FINAL REPORT

FOLAT: A Model for Assessment of Leaching and Transport of Radionuclides in Unsaturated Porous Media

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ABSTRACT

The FOLAT (First-Order-Leach-And-Transport) model was developed to estimate radionuclide fluxes to the aquifer from radionuclide sources either in a waste disposal facility or present in the form of residual contamination in soils from various industrial processes. The model was designed to be simple yet robust, incorporating many of the major processes and assumptions that typically determine the results of prospective radiological assessments. It was not intended to be a predictive tool. The subsurface environment is assumed to be composed of a series of "compartments". Within each compartment, radionuclides enter, mix, sorb, decay, and are eventually removed by the downward movement of water. Each compartment may have its own unique qualities that include horizontal and vertical dimensions, bulk density, porosity, hydraulic conductivity, net water flux through the compartment, and sorptive properties. The model is formulated as a series of ordinary differential equations that are solved through the use of a 4th order Runga Kutta routine. Time variable radionuclide release rates and water fluxes through each compartment is easily incorporated into a simulation. Solubility controls are imposed on radionuclide concentrations in pore water in each of the compartments. The model can handle up to a six-member decay chain. Radioactive progeny move according to their own transport properties.

The model is coded in FORTRAN and input is provided through three ASCII files. Code output includes pore water concentrations, compartment inventories, and radionuclide fluxes through each of the compartments. The code was verified using analytical solutions to the governing equations and benchmarked against two other radionuclide transport codes that incorporate the advection-dispersion transport equation. Benchmark exercises indicate that FOLAT provides aquifer fluxes comparable to those obtained from the advection-dispersion equation.

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INTRODUCTION

Evaluation of radionuclide transport in the unsaturated zone is both a complex and evolving science. Typically, one is presented with the problem of assessing the release and transport of radionuclides to the aquifer from radionuclide sources either in a waste disposal facility or present in the form of residual contamination in soils from various industrial processes. Many models ranging from the simple to complex have been developed to address this problem. Several models specifically designed for this task include the Disposal Unit Source Term Model (DUST) (Sullivan 1996), RESRAD (Yu et al. 2000), and SESOIL (Scott and Hetrick 1994) for non-radiological contaminants. Others may rely on models designed to solve the general governing equations of fluid flow and transport in a variable saturated porous media. Several examples of such models include STOMP (PNNL 1996) and PORFLOW (ACRI 1996). Oftentimes, the available characterization data for an assessment are poor which limits the effectiveness of a complex model. Furthermore, many of assessments are prospective and entail model predictions out to tens of thousands of years. The reliability of any model is questionable under such conditions and by their very nature, such model predictions cannot be confirmed with field observations. The nature of the prospective analysis and the complexity of problem oftentimes leads to simplifying but conservative assumptions about radionuclide release and transport in the subsurface environment. The term conservative is used in the context of providing overestimates of radionuclide concentrations at points where exposure to humans may be possible and thereby ensuring radiological impacts to any real person will not exceed the calculated values.

This report describes the FOLAT (First-Order-Leach-And-Transport) model, which was designed to assess radionuclide leaching and transport in an unsaturated porous media for the purposes of low-level radioactive waste performance assessment. The model may also have other applications. Its primary output is radionuclide fluxes from the base of the unsaturated zone. This is typically the surface of an aquifer. The model employs the soil leaching model proposed by Baes and Sharp (1983) and extends that model to multiple subsurface layers with potentially differing transport properties. The model was designed to incorporate readily available data and the dominant processes that tend to impact the results of such assessments. Such processes include time-variable water infiltration rates and spatially variable equilibrium sorption. Estimated water fluxes in the unsaturated zone from models such as UNSAT-H (Fayer 2000), may be incorporated into the FOLAT model.

CONCEPTUAL MODEL

The conceptual model for FOLAT is relatively simple (Figure 1). The subsurface environment is envisioned to be composed of a series of "compartments". Within each compartment, radionuclides enter, mix, sorb, decay, and are eventually removed by the downward movement of water. Each compartment may have its own unique qualities that include horizontal and vertical dimensions, bulk density, porosity, hydraulic conductivity, net water flux through the compartment, and sorptive properties. Water flux through each compartment may change as a function of time. As the water flux changes, so too does the moisture content of the compartment. Radionuclides sorb on to the solid matrix as described by the equilibrium partitioning coefficient or *Kd*. Sorption retards the overall downward movement of radionuclides. The rate of transport of radioactive decay products or progeny that form during vertical transport

of a parent radionuclide are governed by the sorptive properties of the progeny, and not those of the parent.

Radionuclides may be present in each of the compartments at the start of the simulation, or alternatively, the parent member of the decay chain may be placed over time in the uppermost compartment. Concentrations of radionuclides in pore water are not allowed to exceed their solubility limit. Unit gradient conditions are assumed to apply to each compartment.

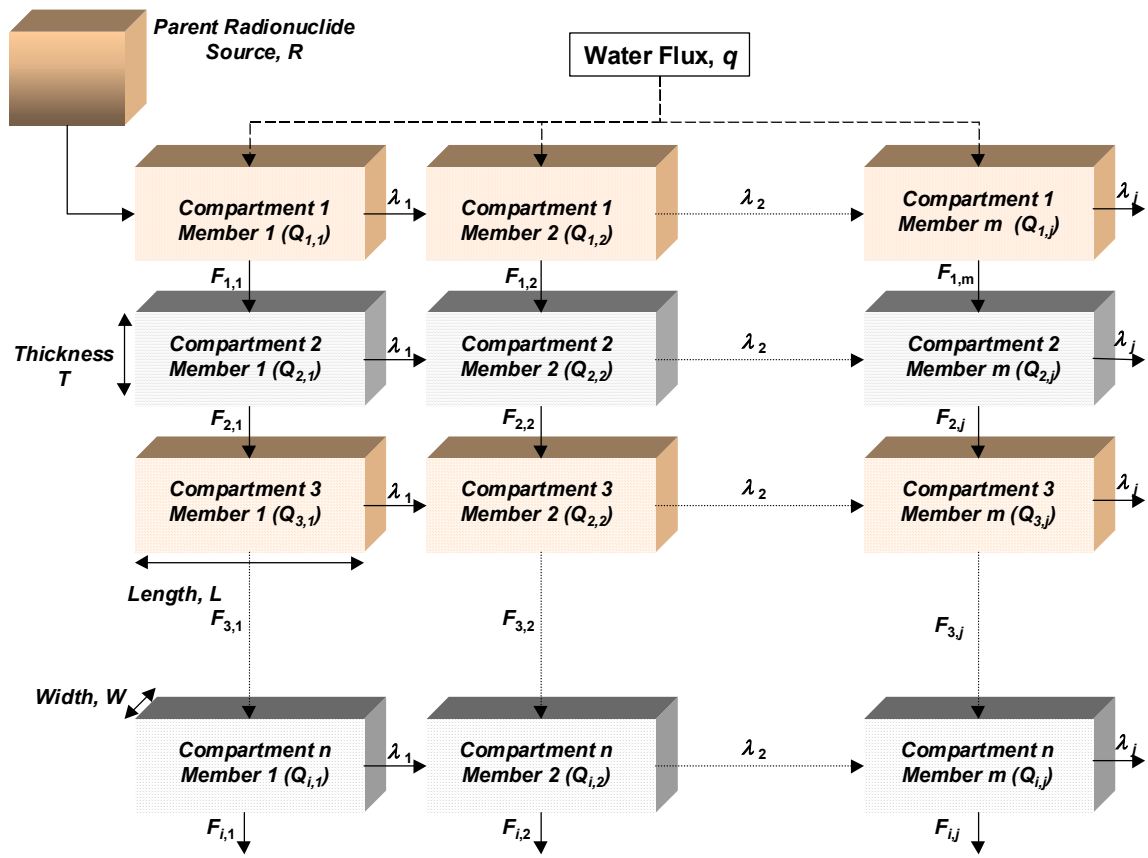

Figure 1. Conceptual model for FOLAT. In this illustration, there are n compartments for a decay chain consisting of m members. The variable $F_{i,j}$, is the removal rate (flux) from compartment i for decay chain member j. The variable, λ_j is the decay rate constant for decay chain member j. The variable $Q_{i,j}$ represents the number of atoms of decay chain member j in the ith compartment. The water flux (q indicated by the dashed line) is shown entering the first compartment but is also an input for all remaining compartments. Arrows connecting each compartment indicate the direction of radionuclide transport. Dotted arrows indicate other compartments or decay chain members may be present.

MATHEMATICAL MODEL

Ordinary differential equations describe the mass balance of radionuclides in each of the compartments. Radionuclide concentrations in pore water and the radionuclide flux from each

compartment are determined from the radionuclide inventory within each compartment. The uppermost or first compartment for the first (parent) member of the decay chain is described by

$$\frac{dQ_{1,1}}{dt} = R(t) - F_{1,1}(t) - \lambda_1 Q_{1,1} \tag{1}$$

where

$Q_{1,1}$ = the number of atoms in compartment 1 for decay chain member 1 (atoms)
$R(t)$ = the input rate of decay chain member 1 into compartment 1 (atoms time^{-1})
$F_{1,1}(t)$ = the removal rate (flux) of decay chain member 1 from compartment 1 to compartment 2 (atoms time^{-1})
λ_1 = the decay rate constant for decay chain member 1 (time^{-1}).

For simplicity and clarity, all equations are written in terms of the number of atoms of each decay chain member. The mass balance equation for the remaining compartments is given by

$$\frac{dQ_{i,j}}{dt} = F_{i-1,j}(t) - \lambda_j Q_{i,j} + \lambda_{j-1} Q_{i,j-1} - F_{i,j}(t) \tag{2}$$

where i is the index for the compartment and j is the index for the decay chain member and $i \neq 1$ and $j \neq 1$. Other terms are defined previously. Equation 2 assumes the branching ratio between the parent and radioactive progeny is 1.0 (i.e. 100% of the parent decays to the progeny). When the radionuclide concentration in pore water is less than the solubility limit, the flux term in Equations 1 and 2 is given by

$$F_{i,j}(t) = \left(\kappa_{i,j}(t) + \eta_{i,j}\right) Q_{i,j} \tag{3}$$

where

$\kappa_{i,j}(t)$ = the leach rate constant for compartment i and decay chain member j (time^{-1})
$F_{i,j}(t)$ = the flux of decay chain member j from compartment i into compartment i+1 (atoms time^{-1})
$\eta_{i,j}$ = a fixed removal rate constant for compartment i and decay chain member j (time^{-1}).

In general, only the leach rate constant is used to remove radionuclides from a compartment. However, the user may which to bypass this calculation and put in their own removal rate constant. We have included $\eta_{i,j}$ for this situation. When the pore water concentration exceeds the solubility limit, then the flux term in Equations 1 and 2 is given by

$$F_{i,j}(t) = S_j \, q_i(t) \, L_i \, W_i \tag{4}$$

where

S_j = the solubility limit of decay chain member j (atoms m^{-3})
$q_i(t)$ = water flux through compartment i as a function of time (m time^{-1})
L_i = length of compartment i (m)

W_i = width of compartment i (m).

In Equations 3 and 4, $i \leq n$, where n is the number of compartments in the simulation. Likewise, $j \leq m$, where m is the number of decay chain members including the parent. The pore water concentration in compartment i for decay chain member j ($C_{i,j}$) is given by

$$C_{i,j}(t) = \frac{Q_{i,j}(t)}{\theta_i(t)\, L_i\, W_i\, T_i \left(1 + \frac{Kd_{i,j}\rho_i}{\theta_i(t)}\right)} \tag{5}$$

where

$\theta_i(t)$ = volumetric moisture content in compartment i as a function of time ($m^3\ m^{-3}$)
$Kd_{i,j}$ = equilibrium partition coefficient for compartment i and decay chain member j ($mL\ g^{-1}$)
ρ_i = bulk density of compartment i ($g\ mL^{-1}$)
T_i = thickness of compartment i (m)
L_i = length of compartment i (m)
W_i = width of compartment i (m).

The term, $1 + Kd_{i,j}\ \rho_i/\theta(t)_i$ is the retardation coefficient and is 1.0 for a Kd of zero. The leach rate constant is given by Baes and Sharp (1983) as

$$\kappa_{i,j}(t) = \frac{q_i(t)}{\theta_i(t)\ T_i \left(1 + \frac{Kd_{i,j}\rho_i}{\theta_i(t)}\right)} \tag{6}$$

and the decay rate constant is given by

$$\lambda_j = \frac{\ln(2)}{T1/2_j} \tag{7}$$

where $T1/2_j$ = half-life of decay chain member j.

Note that $\kappa_{i,j}$ can be set to zero by letting $q_i(t) = 0$ or setting $Kd_{i,j}$ to a sufficiently large value such that $\eta_{i,j} >> \kappa_{i,j}$.

The value q/θ represents the average linear water velocity (pore velocity) through the compartment and is based on the unit gradient model. The unit gradient model assumes water infiltration is driven primarily by gravity flow. Darcy's law in a one dimensional, vertically aligned, unsaturated soil column is given by

$$q = K(\theta)\left(\frac{\partial H}{\partial z} + \frac{\partial \psi}{\partial z}\right) \tag{8}$$

where

H = elevation head (m),
ψ = suction or pressure head (m),

$K(\theta)$ = unsaturated hydraulic conductivity of the column (m time^{-1})
z = length of the column (m).

Under unit gradient conditions, $\partial\psi/\partial z = 0$, $\partial H/\partial z = 1$, and $\partial\theta/\partial t = 0$. Therefore, $q = K(\theta)$. The unsaturated hydraulic conductivity is a function of the volumetric moisture content of the media. The volumetric moisture content is the fraction of the bulk media that is filled with water. When a porous media is saturated (i.e., all the pore spaces are filled with water), the volumetric moisture content is equal to the effective porosity of the media. It is assumed that unit gradient conditions apply to all compartments in the model. Moisture content changes in response to changes in the net water flux through a compartment are assumed to equilibrate rapidly compared to the rate of transfer of radionuclides among compartments. The relationship between hydraulic conductivity and moisture content differs for different rock types. The volumetric water content for a given material and a constant water flux is usually determined using equations that have been fitted to field data relating suction head to volumetric moisture content and hydraulic conductivity. The unsaturated hydraulic conductivity can be written in terms of the moisture content and soil fitting parameters, α and n, described in van Genuchten (1978) and given in Equations 9 and 10.

$$K(\theta) = K_{sat}\left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{1/2}\left\{1 - \left[1 - \left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{\frac{1}{m}}\right]^m\right\}^2 \tag{9}$$

and

$$\left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right) = \left(\frac{1}{1 + \alpha n}\right)^m \tag{10}$$

where
θ = volumetric moisture content (m^3 m^{-3}),
θ_r = residual moisture content (m^3 m^{-3}),
θ_s = saturated moisture content (m^3 m^{-3}),
K_{sat} = saturated hydraulic conductivity (m y^{-1}),
α = fitting parameter (m^{-1}),
n = fitting parameter,
m = $1 - 1/n$.

CODE IMPLEMENTATION

Equations 1-10 are coded into a FORTRAN program that 1) reads user input from ASCII files, 2) computes unit conversions and pore water concentrations, 3) solves Equations 1 and 2, and 4) writes output to ASCII files. Equations 1 and 2 were solved using a 4th-order Runga Kutta ordinary differential equation solver from Press et al. (1992). Input to the code is through three ASCII files. The primary input file is termed the parameter definition file and defines model options, compartment properties, radionuclide parameter values, and initial inventories of radionuclides in each compartment. A second file (listed in the parameter definition file) contains the net water fluxes as a function time for each compartment. A third file contains the parent

radionuclide release rates to the first (uppermost) compartment. Output includes a general output file that echoes back the user input, leach rate constants and pore water concentrations at the start of the simulation, and pore water concentrations, radionuclide flux, and compartment inventories as a function of time for each output time defined in the parameter definition file. File structure for each of the three input files is described in Tables 1–3. All input files are free-form ASCII, which may be created in any standard text editor. Each card in the parameter definition file represents one or more lines of input. The code ignores lines where a dollar sign ($) in placed in the first column, thereby facilitating comments in the input file. Suggested default values (when applicable) are put in the description column of Table 1 in parentheses.

Radionuclide inventories and release rates are input in units of Curies. These quantities are converted to atoms using

$$Q_{mass} = \frac{Q_{activity}\left(3.7\times10^{10}\,\mathrm{dps\,Ci^{-1}}\right)\left(3.1536\times10^{7}\,\mathrm{s\,y^{-1}}\right)MW}{\lambda\, N_A} \tag{11}$$

where

MW = molecular weight (g mol^{-1})
N_A = Avogadro's number (6.023×10^{23})
dps = number of nuclear disintegrations per second
Q_{mass} = number of atoms of a radionuclide in a given compartment (atoms)
Q_{mass} = activity of a radionuclide in a given compartment (Ci)

Release rates are read into the code via an ASCII file containing pairs of time-release rate values. Values at times in between the tabulated values are linearly interpolated. A similar procedure applies to water fluxes.

Water fluxes through each compartment as a function of time are read into the code via an ASCII file. Values at times in between the tabulated values are linearly interpolated. Under steady –state conditions, the water fluxes through each compartment are the same. Under transient conditions, water flux may change as a function of time and space. Unsaturated flow models (such as UNSAT-H) may be used to compute these water fluxes for input into FOLAT. Alternatively, a FOLAT-compatible water flux file may be generated using the preprocessor described in Appendix A.

The code was compiled using Version 5.60a of the Lahey, LF95 FORTRAN compiler for both Microsoft Windows® 9x and Linux operating systems. Run times on an Athlon 760 mHz processor running Linux Mandrake 7.0 were less than a second for the verification and test problems presented in this document.

Code versions are identified by the version date which is printed in all the output files. Furthermore, headers in each of the subroutines describe the purpose of the subroutine, variables passed, the units (if applicable), and a version history.

Table 1. Parameter Definition File for the FOLAT Program

Card	Code variable	Type/format	Units	Description
1	Title	CHAR/A80		Title of run
2	Fileout	CHAR/A60		Output file name
3	Fileppt	CHAR/A60		File containing net water flux in each compartment as a function of time
4	Filerel	CHAR/A60		File containing radionuclide fluxes to the first compartment for the parent nuclide
5	eps	REAL/*		Required accuracy of solution (1×10^{-6})
5	h1	REAL/*	year	Beginning time step (0.0001 year)
5	hmin	REAL/*	year	Minimum time step (1×10^{-30} year)
6	mlayer	INT/*		Number of compartments in the simulation (maximum = 50)
6	nprog	INT/*		Number of decay chain members (maximum = 6)
6	nmat	INT/*		Number of material types (must be ≤ mlayer)
7	cname(*i*)	CHAR*6/*		Name of each member of the decay chain, nprog values are read from a single line. This name is concatenated with ".rel" extension to for the file name where fluxes from the last compartment are output.
8	mw(*j*)	REAL/*	g mol^{-1}	Molecular weight of each decay chain member, nprog values are read from a single line.
9	sol(*j*)	REAL/*	mg L^{-1}	Solubility limit of each decay chain member, nprog values are read from a single line.
10	thalf(*j*)	REAL/*	years	Half life of each decay chain member, nprog values are read from a single line.
NOTE: Card 11 is read nprog times				
11	y(*i,j*)	REAL/*	Ci	Initial activity in each compartment for decay chain member *j*. mlayer number of values are read from each line.
NOTE: Card 12 is read nprog times				
12	kd(*i,j*)	REAL/*	mL g^{-1}	Equilibrium sorption coefficient for each compartment for decay chain member *j*. mlayer number of values are read from each line.
NOTE: Card 13 is read nprog times				
13	kx(*i,j*)	REAL/*	y^{-1}	Alternative removal rate constant for decay chain member *j*. mlayer number of values are read from each line.
NOTE: Card 13a, 13b, and 13c define the compartment properties and are read nmat number of times. Compartments must be defined in ascending order				
13a	h	INT/*		Beginning compartment number to define compartment properties.
13a	j	INT/*		Ending compartment number to define compartment properties.
13b	thick(*i*)	REAL/*	m	Thickness of compartment i
13b	rho(*i*)	REAL/*	g mL^{-1}	Bulk density of compartment i
13b	lth(*i*)	REAL/*	m	Length of compartment i
13b	width(*i*)	REAL/*	m	Width of compartment i
13c	sk(*i*)	REAL/*	m y^{-1}	Saturated hydraulic conductivity of compartment i
13c	ths(i)	REAL/*	m^{-3} m^{-3}	Saturated porosity of compartment i

Table 1. Parameter Definition File for the FOLAT Program

Card	Code variable	Type/format	Units	Description
13c	thr(*i*)	REAL/*	m^{-3} m^{-3}	Residual moisture content of compartment i
13c	alpha(*i*)	REAL/*	m^{-1}	van Genuchten fitting parameter for compartment i
13c	rn(*i*)	REAL/*		van Genuchten fitting parameter for compartment i
14a	ntimes	INT/*		number of output time periods
NOTE: Card 14b is read ntime number of times				
14b	t1	REAL/*	years	Begin time of output
14b	t2	REAL/*	years	End time of output
14b	tp	REAL/*	years	Print step

Table 2. Description of the Water Flux Input File

Line number	Code variable	Description
1	Junk	Column header (discarded)
2 to $n+1$[a]	precip(k,1)	Time in years from the start of the simulation for the kth record
2 to $n+1$[a]	precip(k,i)	Water flux (m y^{-1}) for total number of compartments in the simulation for the kth time record

[a] n is the number of time and water flux records. A minimum of two records is needed to operate the code.

Table 3. Description of the Radionuclide Release Rate Input File

Line number	Code variable	Description
1	Junk	Column header (discarded)
2 to $n+1$[a]	rel(k,1)	Time in years from the start of the simulation for the kth record
2 to $n+1$[a]	rel(k,2)	Radionuclide release rate (Ci y^{-1})for the kth record

[a] n is the number of time, radionuclide release rate records. A minimum of two records is needed to operate the code.

Code Execution

Execution of FOLAT is performed on the command line by typing

[*path*] FOLAT [*parameter definition file*]

where *path* is the full pathname to the executable file. If the parameter definition file is omitted, then the program will look for the default parameter file named, FOLAT.PAR. If this file is not found, the program will abort.

