APPENDIX A

THEORETICAL BACKGROUND OF THE INFILTRATION SUBMODEL

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This appendix contains the background theory of the infiltration submodel (subroutine INFIL) used in the PRESTO-EPA-POP model as developed by Hung (HU83). The original article was published in "The Role of the Unsaturated Zone in Radioactive and Hazardous Waste Disposal" by Ann Arbor Science, 1983.

A MODEL TO SIMULATE INFILTRATION OF RAINWATER THROUGH THE COVER OF A RADIOACTIVE WASTE TRENCH UNDER SATURATED AND UNSATURATED CONDITIONS

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ABSTRACT

This paper presents a mathematical model which simulates the infiltration of rainwater through a homogeneous earthen cover over radioactive, chemical, or municipal waste disposal trenches under saturated and unsaturated conditions. The infiltration model includes overland flow, subsurface flow, and atmospheric diffusion systems. Space-dependent variables in the basic differential equations which govern the movement of water or vapor through these three systems were transformed into space-independent variables by introducing some engineering assumptions. This paper emphasizes the transformation of the subsurface flow system; the other two systems have been investigated by previous investigators. Transformation of the subsurface flow system involves the concept of dividing soil moisture into three components: gravity, pellicular, and hygroscopic waters. The proposed model was tested against the studies conducted by other investigators by applying the model to the Barnwell radioactive waste disposal site. The results indicated close agreement between the results obtained from the proposed model and those obtained from other investigators.

INTRODUCTION

The disposal of low-level radioactive waste by the shallow land burial method has been used for decades and has proven to be an effective disposal method, if the waste treatment, packaging, site selection, and disposal operations are managed properly. An important consideration in evaluating the performance of a waste disposal site is the potential effects on the health of downstream populations. A dynamic simulation model has been commonly used to predict this impact because limited experimental or field data are available. Since one of the major driving forces in accelerating the release of radionuclides is the rainwater which infiltrates through the cover of a disposal trench, the simulation of the infiltration process is an important part of the model for estimating the number of potential health effects.

An accurate model for simulating the infiltration of rainwater through a trench cover involves the modeling of three flow systems: an overland flow system, a subsurface flow system, and an atmospheric diffusion system. The overland flow system receives the rainwater and diverts the excess water from percolation and evaporation into the receiving drainage system.

The subsurface flow system receives the percolated water from the overland flow system and transports the water either downward as infiltration into the trench and/or upward as evaporation into the atmospheric diffusion system. The atmospheric diffusion system receives water/vapor from the overland flow system or subsurface flow system and transports the vapor to the atmosphere. One of the early efforts in simulating this system for storm runoff was the Stanford Watershed Model conceived by Crawford and Linsley [1]. The same model was significantly improved by Moore and Claborn [2], Hung and Keifer [3], and others. However, these models were developed for water resources planning purposes with emphasis on the overland flow system. Significant improvements are required to apply the same models to the simulation of trench cover infiltration. This study presents an efficient and yet accurate infiltration model based on the dynamic equations governing the above systems.

BASIC EQUATIONS

The simulation of rainwater movement through a homogeneous trench cover, defined here as the "total infiltration system," involves analyzing the hydrologic processes of overland flow, subsurface flow, and atmospheric diffusion systems. The basic momentum and continuity equations governing these three systems have been studied thoroughly by other investigators. They are detailed as follows:

Overland Flow System

The one-dimensional momentum and continuity equations governing an overland flow system are expressed by [4]:

$$\frac{1}{g}\frac{\partial u}{\partial t} + \frac{u}{g}\frac{\partial u}{\partial x} + \frac{\partial h}{\partial x} - \sin\alpha + \frac{n^2u^2}{h^{4/3}} = 0 \qquad (1)$$

and

$$\frac{\partial h}{\partial t} + h\frac{\partial u}{\partial x} + u\frac{\partial h}{\partial x} = P - E_0 - q_0 \qquad (2)$$

where

u = velocity of overland flow,

h = depth of flow,

α = average inclination of the trench cover,

n	=	Manning's coefficient of roughness,
P	=	rate of precipitation,
E_0	=	rate of evaporation from the overland flow system,
q_0	=	rate of percolation from the overland flow system,
g	=	acceleration potential due to gravitational force,
x	=	space coordinate along the slope of the trench cover, and
t	=	time.

