --------|----Derived Concentrations-----|
     Use when|  measured values are known    |
     --------|-------------------------------|
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /L      /kg    |
     --------|------- ------- ------- -------|

TIME #########################################################################

1    Intake ends after (yr)
50   Dose calc. ends after (yr)
0    Release ends after (yr)
0    No. of years of air deposition prior to the intake period
50   No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) #####################################

0          Definition option: 1-Use population grid in file POP.IN
0                             2-Use total entered on this line

NEAR-FIELD SCENARIOS #########################################################

           Prior to the beginning of the intake period: (yr)
0            When was the inventory disposed?  (Package degradation starts)
0            When was LOIC?  (Biotic transport starts)
1.0        Fraction of roots in upper soil (top 15 cm)
0          Fraction of roots in deep soil
0.0        Manual redistribution: deep soil/surface soil dilution factor
1250       Source area for external dose modification factor (m2)
```

TABLE B.3 Continued

```
TRANSPORT #######################################################################
          ====AIR TRANSPORT===================================SECTION 1=====
                  0-Calculate PM              |0       Release type (0-3)
 1        Option: 1-Use chi/Q or PM value     |F       Stack release (T/F)
                  2-Select MI dist & dir      |0       Stack height (m)
                  3-Specify MI dist & dir     |0       Stack flow (m3/sec)
0         Chi/Q or PM value                   |0       Stack radius (m)
0         MI sector index (1=S)               |0       Effluent temp. (C)
0         MI distance from release point (m)|0         Building x-section (m2)
T         Use jf data, (T/F) else chi/Q grid|0         Building height (m)

          ====SURFACE WATER TRANSPORT=========================SECTION 2=====
0         Mixing ratio model: 0-use value, 1-river, 2-lake
0         Mixing ratio, dimensionless
0         Average river flow rate for: MIXFLG=0 (m3/s), MIXFLG=1,2 (m/s),
0         Transit time to irrigation withdrawal location (hr)
          If mixing ratio model > 0:
0           Rate of effluent discharge to receiving water body (m3/s)
0           Longshore distance from release point to usage location (m)
0           Offshore distance to the water intake (m)
0           Average water depth in surface water body (m)
0           Average river width (m), MIXFLG=1 only
0           Depth of effluent discharge point to surface water (m), lake only

          ====WASTE FORM AVAILABILITY=========================SECTION 3=====
0         Waste form/package half life, (yr)
0         Waste thickness, (m)
0         Depth of soil overburden, m

          ====BIOTIC TRANSPORT OF BURIED SOURCE================SECTION 4=====
T         Consider during inventory decay/buildup period (T/F)?
T         Consider during intake period (T/F)?   | 1-Arid non agricultural
0         Pre-Intake site condition.............| 2-Humid non agricultural
                                                 | 3-Agricultural

EXPOSURE ########################################################################

          ====EXTERNAL EXPOSURE================================SECTION 5=====
          Exposure time:                |  Residential irrigation:
0           Plume (hr)                  | T       Consider: (T/F)
4383.0      Soil contamination (hr)     | 1       Source: 1-ground water
0           Swimming (hr)               |                 2-surface water
0           Boating (hr)                | 32.4    Application rate (in/yr)
0           Shoreline activities (hr)   | 6.5     Duration (mo/yr)
0         Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
0         Transit time for release to reach aquatic recreation (hr)
0         Average fraction of time submersed in acute cloud (hr/person hr)

          ====INHALATION=======================================SECTION 6=====
8766.0    Hours of exposure to contamination per year
1         0-No resus-  1-Use Mass Loading        2-Use Anspaugh model
0.0001      pension     Mass loading factor (g/m3)  Top soil available (cm)

          ====INGESTION POPULATION=============================SECTION 7=====
0         Atmospheric production definition (select option):
0           0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
            1-Use population-weighted chi/Q
            2-Use uniform production
            3-Use chi/Q and production grids (PRODUCTION will be overridden)
0         Population ingesting aquatic foods, 0 defaults to total (person)
0         Population ingesting drinking water, 0 defaults to total (person)
F         Consider dose from food exported out of region (default=F)
```

TABLE B.3 CONTINUED

Note below: S* or Source: 0-none, 1-ground water, 2-surface water
3-Derived concentration entered above

==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F Salt water? (default is fresh)

USE ? T/F	FOOD TYPE	TRANSIT hr	PRODUCTION kg/yr	-CONSUMPTION- HOLDUP da	RATE kg/yr
F	FISH	0.00	0.0E+00	0.00	0.0
F	MOLLUS	0.00	0.0E+00	0.00	0.0
F	CRUSTA	0.00	0.0E+00	0.00	0.0
F	PLANTS	0.00	0.0E+00	0.00	0.0

DRINKING WATER	
1	Source (see above)
F	Treatment? T/F
1.0	Holdup/transit(da)
655.0	Consumption (L/yr)

====TERRESTRIAL FOOD INGESTION======================SECTION 9=====

USE ? T/F	FOOD TYPE	GROW TIME da	S *	--IRRIGATION-- RATE in/yr	TIME mo/yr	YIELD kg/m2	PRODUCTION kg/yr	--CONSUMPTION-- HOLDUP da	RATE kg/yr
T	LEAF V	90.00	1	32.4	6.5	2.0	0.0E+00	1.0	4.1
T	ROOT V	90.00	1	32.4	6.5	2.0	0.0E+00	14.0	13.9
T	FRUIT	90.00	1	32.4	6.5	3.0	0.0E+00	14.0	7.0
F	GRAIN	90.00	1	0.0	0.0	1.0	0.0E+00	14.0	0.0

====ANIMAL PRODUCTION CONSUMPTION===================SECTION 10====

USE ? T/F	FOOD TYPE	---HUMAN---- CONSUMPTION RATE kg/yr	HOLDUP da	TOTAL PRODUCTION kg/yr	DRINK WATER CONTAM FRACT.	DIET FRACTION	GROW TIME da	S *	-IRRIGATION-- RATE in/yr	TIME mo/yr	YIELD kg/m3	STORAGE da
						-------------STORED FEED						
T	BEEF	22.0	20.0	0.00	1.00	0.25	90.0	1	32.4	6.50	1.00	100.0
T	POULTR	4.6	1.0	0.00	1.00	1.00	90.0	1	32.4	6.50	1.00	100.0
T	MILK	50.8	1.0	0.00	1.00	0.25	90.0	1	32.4	6.50	1.00	100.0
T	EGG	10.6	1.0	0.00	1.00	1.00	90.0	1	32.4	6.50	1.00	100.0
						-------------FRESH FORAGE						
	BEEF					0.75	45.0	1	32.4	6.50	1.00	45.0
	MILK					0.75	45.0	1	32.4	6.50	1.50	45.0

##