CODE VERIFICATION

Code verification is defined here as confirmation that the model was written and implemented in the computer code correctly. To do this, quantities output from the FOLAT code (such as pore water concentrations, fluxes, and radionuclide inventories) were compared with like quantities calculated using other codes or analytical expressions. Four test problems were defined,

which compared these quantities with output from analytical solutions to the governing equations where solutions exist. In one case (Verification Problem 4), output from another code implementing a similar solution is used. Analytical expressions are developed first, followed by presentation of the test problems and results. Differences between FOLAT calcuations and analytical solutions to the test problems are expressed as the percent difference (%*d*) as given by

$$\%d = \frac{V_a - V_f}{V_a} \times 100 \tag{12}$$

where V_a = the value calculated by analytical solution, and V_f = the value calculated by FOLAT. The FOLAT output files are presented in Appendix B.

Analytical Solutions for Governing Equations

Equation 1 has three solutions depending on the initial conditions and whether there is an external radionuclide source involved. For the case where $Q_{1,1} = Qo_{1,1}$ at $t = 0$, $\eta_{1,1} = 0$, $R(t) = 0$ for all time, and $C_{11} \leq S_1$, the solution is

$$Q_{1,1}(t) = Qo_{1,1} \exp\left(-\left(\kappa_{1,1} + \lambda_1\right)t\right) \tag{13}$$

For the case where $Q_{1,1} = 0$ at $t = 0$, $\eta_{1,1} = 0$, and $R(t)$ is a constant, R, for all time, the solution is

$$Q_{1,1}(t) = \frac{R}{\kappa_{1,1} + \lambda}\left(1 - \exp\left[-\left(\kappa_{1,1} + \lambda_1\right)t\right]\right) \tag{14}$$

The solution to the second compartment (Equation 2) for the conditions in Equation 14 and $Q_{2,1}$ = 0 at t = 0 can be found using Laplace transforms. The governing differential equation is given by

$$\frac{dQ_{2,1}}{dt} = \frac{\kappa_{1,1}R}{\gamma}\left[1 - \exp(-\gamma\, t)\right] - \delta\, Q_{2,1} \tag{15}$$

where

γ = $\kappa_{1,1} + \lambda_1$

δ = $\kappa_{2,1} + \lambda_1$.

The solution is

$$Q_{2,1}(t) = \kappa_{1,1}R\left(\frac{1}{\gamma\,\delta} + \frac{\gamma\, e^{-\delta t} - \delta\, e^{-\gamma t}}{\gamma\,\delta\left(\delta - \gamma\right)}\right) \tag{16}$$

For a decay chain of more than one member, a generalized solution to the multiple compartment problem has been developed by Birchall (1986) for the limiting conditions, $R(t) = 0$ for all times, $d\kappa/dt = 0$, $dq/dt = 0$, and $Q_{i,j} = Qo_{i,j}$ at $t = 0$.

When the pore water concentration exceeds the solubility limit of the radionuclide, then a solubility-limited release is calculated. The solubility-limited release in the first compartment where R(t) = 0 for all times and $\eta_{1,1} = 0$ is described by the differential equation

$$\frac{dQ_{1,1}}{dt} = -\lambda_1 Q_{1,1} - R_s \tag{17}$$

where
$R_s = S_1 \times q(t)_1 \times L_1 \times W_1.$

The solution to Equation 17 for the initial conditions, $Q_{1,1}=Qo_{1,1}$ at $t = 0$, is

$$Q_{1,1}(t) = Qo_{1,1}\exp(-\lambda_1 t) - \frac{R_s}{\lambda_1}\left[1 - \exp(-\lambda_1 t)\right] \tag{18}$$

When the pore water concentration is less than the solubility limit, then $Q(t)$ is described by

$$Q_{1,1}(t) = Q_{1,1}(t_{sl})\exp\left[-(\kappa_{1,1} + \lambda_1)(t - t_{sl})\right] \tag{19}$$

where $t \geq t_{sl}$, and t_{sl} is the time when the pore water concentration drops below the solubility limit.

Verification Problem 1

Verification Problem 1 considers a three-compartment model with an initial radioactivity inventory of zero in all compartments and a constant release rate of 1 Ci y^{-1} into the first compartment. A hypothetical radionuclide having a half-life of 100 years and a molecular weight of 138 g mol^{-1} is simulated. Water flux is assumed to be at steady state and different for each compartment. Input data are presented in Table 4. Radionuclide inventories were converted to pore water concentrations using Equation 5. Radioactive inventories were calculated using Equation 14 for the first compartment and Equation 16 for the second compartment.

Table 4. Parameter Values used in Verification Test Problems 1, 2, and 4

Parameter	Compartment 1	Compartment 2	Compartment 3
Thickness (m)	1.00E+00	1.00E+00	1.00E+00
Length (m)	1.00E+01	1.00E+01	1.00E+01
Width (m)	1.00E+01	1.00E+01	1.00E+01
Bulk Density (g cm^{-3})	1.50E+00	1.50E+00	1.50E+00
Saturated hydraulic conductivity (m y^{-1})	1.71E+03	1.71E+03	1.71E+03
Total porosity (m^3 m^{-3})	2.72E-01	2.72E-01	2.72E-01
Residual moisture content (m^3 m^{-3})	3.21E-02	3.21E-02	3.21E-02
van Genuchten alpha (m^{-1})	7.51E+00	7.51E+00	7.51E+00
van Genuchten n	2.30E+00	2.30E+00	2.30E+00
Water flux (m y^{-1})	1.00E-01	5.00E-02	2.50E-02

Half-life (y)	1.00E+02	1.00E+02	1.00E+02
Molecular weight (g mol^{-1})	1.38E+02	1.38E+02	1.38E+02
Solubility limit (mg L^{-1})	1.00E+00	1.00E+00	1.00E+00
Partition coefficient (mL g^{-1})	1.00E-01	5.00E-01	1.00E+00
Initial moisture content[a]	6.06E-02	5.61E-02	5.24E-02
Leach rate constants[a] (y^{-1})	4.75E-01	6.20E-02	1.61E-02
Solubility limit[a] (Ci m^{-3})	2.59E+01	2.59E+01	2.59E+01

[a.] Calculated values

Results of Verification Problem 1 (Table 5) for the first two compartments indicate good agreement between FOLAT and the analytical solution. The differences are ≤0.004%.

Table 5. Results of Verification Problem 1

	Compartment 1						Compartment 2		
Time (y)	FOLAT Inventory (Ci)	Analytical solution (Ci)	% Difference	FOLAT Conc. (Ci m^{-3})	Analytical solution (Ci m^{-3})	% Difference	FOLAT Inventory (Ci)	Analytical solution (Ci)	% Difference
2	1.28E+00	1.28E+00	0.003%	6.10E-02	6.10E-02	0.002%	6.723E-01	6.723E-01	0.001%
6	1.96E+00	1.96E+00	0.002%	9.31E-02	9.31E-02	0.001%	3.397E+00	3.397E+00	0.001%
10	2.06E+00	2.06E+00	0.002%	9.78E-02	9.78E-02	0.002%	5.942E+00	5.942E+00	0.000%
14	2.07E+00	2.07E+00	0.000%	9.84E-02	9.84E-02	0.002%	7.943E+00	7.943E+00	0.001%
20	2.08E+00	2.08E+00	0.000%	9.86E-02	9.86E-02	0.001%	1.009E+01	1.009E+01	0.002%
28	2.08E+00	2.08E+00	0.002%	9.86E-02	9.86E-02	0.002%	1.187E+01	1.187E+01	0.000%
36	2.08E+00	2.08E+00	0.002%	9.86E-02	9.86E-02	0.002%	1.290E+01	1.290E+01	-0.002%
42	2.08E+00	2.08E+00	0.002%	9.86E-02	9.86E-02	0.002%	1.337E+01	1.337E+01	0.000%
54	2.08E+00	2.08E+00	0.002%	9.86E-02	9.86E-02	0.002%	1.389E+01	1.389E+01	0.004%

Verification Problem 2

Verification Problem 2 considers the same model as Verification Problem 1 but $R(t) = 0$ and $Q_{1,1}(0) = 1.0$ Ci. Radionuclide inventories and pore water concentrations for compartment 1 were calculated using Equations 13 and 5, respectively. The results (Table 6) indicate very little difference between the analytical solution and FOLAT. Differences between the analytical solution and FOLAT increase as the inventory decreases. However, differences are still less than 0.05 percent, and the inventory at those times (42 and 54 years) is nine orders of magnitude smaller than the initial inventory.

Table 6. Results of Verification Problem 2 for Compartment 1

Time (y)	FOLAT Inventory (Ci)	Analytical solution (Ci)	% Difference	FOLAT Conc. (Ci m^{-3})	Analytical solution (Ci m^{-3})	% Difference
2	3.82E-01	3.82E-01	-0.002%	1.81E-02	1.81E-02	0.002%
6	5.55E-02	5.55E-02	-0.005%	2.64E-03	2.64E-03	0.005%
10	8.09E-03	8.09E-03	-0.008%	3.84E-04	3.84E-04	-0.08%
14	1.18E-03	1.18E-03	-0.010%	5.59E-05	5.59E-05	-0.010%
20	6.54E-05	6.54E-05	-0.016%	3.10E-06	3.10E-06	-0.016%
28	1.39E-06	1.39E-06	-0.019%	6.58E-08	6.58E-08	-0.019%
36	2.94E-08	2.94E-08	-0.029%	1.39E-09	1.39E-09	-0.029%
42	1.63E-09	1.63E-09	-0.031%	7.75E-11	7.74E-11	-0.031%
54	5.03E-12	5.03E-12	-0.044%	2.39E-13	2.39E-13	-0.044%

Verification Problem 3

Verification Problem 3 uses the general solution developed by Birchall (1986) to solve a four compartment model with a two member decay chain consisting of Pu-241 ($T1/2$ = 14.4 years) and Am-241 ($T1/2$ = 432 years). Parameters values (Table 7) include the initial inventories of Pu-241 and Am-241 in each of the compartments, compartment-specific partition coefficients, and a constant water flux.

Table 7. Parameters Values for Verification Problem 3

Parameter	Compartment 1	Compartment 2	Compartment 3	Compartment 4
Length (m)	1.0	1.0	1.0	1.0
Width (m)	1.0	1.0	1.0	1.0
Thickness (m)	0.02	0.13	0.15	0.2
Bulk density (g cm^{-3})	1.2	1.5	1.5	1.8
Saturated hydraulic conductivity (m y^{-1})	1710	1710	1710	1710
Porosity	0.2724	0.2724	0.2724	0.2724
Residual moisture content	0.0321	0.0321	0.0321	0.0321
Alpha (m^{-1})	7.71	7.71	7.71	7.71
rn	2.28	2.28	2.28	2.28
Calculated moisture content	0.0659	0.0659	0.0659	0.0659
Water flux, $t = 0$ to $t = \infty$ (m y^{-1})	0.2	0.2	0.2	0.2
Pu-241 partition coefficient (mL g^{-1})	10	15	22	22
Am-241 partition coefficient (mL g^{-1})	50	60	70	70
Pu-241 solubility (mg L^{-1})	infinite	infinite	infinite	infinite
Am-241 solubility (mg L^{-1})	infinite	infinite	infinite	infinite
Pu-241 initial inventory (Ci)	2.40E-05	5.46E-04	6.75E-05	2.72E-11
Am-241 initial inventory (Ci)	4.80E-07	2.93E-06	2.25E-07	2.86E-14

As shown in Figure 2 (for Pu-241) and Figure 3 (for Am-241), there is excellent agreement between the analytical solution and FOLAT. Differences between the analytical expression and FOLAT for the maximum inventory beyond 1-year ranged from 0.0000% for Pu-241 in compartment 3, to 0.1277% for Am-241 in compartment 4.

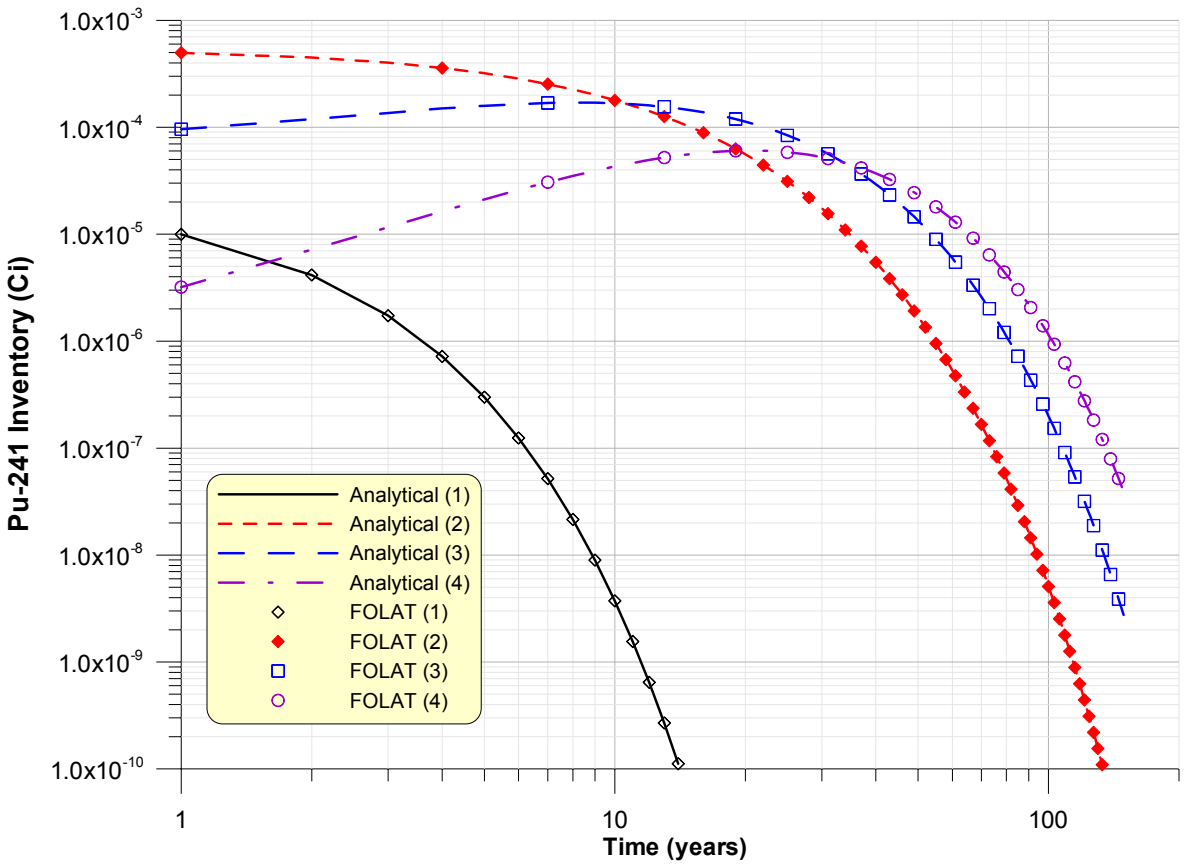

Figure 2. Plutonium-241 inventory as a function of time calculated with the analytical solution developed by Birchall (1986) and FOLAT. The numbers in parentheses in the legend refer to the compartment number.

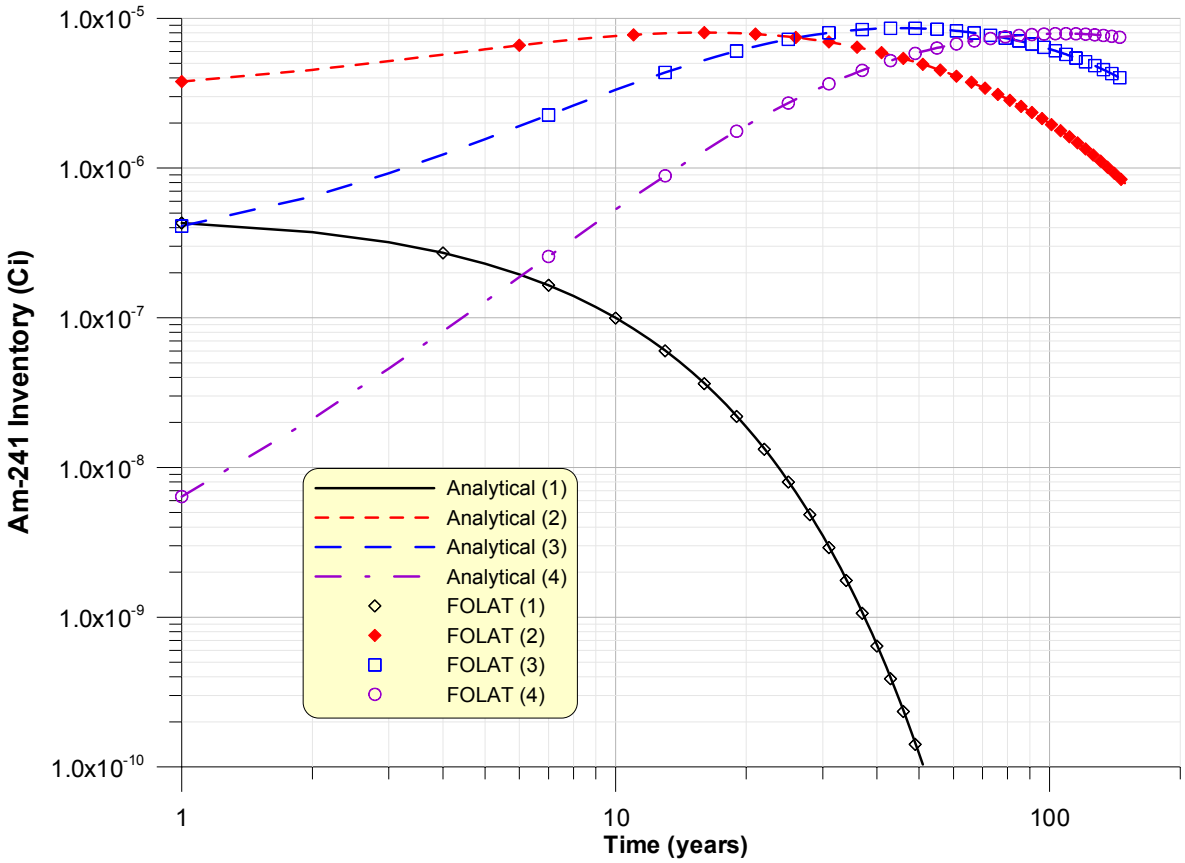

Figure 3. Americium-241 inventory as a function of time calculated with the analytical solution developed by Birchall (1986) and FOLAT. The numbers in parentheses in the legend refer to the compartment number.

Verification Problem 4

Verification Problem 4 checks the solubility limited release function in FOLAT with the analytical solution expressed by Equations 18 and 19. The problem uses the same parameters used in Verification Problem 2, except the initial inventory is set to 1×10^4 Ci. The flux from compartment 1 was also output and compared with output from the GWSCREEN model (Rood 1999), which includes the solubility release model described in Equations 18 and 19. Results (Table 8) show good agreement between FOLAT, the analytical solution, and GWSCREEN. Differences are no greater than 0.163 percent.

Table 8. Inventory and Flux from Compartment 1 for Verification Problem 4

Time (y)	FOLAT Inventory (Ci)	Analytical solution (Ci)	% Difference	FOLAT flux. (Ci y^{-1})	GWSCREEN flux (Ci y^{-1})	% Difference
2	9.35E+03	9.35E+03	-0.001%	2.59E+02	2.59E+02	0.012%
6	8.07E+03	8.07E+03	-0.002%	2.59E+02	2.59E+02	0.012%
10	6.83E+03	6.83E+03	-0.005%	2.59E+02	2.59E+02	0.012%
14	5.62E+03	5.62E+03	-0.008%	2.59E+02	2.59E+02	0.012%
20	3.86E+03	3.86E+03	-0.015%	2.59E+02	2.59E+02	0.012%
28	1.64E+03	1.64E+03	-0.048%	2.59E+02	2.59E+02	0.012%
36	8.30E+01	8.29E+01	-0.162%	3.94E+01	3.95E+01	0.119%
42	4.61E+00	4.60E+00	-0.162%	2.19E+00	2.19E+00	0.146%
54	1.42E-02	1.42E-02	-0.163%	6.76E-03	6.76E-03	0.115%

CODE BENCHMARKS

The primary output of FOLAT is the radionuclide flux from the unsaturated zone to the aquifer. In this section, we compare the radionuclide flux to the aquifer calculated with FOLAT to radionuclide fluxes calculated using the various solutions to the one-dimensional advection-dispersion equation as implemented in other assessment codes. Because the model formulation for unsaturated transport in FOLAT is quite different from that of the advection-dispersion equation, we do not expect results to match exactly. However, for an assessment model, several values are key for describing the overall behavior system. Namely, the magnitude of the maximum flux, the time of maximum flux, and the cumulative flux. We compare these three values as a means of quantifying the differences between the models. The transport equations are described first followed by four benchmark exercises.

Transport Equation

The governing transport equation in one dimension for a radionuclide with chain decay is given by

$$\theta\, Rd_j \frac{\partial C_j}{\partial t} = \nabla \cdot \theta\, D_j \nabla C_j + \nabla \cdot q\, C_j - \lambda_j \theta\, Rd_j C_j + \sum_{k=1-N}^{j \neq k} f_{i,j} \lambda_k Rd_k C_k + R_j \qquad (20)$$

where Rd is the retardation coefficient (unitless), D is the dispersion coefficient (m^2 $time^{-1}$), $f_{i,j}$ is the decay branching ratio, and other terms as defined previously.