The above equation is derived from the assumptions that Corioli's energy correction factor, Boussinesq's momentum correction factor, and Jaeger's hydrostatic pressure correction factor are all unity; the flow is one dimensional, i.e., the velocity component in the longitudinal direction predominates the velocity component in lateral directions, and the flow is a gradually varied flow. The above system equations cannot be solved independently and must be coupled with the basic equations governing the other two systems.

Because Manning's law of resistance is an empirical formula developed for open-channel flow, the application of the same law to a thin overland flow may be questionable. However, comprehensive laboratory and field studies conducted by Takasao et al. [5-8] indicated that the Manning Law can also reasonably be applied to an overland flow system. This finding was confirmed by Foster et al. [9], Hjelmfelt [10], and others.

Subsurface Flow System

The movement of soil moisture in a subsurface flow system can be either upward or downward depending on the direction of potential head gradient. In general, the moisture in the soil is simultaneously transported in both liquid and vapor phases. The basic equation governing this system has been derived by Currie [11] and Hillel [12]. The results of their studies for the momentum and continuity equations are summarized as follows:

$$q = -D_L(\theta)\frac{\partial\theta}{\partial z} + K(\theta) - \gamma D_v \frac{\partial\rho_v}{\partial z} \tag{3}$$

and

$$\frac{\partial\theta}{\partial t} = -\frac{\partial q}{\partial z} \tag{4}$$

where

q	=	flux of moisture in the vertical direction,
θ	=	volumetric wetness of soil,
K	=	hydraulic conductivity,
D_L	=	hydraulic diffusivity,
τ	=	conversion factor for transforming the vapor flux into liquid water flux,
D_V	=	diffusivity for water vapor, and
ρ_V	=	concentration of water vapor in the air-filled void.

The above equations were based on an isothermal condition and assumed that both viscous flow in the liquid phase and diffusion of vapor are impelled by the force field of capillarity and gravity. No explicit account has been taken of osmotic or solute effects on vapor pressure. In reality, the upper layer of the soil surface is warmer during the daytime and is cooler than the deeper layer during night time. The movement of vapor due to the thermal gradient effect tends to be downward during the day and upward during the night. Therefore, the error due to the assumption that the system is isothermal may compensate each other within the same day and will not significantly affect the accuracy of simulation.

Atmospheric Diffusion System

The atmospheric diffusion system transports the water vapor through the turbulent boundary layer into the atmosphere. The vapor transport through an unsteady turbulent boundary layer involves the analysis of time-averaged, boundary-layer equations for the air stream and the continuity equation for the water vapor. This analysis is extremely complicated. However, by assuming the system is quasi-steady, the solution of the system equation becomes obtainable. The "quasi-steady" technique has been commonly used in solving unsteady, mass-transport systems. It assumes that within a small time increment the flow of the carrying fluid is steady and that the effect of the change from one flow state to the other due to the change in time step is negligible. By imposing the above assumption, the water vapor flux within the fully developed boundary layer was expressed by employing Fick's law for diffusion [13] as:

$$J = -k^2 y^2 \left[\frac{dv}{dy}\right] \frac{d\rho}{dy} \qquad (5)$$

where

J = water vapor flux,

k = Prandtl's mixing length coefficient,

v = time averaged wind speed,

ρ = concentration of water vapor in the boundary layer,

y = distance from ground surface.

BASIC EQUATIONS FOR THE PRACTICAL MODEL

Theoretically, the basic equations compiled in the previous section can be solved numerically. However, the processes of analysis are complicated and consume excessive computation time. Several attempts have been made to simplify the system equations. For example, a conjunctive overland and subsurface flow model without an atmospheric diffusion system has been developed by Akan and Yen [14], and a subsurface flow-atmospheric diffusion model without overland flow system was reported by Hillel [15, 16]. The above models solved the dependent variables as functions of space and time and involve long and costly calculations if the real time of simulation is prolonged. For example, the time increment used in Akan and Yen's overland flow system was 30 seconds which would require excessive computation costs if the simulation was for a year or more.

One may simplify the above system equations by transforming all of the space-dependent variables into space-independent variables to avoid time-consuming simulation. The transformation for each system is described in the following sections.

Atmospheric Diffusion System

The solution of Equation 5 depends on many complicated fluid dynamic and boundary conditions. One of the simplest solutions is obtained by assuming that the vapor flux will not be limited by the availability of vapor transmitted from the subsurface system or the overland flow system. The vapor flux under this condition is known as the evaporation potential and is normally used as the upper bound of the evaporation rate from the overland flow and subsurface flow systems. The actual evaporation rate from these systems may then be calculated from the conjunctive system to be discussed later. The solution of Equation 5 under the above condition was proposed by Rohwer [17] as:

$$E_p = 0.372 \cdot (1 - 0.000374 p_a)(1. + 0.6 V_w)(e_s - e_a) \qquad (6)$$

where

E_p = evaporation potential (mm/day),

P_a = atmospheric pressure (mb),

V_w = wind speed (m/sec),

e_s = saturated vapor pressure (mb), and

e_a = vapor pressure in the atmosphere (mb).

Equation 6 requires time-dependent input for atmospheric pressure, wind velocity, and vapor pressure to compute the diurnal variation of evaporation potential. The above information is normally not readily available from existing records. Therefore, from a practical viewpoint, the computation of evaporation potential may be reduced to a daily average level by using the Hamon Equation [18]:

$$E_p = \eta \Gamma^2 s \tag{7}$$

where

η = coefficient of daily evaporation potential,

Γ = duration of daylight in 12-hour unit/day,

s = saturated absolute humidity corresponding to the daily average temperature.

Equation 7 is used to calculate the evaporation potential which is the upper bound of the evaporation rate.

<u>Overland Flow System</u>

It is well known that the local and convective acceleration terms in Equation 1 govern the wave form and the celerity of flood waves. Kichikawa [19] indicated that these terms are predominated by the friction term and suggested that they may be ignored. This conclusion was also confirmed by Takasao [5,6] in his comprehensive study of overland flow systems through laboratory and field observations. Takasao further simplified the system equations by replacing the space-dependent depth of flow, h, with an average flow depth. After this modification, Equations 1 and 2 become:

$$Q_o = \frac{\sin^{1/2}\alpha}{n} H^{5/3} \tag{8}$$

and

$$\frac{dH}{dt} = P - E_o - q_o - \frac{Q_o}{L} \qquad (9)$$

where

Q_o	=	rate of overland flow per unit width of trench cover,
H	=	average depth of overland flow over the entire trench cover, and
L	=	length of slope (or half of trench width).

Furthermore, it is assumed that the rate of evaporation from the total infiltration system will be preferentially obtained from the overland flow system; then the component of evaporation rate may be written as:

$$\begin{aligned} E_o &= E_p, && \text{when } P + H/\Delta t > E_p \\ E_o &= P + H/\Delta t, && \text{when } E_p > P + H/\Delta t > O \\ E_o &= O, && \text{when } P + H/\Delta t = 0 \end{aligned} \qquad (10)$$

where

E_o = component of evaporation rate contributed by the overland flow system.

On the other hand, since the maximum rate of percolation from the overland flow system cannot exceed the saturated hydraulic conductivity of the trench cap, the percolation rate can be written as:

$$\begin{aligned} q_o &= K_s, && \text{when } P - E_o + H/\Delta t > K_s \\ q_o &= P - E_o + H/\Delta t, && \text{when } K_s > P - E_o + H/\Delta t > 0 \\ q_o &= 0, && \text{when } P - E_o + H/\Delta t = O. \end{aligned} \qquad (11)$$

The above expressions show that there are four equations available for solving four dependent variables, Q_o, H, E_o and q_o. Therefore, the system can be solved independently.

<u>Subsurface Flow System</u>

For the purpose of transforming the space-dependent variables into space-independent variables, one may subdivide the moisture contained in the system into three components: gravity, pellicular, and hygroscopic waters. Gravity water is the moisture in a soil which can be drained by gravity force; pellicular water is the moisture in a soil which cannot be drained by gravity force but can be lost to the atmosphere through natural evaporation, and hygroscopic water is the moisture which will never be lost through the above natural processes. Furthermore, it is assumed that soil wetness can be mathematically approximated by a step-wise distribution composed of these three components. Figure 1 shows a comparison of the step-wise wetness distribution and its corresponding original wetness distribution.

Based on the above concept, one may subdivide the dependent variables appearing in the basic differential equations into three components; i.e.,

$$\theta = \theta_1 + \theta_2 + \theta_3$$
$$q = q_1 + (q_2 + q_t) + (q_3 - q_t) \qquad (12)$$

where

θ_1 = component of wetness for the hygroscopic water,

θ_2 = component of wetness for the pellicular water,

θ_3 = component of wetness for the gravity water,

q_1 = component of flux for the hygroscopic water,

q_2 = companion of flux for the pellicular water,

q_3 = component of flux for the gravity water, and

q_t = flux of moisture being transformed from gravity water to pellicular water.