Equation 20 was taken from the formulation in DUST (Sullivan 1996). In FOLAT, the branching ratio for all radioactive progeny is assumed to be 1. Analytical solutions exist for Equation 20 for the limiting case of a single decay chain member subjected to a constant water flux through a homogeneous isotropic porous media of infinite extent and constant dispersion

coefficient and retardation factor. In terms of a Cartesian coordinate system with water flow in the positive x direction, Equation 20 is rewritten as

$$\frac{\partial C}{\partial t} + \frac{q}{R\theta}\frac{\partial C}{\partial x} = \frac{D}{R\theta}\frac{\partial^2 C}{\partial x^2} - \lambda C \tag{21}$$

Assuming an instantaneous release of a unit mass at $x = 0$ and $t = 0$ for the initial conditions, $C = 0$ for all x at $t = 0$, and boundary condition $C = 0$ at $x = \pm\infty$, the solution to Equation 21 is

$$C(x,t) = \frac{1}{\theta\, Rd\sqrt{4\pi\, D\, t/R\, d}}\exp\left(\frac{\left(x - (q/\theta)t/R\, d\right)^2}{4Dt/Rd} - \lambda t\right) \tag{22}$$

The radionuclide flux at a distance x for the initial and boundary conditions given in Equation 22 is (Codell et al. 1982)

$$F(x,t) = \theta\left(\frac{q}{\theta}C(x,t) - D\frac{\partial C}{\partial x}\right) = \frac{x + \dfrac{qt}{\theta\, Rd}}{4\sqrt{D\pi t^3/Rd}}\exp\left(\frac{-\left(x - \dfrac{qt}{\theta Rd}\right)}{4Dt/Rd} - \lambda t\right) \tag{23}$$

Equation 22 is formulated in terms of an instantaneous release. Solutions for an arbitrary release can be arrived at through the use of the convolution integral as given in Equation 23.

$$F = \int_0^t F(x, t-\tau)\, R(\tau)\, d\tau \tag{24}$$

Equation 24 in implemented in the GWSCREEN model (Rood 1999) for a source function described by

$$R(t) = \kappa Qo \exp\left(-\left(\kappa + \lambda_1\right)t\right) \tag{25}$$

Both the GWSCREEN and DUST models are used in benchmark exercises 1 through 4. An implicit finite difference scheme is used to solve Equation 20 in DUST while GWSCREEN uses Equation 24 and 25 to calculate the flux to the aquifer from an initial inventory of a radionuclide in the soil.

Benchmark Exercise 1

Benchmark problem 1 simulates 1 Ci of I-129 in a 10 m surface soil compartment and compares the flux to the aquifer calculated with FOLAT and GWSCREEN for different values of the dispersion coefficient. The dispersion coefficient describes the spreading of the plume as it is transported down the soil column and is given by

$$D = \alpha_L \, q / \theta \tag{26}$$

where α_L = the dispersivity (m). Radionuclide independent transport parameter values are listed in Table 9. For this exercise, I-129 is assumed to have infinite solubility and a partition coefficient of zero throughout the model domain.

Table 9. Parameter Values used in Benchmark Exercises 1, 2, and 3

Parameter	Value
Thickness of source compartment (m)	10
Length of source and unsaturated compartments (m)	382
Width of source and unsaturated compartments (m)	518
Bulk density of source compartment (g cm^{-3})	1.26
Saturated hydraulic conductivity of source and unsaturated zone (m y^{-1})	1.710
Total porosity of source and unsaturated zone	0.272
Residual moisture content of source and unsaturated zone	0.0321
Alpha of source and unsaturated zone (m^{-1})	7.51
n of source and unsaturated zone	2.3
Water flux through source and unsaturated zone (m y^{-1})	0.02
Number of unsaturated compartments in FOLAT	17
Thickness of each unsaturated compartment (m)	5
Total unsaturated thickness (m)	85

The results of Benchmark Exercise 1 (Figure 4) show differences between FOLAT and GWSCREEN depending on the dispersivity value chosen. Using a dispersivity value (α_L) of 2.5 m results in nearly identical maximum flux and time of maximum flux (Table 10). Dispersion effects are represented in FOLAT by the number of compartments the unsaturated zone is composed of. The amount of spreading that occurs at a distance *x* can be described by the standard deviation of the plume as given by

$$\sigma = \sqrt{2Dt / Rd} = \sqrt{\frac{2\alpha_L q t}{\theta Rd}} \tag{27}$$

Under a state-state water flux, the mean contaminant travel time (*tt*) at a distance, *x* from the source can be approximated by

$$tt = \frac{x\theta}{q} Rd \tag{28}$$

Substitution of *tt* in Equation 28 for *t* in Equation 27 gives

$$\sigma = \sqrt{2\alpha_L x} \tag{29}$$

which provides a measure of the amount of plume spreading at the time of maximum flux. For an α_L value of 2.5 m and x = 85 m, σ = 20.6 m. Because we are interested in mimicking the behavior of the transport equation (Equations 20 and 23) in FOLAT, a relationship between σ and the thickness of the unsaturated zone compartments can be made and used as a general rule of thumb when selecting the number of compartments to use in a model simulation. The ratio of the two values is 5 m/20.61 m = 0.243. Or in other words, compartment size should be about 25% of the standard deviation of the plume at the time of maximum flux. This rule of thumb is tested in Benchmark Exercise 4.

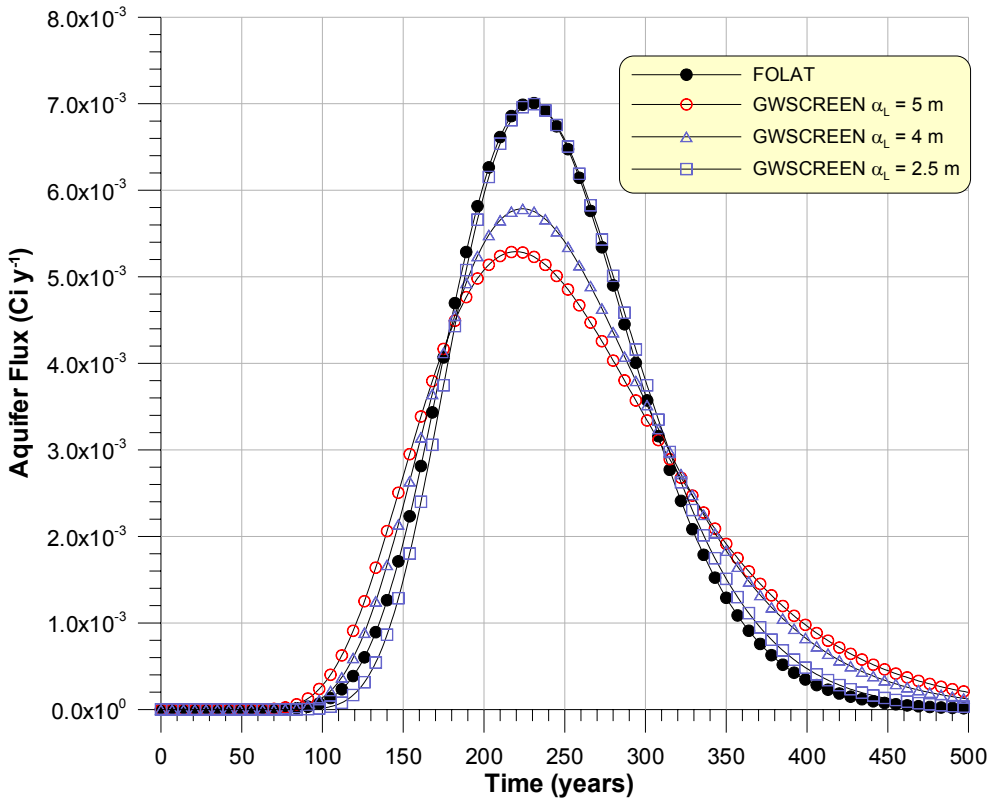

Figure 4. Iodine-129 flux to the aquifer for Benchmark Exercise 1 for GWSCREEN and FOLAT for different values of α_L.

Table 10 Maximum Flux and Time of Maximum Flux in Benchmark 1 for FOLAT and GWSCREEN

	α (m)	GWSCREEN	FOLAT	GWSCREEN/FOLAT Ratio
Maximum flux (Ci y^{-1})		5.29×10^{-3}	7.01×10^{-3}	0.755
Time of maximum flux (years)	5	217	227	0.956
Cumulative flux (Ci)		0.362	0.423	0.857
Maximum flux (Ci y^{-1})		5.79×10^{-3}	7.01×10^{-3}	0.826
Time of maximum flux (years)	4	223	227	0.982
Cumulative flux (Ci)[a]		0.385	0.423	0.910
Maximum flux (Ci y^{-1})		6.50×10^{-3}	7.01×10^{-3}	0.927
Time of maximum flux (years)	3	226	227	0.996
Cumulative flux (Ci)[a]		0.392	0.423	0.926
Maximum flux (Ci y^{-1})		7.00×10^{-3}	7.01×10^{-3}	0.999
Time of maximum flux (years)	2.5	229	227	1.01
Cumulative flux (Ci)[a]		0.406	0.423	0.959

[a.] Cumulative flux at time of maximum flux

Benchmark Exercise 2

Benchmark Exercise 2 simulates a 10 Ci U-238 source using the same model parameters as used in Benchmark Exercise 1. The partition coefficient is assumed to be zero in all layers and a solubility limit of 25 mg L^{-1} in the source is imposed. Initial pore water concentrations exceed the solubility of uranium in this case and results in a constant release rate from the source for some portion of the release history. A dispersivity value α_L of 2.5 m was used in the GWSCREEN simulation. Results (Figure 5) shows reasonably good agreement between GWSCREEN and FOLAT. The maximum flux to the aquifer for GWSCREEN and FOLAT was 3.30×10^{-2} Ci y^{-1} and 3.31×10^{-2} Ci y^{-1}, respectively. The time of maximum flux occurred during the period from 380 years to 407 years for GWSCREEN and from 370 to 393 years for FOLAT. Cumulative flux at 500 years was 1.9842 Ci and 1.9832 Ci for GWSCREEN and FOLAT, respectively.

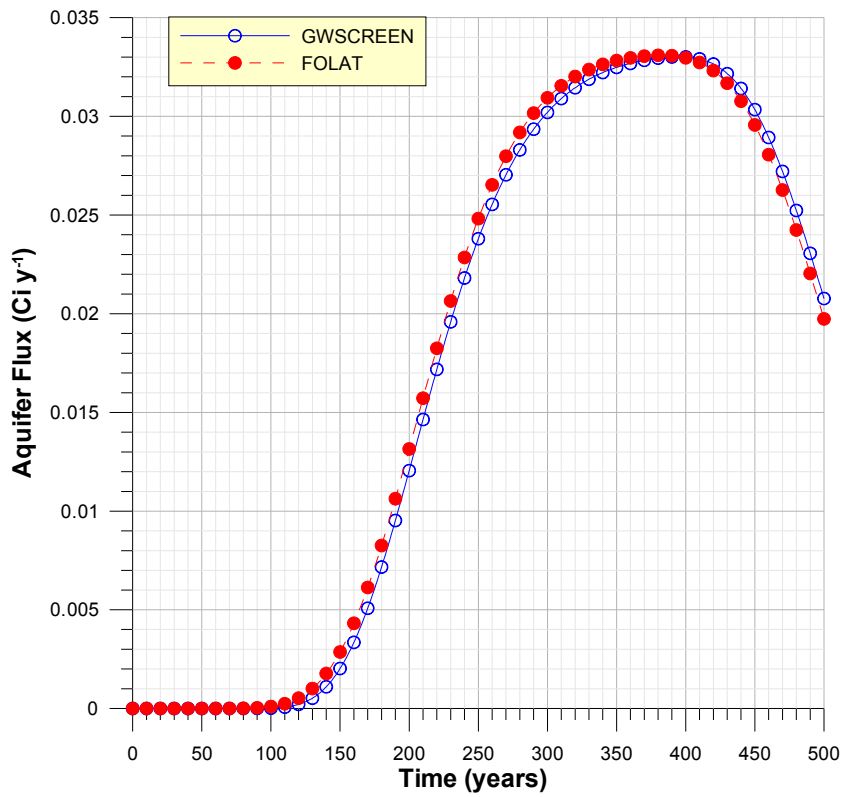

Figure 5. Uranium-238 aquifer flux as a function of time for Benchmark Exercise 2.

Benchmark Exercise 3

Benchmark Exercise 3 simulates a 2 Ci U-238 source using the same model parameters as used in Benchmark Exercise 1. The partition coefficient is assumed to be 0.5 mL g^{-1} in the source and 1.0 mL g^{-1} in the unsaturated zone. A dispersivity value of 2.5 m was used in the GWSCREEN simulation. Results (Figure 6) shows reasonably good agreement between GWSCREEN and FOLAT. The maximum flux to the aquifer for GWSCREEN and FOLAT was 4.72×10^{-4} Ci y^{-1} and 4.66×10^{-4} Ci y^{-1}, respectively. The time of maximum flux occurred during the period from 6880 years to 7004 years for GWSCREEN and from 7000 to 7006 years for FOLAT. The cumulative flux at t = 9000 years was 1.61 and 1.64 Ci for GWSCREEN and FOLAT, respectively.

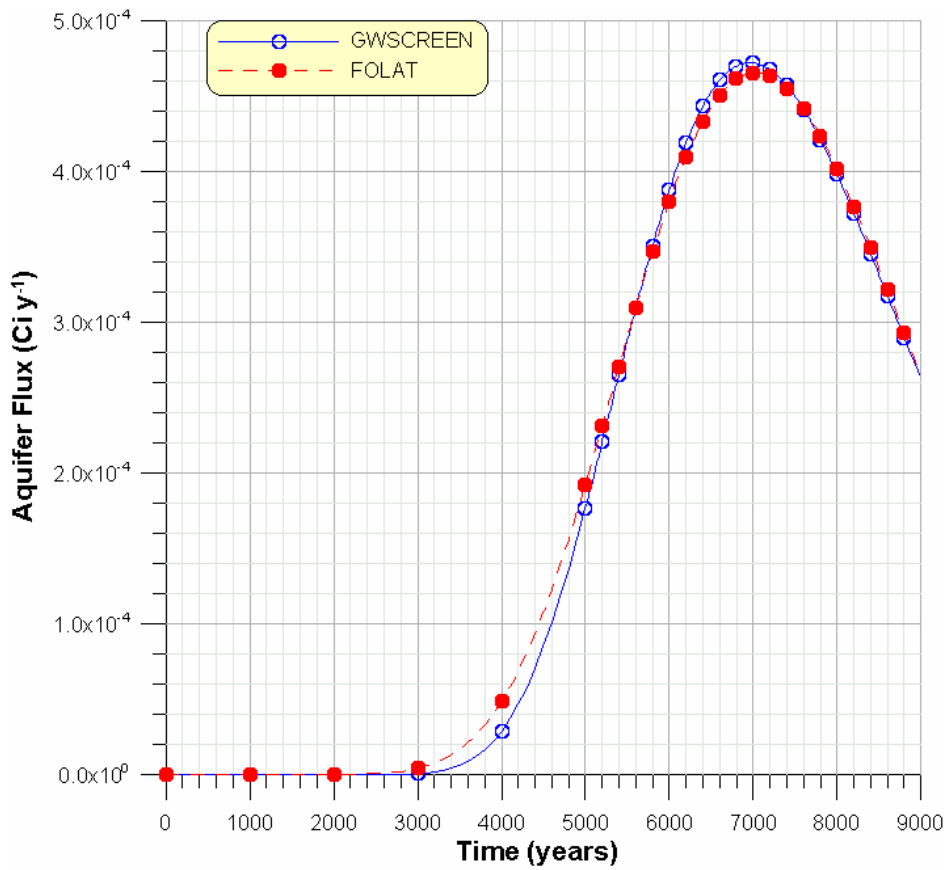

Figure 6. Uranium-238 aquifer flux as a function of time for Benchmark Exercise 3.

Benchmark Exercise 4

Benchmark Exercise 4 considers a 6.42 Ci U-238 source in a 10.6 m surface soil compartment and compares the aquifer flux of U-238 and its progeny, U-234, Th-230, and Ra-226 with values calculated by DUST. Transport parameters (Table 11) include a time-varying water flux of 0.075 m y^{-1} for the first 40 years decreasing to 0.02 m y^{-1} for all future times. The change in water flux simulates the placement of an infiltration reducing barrier over the contaminated soil. Moisture contents in DUST are not allowed to change as a function of time. Therefore, a fixed value of 0.05 was used throughout the model domain.

The number of compartments in the model was selected based on the procedure outlined earlier in Equations 27 through 29. The standard deviation of the plume at the aquifer is

$$\sigma = \sqrt{2 \times 4.1\,\mathrm{m} \times 82.3\,\mathrm{m}} = 27.978\,\mathrm{m} \tag{30}$$

Therefore, the estimated compartment thickness is 0.243 × 27.978 m = 6.31 m. Some minor adjustments were made to this value so that the number of compartments in the unsaturated zone represented a whole number.

Table 11 Parameter Values used in Benchmark Exercise 4

Parameter	Value
Thickness of source compartment (m)	10.6
Finite difference node spacing in DUST (m)	0.5
Length of source and unsaturated compartments (m)	382
Width of source and unsaturated compartments (m)	518
Initial U-238 activity (Ci)[a]	6.42
Bulk density of source compartment (g cm^{-3})	1.26
Moisture content throughout model domain (m^3 m^{-3})	0.05
Uranium partition coefficient, 0 m to 23.26 m (mL g^{-1})	0.2
Thorium partition coefficient, 0 m to 23.26 m (mL g^{-1})	5.0
Radium partition coefficient, 0 m to 23.26 m (mL g^{-1})	0.4
Uranium partition coefficient, 23.27 m to 92.9 m (mL g^{-1})	3
Thorium partition coefficient, 23.27 m to 92.9 m (mL g^{-1})	1000
Radium partition coefficient, 23.27 m to 92.9 m (mL g^{-1})	20
Water flux through source and unsaturated zone, 0 to 40 years (m y^{-1})	0.075
Water flux through source and unsaturated zone, 45 to ∞ years (m y^{-1})	0.02
Dispersivity in Dust (m)	4.1
Number of unsaturated compartments in FOLAT	13
Thickness of each unsaturated compartment (m)	6.33
Total unsaturated thickness (m)	82.3

a. In DUST, this was simulated by setting the initial U-238 pore water concentration at 10 pCi cm^{-3} in the first 22 nodes of the model domain.

Results of the simulation are presented in Table 12 and Figure 7. There are some substantial differences between the aquifer fluxes predicted by both models during the early time periods. In general, FOLAT predicts an earlier arrival of the U-238 plume compared to DUST. However, when the magnitude of the maximum flux and time of maximum flux are compared between the two models, there is no substantial difference, especially when considering the accuracy of a prospective analysis extending out to tens of thousands of years in the future. There appears to be about a 9% mass balance error in the DUST simulation for U-238, which might be improved on with smaller time steps or more finite difference nodes. Nevertheless, these benchmarks illustrate that FOLAT can mimic the behavior of the advection-dispersion transport equation.

CONCLUSIONS

The FOLAT model offers a simple approach to addressing transport of radionuclides in the unsaturated zone. Its formulation incorporates many of the processes that govern the overall behavior of radionuclide transport in the unsaturated zone when performing a prospective analysis. Some of the major processes include temporally and spatially variable water fluxes, spatially variable sorption coefficients, and radioactive progeny that travel according to their own properties. FOLAT approximates the classic advection-dispersion equation solution using ordinary differential equations. Comparison of aquifer fluxes between FOLAT and advection-

dispersion show little meaningful difference when the model is properly parameterized. The model is intended for assessment purposes and is not intended to be a mechanistic model of radionuclide transport in the unsaturated zone.

Table 12 Maximum Flux , Time of Maximum Flux, and Total Activity Released in Benchmark 4 for FOLAT and DUST

	DUST	FOLAT	DUST/FOLAT Ratio
Maximum U-238 flux (Ci y^{-1})	4.79E-04	5.23E-04	0.92
Maximum U-234 flux (Ci y^{-1})	1.88E-05	2.36E-05	0.80
Maximum Th-232 flux (Ci y^{-1})	6.09E-09	7.39E-09	0.82
Maximum Ra-226 flux (Ci y^{-1})	2.96E-07	3.59E-07	0.82
Time of U-238 maximum flux (years)	1.34E+04	1.56E+04	0.86
Time of U-234 maximum flux (years)	1.49E+04	1.67E+04	0.89
Time of Th-232 maximum flux (years)	3.12E+04	2.98E+04	1.05
Time of Ra-226 maximum flux (years)	3.23E+04	3.18E+04	1.02
Cumulative U-238 flux (Ci)	5.84E+00	6.42E+00	0.91
Cumulative U-234 flux (Ci)	2.57E-01	3.037E-01	0.85
Cumulative Th-230 flux (Ci)	6.26E-04	7.364E-04	0.85
Cumulative Ra-226 flux (Ci)	3.05E-02	3.587E-02	0.85

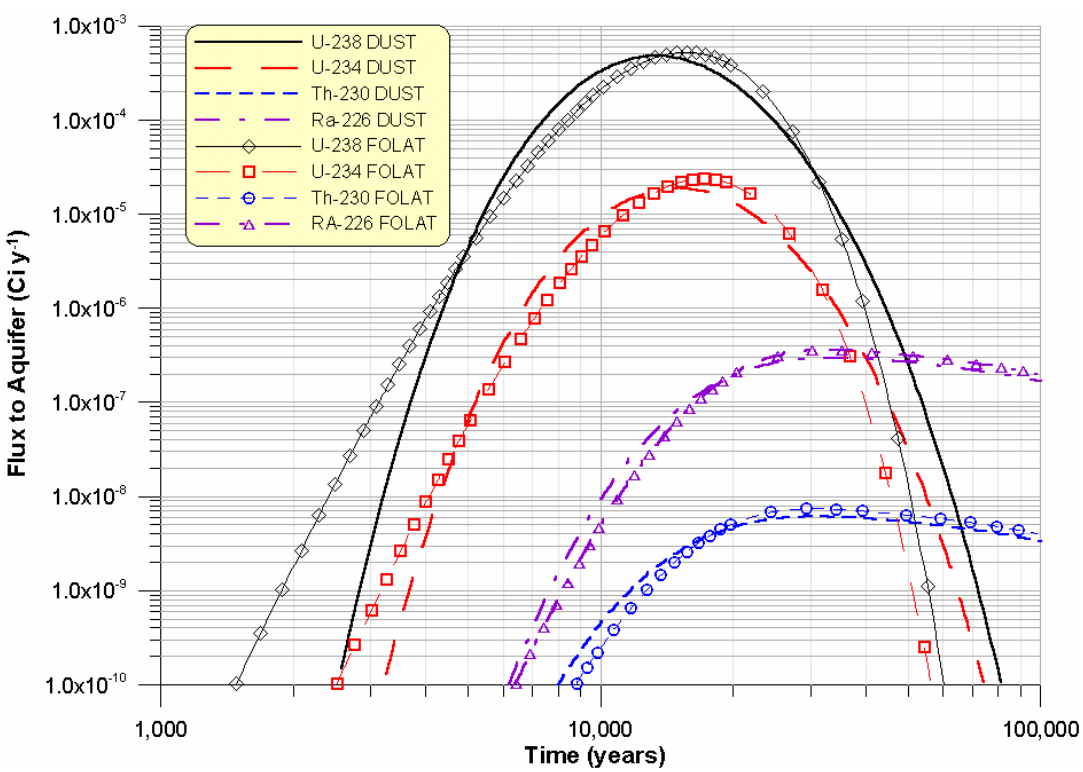

Figure 7. Flux to the aquifer as a function of time as calculated by DUST and FOLAT for the U-238 decay chain.

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APPENDIX A: FOWL: WATER FLUX PRE-PROCESSOR FOR FOLAT

APPENDIX A: A WATER FLUX PREPROCESSOR FOR FOLAT

The FOWL program is a water flux preprocessor that calculates a FOLAT compatible water flux file for either steady state or transient fluxes. The net water flux as a function of time at the surface (first compartment) is provided by the user. The FOWL model then calculates the flux through all reaming compartments as a function of time. A simple water-balance model coupled with the soil-specific moisture characteristic curve is used to calculate the net water flux through each compartment. Unit gradient conditions are assumed to exist.

The water balance equation in the first (uppermost) compartment is given by

$$\frac{d\phi_1}{dt} = q(t) - K_1(\theta_1) \tag{A-1}$$

where

ϕ_1 = the total water contained in a unit area of compartment 1 (m),
$q(t)$ = the net water flux into compartment 1 (m y^{-1}),
$K_1(\theta)$ = hydraulic conductivity as a function of moisture content (m y^{-1}).

The water balance equation in the remainder of the compartments is given by

$$\frac{d\phi_i}{dt} = K_{i-1}(\theta_{i-1}) - K_i(\theta_i) \tag{A-2}$$

where $i \neq 1$.

The moisture content for the ith compartment is given by

$$\theta_i = \frac{\phi_i}{T_i} \tag{A-3}$$

where

T_i = the thickness of the ith compartment (m),

The hydraulic conductivity as a function of moisture content is calculated using (van Genuchten 1978)

$$K(\theta) = K_{sat}\left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{1/2}\left\{1 - \left[1 - \left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{\frac{1}{m}}\right]^m\right\}^2 \tag{A-4}$$

and

$$\left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right) = \left(\frac{1}{1 + \alpha n}\right)^m \tag{A-5}$$

where

θ = volumetric moisture content ($m^3\ m^{-3}$),
θ_r = residual moisture content ($m^3\ m^{-3}$),
θ_s = saturated moisture content ($m^3\ m^{-3}$),
K_{sat} = saturated hydraulic conductivity ($m\ y^{-1}$),
α = fitting parameter (m^{-1}),
n = fitting parameter,
m = $1 - 1/n$.

Equations A-1 and A-2 are solved using a forth-order Runga-Kutta solver described in Press et al. (1992). The water flux (q) through a compartment at time t is then given by the hydraulic conductivity function for the calculated moisture content.

$$q_i(t) = K\left(\frac{\phi_i(t)}{T_i}\right) \tag{A-6}$$

The preprocessor is written in FORTRAN and is run by constructing two ASCII input files; a parameter definition file and a net infiltration file. The parameter definition file defines model options and compartment properties. Moisture contents are initialized based on the first record in the net infiltration file. Tables A-1 and A-2 describe the structure of these two files.

Execution of FOWL is performed on the command line by typing

[*path*] FOWL [*parameter definition file*]

where *path* is path to the FOWL executable. If the parameter definition file is omitted, then the program will look for the default parameter file name, FOWL.PAR. If this file is not found, the program will abort. The program will echo all input data and raw output to the file, FOWL.OUT. The output file name specified in the parameter definition file contains the FOLAT-formatted water flux in each compartment as a function of time. The number of compartments and compartment dimensions in the FOWL simulation must equal that in the FOLAT simulation.

Table A-1. Parameter Definition File for the FOWL Program

Card	Code variable	Type/format	Units	Description
1	Title	CHAR/A80		Title of run
2	Fileout	CHAR/A60		Output file name
3	Fileppt	CHAR/A60		File containing net water flux in the first compartment as a function of time
4	eps	REAL/*		Required accuracy of solution (1×10^{-6})
4	h1	REAL/*	year	Beginning time step (0.0001 year)
4	hmin	REAL/*	year	Minimum time step (1×10^{-30} year)
5	mlayer	INT/*		Number of compartments in the simulation (maximum

Table A-1. Parameter Definition File for the FOWL Program

Card	Code variable	Type/format	Units	Description
				= 50)
5	nmat	INT/*		Number of material types (must be ≤ mlayer)
5	nkt	INT/*		Number of points to describe hydraulic conductivity curve as a function of moisture content
5	qmax	REAL/*	$m\ y^{-1}$	Maximum infiltration rate for hydraulic conductivity curve vs. moisture content curve
NOTE: Card 6a, 6b, and 6c define the compartment properties and are read nmat number of times. Compartments must be defined in ascending order				
6a	h	INT/*		Beginning compartment number to define compartment properties.
6a	j	INT/*		Ending compartment number to define compartment properties.
6b	thick(*i*)	REAL/*	m	Thickness of compartment i
6c	sk(*i*)	REAL/*	$m\ y^{-1}$	Saturated hydraulic conductivity of compartment i
6c	ths(i)	REAL/*	$m^{-3}\ m^{-3}$	Saturated porosity of compartment i
6c	thr(*i*)	REAL/*	$m^{-3}\ m^{-3}$	Residual moisture content of compartment i
6c	alpha(*i*)	REAL/*	m^{-1}	van Genuchten fitting parameter for compartment i
6c	rn(*i*)	REAL/*		van Genuchten fitting parameter for compartment i
7a	ntimes	INT/*		number of output time periods
NOTE: Card 7b is read ntime number of times				
7b	t1	REAL/*	years	Begin time of output
7b	t2	REAL/*	years	End time of output
7b	tp	REAL/*	years	Print step
8	tmax	REAL/*	years	Maximum time of simulation

Table A-2. Description of the Net Infiltration Rate Input File

Line number	Code variable	Description
1	Junk	Column header (discarded)
2 to $n+1$[a]	q(k,1)	Time in years from the start of the simulation for the kth record
2 to $n+1$[a]	q(k,2)	Net infiltration rate ($m\ y^{-1}$)for the kth record

[a] n is the number of time, of infiltration rate records. A minimum of two records is needed to operate the code.

APPENDIX B: FOLAT INPUT AND OUTPUT FILES

Verification Problem 1

Parameter Definition File

```
Verification problem #1 for FOLAT
'verify1.out'
'verify1.pcp'
'verify1.inv'
1.0e-6  .1    1.0e-20                eps h1 hmin
3   1   1                             mlayer  nprog nmat
'verify1'                            cname
138                                  mw
1.                                    sol
100.                                 thalf
0. 0.  0.                            y(i)
.1  .5   1.0                         kd(i,j)
0.  0.  0.                           kx(i,j)
$ layer 1-3
1 3
1  1.5  10  10                       thick(1),rho(1) len(1) width(1)
1710,0.2724,0.0321,7.51,2.298        sk(1),ths(1),thr(1),alpha(1),rn(1)
$ output times
1                                    ntimes
0. 466. 2.0                            t1,t2,tp
```

Water Flux File

```
Time(y)  ppt (m/y)
0.0      0.1     0.05      0.025
1.0E5    0.1     0.05      0.025
```

Release Rate File

```
Time (y)      Rel (Ci/y)
0.0           1.0
1e5           1.0
```

Output File

Note: Output is truncated after 60 years

```
   ***************************************************
   *                                                 *
   *     This output was produced by the model:      *
   *                                                 *
   *                      FOLAT                      *
   *    The First-Order-Leach-And-Transport model.   *
   *    A general purpose solver for leaching and    *
   *    subsurface transport of radionuclides in     *
   *  surface or buried locations. Version date:     *
   *                     111602                      *
   *                  Arthur S. Rood                 *
   *                    K-Spar Inc                   *
   *             493 N 4154 E Rigby ID 83442         *
   *                    asr@srv.net                  *
   ***************************************************
 Date: 11/16/2002 Time: 20:19:38.990
 Input File:         verify1.par
 Output File:        verify1.out
 Pecipitation File:  verify1.pcp
 Release File:       verify1.inv
 Number of layers:          3
 Number of progeny          1
 Nuclide Names            verify
 Half lifes (y)            1.000E+02
```

```
Solubility (mg/L)         1.000E+00
Molar Weight (g/mol)      1.380E+02
Kd Value for Member 1 for Each Layer (mL/g)
 1.000E-01  5.000E-01  1.000E+00
Kx Value for Member 1 for Each Layer (1/y)
 0.000E+00  0.000E+00  0.000E+00
Initial Activity for Member 1 for Each Layer (Ci)
 0.000E+00  0.000E+00  0.000E+00
Thickness of each layer (m)
 1.000E+00  1.000E+00  1.000E+00
Bulk Density (g/cm**3)
 1.500E+00  1.500E+00  1.500E+00
K-sat (m/y)
 1.710E+03  1.710E+03  1.710E+03
Porosity
 2.724E-01  2.724E-01  2.724E-01
Residual Moisture Content
 3.210E-02  3.210E-02  3.210E-02
Alpha (1/m)
 7.510E+00  7.510E+00  7.510E+00
Van Genuchten n
 2.298E+00  2.298E+00  2.298E+00
Length (m)
 1.000E+01  1.000E+01  1.000E+01
Width (m)
 1.000E+01  1.000E+01  1.000E+01
---------------------
  Calculated Values
---------------------
Moisture Content in each Layer at each Time
 0.000E+00  6.060E-02  5.613E-02  5.235E-02
 1.000E+05  6.060E-02  5.613E-02  5.235E-02
Decay Constants of each Member (1/y)
 6.931E-03
Solubility of Each Member (Ci/m**3)
 2.593E+01
Initial Pore Water Conconcentration for Member 1 for Each Layer (Ci/m**3)
 0.000E+00  0.000E+00  0.000E+00
Initial Leach Rate for Member 1 for Each Layer (1/y)
 4.748E-01  6.203E-02  1.610E-02
Conversion factors from activity (Ci) to mass (atoms)
 1.683E+20
Conversion factors from mass (atoms) to activity (Ci)
 5.940E-21
----------------------
 Start of Calculation
----------------------
C=Concentration (Ci/m**3), I=Inventory (Ci) F=Flux (Ci/y)

ID  Time (y)      Layer  1    Layer  2    Layer  3
C1  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
I1  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
F1  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
C1  2.0000E+00  6.0955E-02  8.3398E-03  1.9270E-04
I1  2.0000E+00  1.2837E+00  6.7230E-01  2.9913E-02
F1  2.0000E+00  6.0955E-01  4.1699E-02  4.8174E-04
C1  4.0000E+00  8.4213E-02  2.4574E-02  1.2061E-03
I1  4.0000E+00  1.7735E+00  1.9810E+00  1.8722E-01
F1  4.0000E+00  8.4213E-01  1.2287E-01  3.0151E-03
C1  6.0000E+00  9.3087E-02  4.2139E-02  3.2574E-03
I1  6.0000E+00  1.9604E+00  3.3969E+00  5.0566E-01
F1  6.0000E+00  9.3087E-01  2.1069E-01  8.1435E-03
C1  8.0000E+00  9.6472E-02  5.8746E-02  6.2981E-03
I1  8.0000E+00  2.0317E+00  4.7357E+00  9.7769E-01
F1  8.0000E+00  9.6472E-01  2.9373E-01  1.5745E-02
C1  1.0000E+01  9.7764E-02  7.3713E-02  1.0197E-02
I1  1.0000E+01  2.0589E+00  5.9422E+00  1.5829E+00
F1  1.0000E+01  9.7764E-01  3.6856E-01  2.5492E-02
C1  1.2000E+01  9.8257E-02  8.6941E-02  1.4807E-02
```

I1	1.2000E+01	2.0693E+00	7.0086E+00	2.2986E+00
F1	1.2000E+01	9.8257E-01	4.3471E-01	3.7018E-02
C1	1.4000E+01	9.8445E-02	9.8538E-02	1.9990E-02
I1	1.4000E+01	2.0733E+00	7.9434E+00	3.1031E+00
F1	1.4000E+01	9.8445E-01	4.9269E-01	4.9975E-02
C1	1.6000E+01	9.8517E-02	1.0867E-01	2.5622E-02
I1	1.6000E+01	2.0748E+00	8.7601E+00	3.9774E+00
F1	1.6000E+01	9.8517E-01	5.4334E-01	6.4055E-02
C1	1.8000E+01	9.8544E-02	1.1750E-01	3.1597E-02
I1	1.8000E+01	2.0754E+00	9.4723E+00	4.9049E+00
F1	1.8000E+01	9.8544E-01	5.8752E-01	7.8991E-02
C1	2.0000E+01	9.8555E-02	1.2521E-01	3.7821E-02
I1	2.0000E+01	2.0756E+00	1.0093E+01	5.8712E+00
F1	2.0000E+01	9.8555E-01	6.2603E-01	9.4554E-02
C1	2.2000E+01	9.8559E-02	1.3192E-01	4.4219E-02
I1	2.2000E+01	2.0757E+00	1.0634E+01	6.8643E+00
F1	2.2000E+01	9.8559E-01	6.5959E-01	1.1055E-01
C1	2.4000E+01	9.8560E-02	1.3776E-01	5.0723E-02
I1	2.4000E+01	2.0757E+00	1.1106E+01	7.8739E+00
F1	2.4000E+01	9.8560E-01	6.8882E-01	1.2681E-01
C1	2.6000E+01	9.8561E-02	1.4286E-01	5.7277E-02
I1	2.6000E+01	2.0757E+00	1.1516E+01	8.8914E+00
F1	2.6000E+01	9.8561E-01	7.1429E-01	1.4319E-01
C1	2.8000E+01	9.8561E-02	1.4730E-01	6.3836E-02
I1	2.8000E+01	2.0757E+00	1.1874E+01	9.9096E+00
F1	2.8000E+01	9.8561E-01	7.3648E-01	1.5959E-01
C1	3.0000E+01	9.8561E-02	1.5116E-01	7.0361E-02
I1	3.0000E+01	2.0757E+00	1.2186E+01	1.0922E+01
F1	3.0000E+01	9.8561E-01	7.5581E-01	1.7590E-01
C1	3.2000E+01	9.8561E-02	1.5453E-01	7.6818E-02
I1	3.2000E+01	2.0757E+00	1.2457E+01	1.1925E+01
F1	3.2000E+01	9.8561E-01	7.7265E-01	1.9205E-01
C1	3.4000E+01	9.8561E-02	1.5746E-01	8.3184E-02
I1	3.4000E+01	2.0757E+00	1.2694E+01	1.2913E+01
F1	3.4000E+01	9.8561E-01	7.8732E-01	2.0796E-01
C1	3.6000E+01	9.8561E-02	1.6002E-01	8.9435E-02
I1	3.6000E+01	2.0757E+00	1.2900E+01	1.3883E+01
F1	3.6000E+01	9.8561E-01	8.0011E-01	2.2359E-01
C1	3.8000E+01	9.8561E-02	1.6225E-01	9.5554E-02
I1	3.8000E+01	2.0757E+00	1.3079E+01	1.4833E+01
F1	3.8000E+01	9.8561E-01	8.1124E-01	2.3889E-01
C1	4.0000E+01	9.8561E-02	1.6419E-01	1.0153E-01
I1	4.0000E+01	2.0757E+00	1.3236E+01	1.5761E+01
F1	4.0000E+01	9.8561E-01	8.2094E-01	2.5382E-01
C1	4.2000E+01	9.8561E-02	1.6588E-01	1.0735E-01
I1	4.2000E+01	2.0757E+00	1.3372E+01	1.6664E+01
F1	4.2000E+01	9.8561E-01	8.2939E-01	2.6837E-01
C1	4.4000E+01	9.8561E-02	1.6735E-01	1.1301E-01
I1	4.4000E+01	2.0757E+00	1.3491E+01	1.7543E+01
F1	4.4000E+01	9.8561E-01	8.3675E-01	2.8252E-01
C1	4.6000E+01	9.8561E-02	1.6863E-01	1.1850E-01
I1	4.6000E+01	2.0757E+00	1.3594E+01	1.8395E+01
F1	4.6000E+01	9.8561E-01	8.4317E-01	2.9624E-01
C1	4.8000E+01	9.8561E-02	1.6975E-01	1.2381E-01
I1	4.8000E+01	2.0757E+00	1.3684E+01	1.9220E+01
F1	4.8000E+01	9.8561E-01	8.4875E-01	3.0953E-01
C1	5.0000E+01	9.8561E-02	1.7072E-01	1.2896E-01
I1	5.0000E+01	2.0757E+00	1.3763E+01	2.0019E+01
F1	5.0000E+01	9.8561E-01	8.5362E-01	3.2239E-01
C1	5.2000E+01	9.8561E-02	1.7157E-01	1.3393E-01
I1	5.2000E+01	2.0757E+00	1.3831E+01	2.0790E+01
F1	5.2000E+01	9.8561E-01	8.5786E-01	3.3482E-01
C1	5.4000E+01	9.8561E-02	1.7231E-01	1.3872E-01
I1	5.4000E+01	2.0757E+00	1.3890E+01	2.1534E+01
F1	5.4000E+01	9.8561E-01	8.6156E-01	3.4680E-01
C1	5.6000E+01	9.8561E-02	1.7296E-01	1.4334E-01
I1	5.6000E+01	2.0757E+00	1.3942E+01	2.2252E+01
F1	5.6000E+01	9.8561E-01	8.6478E-01	3.5836E-01
C1	5.8000E+01	9.8561E-02	1.7352E-01	1.4780E-01
I1	5.8000E+01	2.0757E+00	1.3988E+01	2.2943E+01

```
 F1  5.8000E+01  9.8561E-01  8.6758E-01  3.6949E-01
```

Verification Problem 2

Parameter Definition File

```
Verification problem #2 for FOLAT
'verify2.out'
'verify2.pcp'
'verify2.inv'
1.0e-6  .1    1.0e-20                eps h1 hmin
3   1  1                              mlayer  nprog  nmat
'verify2'                            rel file name
138                                   mw
1.                                     sol
100.                                  thalf
1.  0   0                             initial y(i)
.1 .5  1.0                                 kd(i,j)
0. 0. 0.                              kx(i.j)
1 3
$ layer 1-3
1  1.5  10  10                        thick(1),rho(1) len(1) width(1)
1710,0.2724,0.0321,7.51,2.298         sk(1),ths(1),thr(1),alpha(1),rn(1)
$ output times
1                                     ntimes
0. 466. 2.0                             t1,t2,tp
```

Water Flux File

```
time     layer1  layer2    layer3  (m/y)
0.0      0.1     0.05      0.025
1.0E5    0.1     0.05      0.025
```

Release File

```
Time (y)      Rel (Ci/y)
0.0           0.0
1e5           0.0
```

Output File

Note: Output is truncated after 60 years

```
   ***************************************************
   *                                                 *
   *     This output was produced by the model:      *
   *                                                 *
   *                      FOLAT                      *
   *    The First-Order-Leach-And-Transport model.   *
   *    A general purpose solver for leaching and    *
   *    subsurface transport of radionuclides in     *
   *  surface or buried locations. Version date:     *
   *                     111602                      *
   *                  Arthur S. Rood                 *
   *                    K-Spar Inc                   *
   *             493 N 4154 E Rigby ID 83442         *
   *                    asr@srv.net                  *
   ***************************************************
 Date: 11/16/2002 Time: 20:19:42.720
 Input File:         verify2.par
 Output File:        verify2.out
 Pecipitation File:  verify2.pcp
```

```
Release File:       verify2.inv
Number of layers:          3
Number of progeny          1
Nuclide Names            verify
Half lifes (y)            1.000E+02
Solubility (mg/L)         1.000E+00
Molar Weight (g/mol)      1.380E+02
Kd Value for Member 1 for Each Layer (mL/g)
 1.000E-01  5.000E-01  1.000E+00
Kx Value for Member 1 for Each Layer (1/y)
 0.000E+00  0.000E+00  0.000E+00
Initial Activity for Member 1 for Each Layer (Ci)
 1.000E+00  0.000E+00  0.000E+00
Thickness of each layer (m)
 1.000E+00  1.000E+00  1.000E+00
Bulk Density (g/cm**3)
 1.500E+00  1.500E+00  1.500E+00
K-sat (m/y)
 1.710E+03  1.710E+03  1.710E+03
Porosity
 2.724E-01  2.724E-01  2.724E-01
Residual Moisture Content
 3.210E-02  3.210E-02  3.210E-02
Alpha (1/m)
 7.510E+00  7.510E+00  7.510E+00
Van Genuchten n
 2.298E+00  2.298E+00  2.298E+00
Length (m)
 1.000E+01  1.000E+01  1.000E+01
Width (m)
 1.000E+01  1.000E+01  1.000E+01
---------------------
  Calculated Values
---------------------
Moisture Content in each Layer at each Time
 0.000E+00  6.060E-02  5.613E-02  5.235E-02
 1.000E+05  6.060E-02  5.613E-02  5.235E-02
Decay Constants of each Member (1/y)
 6.931E-03
Solubility of Each Member (Ci/m**3)
 2.593E+01
Initial Pore Water Conconcentration for Member 1 for Each Layer (Ci/m**3)
 4.748E-02  0.000E+00  0.000E+00
Initial Leach Rate for Member 1 for Each Layer (1/y)
 4.748E-01  6.203E-02  1.610E-02
Conversion factors from activity (Ci) to mass (atoms)
 1.683E+20
Conversion factors from mass (atoms) to activity (Ci)
 5.940E-21
----------------------
 Start of Calculation
----------------------
C=Concentration (Ci/m**3), I=Inventory (Ci) F=Flux (Ci/y)

ID  Time (y)      Layer  1    Layer  2    Layer  3
C1  0.0000E+00  4.7483E-02  0.0000E+00  0.0000E+00
I1  0.0000E+00  1.0000E+00  0.0000E+00  0.0000E+00
F1  0.0000E+00  4.7483E-01  0.0000E+00  0.0000E+00
C1  2.0000E+00  1.8117E-02  6.9864E-03  2.6418E-04
I1  2.0000E+00  3.8155E-01  5.6319E-01  4.1010E-02
F1  2.0000E+00  1.8117E-01  3.4932E-02  6.6045E-04
C1  4.0000E+00  6.9125E-03  8.7520E-03  7.6373E-04
I1  4.0000E+00  1.4558E-01  7.0553E-01  1.1856E-01
F1  4.0000E+00  6.9125E-02  4.3760E-02  1.9093E-03
C1  6.0000E+00  2.6375E-03  8.6416E-03  1.2822E-03
I1  6.0000E+00  5.5546E-02  6.9663E-01  1.9905E-01
F1  6.0000E+00  2.6375E-02  4.3208E-02  3.2056E-03
C1  8.0000E+00  1.0063E-03  7.9164E-03  1.7471E-03
I1  8.0000E+00  2.1194E-02  6.3817E-01  2.7121E-01
F1  8.0000E+00  1.0063E-02  3.9582E-02  4.3677E-03
```

C1	1.0000E+01	3.8396E-04	7.0447E-03	2.1393E-03
I1	1.0000E+01	8.0864E-03	5.6789E-01	3.3210E-01
F1	1.0000E+01	3.8396E-03	3.5223E-02	5.3483E-03
C1	1.2000E+01	1.4650E-04	6.1936E-03	2.4592E-03
I1	1.2000E+01	3.0854E-03	4.9929E-01	3.8176E-01
F1	1.2000E+01	1.4650E-03	3.0968E-02	6.1480E-03
C1	1.4000E+01	5.5897E-05	5.4173E-03	2.7133E-03
I1	1.4000E+01	1.1772E-03	4.3670E-01	4.2121E-01
F1	1.4000E+01	5.5897E-04	2.7086E-02	6.7834E-03
C1	1.6000E+01	2.1328E-05	4.7276E-03	2.9099E-03
I1	1.6000E+01	4.4917E-04	3.8111E-01	4.5172E-01
F1	1.6000E+01	2.1328E-04	2.3638E-02	7.2747E-03
C1	1.8000E+01	8.1375E-06	4.1217E-03	3.0569E-03
I1	1.8000E+01	1.7138E-04	3.3226E-01	4.7453E-01
F1	1.8000E+01	8.1375E-05	2.0609E-02	7.6422E-03
C1	2.0000E+01	3.1049E-06	3.5919E-03	3.1615E-03
I1	2.0000E+01	6.5390E-05	2.8956E-01	4.9078E-01
F1	2.0000E+01	3.1049E-05	1.7960E-02	7.9039E-03
C1	2.2000E+01	1.1847E-06	3.1297E-03	3.2303E-03
I1	2.2000E+01	2.4949E-05	2.5229E-01	5.0146E-01
F1	2.2000E+01	1.1847E-05	1.5648E-02	8.0758E-03
C1	2.4000E+01	4.5201E-07	2.7267E-03	3.2688E-03
I1	2.4000E+01	9.5195E-06	2.1980E-01	5.0744E-01
F1	2.4000E+01	4.5201E-06	1.3633E-02	8.1721E-03
C1	2.6000E+01	1.7246E-07	2.3755E-03	3.2819E-03
I1	2.6000E+01	3.6321E-06	1.9149E-01	5.0947E-01
F1	2.6000E+01	1.7246E-06	1.1877E-02	8.2048E-03
C1	2.8000E+01	6.5803E-08	2.0695E-03	3.2738E-03
I1	2.8000E+01	1.3858E-06	1.6683E-01	5.0820E-01
F1	2.8000E+01	6.5803E-07	1.0347E-02	8.1844E-03
C1	3.0000E+01	2.5107E-08	1.8029E-03	3.2480E-03
I1	3.0000E+01	5.2877E-07	1.4533E-01	5.0420E-01
F1	3.0000E+01	2.5107E-07	9.0144E-03	8.1200E-03
C1	3.2000E+01	9.5797E-09	1.5706E-03	3.2077E-03
I1	3.2000E+01	2.0175E-07	1.2661E-01	4.9795E-01
F1	3.2000E+01	9.5797E-08	7.8531E-03	8.0193E-03
C1	3.4000E+01	3.6551E-09	1.3683E-03	3.1556E-03
I1	3.4000E+01	7.6978E-08	1.1030E-01	4.8986E-01
F1	3.4000E+01	3.6551E-08	6.8414E-03	7.8890E-03
C1	3.6000E+01	1.3946E-09	1.1920E-03	3.0939E-03
I1	3.6000E+01	2.9371E-08	9.6092E-02	4.8029E-01
F1	3.6000E+01	1.3946E-08	5.9601E-03	7.7349E-03
C1	3.8000E+01	5.3211E-10	1.0385E-03	3.0247E-03
I1	3.8000E+01	1.1206E-08	8.3713E-02	4.6954E-01
F1	3.8000E+01	5.3211E-09	5.1923E-03	7.5617E-03
C1	4.0000E+01	2.0303E-10	9.0468E-04	2.9495E-03
I1	4.0000E+01	4.2758E-09	7.2928E-02	4.5787E-01
F1	4.0000E+01	2.0303E-09	4.5234E-03	7.3739E-03
C1	4.2000E+01	7.7465E-11	7.8813E-04	2.8699E-03
I1	4.2000E+01	1.6314E-09	6.3533E-02	4.4551E-01
F1	4.2000E+01	7.7465E-10	3.9407E-03	7.1748E-03
C1	4.4000E+01	2.9557E-11	6.8660E-04	2.7870E-03
I1	4.4000E+01	6.2248E-10	5.5349E-02	4.3264E-01
F1	4.4000E+01	2.9557E-10	3.4330E-03	6.9675E-03
C1	4.6000E+01	1.1277E-11	5.9815E-04	2.7019E-03
I1	4.6000E+01	2.3751E-10	4.8218E-02	4.1943E-01
F1	4.6000E+01	1.1277E-10	2.9907E-03	6.7547E-03
C1	4.8000E+01	4.3029E-12	5.2109E-04	2.6154E-03
I1	4.8000E+01	9.0620E-11	4.2007E-02	4.0600E-01
F1	4.8000E+01	4.3029E-11	2.6055E-03	6.5384E-03
C1	5.0000E+01	1.6418E-12	4.5396E-04	2.5282E-03
I1	5.0000E+01	3.4576E-11	3.6595E-02	3.9247E-01
F1	5.0000E+01	1.6418E-11	2.2698E-03	6.3206E-03
C1	5.2000E+01	6.2641E-13	3.9548E-04	2.4411E-03
I1	5.2000E+01	1.3192E-11	3.1881E-02	3.7894E-01
F1	5.2000E+01	6.2641E-12	1.9774E-03	6.1027E-03
C1	5.4000E+01	2.3901E-13	3.4453E-04	2.3544E-03
I1	5.4000E+01	5.0336E-12	2.7774E-02	3.6549E-01
F1	5.4000E+01	2.3901E-12	1.7227E-03	5.8860E-03

```
 C1  5.6000E+01  9.1193E-14  3.0015E-04  2.2687E-03
 I1  5.6000E+01  1.9206E-12  2.4196E-02  3.5217E-01
 F1  5.6000E+01  9.1193E-13  1.5007E-03  5.6716E-03
 C1  5.8000E+01  3.4795E-14  2.6148E-04  2.1841E-03
 I1  5.8000E+01  7.3279E-13  2.1079E-02  3.3906E-01
 F1  5.8000E+01  3.4795E-13  1.3074E-03  5.4604E-03
 C1  6.0000E+01  1.3276E-14  2.2780E-04  2.1012E-03
 I1  6.0000E+01  2.7960E-13  1.8363E-02  3.2617E-01
 F1  6.0000E+01  1.3276E-13  1.1390E-03  5.2529E-03
```

Verification Problem 3

Parameter Definition File

```
Verification problem #3 for FOLAT - Comparison with BOXRAD for Lab 2 Problem
'verify3.out'
'verify3.pcp'
'verify3.inv'
1.0e-4  .001    1.0e-30                eps h1 hmin
4   2    4                            mlayer  nprog  nmat
'Pu-241' 'Am-241'                       rel file name
241   241                               mw
10000.  10000                                  sol
14.4   432                              thalf
$
2.40E-05  5.46E-04  6.75e-5 2.72e-11     initial pu241 layer 1-4
4.80E-07  2.93E-06  2.25e-7 2.86e-14   initial am241 layer 1-4
10  15  22  22                         kd pu241 layer 1-4
50  60  70  70                         kd am241 layer 1-4
0.  0.  0.  0.                         kx pu241 layer 1-4
0.  0.  0.  0.                         kx am241 layer 1-4
$ layer 1
1 1
0.02  1.2  1  1                       thick(1),rho(1) len(1) width(1)
1710,0.2724,0.0321,7.51,2.298        sk(1),ths(1),thr(1),alpha(1),rn(1)
$  layer 2
2  2
0.13  1.5  1  1                       thick(2),rho(2)  len(2) width(2)
1710,0.2724,0.0321,7.51,2.298        sk(2),ths(2),thr(2),alpha(2),rn(2)
$  layer 3
3  3
0.15  1.5   1  1                      thick(3),rho(3)  len(2) width(2)
1710,0.2724,0.0321,7.51,2.298        sk(3),ths(3),thr(3),alpha(3),rn(3)
$  layer 4
4  4
0.2  1.8   1  1                      thick(3),rho(3)  len(2) width(2)
1710,0.2724,0.0321,7.51,2.298        sk(3),ths(3),thr(3),alpha(3),rn(3)
$
1                                   ntimes
0.00   150    1.00E+00          tstart tend tp
```

Water Flux File

```
time     layer1  layer2    layer3  layer 4 (m/y)
0.0      0.2     0.2        0.2    0.2
1.0E5    0.2     0.2        0.2    0.2
```

Release File

```
Time (y)      Rel (Ci/y)
0.0           0.0
1e5           0.0
```

Output File

Note: Output is truncated after 100 years

```
  ****************************************************
  *                                                  *
  *     This output was produced by the model:       *
  *                                                  *
  *                       FOLAT                      *
  *    The First-Order-Leach-And-Transport model.    *
  *    A general purpose solver for leaching and     *
  *    subsurface transport of radionuclides in      *
  *  surface or buried locations. Version date:      *
  *                      111602                      *
  *                  Arthur S. Rood                  *
  *                    K-Spar Inc                    *
  *             493 N 4154 E Rigby ID 83442          *
  *                    asr@srv.net                   *
  ****************************************************
Date: 11/16/2002 Time: 20:19:45.520
Input File:         verify3.par
Output File:        verify3.out
Pecipitation File:  verify3.pcp
Release File:       verify3.inv
Number of layers:          4
Number of progeny          2
Nuclide Names            Pu-241 Am-241
Half lifes (y)            1.440E+01  4.320E+02
Solubility (mg/L)         1.000E+04  1.000E+04
Molar Weight (g/mol)      2.410E+02  2.410E+02
Kd Value for Member 1 for Each Layer (mL/g)
 1.000E+01  1.500E+01  2.200E+01  2.200E+01
Kd Value for Member 2 for Each Layer (mL/g)
 5.000E+01  6.000E+01  7.000E+01  7.000E+01
Kx Value for Member 1 for Each Layer (1/y)
 0.000E+00  0.000E+00  0.000E+00  0.000E+00
Kx Value for Member 2 for Each Layer (1/y)
 0.000E+00  0.000E+00  0.000E+00  0.000E+00
Initial Activity for Member 1 for Each Layer (Ci)
 2.400E-05  5.460E-04  6.750E-05  2.720E-11
Initial Activity for Member 2 for Each Layer (Ci)
 4.800E-07  2.930E-06  2.250E-07  2.860E-14
Thickness of each layer (m)
 2.000E-02  1.300E-01  1.500E-01  2.000E-01
Bulk Density (g/cm**3)
 1.200E+00  1.500E+00  1.500E+00  1.800E+00
K-sat (m/y)
 1.710E+03  1.710E+03  1.710E+03  1.710E+03
Porosity
 2.724E-01  2.724E-01  2.724E-01  2.724E-01
Residual Moisture Content
 3.210E-02  3.210E-02  3.210E-02  3.210E-02
Alpha (1/m)
 7.510E+00  7.510E+00  7.510E+00  7.510E+00
Van Genuchten n
 2.298E+00  2.298E+00  2.298E+00  2.298E+00
Length (m)
 1.000E+00  1.000E+00  1.000E+00  1.000E+00
Width (m)
 1.000E+00  1.000E+00  1.000E+00  1.000E+00
---------------------
  Calculated Values
---------------------
Moisture Content in each Layer at each Time
 0.000E+00  6.591E-02  6.591E-02  6.591E-02  6.591E-02
 1.000E+05  6.591E-02  6.591E-02  6.591E-02  6.591E-02
Decay Constants of each Member (1/y)
 4.814E-02  1.605E-03
Solubility of Each Member (Ci/m**3)
```

```
 1.031E+06  3.437E+04
Initial Pore Water Conconcentration for Member 1 for Each Layer (Ci/m**3)
 9.945E-05  1.861E-04  1.361E-05  3.429E-12
Initial Pore Water Conconcentration for Member 2 for Each Layer (Ci/m**3)
 1.989E-06  9.988E-07  4.536E-08  3.605E-15
Initial Leach Rate for Member 1 for Each Layer (1/y)
 8.288E-01  6.818E-02  4.032E-02  2.521E-02
Initial Leach Rate for Member 2 for Each Layer (1/y)
 1.665E-01  1.708E-02  1.269E-02  7.932E-03
Conversion factors from activity (Ci) to mass (atoms)
 2.424E+19  7.272E+20
Conversion factors from mass (atoms) to activity (Ci)
 4.125E-20  1.375E-21
----------------------
 Start of Calculation
----------------------
C=Concentration (Ci/m**3), I=Inventory (Ci) F=Flux (Ci/y)

ID  Time (y)      Layer  1    Layer  2    Layer  3    Layer  4
C1  0.0000E+00  9.9454E-05  1.8612E-04  1.3609E-05  3.4286E-12
I1  0.0000E+00  2.4000E-05  5.4600E-04  6.7500E-05  2.7200E-11
F1  0.0000E+00  1.9891E-05  3.7224E-05  2.7218E-06  6.8573E-13
C2  0.0000E+00  1.9891E-06  9.9878E-07  4.5364E-08  3.6051E-15
I2  0.0000E+00  4.8000E-07  2.9300E-06  2.2500E-07  2.8600E-14
F2  0.0000E+00  7.9912E-08  5.0049E-08  2.8554E-09  2.2687E-16
C1  1.0000E+00  4.1379E-05  1.6991E-04  1.9329E-05  4.0354E-07
I1  1.0000E+00  9.9855E-06  4.9845E-04  9.5869E-05  3.2013E-06
F1  1.0000E+00  8.2758E-06  3.3982E-05  3.8658E-06  8.0708E-08
C2  1.0000E+00  3.5715E-07  3.2299E-07  2.6005E-08  2.5343E-10
I2  1.0000E+00  4.2905E-07  3.7817E-06  4.0983E-07  6.3897E-09
F2  1.0000E+00  7.1430E-08  6.4597E-08  5.2009E-09  5.0685E-11
C1  2.0000E+00  1.7216E-05  1.5301E-04  2.3918E-05  9.0351E-07
I1  2.0000E+00  4.1546E-06  4.4888E-04  1.1863E-04  7.1677E-06
F1  2.0000E+00  3.4433E-06  3.0603E-05  4.7835E-06  1.8070E-07
C2  2.0000E+00  3.0997E-07  3.8693E-07  4.1008E-08  8.3898E-10
I2  2.0000E+00  3.7237E-07  4.5304E-06  6.4628E-07  2.1153E-08
F2  2.0000E+00  6.1994E-08  7.7387E-08  8.2016E-09  1.6780E-10
C1  3.0000E+00  7.1631E-06  1.3694E-04  2.7479E-05  1.4668E-06
I1  3.0000E+00  1.7286E-06  4.0173E-04  1.3629E-04  1.1636E-05
F1  3.0000E+00  1.4326E-06  2.7389E-05  5.4959E-06  2.9335E-07
C2  3.0000E+00  2.6537E-07  4.4232E-07  5.8587E-08  1.8164E-09
I2  3.0000E+00  3.1879E-07  5.1790E-06  9.2332E-07  4.5798E-08
F2  3.0000E+00  5.3074E-08  8.8465E-08  1.1717E-08  3.6329E-10
C1  4.0000E+00  2.9803E-06  1.2221E-04  3.0145E-05  2.0655E-06
I1  4.0000E+00  7.1920E-07  3.5852E-04  1.4951E-04  1.6386E-05
F1  4.0000E+00  5.9606E-07  2.4442E-05  6.0289E-06  4.1310E-07
C2  4.0000E+00  2.2571E-07  4.8983E-07  7.8118E-08  3.2245E-09
I2  4.0000E+00  2.7115E-07  5.7352E-06  1.2311E-06  8.1300E-08
F2  4.0000E+00  4.5142E-08  9.7967E-08  1.5624E-08  6.4490E-10
C1  5.0000E+00  1.2400E-06  1.0892E-04  3.2044E-05  2.6770E-06
I1  5.0000E+00  2.9923E-07  3.1952E-04  1.5894E-04  2.1237E-05
F1  5.0000E+00  2.4800E-07  2.1784E-05  6.4088E-06  5.3539E-07
C2  5.0000E+00  1.9137E-07  5.3026E-07  9.9064E-08  5.0842E-09
I2  5.0000E+00  2.2990E-07  6.2085E-06  1.5612E-06  1.2819E-07
F2  5.0000E+00  3.8274E-08  1.0605E-07  1.9813E-08  1.0168E-09
C1  6.0000E+00  5.1592E-07  9.7012E-05  3.3297E-05  3.2832E-06
I1  6.0000E+00  1.2450E-07  2.8459E-04  1.6515E-04  2.6046E-05
F1  6.0000E+00  1.0318E-07  1.9402E-05  6.6595E-06  6.5664E-07
C2  6.0000E+00  1.6200E-07  5.6438E-07  1.2097E-07  7.4023E-09
I2  6.0000E+00  1.9462E-07  6.6081E-06  1.9064E-06  1.8663E-07
F2  6.0000E+00  3.2400E-08  1.1288E-07  2.4193E-08  1.4805E-09
C1  7.0000E+00  2.1465E-07  8.6382E-05  3.4010E-05  3.8702E-06
I1  7.0000E+00  5.1800E-08  2.5341E-04  1.6869E-04  3.0703E-05
F1  7.0000E+00  4.2931E-08  1.7276E-05  6.8020E-06  7.7404E-07
C2  7.0000E+00  1.3704E-07  5.9293E-07  1.4344E-07  1.0174E-08
I2  7.0000E+00  1.6463E-07  6.9424E-06  2.2606E-06  2.5652E-07
F2  7.0000E+00  2.7408E-08  1.1859E-07  2.8688E-08  2.0348E-09
C1  8.0000E+00  8.9309E-08  7.6906E-05  3.4275E-05  4.4273E-06
I1  8.0000E+00  2.1552E-08  2.2561E-04  1.7000E-04  3.5122E-05
F1  8.0000E+00  1.7862E-08  1.5381E-05  6.8551E-06  8.8546E-07
```

C2	8.0000E+00	1.1588E-07	6.1656E-07	1.6617E-07	1.3386E-08
I2	8.0000E+00	1.3921E-07	7.2191E-06	2.6187E-06	3.3750E-07
F2	8.0000E+00	2.3175E-08	1.2331E-07	3.3233E-08	2.6772E-09
C1	9.0000E+00	3.7158E-08	6.8466E-05	3.4173E-05	4.9468E-06
I1	9.0000E+00	8.9670E-09	2.0085E-04	1.6950E-04	3.9244E-05
F1	9.0000E+00	7.4317E-09	1.3693E-05	6.8346E-06	9.8936E-07
C2	9.0000E+00	9.7966E-08	6.3586E-07	1.8887E-07	1.7017E-08
I2	9.0000E+00	1.1769E-07	7.4451E-06	2.9766E-06	4.2906E-07
F2	9.0000E+00	1.9593E-08	1.2717E-07	3.7775E-08	3.4035E-09
C1	1.0000E+01	1.5460E-08	6.0949E-05	3.3772E-05	5.4232E-06
I1	1.0000E+01	3.7308E-09	1.7880E-04	1.6751E-04	4.3024E-05
F1	1.0000E+01	3.0921E-09	1.2190E-05	6.7545E-06	1.0846E-06
C2	1.0000E+01	8.2816E-08	6.5136E-07	2.1135E-07	2.1043E-08
I2	1.0000E+01	9.9488E-08	7.6264E-06	3.3309E-06	5.3057E-07
F2	1.0000E+01	1.6563E-08	1.3027E-07	4.2270E-08	4.2087E-09
C1	1.1000E+01	6.4324E-09	5.4258E-05	3.3132E-05	5.8532E-06
I1	1.1000E+01	1.5523E-09	1.5917E-04	1.6433E-04	4.6434E-05
F1	1.1000E+01	1.2865E-09	1.0852E-05	6.6264E-06	1.1706E-06
C2	1.1000E+01	7.0006E-08	6.6350E-07	2.3342E-07	2.5435E-08
I2	1.1000E+01	8.4099E-08	7.7686E-06	3.6787E-06	6.4129E-07
F2	1.1000E+01	1.4001E-08	1.3270E-07	4.6684E-08	5.0869E-09
C1	1.2000E+01	2.6763E-09	4.8300E-05	3.2302E-05	6.2348E-06
I1	1.2000E+01	6.4584E-10	1.4169E-04	1.6021E-04	4.9461E-05
F1	1.2000E+01	5.3526E-10	9.6601E-06	6.4604E-06	1.2470E-06
C2	1.2000E+01	5.9175E-08	6.7270E-07	2.5494E-07	3.0161E-08
I2	1.2000E+01	7.1089E-08	7.8764E-06	4.0178E-06	7.6044E-07
F2	1.2000E+01	1.1835E-08	1.3454E-07	5.0987E-08	6.0321E-09
C1	1.3000E+01	1.1135E-09	4.2997E-05	3.1325E-05	6.5673E-06
I1	1.3000E+01	2.6871E-10	1.2613E-04	1.5537E-04	5.2099E-05
F1	1.3000E+01	2.2270E-10	8.5994E-06	6.2651E-06	1.3135E-06
C2	1.3000E+01	5.0020E-08	6.7933E-07	2.7579E-07	3.5188E-08
I2	1.3000E+01	6.0090E-08	7.9540E-06	4.3465E-06	8.8721E-07
F2	1.3000E+01	1.0004E-08	1.3587E-07	5.5159E-08	7.0376E-09
C1	1.4000E+01	4.6329E-10	3.8276E-05	3.0239E-05	6.8511E-06
I1	1.4000E+01	1.1180E-10	1.1228E-04	1.4998E-04	5.4351E-05
F1	1.4000E+01	9.2658E-11	7.6552E-06	6.0477E-06	1.3702E-06
C2	1.4000E+01	4.2281E-08	6.8369E-07	2.9591E-07	4.0485E-08
I2	1.4000E+01	5.0793E-08	8.0051E-06	4.6634E-06	1.0207E-06
F2	1.4000E+01	8.4563E-09	1.3674E-07	5.9181E-08	8.0969E-09
C1	1.5000E+01	1.9276E-10	3.4073E-05	2.9072E-05	7.0874E-06
I1	1.5000E+01	4.6516E-11	9.9956E-05	1.4419E-04	5.6226E-05
F1	1.5000E+01	3.8552E-11	6.8146E-06	5.8144E-06	1.4175E-06
C2	1.5000E+01	3.5740E-08	6.8608E-07	3.1521E-07	4.6017E-08
I2	1.5000E+01	4.2935E-08	8.0331E-06	4.9676E-06	1.1602E-06
F2	1.5000E+01	7.1479E-09	1.3722E-07	6.3042E-08	9.2034E-09
C1	1.6000E+01	8.0200E-11	3.0332E-05	2.7851E-05	7.2780E-06
I1	1.6000E+01	1.9354E-11	8.8981E-05	1.3814E-04	5.7737E-05
F1	1.6000E+01	1.6040E-11	6.0664E-06	5.5702E-06	1.4556E-06
C2	1.6000E+01	3.0210E-08	6.8675E-07	3.3366E-07	5.1753E-08
I2	1.6000E+01	3.6292E-08	8.0408E-06	5.2584E-06	1.3049E-06
F2	1.6000E+01	6.0420E-09	1.3735E-07	6.6731E-08	1.0351E-08
C1	1.7000E+01	3.3368E-11	2.7001E-05	2.6597E-05	7.4249E-06
I1	1.7000E+01	8.0524E-12	7.9210E-05	1.3192E-04	5.8903E-05
F1	1.7000E+01	6.6736E-12	5.4003E-06	5.3194E-06	1.4850E-06
C2	1.7000E+01	2.5536E-08	6.8591E-07	3.5122E-07	5.7662E-08
I2	1.7000E+01	3.0677E-08	8.0310E-06	5.5352E-06	1.4538E-06
F2	1.7000E+01	5.1072E-09	1.3718E-07	7.0244E-08	1.1532E-08
C1	1.8000E+01	1.3883E-11	2.4037E-05	2.5328E-05	7.5307E-06
I1	1.8000E+01	3.3503E-12	7.0513E-05	1.2563E-04	5.9743E-05
F1	1.8000E+01	2.7767E-12	4.8073E-06	5.0657E-06	1.5061E-06
C2	1.8000E+01	2.1585E-08	6.8376E-07	3.6788E-07	6.3713E-08
I2	1.8000E+01	2.5930E-08	8.0058E-06	5.7978E-06	1.6064E-06
F2	1.8000E+01	4.3170E-09	1.3675E-07	7.3576E-08	1.2743E-08
C1	1.9000E+01	5.7763E-12	2.1397E-05	2.4059E-05	7.5982E-06
I1	1.9000E+01	1.3939E-12	6.2770E-05	1.1933E-04	6.0278E-05
F1	1.9000E+01	1.1553E-12	4.2795E-06	4.8118E-06	1.5196E-06
C2	1.9000E+01	1.8245E-08	6.8047E-07	3.8364E-07	6.9877E-08
I2	1.9000E+01	2.1918E-08	7.9673E-06	6.0460E-06	1.7618E-06
F2	1.9000E+01	3.6491E-09	1.3609E-07	7.6727E-08	1.3975E-08

C1	2.0000E+01	2.4033E-12	1.9048E-05	2.2801E-05	7.6302E-06
I1	2.0000E+01	5.7997E-13	5.5878E-05	1.1309E-04	6.0532E-05
F1	2.0000E+01	4.8066E-13	3.8096E-06	4.5602E-06	1.5260E-06
C2	2.0000E+01	1.5422E-08	6.7620E-07	3.9848E-07	7.6129E-08
I2	2.0000E+01	1.8527E-08	7.9174E-06	6.2801E-06	1.9195E-06
F2	2.0000E+01	3.0845E-09	1.3524E-07	7.9697E-08	1.5226E-08
C1	2.1000E+01	9.9993E-13	1.6956E-05	2.1564E-05	7.6296E-06
I1	2.1000E+01	2.4130E-13	4.9743E-05	1.0696E-04	6.0527E-05
F1	2.1000E+01	1.9999E-13	3.3913E-06	4.3128E-06	1.5259E-06
C2	2.1000E+01	1.3036E-08	6.7108E-07	4.1244E-07	8.2443E-08
I2	2.1000E+01	1.5661E-08	7.8574E-06	6.5000E-06	2.0787E-06
F2	2.1000E+01	2.6072E-09	1.3422E-07	8.2487E-08	1.6489E-08
C1	2.2000E+01	4.1604E-13	1.5094E-05	2.0356E-05	7.5992E-06
I1	2.2000E+01	1.0040E-13	4.4281E-05	1.0096E-04	6.0286E-05
F1	2.2000E+01	8.3207E-14	3.0189E-06	4.0711E-06	1.5198E-06
C2	2.2000E+01	1.1019E-08	6.6524E-07	4.2551E-07	8.8796E-08
I2	2.2000E+01	1.3238E-08	7.7890E-06	6.7060E-06	2.2388E-06
F2	2.2000E+01	2.2039E-09	1.3305E-07	8.5102E-08	1.7759E-08
C1	2.3000E+01	1.7310E-13	1.3437E-05	1.9182E-05	7.5421E-06
I1	2.3000E+01	4.1772E-14	3.9419E-05	9.5140E-05	5.9833E-05
F1	2.3000E+01	3.4619E-14	2.6874E-06	3.8364E-06	1.5084E-06
C2	2.3000E+01	9.3144E-09	6.5877E-07	4.3772E-07	9.5166E-08
I2	2.3000E+01	1.1190E-08	7.7132E-06	6.8984E-06	2.3994E-06
F2	2.3000E+01	1.8629E-09	1.3175E-07	8.7544E-08	1.9033E-08
C1	2.4000E+01	7.2019E-14	1.1962E-05	1.8047E-05	7.4610E-06
I1	2.4000E+01	1.7380E-14	3.5090E-05	8.9511E-05	5.9189E-05
F1	2.4000E+01	1.4404E-14	2.3923E-06	3.6094E-06	1.4922E-06
C2	2.4000E+01	7.8732E-09	6.5177E-07	4.4910E-07	1.0153E-07
I2	2.4000E+01	9.4583E-09	7.6313E-06	7.0777E-06	2.5600E-06
F2	2.4000E+01	1.5746E-09	1.3035E-07	8.9819E-08	2.0307E-08
C1	2.5000E+01	2.9965E-14	1.0648E-05	1.6955E-05	7.3585E-06
I1	2.5000E+01	7.2310E-15	3.1237E-05	8.4093E-05	5.8376E-05
F1	2.5000E+01	5.9929E-15	2.1296E-06	3.3909E-06	1.4717E-06
C2	2.5000E+01	6.6551E-09	6.4432E-07	4.5966E-07	1.0788E-07
I2	2.5000E+01	7.9949E-09	7.5441E-06	7.2442E-06	2.7200E-06
F2	2.5000E+01	1.3310E-09	1.2886E-07	9.1932E-08	2.1576E-08
C1	2.6000E+01	1.2467E-14	9.4790E-06	1.5907E-05	7.2372E-06
I1	2.6000E+01	3.0086E-15	2.7807E-05	7.8896E-05	5.7414E-05
F1	2.6000E+01	2.4934E-15	1.8958E-06	3.1814E-06	1.4474E-06
C2	2.6000E+01	5.6254E-09	6.3650E-07	4.6944E-07	1.1419E-07
I2	2.6000E+01	6.7579E-09	7.4525E-06	7.3983E-06	2.8792E-06
F2	2.6000E+01	1.1251E-09	1.2730E-07	9.3888E-08	2.2839E-08
C1	2.7000E+01	5.1871E-15	8.4382E-06	1.4905E-05	7.0997E-06
I1	2.7000E+01	1.2518E-15	2.4754E-05	7.3928E-05	5.6323E-05
F1	2.7000E+01	1.0374E-15	1.6876E-06	2.9811E-06	1.4199E-06
C2	2.7000E+01	4.7550E-09	6.2837E-07	4.7847E-07	1.2045E-07
I2	2.7000E+01	5.7123E-09	7.3573E-06	7.5406E-06	3.0370E-06
F2	2.7000E+01	9.5101E-10	1.2567E-07	9.5694E-08	2.4091E-08
C1	2.8000E+01	2.1582E-15	7.5117E-06	1.3951E-05	6.9481E-06
I1	2.8000E+01	5.2081E-16	2.2036E-05	6.9193E-05	5.5120E-05
F1	2.8000E+01	4.3164E-16	1.5023E-06	2.7901E-06	1.3896E-06
C2	2.8000E+01	4.0193E-09	6.1998E-07	4.8677E-07	1.2665E-07
I2	2.8000E+01	4.8285E-09	7.2591E-06	7.6715E-06	3.1933E-06
F2	2.8000E+01	8.0387E-10	1.2400E-07	9.7355E-08	2.5330E-08
C1	2.9000E+01	8.9794E-16	6.6869E-06	1.3043E-05	6.7845E-06
I1	2.9000E+01	2.1669E-16	1.9616E-05	6.4691E-05	5.3823E-05
F1	2.9000E+01	1.7959E-16	1.3374E-06	2.6086E-06	1.3569E-06
C2	2.9000E+01	3.3975E-09	6.1139E-07	4.9439E-07	1.3277E-07
I2	2.9000E+01	4.0814E-09	7.1585E-06	7.7915E-06	3.3476E-06
F2	2.9000E+01	6.7949E-10	1.2228E-07	9.8877E-08	2.6555E-08
C1	3.0000E+01	3.7360E-16	5.9526E-06	1.2182E-05	6.6111E-06
I1	3.0000E+01	9.0157E-17	1.7463E-05	6.0422E-05	5.2447E-05
F1	3.0000E+01	7.4720E-17	1.1905E-06	2.4364E-06	1.3222E-06
C2	3.0000E+01	2.8718E-09	6.0264E-07	5.0134E-07	1.3881E-07
I2	3.0000E+01	3.4499E-09	7.0560E-06	7.9010E-06	3.4998E-06
F2	3.0000E+01	5.7436E-10	1.2053E-07	1.0027E-07	2.7762E-08
C1	3.1000E+01	1.5544E-16	5.2990E-06	1.1367E-05	6.4296E-06
I1	3.1000E+01	3.7511E-17	1.5545E-05	5.6381E-05	5.1007E-05
F1	3.1000E+01	3.1088E-17	1.0598E-06	2.2735E-06	1.2859E-06
C2	3.1000E+01	2.4275E-09	5.9377E-07	5.0766E-07	1.4475E-07

I2	3.1000E+01	2.9162E-09	6.9521E-06	8.0007E-06	3.6496E-06
F2	3.1000E+01	4.8549E-10	1.1875E-07	1.0153E-07	2.8950E-08
C1	3.2000E+01	6.4673E-17	4.7172E-06	1.0598E-05	6.2416E-06
I1	3.2000E+01	1.5607E-17	1.3838E-05	5.2565E-05	4.9516E-05
F1	3.2000E+01	1.2935E-17	9.4344E-07	2.1196E-06	1.2483E-06
C2	3.2000E+01	2.0519E-09	5.8480E-07	5.1339E-07	1.5059E-07
I2	3.2000E+01	2.4650E-09	6.8472E-06	8.0909E-06	3.7969E-06
F2	3.2000E+01	4.1038E-10	1.1696E-07	1.0268E-07	3.0118E-08
C1	3.3000E+01	2.6908E-17	4.1992E-06	9.8725E-06	6.0488E-06
I1	3.3000E+01	6.4935E-18	1.2319E-05	4.8966E-05	4.7986E-05
F1	3.3000E+01	5.3817E-18	8.3985E-07	1.9745E-06	1.2098E-06
C2	3.3000E+01	1.7344E-09	5.7578E-07	5.1854E-07	1.5632E-07
I2	3.3000E+01	2.0836E-09	6.7416E-06	8.1721E-06	3.9414E-06
F2	3.3000E+01	3.4688E-10	1.1516E-07	1.0371E-07	3.1265E-08
C1	3.4000E+01	1.1196E-17	3.7381E-06	9.1896E-06	5.8525E-06
I1	3.4000E+01	2.7017E-18	1.0966E-05	4.5579E-05	4.6429E-05
F1	3.4000E+01	2.2391E-18	7.4763E-07	1.8379E-06	1.1705E-06
C2	3.4000E+01	1.4661E-09	5.6673E-07	5.2315E-07	1.6194E-07
I2	3.4000E+01	1.7612E-09	6.6356E-06	8.2449E-06	4.0831E-06
F2	3.4000E+01	2.9321E-10	1.1335E-07	1.0463E-07	3.2389E-08
C1	3.5000E+01	4.6581E-18	3.3277E-06	8.5476E-06	5.6541E-06
I1	3.5000E+01	1.1241E-18	9.7620E-06	4.2395E-05	4.4855E-05
F1	3.5000E+01	9.3161E-19	6.6554E-07	1.7095E-06	1.1308E-06
C2	3.5000E+01	1.2392E-09	5.5767E-07	5.2726E-07	1.6744E-07
I2	3.5000E+01	1.4887E-09	6.5295E-06	8.3095E-06	4.2218E-06
F2	3.5000E+01	2.4785E-10	1.1153E-07	1.0545E-07	3.3489E-08
C1	3.6000E+01	1.9380E-18	2.9623E-06	7.9451E-06	5.4545E-06
I1	3.6000E+01	4.6769E-19	8.6901E-06	3.9407E-05	4.3271E-05
F1	3.6000E+01	3.8761E-19	5.9246E-07	1.5890E-06	1.0909E-06
C2	3.6000E+01	1.0475E-09	5.4861E-07	5.3088E-07	1.7282E-07
I2	3.6000E+01	1.2584E-09	6.4235E-06	8.3665E-06	4.3574E-06
F2	3.6000E+01	2.0950E-10	1.0972E-07	1.0618E-07	3.4564E-08
C1	3.7000E+01	8.0635E-19	2.6370E-06	7.3803E-06	5.2548E-06
I1	3.7000E+01	1.9459E-19	7.7359E-06	3.6606E-05	4.1688E-05
F1	3.7000E+01	1.6127E-19	5.2741E-07	1.4761E-06	1.0510E-06
C2	3.7000E+01	8.8543E-10	5.3959E-07	5.3404E-07	1.7808E-07
I2	3.7000E+01	1.0637E-09	6.3178E-06	8.4164E-06	4.4898E-06
F2	3.7000E+01	1.7709E-10	1.0792E-07	1.0681E-07	3.5615E-08
C1	3.8000E+01	3.3549E-19	2.3475E-06	6.8515E-06	5.0560E-06
I1	3.8000E+01	8.0961E-20	6.8865E-06	3.3983E-05	4.0111E-05
F1	3.8000E+01	6.7099E-20	4.6950E-07	1.3703E-06	1.0112E-06
C2	3.8000E+01	7.4844E-10	5.3060E-07	5.3676E-07	1.8320E-07
I2	3.8000E+01	8.9911E-10	6.2126E-06	8.4594E-06	4.6191E-06
F2	3.8000E+01	1.4969E-10	1.0612E-07	1.0735E-07	3.6640E-08
C1	3.9000E+01	1.3959E-19	2.0897E-06	6.3569E-06	4.8589E-06
I1	3.9000E+01	3.3685E-20	6.1303E-06	3.1530E-05	3.8546E-05
F1	3.9000E+01	2.7917E-20	4.1794E-07	1.2714E-06	9.7178E-07
C2	3.9000E+01	6.3264E-10	5.2167E-07	5.3909E-07	1.8820E-07
I2	3.9000E+01	7.6000E-10	6.1080E-06	8.4959E-06	4.7452E-06
F2	3.9000E+01	1.2653E-10	1.0433E-07	1.0782E-07	3.7640E-08
C1	4.0000E+01	5.8077E-20	1.8603E-06	5.8948E-06	4.6640E-06
I1	4.0000E+01	1.4015E-20	5.4572E-06	2.9238E-05	3.7001E-05
F1	4.0000E+01	1.1615E-20	3.7205E-07	1.1790E-06	9.3281E-07
C2	4.0000E+01	5.3476E-10	5.1281E-07	5.4102E-07	1.9307E-07
I2	4.0000E+01	6.4241E-10	6.0043E-06	8.5264E-06	4.8679E-06
F2	4.0000E+01	1.0695E-10	1.0256E-07	1.0820E-07	3.8614E-08
C1	4.1000E+01	2.4164E-20	1.6560E-06	5.4635E-06	4.4721E-06
I1	4.1000E+01	5.8311E-21	4.8580E-06	2.7098E-05	3.5478E-05
F1	4.1000E+01	4.8327E-21	3.3120E-07	1.0927E-06	8.9442E-07
C2	4.1000E+01	4.5202E-10	5.0403E-07	5.4259E-07	1.9781E-07
I2	4.1000E+01	5.4302E-10	5.9014E-06	8.5512E-06	4.9874E-06
F2	4.1000E+01	9.0404E-11	1.0081E-07	1.0852E-07	3.9562E-08
C1	4.2000E+01	1.0054E-20	1.4742E-06	5.0612E-06	4.2836E-06
I1	4.2000E+01	2.4261E-21	4.3246E-06	2.5103E-05	3.3983E-05
F1	4.2000E+01	2.0107E-21	2.9483E-07	1.0122E-06	8.5673E-07
C2	4.2000E+01	3.8208E-10	4.9532E-07	5.4383E-07	2.0242E-07
I2	4.2000E+01	4.5900E-10	5.7995E-06	8.5706E-06	5.1037E-06
F2	4.2000E+01	7.6416E-11	9.9065E-08	1.0877E-07	4.0484E-08
C1	4.3000E+01	4.1829E-21	1.3123E-06	4.6864E-06	4.0991E-06

I1	4.3000E+01	1.0094E-21	3.8497E-06	2.3244E-05	3.2519E-05
F1	4.3000E+01	8.3659E-22	2.6246E-07	9.3728E-07	8.1981E-07
C2	4.3000E+01	3.2297E-10	4.8671E-07	5.4474E-07	2.0690E-07
I2	4.3000E+01	3.8798E-10	5.6987E-06	8.5850E-06	5.2167E-06
F2	4.3000E+01	6.4593E-11	9.7343E-08	1.0895E-07	4.1381E-08
C1	4.4000E+01	1.7404E-21	1.1682E-06	4.3374E-06	3.9188E-06
I1	4.4000E+01	4.1998E-22	3.4270E-06	2.1513E-05	3.1088E-05
F1	4.4000E+01	3.4807E-22	2.3364E-07	8.6749E-07	7.8375E-07
C2	4.4000E+01	2.7300E-10	4.7820E-07	5.4534E-07	2.1126E-07
I2	4.4000E+01	3.2796E-10	5.5991E-06	8.5946E-06	5.3264E-06
F2	4.4000E+01	5.4599E-11	9.5640E-08	1.0907E-07	4.2251E-08
C1	4.5000E+01	7.2410E-22	1.0399E-06	4.0128E-06	3.7430E-06
I1	4.5000E+01	1.7474E-22	3.0507E-06	1.9903E-05	2.9694E-05
F1	4.5000E+01	1.4482E-22	2.0799E-07	8.0255E-07	7.4860E-07
C2	4.5000E+01	2.3076E-10	4.6979E-07	5.4567E-07	2.1548E-07
I2	4.5000E+01	2.7721E-10	5.5006E-06	8.5997E-06	5.4330E-06
F2	4.5000E+01	4.6152E-11	9.3959E-08	1.0913E-07	4.3097E-08
C1	4.6000E+01	3.0127E-22	9.2575E-07	3.7109E-06	3.5721E-06
I1	4.6000E+01	7.2703E-23	2.7158E-06	1.8406E-05	2.8338E-05
F1	4.6000E+01	6.0255E-23	1.8515E-07	7.4218E-07	7.1442E-07
C2	4.6000E+01	1.9505E-10	4.6149E-07	5.4572E-07	2.1958E-07
I2	4.6000E+01	2.3432E-10	5.4034E-06	8.6006E-06	5.5364E-06
F2	4.6000E+01	3.9011E-11	9.2298E-08	1.0914E-07	4.3917E-08
C1	4.7000E+01	1.2535E-22	8.2410E-07	3.4304E-06	3.4062E-06
I1	4.7000E+01	3.0249E-23	2.4176E-06	1.7015E-05	2.7022E-05
F1	4.7000E+01	2.5070E-23	1.6482E-07	6.8609E-07	6.8124E-07
C2	4.7000E+01	1.6488E-10	4.5330E-07	5.4553E-07	2.2356E-07
I2	4.7000E+01	1.9807E-10	5.3075E-06	8.5975E-06	5.6366E-06
F2	4.7000E+01	3.2975E-11	9.0660E-08	1.0911E-07	4.4712E-08
C1	4.8000E+01	5.2153E-23	7.3361E-07	3.1700E-06	3.2454E-06
I1	4.8000E+01	1.2585E-23	2.1521E-06	1.5723E-05	2.5747E-05
F1	4.8000E+01	1.0431E-23	1.4672E-07	6.3400E-07	6.4909E-07
C2	4.8000E+01	1.3937E-10	4.4522E-07	5.4510E-07	2.2741E-07
I2	4.8000E+01	1.6742E-10	5.2129E-06	8.5908E-06	5.7338E-06
F2	4.8000E+01	2.7873E-11	8.9044E-08	1.0902E-07	4.5483E-08
C1	4.9000E+01	2.1699E-23	6.5306E-07	2.9283E-06	3.0900E-06
I1	4.9000E+01	5.2363E-24	1.9158E-06	1.4524E-05	2.4513E-05
F1	4.9000E+01	4.3398E-24	1.3061E-07	5.8567E-07	6.1799E-07
C2	4.9000E+01	1.1780E-10	4.3725E-07	5.4445E-07	2.3115E-07
I2	4.9000E+01	1.4152E-10	5.1196E-06	8.5805E-06	5.8280E-06
F2	4.9000E+01	2.3561E-11	8.7451E-08	1.0889E-07	4.6229E-08
C1	5.0000E+01	9.0281E-24	5.8135E-07	2.7042E-06	2.9398E-06
I1	5.0000E+01	2.1787E-24	1.7054E-06	1.3413E-05	2.3322E-05
F1	5.0000E+01	1.8056E-24	1.1627E-07	5.4084E-07	5.8797E-07
C2	5.0000E+01	9.9577E-11	4.2941E-07	5.4360E-07	2.3476E-07
I2	5.0000E+01	1.1962E-10	5.0277E-06	8.5670E-06	5.9191E-06
F2	5.0000E+01	1.9915E-11	8.5881E-08	1.0872E-07	4.6953E-08
C1	5.1000E+01	3.7563E-24	5.1752E-07	2.4964E-06	2.7951E-06
I1	5.1000E+01	9.0646E-25	1.5182E-06	1.2382E-05	2.2174E-05
F1	5.1000E+01	7.5126E-25	1.0350E-07	4.9929E-07	5.5901E-07
C2	5.1000E+01	8.4170E-11	4.2168E-07	5.4255E-07	2.3826E-07
I2	5.1000E+01	1.0112E-10	4.9372E-06	8.5505E-06	6.0074E-06
F2	5.1000E+01	1.6834E-11	8.4336E-08	1.0851E-07	4.7653E-08
C1	5.2000E+01	1.5628E-24	4.6070E-07	2.3039E-06	2.6557E-06
I1	5.2000E+01	3.7714E-25	1.3515E-06	1.1427E-05	2.1068E-05
F1	5.2000E+01	3.1257E-25	9.2139E-08	4.6078E-07	5.3114E-07
C2	5.2000E+01	7.1147E-11	4.1407E-07	5.4131E-07	2.4165E-07
I2	5.2000E+01	8.5470E-11	4.8481E-06	8.5310E-06	6.0927E-06
F2	5.2000E+01	1.4229E-11	8.2814E-08	1.0826E-07	4.8330E-08
C1	5.3000E+01	6.5024E-25	4.1011E-07	2.1256E-06	2.5217E-06
I1	5.3000E+01	1.5692E-25	1.2031E-06	1.0543E-05	2.0005E-05
F1	5.3000E+01	1.3005E-25	8.2022E-08	4.2513E-07	5.0433E-07
C2	5.3000E+01	6.0139E-11	4.0658E-07	5.3991E-07	2.4492E-07
I2	5.3000E+01	7.2246E-11	4.7604E-06	8.5089E-06	6.1753E-06
F2	5.3000E+01	1.2028E-11	8.1315E-08	1.0798E-07	4.8985E-08
C1	5.4000E+01	2.7054E-25	3.6508E-07	1.9606E-06	2.3929E-06
I1	5.4000E+01	6.5287E-26	1.0710E-06	9.7244E-06	1.8984E-05
F1	5.4000E+01	5.4109E-26	7.3016E-08	3.9212E-07	4.7859E-07
C2	5.4000E+01	5.0834E-11	3.9920E-07	5.3835E-07	2.4809E-07
I2	5.4000E+01	6.1068E-11	4.6741E-06	8.4843E-06	6.2551E-06

F2	5.4000E+01	1.0167E-11	7.9841E-08	1.0767E-07	4.9618E-08
C1	5.5000E+01	1.1256E-25	3.2499E-07	1.8079E-06	2.2695E-06
I1	5.5000E+01	2.7163E-26	9.5339E-07	8.9671E-06	1.8004E-05
F1	5.5000E+01	2.2513E-26	6.4998E-08	3.6158E-07	4.5389E-07
C2	5.5000E+01	4.2969E-11	3.9195E-07	5.3663E-07	2.5115E-07
I2	5.5000E+01	5.1620E-11	4.5892E-06	8.4573E-06	6.3323E-06
F2	5.5000E+01	8.5939E-12	7.8391E-08	1.0733E-07	5.0230E-08
C1	5.6000E+01	4.6833E-26	2.8931E-07	1.6667E-06	2.1512E-06
I1	5.6000E+01	1.1302E-26	8.4870E-07	8.2666E-06	1.7066E-05
F1	5.6000E+01	9.3667E-27	5.7862E-08	3.3334E-07	4.3023E-07
C2	5.6000E+01	3.6321E-11	3.8482E-07	5.3478E-07	2.5410E-07
I2	5.6000E+01	4.3633E-11	4.5057E-06	8.4281E-06	6.4068E-06
F2	5.6000E+01	7.2642E-12	7.6964E-08	1.0696E-07	5.0821E-08
C1	5.7000E+01	1.9486E-26	2.5754E-07	1.5361E-06	2.0379E-06
I1	5.7000E+01	4.7022E-27	7.5551E-07	7.6190E-06	1.6167E-05
F1	5.7000E+01	3.8971E-27	5.1508E-08	3.0722E-07	4.0758E-07
C2	5.7000E+01	3.0701E-11	3.7780E-07	5.3280E-07	2.5696E-07
I2	5.7000E+01	3.6882E-11	4.4236E-06	8.3968E-06	6.4788E-06
F2	5.7000E+01	6.1403E-12	7.5561E-08	1.0656E-07	5.1392E-08
C1	5.8000E+01	8.1073E-27	2.2926E-07	1.4155E-06	1.9296E-06
I1	5.8000E+01	1.9564E-27	6.7256E-07	7.0205E-06	1.5308E-05
F1	5.8000E+01	1.6215E-27	4.5852E-08	2.8309E-07	3.8593E-07
C2	5.8000E+01	2.5951E-11	3.7091E-07	5.3069E-07	2.5971E-07
I2	5.8000E+01	3.1176E-11	4.3428E-06	8.3636E-06	6.5482E-06
F2	5.8000E+01	5.1903E-12	7.4182E-08	1.0614E-07	5.1943E-08
C1	5.9000E+01	3.3731E-27	2.0409E-07	1.3040E-06	1.8262E-06
I1	5.9000E+01	8.1400E-28	5.9871E-07	6.4675E-06	1.4487E-05
F1	5.9000E+01	6.7463E-28	4.0818E-08	2.6079E-07	3.6524E-07
C2	5.9000E+01	2.1936E-11	3.6413E-07	5.2847E-07	2.6237E-07
I2	5.9000E+01	2.6352E-11	4.2634E-06	8.3287E-06	6.6153E-06
F2	5.9000E+01	4.3872E-12	7.2826E-08	1.0569E-07	5.2475E-08
C1	6.0000E+01	1.4034E-27	1.8168E-07	1.2010E-06	1.7274E-06
I1	6.0000E+01	3.3868E-28	5.3297E-07	5.9568E-06	1.3704E-05
F1	6.0000E+01	2.8069E-28	3.6336E-08	2.4020E-07	3.4549E-07
C2	6.0000E+01	1.8542E-11	3.5746E-07	5.2614E-07	2.6494E-07
I2	6.0000E+01	2.2275E-11	4.1854E-06	8.2920E-06	6.6800E-06
F2	6.0000E+01	3.7084E-12	7.1493E-08	1.0523E-07	5.2988E-08
C1	6.1000E+01	5.8392E-28	1.6173E-07	1.1059E-06	1.6333E-06
I1	6.1000E+01	1.4091E-28	4.7445E-07	5.4853E-06	1.2957E-05
F1	6.1000E+01	1.1678E-28	3.2346E-08	2.2119E-07	3.2666E-07
C2	6.1000E+01	1.5673E-11	3.5092E-07	5.2372E-07	2.6741E-07
I2	6.1000E+01	1.8829E-11	4.1087E-06	8.2537E-06	6.7423E-06
F2	6.1000E+01	3.1347E-12	7.0183E-08	1.0474E-07	5.3483E-08
C1	6.2000E+01	2.4295E-28	1.4397E-07	1.0182E-06	1.5436E-06
I1	6.2000E+01	5.8628E-29	4.2235E-07	5.0502E-06	1.2245E-05
F1	6.2000E+01	4.8589E-29	2.8794E-08	2.0364E-07	3.0871E-07
C2	6.2000E+01	1.3248E-11	3.4448E-07	5.2120E-07	2.6980E-07
I2	6.2000E+01	1.5915E-11	4.0334E-06	8.2140E-06	6.8024E-06
F2	6.2000E+01	2.6497E-12	6.8896E-08	1.0424E-07	5.3959E-08
C1	6.3000E+01	1.0108E-28	1.2816E-07	9.3724E-07	1.4582E-06
I1	6.3000E+01	2.4393E-29	3.7598E-07	4.6486E-06	1.1568E-05
F1	6.3000E+01	2.0216E-29	2.5633E-08	1.8745E-07	2.9163E-07
C2	6.3000E+01	1.1199E-11	3.3816E-07	5.1859E-07	2.7209E-07
I2	6.3000E+01	1.3453E-11	3.9593E-06	8.1729E-06	6.8604E-06
F2	6.3000E+01	2.2397E-12	6.7631E-08	1.0372E-07	5.4419E-08
C1	6.4000E+01	4.2056E-29	1.1409E-07	8.6256E-07	1.3769E-06
I1	6.4000E+01	1.0149E-29	3.3469E-07	4.2782E-06	1.0923E-05
F1	6.4000E+01	8.4113E-30	2.2818E-08	1.7251E-07	2.7538E-07
C2	6.4000E+01	9.4659E-12	3.3195E-07	5.1590E-07	2.7431E-07
I2	6.4000E+01	1.1372E-11	3.8866E-06	8.1305E-06	6.9162E-06
F2	6.4000E+01	1.8932E-12	6.6389E-08	1.0318E-07	5.4862E-08
C1	6.5000E+01	1.7498E-29	1.0156E-07	7.9369E-07	1.2996E-06
I1	6.5000E+01	4.2226E-30	2.9794E-07	3.9366E-06	1.0310E-05
F1	6.5000E+01	3.4996E-30	2.0313E-08	1.5874E-07	2.5992E-07
C2	6.5000E+01	8.0013E-12	3.2584E-07	5.1314E-07	2.7644E-07
I2	6.5000E+01	9.6121E-12	3.8152E-06	8.0870E-06	6.9699E-06
F2	6.5000E+01	1.6003E-12	6.5169E-08	1.0263E-07	5.5288E-08
C1	6.6000E+01	7.2803E-30	9.0412E-08	7.3019E-07	1.2262E-06
I1	6.6000E+01	1.7569E-30	2.6523E-07	3.6217E-06	9.7277E-06

F1	6.6000E+01	1.4561E-30	1.8082E-08	1.4604E-07	2.4524E-07
C2	6.6000E+01	6.7633E-12	3.1985E-07	5.1030E-07	2.7849E-07
I2	6.6000E+01	8.1249E-12	3.7450E-06	8.0423E-06	7.0216E-06
F2	6.6000E+01	1.3527E-12	6.3970E-08	1.0206E-07	5.5698E-08
C1	6.7000E+01	3.0291E-30	8.0484E-08	6.7167E-07	1.1565E-06
I1	6.7000E+01	7.3097E-31	2.3611E-07	3.3314E-06	9.1748E-06
F1	6.7000E+01	6.0581E-31	1.6097E-08	1.3433E-07	2.3130E-07
C2	6.7000E+01	5.7169E-12	3.1396E-07	5.0741E-07	2.8046E-07
I2	6.7000E+01	6.8678E-12	3.6760E-06	7.9967E-06	7.0713E-06
F2	6.7000E+01	1.1434E-12	6.2792E-08	1.0148E-07	5.6092E-08
C1	6.8000E+01	1.2603E-30	7.1647E-08	6.1773E-07	1.0904E-06
I1	6.8000E+01	3.0413E-31	2.1018E-07	3.0639E-06	8.6501E-06
F1	6.8000E+01	2.5206E-31	1.4329E-08	1.2355E-07	2.1808E-07
C2	6.8000E+01	4.8324E-12	3.0818E-07	5.0445E-07	2.8236E-07
I2	6.8000E+01	5.8052E-12	3.6083E-06	7.9500E-06	7.1191E-06
F2	6.8000E+01	9.6648E-13	6.1636E-08	1.0089E-07	5.6472E-08
C1	6.9000E+01	5.2436E-31	6.3780E-08	5.6804E-07	1.0277E-06
I1	6.9000E+01	1.2654E-31	1.8710E-07	2.8174E-06	8.1526E-06
F1	6.9000E+01	1.0487E-31	1.2756E-08	1.1361E-07	2.0553E-07
C2	6.9000E+01	4.0847E-12	3.0250E-07	5.0143E-07	2.8418E-07
I2	6.9000E+01	4.9070E-12	3.5419E-06	7.9025E-06	7.1651E-06
F2	6.9000E+01	8.1694E-13	6.0500E-08	1.0029E-07	5.6836E-08
C1	7.0000E+01	2.1817E-31	5.6777E-08	5.2228E-07	9.6822E-07
I1	7.0000E+01	5.2648E-32	1.6656E-07	2.5904E-06	7.6811E-06
F1	7.0000E+01	4.3633E-32	1.1355E-08	1.0446E-07	1.9364E-07
C2	7.0000E+01	3.4527E-12	2.9693E-07	4.9836E-07	2.8593E-07
I2	7.0000E+01	4.1478E-12	3.4766E-06	7.8541E-06	7.2092E-06
F2	7.0000E+01	6.9054E-13	5.9385E-08	9.9673E-08	5.7186E-08
C1	7.1000E+01	9.0771E-32	5.0543E-08	4.8013E-07	9.1192E-07
I1	7.1000E+01	2.1905E-32	1.4827E-07	2.3814E-06	7.2344E-06
F1	7.1000E+01	1.8154E-32	1.0109E-08	9.6025E-08	1.8238E-07
C2	7.1000E+01	2.9185E-12	2.9145E-07	4.9525E-07	2.8761E-07
I2	7.1000E+01	3.5061E-12	3.4125E-06	7.8050E-06	7.2516E-06
F2	7.1000E+01	5.8370E-13	5.8290E-08	9.9050E-08	5.7522E-08
C1	7.2000E+01	3.7767E-32	4.4993E-08	4.4132E-07	8.5861E-07
I1	7.2000E+01	9.1138E-33	1.3199E-07	2.1889E-06	6.8115E-06
F1	7.2000E+01	7.5533E-33	8.9986E-09	8.8264E-08	1.7172E-07
C2	7.2000E+01	2.4670E-12	2.8607E-07	4.9209E-07	2.8922E-07
I2	7.2000E+01	2.9636E-12	3.3495E-06	7.7552E-06	7.2922E-06
F2	7.2000E+01	4.9339E-13	5.7215E-08	9.8417E-08	5.7845E-08
C1	7.3000E+01	1.5713E-32	4.0053E-08	4.0560E-07	8.0817E-07
I1	7.3000E+01	3.7919E-33	1.1750E-07	2.0117E-06	6.4114E-06
F1	7.3000E+01	3.1427E-33	8.0105E-09	8.1119E-08	1.6163E-07
C2	7.3000E+01	2.0853E-12	2.8080E-07	4.8889E-07	2.9077E-07
I2	7.3000E+01	2.5051E-12	3.2877E-06	7.7048E-06	7.3312E-06
F2	7.3000E+01	4.1705E-13	5.6159E-08	9.7777E-08	5.8154E-08
C1	7.4000E+01	6.5377E-33	3.5655E-08	3.7272E-07	7.6047E-07
I1	7.4000E+01	1.5777E-33	1.0460E-07	1.8486E-06	6.0329E-06
F1	7.4000E+01	1.3075E-33	7.1309E-09	7.4543E-08	1.5209E-07
C2	7.4000E+01	1.7626E-12	2.7561E-07	4.8565E-07	2.9225E-07
I2	7.4000E+01	2.1175E-12	3.2270E-06	7.6538E-06	7.3685E-06
F2	7.4000E+01	3.5253E-13	5.5122E-08	9.7130E-08	5.8450E-08
C1	7.5000E+01	2.7201E-33	3.1740E-08	3.4246E-07	7.1537E-07
I1	7.5000E+01	6.5641E-34	9.3111E-08	1.6986E-06	5.6752E-06
F1	7.5000E+01	5.4402E-34	6.3480E-09	6.8492E-08	1.4307E-07
C2	7.5000E+01	1.4899E-12	2.7052E-07	4.8237E-07	2.9367E-07
I2	7.5000E+01	1.7899E-12	3.1674E-06	7.6022E-06	7.4043E-06
F2	7.5000E+01	2.9798E-13	5.4105E-08	9.6475E-08	5.8733E-08
C1	7.6000E+01	1.1317E-33	2.8255E-08	3.1462E-07	6.7276E-07
I1	7.6000E+01	2.7311E-34	8.2887E-08	1.5605E-06	5.3371E-06
F1	7.6000E+01	2.2635E-34	5.6509E-09	6.2925E-08	1.3455E-07
C2	7.6000E+01	1.2594E-12	2.6553E-07	4.7907E-07	2.9502E-07
I2	7.6000E+01	1.5129E-12	3.1089E-06	7.5501E-06	7.4385E-06
F2	7.6000E+01	2.5188E-13	5.3105E-08	9.5814E-08	5.9005E-08
C1	7.7000E+01	4.7087E-34	2.5152E-08	2.8902E-07	6.3251E-07
I1	7.7000E+01	1.1363E-34	7.3786E-08	1.4335E-06	5.0178E-06
F1	7.7000E+01	9.4175E-35	5.0304E-09	5.7803E-08	1.2650E-07
C2	7.7000E+01	1.0645E-12	2.6062E-07	4.7574E-07	2.9632E-07
I2	7.7000E+01	1.2789E-12	3.0515E-06	7.4975E-06	7.4712E-06
F2	7.7000E+01	2.1291E-13	5.2124E-08	9.5147E-08	5.9264E-08

C1	7.8000E+01	1.9591E-34	2.2390E-08	2.6546E-07	5.9451E-07
I1	7.8000E+01	4.7278E-35	6.5684E-08	1.3167E-06	4.7163E-06
F1	7.8000E+01	3.9183E-35	4.4781E-09	5.3093E-08	1.1890E-07
C2	7.8000E+01	8.9983E-13	2.5581E-07	4.7238E-07	2.9756E-07
I2	7.8000E+01	1.0810E-12	2.9951E-06	7.4446E-06	7.5024E-06
F2	7.8000E+01	1.7997E-13	5.1161E-08	9.4475E-08	5.9512E-08
C1	7.9000E+01	8.1513E-35	1.9932E-08	2.4380E-07	5.5865E-07
I1	7.9000E+01	1.9670E-35	5.8472E-08	1.2092E-06	4.4318E-06
F1	7.9000E+01	1.6303E-35	3.9864E-09	4.8761E-08	1.1173E-07
C2	7.9000E+01	7.6061E-13	2.5108E-07	4.6899E-07	2.9874E-07
I2	7.9000E+01	9.1374E-13	2.9398E-06	7.3913E-06	7.5322E-06
F2	7.9000E+01	1.5212E-13	5.0216E-08	9.3798E-08	5.9748E-08
C1	8.0000E+01	3.3914E-35	1.7743E-08	2.2389E-07	5.2482E-07
I1	8.0000E+01	8.1842E-36	5.2051E-08	1.1105E-06	4.1635E-06
F1	8.0000E+01	6.7829E-36	3.5487E-09	4.4778E-08	1.0496E-07
C2	8.0000E+01	6.4293E-13	2.4644E-07	4.6559E-07	2.9987E-07
I2	8.0000E+01	7.7236E-13	2.8854E-06	7.3376E-06	7.5606E-06
F2	8.0000E+01	1.2859E-13	4.9288E-08	9.3117E-08	5.9973E-08
C1	8.1000E+01	1.4111E-35	1.5795E-08	2.0558E-07	4.9292E-07
I1	8.1000E+01	3.4051E-36	4.6336E-08	1.0197E-06	3.9104E-06
F1	8.1000E+01	2.8221E-36	3.1590E-09	4.1116E-08	9.8583E-08
C2	8.1000E+01	5.4345E-13	2.4188E-07	4.6216E-07	3.0094E-07
I2	8.1000E+01	6.5286E-13	2.8321E-06	7.2836E-06	7.5876E-06
F2	8.1000E+01	1.0869E-13	4.8377E-08	9.2433E-08	6.0187E-08
C1	8.2000E+01	5.8709E-36	1.4061E-08	1.8875E-07	4.6284E-07
I1	8.2000E+01	1.4167E-36	4.1248E-08	9.3619E-07	3.6718E-06
F1	8.2000E+01	1.1742E-36	2.8122E-09	3.7750E-08	9.2569E-08
C2	8.2000E+01	4.5937E-13	2.3741E-07	4.5872E-07	3.0196E-07
I2	8.2000E+01	5.5185E-13	2.7797E-06	7.2294E-06	7.6133E-06
F2	8.2000E+01	9.1874E-14	4.7482E-08	9.1744E-08	6.0391E-08
C1	8.3000E+01	2.4427E-36	1.2517E-08	1.7328E-07	4.3451E-07
I1	8.3000E+01	5.8946E-37	3.6719E-08	8.5947E-07	3.4470E-06
F1	8.3000E+01	4.8853E-37	2.5034E-09	3.4657E-08	8.6901E-08
C2	8.3000E+01	3.8830E-13	2.3302E-07	4.5527E-07	3.0292E-07
I2	8.3000E+01	4.6647E-13	2.7284E-06	7.1749E-06	7.6376E-06
F2	8.3000E+01	7.7659E-14	4.6604E-08	9.1053E-08	6.0585E-08
C1	8.4000E+01	1.0163E-36	1.1142E-08	1.5907E-07	4.0781E-07
I1	8.4000E+01	2.4525E-37	3.2687E-08	7.8897E-07	3.2353E-06
F1	8.4000E+01	2.0326E-37	2.2285E-09	3.1814E-08	8.1563E-08
C2	8.4000E+01	3.2822E-13	2.2871E-07	4.5180E-07	3.0384E-07
I2	8.4000E+01	3.9430E-13	2.6779E-06	7.1202E-06	7.6608E-06
F2	8.4000E+01	6.5644E-14	4.5743E-08	9.0359E-08	6.0768E-08
C1	8.5000E+01	4.2285E-37	9.9190E-09	1.4601E-07	3.8268E-07
I1	8.5000E+01	1.0204E-37	2.9098E-08	7.2419E-07	3.0358E-06
F1	8.5000E+01	8.4569E-38	1.9838E-09	2.9202E-08	7.6535E-08
C2	8.5000E+01	2.7744E-13	2.2448E-07	4.4831E-07	3.0471E-07
I2	8.5000E+01	3.3329E-13	2.6284E-06	7.0654E-06	7.6826E-06
F2	8.5000E+01	5.5487E-14	4.4897E-08	8.9663E-08	6.0941E-08
C1	8.6000E+01	1.7593E-37	8.8299E-09	1.3401E-07	3.5901E-07
I1	8.6000E+01	4.2455E-38	2.5903E-08	6.6467E-07	2.8481E-06
F1	8.6000E+01	3.5186E-38	1.7660E-09	2.6802E-08	7.1802E-08
C2	8.6000E+01	2.3451E-13	2.2033E-07	4.4482E-07	3.0553E-07
I2	8.6000E+01	2.8172E-13	2.5798E-06	7.0104E-06	7.7033E-06
F2	8.6000E+01	4.6902E-14	4.4066E-08	8.8965E-08	6.1105E-08
C1	8.7000E+01	7.3198E-38	7.8604E-09	1.2299E-07	3.3674E-07
I1	8.7000E+01	1.7664E-38	2.3059E-08	6.0999E-07	2.6714E-06
F1	8.7000E+01	1.4640E-38	1.5721E-09	2.4597E-08	6.7349E-08
C2	8.7000E+01	1.9823E-13	2.1626E-07	4.4132E-07	3.0630E-07
I2	8.7000E+01	2.3813E-13	2.5320E-06	6.9552E-06	7.7228E-06
F2	8.7000E+01	3.9646E-14	4.3251E-08	8.8265E-08	6.1260E-08
C1	8.8000E+01	3.0455E-38	6.9973E-09	1.1286E-07	3.1579E-07
I1	8.8000E+01	7.3494E-39	2.0527E-08	5.5977E-07	2.5052E-06
F1	8.8000E+01	6.0910E-39	1.3995E-09	2.2572E-08	6.3158E-08
C2	8.8000E+01	1.6756E-13	2.1225E-07	4.3782E-07	3.0703E-07
I2	8.8000E+01	2.0129E-13	2.4852E-06	6.9000E-06	7.7411E-06
F2	8.8000E+01	3.3512E-14	4.2451E-08	8.7564E-08	6.1405E-08
C1	8.9000E+01	1.2671E-38	6.2290E-09	1.0356E-07	2.9609E-07
I1	8.9000E+01	3.0578E-39	1.8273E-08	5.1364E-07	2.3489E-06
F1	8.9000E+01	2.5343E-39	1.2458E-09	2.0712E-08	5.9217E-08

C2	8.9000E+01	1.4163E-13	2.0833E-07	4.3431E-07	3.0771E-07
I2	8.9000E+01	1.7015E-13	2.4392E-06	6.8447E-06	7.7583E-06
F2	8.9000E+01	2.8327E-14	4.1666E-08	8.6862E-08	6.1542E-08
C1	9.0000E+01	5.2720E-39	5.5450E-09	9.5019E-08	2.7756E-07
I1	9.0000E+01	1.2722E-39	1.6267E-08	4.7128E-07	2.2019E-06
F1	9.0000E+01	1.0544E-39	1.1090E-09	1.9004E-08	5.5511E-08
C2	9.0000E+01	1.1972E-13	2.0447E-07	4.3080E-07	3.0835E-07
I2	9.0000E+01	1.4382E-13	2.3941E-06	6.7893E-06	7.7744E-06
F2	9.0000E+01	2.3944E-14	4.0895E-08	8.6159E-08	6.1669E-08
C1	9.1000E+01	2.1935E-39	4.9361E-09	8.7177E-08	2.6014E-07
I1	9.1000E+01	5.2933E-40	1.4481E-08	4.3239E-07	2.0637E-06
F1	9.1000E+01	4.3870E-40	9.8723E-10	1.7435E-08	5.2028E-08
C2	9.1000E+01	1.0120E-13	2.0069E-07	4.2728E-07	3.0894E-07
I2	9.1000E+01	1.2157E-13	2.3498E-06	6.7339E-06	7.7894E-06
F2	9.1000E+01	2.0239E-14	4.0138E-08	8.5456E-08	6.1788E-08
C1	9.2000E+01	9.1264E-40	4.3941E-09	7.9976E-08	2.4377E-07
I1	9.2000E+01	2.2024E-40	1.2891E-08	3.9667E-07	1.9339E-06
F1	9.2000E+01	1.8253E-40	8.7883E-10	1.5995E-08	4.8754E-08
C2	9.2000E+01	8.5539E-14	1.9698E-07	4.2376E-07	3.0950E-07
I2	9.2000E+01	1.0276E-13	2.3063E-06	6.6784E-06	7.8034E-06
F2	9.2000E+01	1.7108E-14	3.9395E-08	8.4752E-08	6.1899E-08
C1	9.3000E+01	3.7972E-40	3.9117E-09	7.3365E-08	2.2839E-07
I1	9.3000E+01	9.1632E-41	1.1475E-08	3.6388E-07	1.8119E-06
F1	9.3000E+01	7.5943E-41	7.8233E-10	1.4673E-08	4.5679E-08
C2	9.3000E+01	7.2305E-14	1.9333E-07	4.2024E-07	3.1001E-07
I2	9.3000E+01	8.6861E-14	2.2636E-06	6.6230E-06	7.8163E-06
F2	9.3000E+01	1.4461E-14	3.8666E-08	8.4049E-08	6.2002E-08
C1	9.4000E+01	1.5799E-40	3.4822E-09	6.7297E-08	2.1395E-07
I1	9.4000E+01	3.8125E-41	1.0215E-08	3.3378E-07	1.6973E-06
F1	9.4000E+01	3.1597E-41	6.9643E-10	1.3459E-08	4.2790E-08
C2	9.4000E+01	6.1117E-14	1.8975E-07	4.1673E-07	3.1048E-07
I2	9.4000E+01	7.3422E-14	2.2218E-06	6.5676E-06	7.8282E-06
F2	9.4000E+01	1.2223E-14	3.7951E-08	8.3346E-08	6.2096E-08
C1	9.5000E+01	6.5732E-41	3.0998E-09	6.1726E-08	2.0039E-07
I1	9.5000E+01	1.5862E-41	9.0935E-09	3.0615E-07	1.5897E-06
F1	9.5000E+01	1.3146E-41	6.1996E-10	1.2345E-08	4.0077E-08
C2	9.5000E+01	5.1661E-14	1.8624E-07	4.1321E-07	3.1091E-07
I2	9.5000E+01	6.2062E-14	2.1806E-06	6.5122E-06	7.8391E-06
F2	9.5000E+01	1.0332E-14	3.7249E-08	8.2643E-08	6.2183E-08
C1	9.6000E+01	2.7349E-41	2.7594E-09	5.6613E-08	1.8765E-07
I1	9.6000E+01	6.5997E-42	8.0950E-09	2.8080E-07	1.4887E-06
F1	9.6000E+01	5.4697E-42	5.5189E-10	1.1323E-08	3.7530E-08
C2	9.6000E+01	4.3668E-14	1.8280E-07	4.0970E-07	3.1131E-07
I2	9.6000E+01	5.2459E-14	2.1403E-06	6.4569E-06	7.8491E-06
F2	9.6000E+01	8.7337E-15	3.6559E-08	8.1941E-08	6.2262E-08
C1	9.7000E+01	1.1379E-41	2.4564E-09	5.1921E-08	1.7570E-07
I1	9.7000E+01	2.7459E-42	7.2061E-09	2.5752E-07	1.3938E-06
F1	9.7000E+01	2.2758E-42	4.9129E-10	1.0384E-08	3.5140E-08
C2	9.7000E+01	3.6912E-14	1.7941E-07	4.0620E-07	3.1167E-07
I2	9.7000E+01	4.4343E-14	2.1007E-06	6.4016E-06	7.8581E-06
F2	9.7000E+01	7.3824E-15	3.5883E-08	8.1240E-08	6.2333E-08
C1	9.8000E+01	4.7343E-42	2.1867E-09	4.7615E-08	1.6448E-07
I1	9.8000E+01	1.1425E-42	6.4149E-09	2.3616E-07	1.3049E-06
F1	9.8000E+01	9.4686E-43	4.3734E-10	9.5230E-09	3.2896E-08
C2	9.8000E+01	3.1201E-14	1.7609E-07	4.0270E-07	3.1199E-07
I2	9.8000E+01	3.7482E-14	2.0618E-06	6.3465E-06	7.8661E-06
F2	9.8000E+01	6.2402E-15	3.5219E-08	8.0540E-08	6.2397E-08
C1	9.9000E+01	1.9698E-42	1.9466E-09	4.3663E-08	1.5396E-07
I1	9.9000E+01	4.7534E-43	5.7105E-09	2.1657E-07	1.2214E-06
F1	9.9000E+01	3.9395E-43	3.8932E-10	8.7327E-09	3.0791E-08
C2	9.9000E+01	2.6373E-14	1.7283E-07	3.9920E-07	3.1227E-07
I2	9.9000E+01	3.1683E-14	2.0236E-06	6.2914E-06	7.8733E-06
F2	9.9000E+01	5.2747E-15	3.4567E-08	7.9841E-08	6.2454E-08
C1	1.0000E+02	8.1955E-43	1.7329E-09	4.0038E-08	1.4408E-07
I1	1.0000E+02	1.9777E-43	5.0835E-09	1.9858E-07	1.1431E-06
F1	1.0000E+02	1.6391E-43	3.4657E-10	8.0075E-09	2.8817E-08
C2	1.0000E+02	2.2293E-14	1.6963E-07	3.9572E-07	3.1252E-07
I2	1.0000E+02	2.6781E-14	1.9862E-06	6.2364E-06	7.8796E-06
F2	1.0000E+02	4.4586E-15	3.3927E-08	7.9143E-08	6.2504E-08

Verification Problem 4

Parameter Definition File

```
Verification problem #4 for FOLAT using solubility limited release
'verify4.out'
'verify2.pcp'
'verify2.inv'
1.0e-6  .0001    1.0e-30                eps h1 hmin
3   1  1                             mlayer  nprog  nmat
'verify2'                           rel file name
138                                  mw
1.                                    sol
100.                                 thalf
10000.  0   0                            initial y(i)
.1 .5  1.0                                kd(i,j)
0. 0. 0.                             kx(i.j)
1 3
$ layer 1-3
1  1.5  10  10                       thick(1),rho(1) len(1) width(1)
1710,0.2724,0.0321,7.51,2.298        sk(1),ths(1),thr(1),alpha(1),rn(1)
$ output times
1                                    ntimes
0. 466. 2.0                            t1,t2,tp
```

Water Flux File- Same as Verification Problem 2

Release File- Same as Verification Problem 2

Output File

Note: Output is truncated after 60 years

```
   ***************************************************
   *                                                 *
   *     This output was produced by the model:      *
   *                                                 *
   *                      FOLAT                      *
   *    The First-Order-Leach-And-Transport model.   *
   *    A general purpose solver for leaching and    *
   *    subsurface transport of radionuclides in     *
   *  surface or buried locations. Version date:     *
   *                     111602                      *
   *                  Arthur S. Rood                 *
   *                    K-Spar Inc                   *
   *             493 N 4154 E Rigby ID 83442         *
   *                    asr@srv.net                  *
   ***************************************************
 Date: 11/16/2002 Time: 20:19:48.600
 Input File:         verify4.par
 Output File:        verify4.out
 Pecipitation File:  verify2.pcp
 Release File:       verify2.inv
 Number of layers:          3
 Number of progeny          1
 Nuclide Names            verify
 Half lifes (y)            1.000E+02
 Solubility (mg/L)         1.000E+00
 Molar Weight (g/mol)      1.380E+02
 Kd Value for Member 1 for Each Layer (mL/g)
  1.000E-01  5.000E-01  1.000E+00
 Kx Value for Member 1 for Each Layer (1/y)
  0.000E+00  0.000E+00  0.000E+00
 Initial Activity for Member 1 for Each Layer (Ci)
```

```
 1.000E+04  0.000E+00  0.000E+00
Thickness of each layer (m)
 1.000E+00  1.000E+00  1.000E+00
Bulk Density (g/cm**3)
 1.500E+00  1.500E+00  1.500E+00
K-sat (m/y)
 1.710E+03  1.710E+03  1.710E+03
Porosity
 2.724E-01  2.724E-01  2.724E-01
Residual Moisture Content
 3.210E-02  3.210E-02  3.210E-02
Alpha (1/m)
 7.510E+00  7.510E+00  7.510E+00
Van Genuchten n
 2.298E+00  2.298E+00  2.298E+00
Length (m)
 1.000E+01  1.000E+01  1.000E+01
Width (m)
 1.000E+01  1.000E+01  1.000E+01
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  Calculated Values
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Moisture Content in each Layer at each Time
 0.000E+00  6.060E-02  5.613E-02  5.235E-02
 1.000E+05  6.060E-02  5.613E-02  5.235E-02
Decay Constants of each Member (1/y)
 6.931E-03
Solubility of Each Member (Ci/m**3)
 2.593E+01
Initial Pore Water Conconcentration for Member 1 for Each Layer (Ci/m**3)
 4.748E+02  0.000E+00  0.000E+00
Initial Leach Rate for Member 1 for Each Layer (1/y)
 4.748E-01  6.203E-02  1.610E-02
Conversion factors from activity (Ci) to mass (atoms)
 1.683E+20
Conversion factors from mass (atoms) to activity (Ci)
 5.940E-21
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 Start of Calculation
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C=Concentration (Ci/m**3), I=Inventory (Ci) F=Flux (Ci/y)

ID  Time (y)      Layer  1    Layer  2    Layer  3
C1  0.0000E+00  4.7483E+02  0.0000E+00  0.0000E+00
I1  0.0000E+00  1.0000E+04  0.0000E+00  0.0000E+00
F1  0.0000E+00  4.7483E+03  0.0000E+00  0.0000E+00
C1  2.0000E+00  2.5927E+01  6.0086E+00  1.9494E-01
I1  2.0000E+00  9.3474E+03  4.8437E+02  3.0262E+01
F1  2.0000E+00  2.5927E+02  3.0043E+01  4.8735E-01
C1  4.0000E+00  2.5927E+01  1.1243E+01  7.3427E-01
I1  4.0000E+00  8.7037E+03  9.0634E+02  1.1399E+02
F1  4.0000E+00  2.5927E+02  5.6216E+01  1.8357E+00
C1  6.0000E+00  2.5927E+01  1.5803E+01  1.5570E+00
I1  6.0000E+00  8.0689E+03  1.2740E+03  2.4170E+02
F1  6.0000E+00  2.5927E+02  7.9017E+01  3.8925E+00
C1  8.0000E+00  2.5927E+01  1.9776E+01  2.6107E+00
I1  8.0000E+00  7.4429E+03  1.5942E+03  4.0527E+02
F1  8.0000E+00  2.5927E+02  9.8881E+01  6.5268E+00
C1  1.0000E+01  2.5927E+01  2.3237E+01  3.8505E+00
I1  1.0000E+01  6.8255E+03  1.8732E+03  5.9773E+02
F1  1.0000E+01  2.5927E+02  1.1619E+02  9.6262E+00
C1  1.2000E+01  2.5927E+01  2.5927E+01  5.2367E+00
I1  1.2000E+01  6.2165E+03  2.1164E+03  8.1291E+02
F1  1.2000E+01  2.5927E+02  1.2963E+02  1.3092E+01
C1  1.4000E+01  2.5927E+01  2.5927E+01  6.6332E+00
I1  1.4000E+01  5.6160E+03  2.3448E+03  1.0297E+03
F1  1.4000E+01  2.5927E+02  1.2963E+02  1.6583E+01
C1  1.6000E+01  2.5927E+01  2.5927E+01  7.9668E+00
I1  1.6000E+01  5.0237E+03  2.5700E+03  1.2367E+03
F1  1.6000E+01  2.5927E+02  1.2963E+02  1.9917E+01
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C1	1.8000E+01	2.5927E+01	2.5927E+01	9.2403E+00
I1	1.8000E+01	4.4396E+03	2.7921E+03	1.4344E+03
F1	1.8000E+01	2.5927E+02	1.2963E+02	2.3101E+01
C1	2.0000E+01	2.5927E+01	2.5927E+01	1.0457E+01
I1	2.0000E+01	3.8635E+03	3.0111E+03	1.6232E+03
F1	2.0000E+01	2.5927E+02	1.2963E+02	2.6141E+01
C1	2.2000E+01	2.5927E+01	2.5927E+01	1.1618E+01
I1	2.2000E+01	3.2953E+03	3.2271E+03	1.8035E+03
F1	2.2000E+01	2.5927E+02	1.2963E+02	2.9045E+01
C1	2.4000E+01	2.5927E+01	2.5927E+01	1.2727E+01
I1	2.4000E+01	2.7350E+03	3.4402E+03	1.9757E+03
F1	2.4000E+01	2.5927E+02	1.2963E+02	3.1818E+01
C1	2.6000E+01	2.5927E+01	2.5927E+01	1.3786E+01
I1	2.6000E+01	2.1824E+03	3.6503E+03	2.1401E+03
F1	2.6000E+01	2.5927E+02	1.2963E+02	3.4466E+01
C1	2.8000E+01	2.5927E+01	2.5927E+01	1.4798E+01
I1	2.8000E+01	1.6374E+03	3.8575E+03	2.2972E+03
F1	2.8000E+01	2.5927E+02	1.2963E+02	3.6995E+01
C1	3.0000E+01	2.5927E+01	2.5927E+01	1.5764E+01
I1	3.0000E+01	1.0999E+03	4.0619E+03	2.4471E+03
F1	3.0000E+01	2.5927E+02	1.2963E+02	3.9410E+01
C1	3.2000E+01	2.5927E+01	2.5927E+01	1.6686E+01
I1	3.2000E+01	5.6979E+02	4.2635E+03	2.5903E+03
F1	3.2000E+01	2.5927E+02	1.2963E+02	4.1716E+01
C1	3.4000E+01	1.0332E+01	2.5927E+01	1.7567E+01
I1	3.4000E+01	2.1760E+02	4.2916E+03	2.7271E+03
F1	3.4000E+01	1.0332E+02	1.2963E+02	4.3918E+01
C1	3.6000E+01	3.9423E+00	2.5927E+01	1.8409E+01
I1	3.6000E+01	8.3025E+01	4.1067E+03	2.8577E+03
F1	3.6000E+01	3.9423E+01	1.2963E+02	4.6022E+01
C1	3.8000E+01	1.5042E+00	2.5927E+01	1.9212E+01
I1	3.8000E+01	3.1678E+01	3.8428E+03	2.9824E+03
F1	3.8000E+01	1.5042E+01	1.2963E+02	4.8030E+01
C1	4.0000E+01	5.7391E-01	2.5927E+01	1.9979E+01
I1	4.0000E+01	1.2087E+01	3.5516E+03	3.1015E+03
F1	4.0000E+01	5.7391E+00	1.2963E+02	4.9948E+01
C1	4.2000E+01	2.1898E-01	2.5927E+01	2.0712E+01
I1	4.2000E+01	4.6117E+00	3.2525E+03	3.2152E+03
F1	4.2000E+01	2.1898E+00	1.2963E+02	5.1780E+01
C1	4.4000E+01	8.3550E-02	2.5927E+01	2.1412E+01
I1	4.4000E+01	1.7596E+00	2.9531E+03	3.3238E+03
F1	4.4000E+01	8.3550E-01	1.2963E+02	5.3529E+01
C1	4.6000E+01	3.1879E-02	2.5927E+01	2.2080E+01
I1	4.6000E+01	6.7138E-01	2.6560E+03	3.4276E+03
F1	4.6000E+01	3.1879E-01	1.2963E+02	5.5199E+01
C1	4.8000E+01	1.2163E-02	2.5927E+01	2.2718E+01
I1	4.8000E+01	2.5616E-01	2.3624E+03	3.5266E+03
F1	4.8000E+01	1.2163E-01	1.2963E+02	5.6795E+01
C1	5.0000E+01	4.6409E-03	2.5710E+01	2.3327E+01
I1	5.0000E+01	9.7739E-02	2.0726E+03	3.6211E+03
F1	5.0000E+01	4.6409E-02	1.2855E+02	5.8317E+01
C1	5.2000E+01	1.7707E-03	2.2399E+01	2.3788E+01
I1	5.2000E+01	3.7292E-02	1.8056E+03	3.6927E+03
F1	5.2000E+01	1.7707E-02	1.1199E+02	5.9469E+01
C1	5.4000E+01	6.7562E-04	1.9514E+01	2.4033E+01
I1	5.4000E+01	1.4229E-02	1.5730E+03	3.7308E+03
F1	5.4000E+01	6.7562E-03	9.7568E+01	6.0083E+01
C1	5.6000E+01	2.5778E-04	1.7000E+01	2.4098E+01
I1	5.6000E+01	5.4290E-03	1.3704E+03	3.7408E+03
F1	5.6000E+01	2.5778E-03	8.4999E+01	6.0245E+01
C1	5.8000E+01	9.8357E-05	1.4810E+01	2.4012E+01
I1	5.8000E+01	2.0714E-03	1.1939E+03	3.7275E+03
F1	5.8000E+01	9.8357E-04	7.4049E+01	6.0030E+01
C1	6.0000E+01	3.7528E-05	1.2902E+01	2.3801E+01
I1	6.0000E+01	7.9036E-04	1.0401E+03	3.6948E+03
F1	6.0000E+01	3.7528E-04	6.4510E+01	5.9504E+01