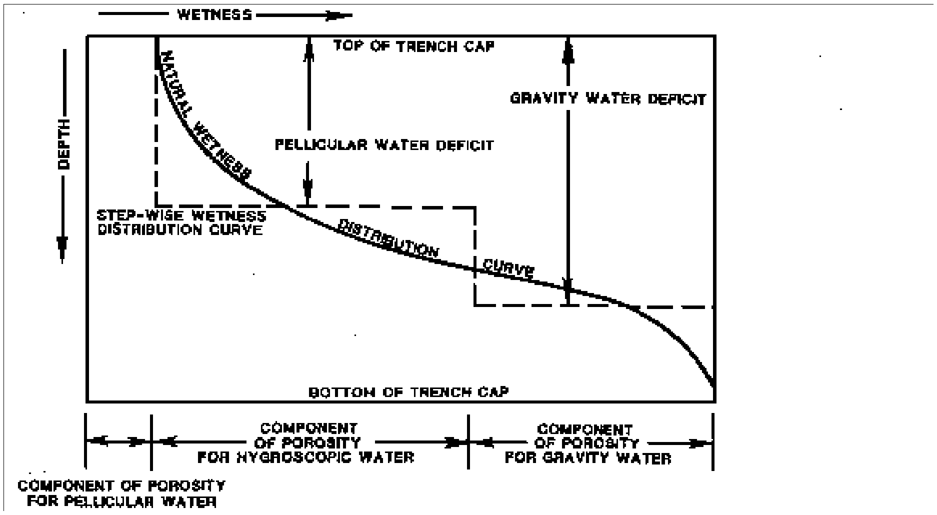

Figure 1. Comparison of a schematic natural wetness distribution curve and its corresponding step-wise wetness distribution curve.

Substituting Equation 12 into Equations 3 and 4, one obtains:

$$q_3 = -D_L(\theta)\frac{\partial\theta_3}{\partial z} + K(\theta) \qquad (13)$$

$$(K(\theta) = 0, \text{ when } \theta_3 = 0)$$

$$\frac{\partial\theta_3}{\partial t} = -\frac{\partial(q_3 - q_t)}{\partial z} \qquad (14)$$

for the component of gravity water and

$$q_2 = -D_L(\theta)\frac{\partial\theta_2}{\partial z} + K(\theta) - \gamma D_v\frac{\partial\rho_v}{\partial z} \qquad (15)$$

$$(K(\theta) = 0, \text{ when } \theta_2 > 0)$$

$$\frac{\partial\theta_2}{\partial t} = \frac{\partial(q_2 + q_t)}{\partial z} \qquad (16)$$

for the component of pellicular water.

Applying the step-wise wetness distribution concept to the above system equations, Equations 13 and 14 may be rewritten by substituting the proper difference forms of the dependent variables. The result is:

$$q_i = K_s, \quad \text{when } Z_g < Z_{max}$$
$$q_i = 0, \quad \text{when } Z_g = Z_{max} \qquad (17)$$

and

$$\frac{dZ_g}{dt} = \frac{(q_i - q_o + q_t)}{\theta_g} \qquad (18)$$

where

q_i = flux of moisture infiltrating into the trench,

K_s = saturated hydraulic conductivity of the soil,

Z_g = deficit of gravity water,

Z_{max} = maximum deficit of gravity water (equivalent to the thickness of the trench cover), and

θ_g = component of wetness for the gravity water under a fully saturated condition; is numerically identical to the porosity for the gravity water.

To simplify the solution of Equation 15, one may compute the component of moisture flux for the pellicular water, q_2, based on the assumptions that (1) the flow is predominated by liquid phase transport, or (2) the flow is predominated by vapor phase transport. The moisture flux for the pellicular water at any instant is then chosen from the larger flux calculated from the above two assumptions.

When the flow is predominated by liquid-phase transport, the third term in Equation 15 vanishes. By substituting the proper difference form of the dependent variables, one obtains:

$$q_L = -D_e\theta_p/Z_p + K_e$$
$$q_L < E_p - E_o \qquad (19)$$

where

q_L = flux of pellicular water transported in the liquid phase,

θ_p	=	component of wetness for the pellicular water under fully saturated conditions and is numerically identical to the porosity for pellicular water,
Z_p	=	deficit of the pellicular water,
D_e	=	hydraulic diffusivity at equivalent wetness, and
K_e	=	hydraulic conductivity at equivalent wetness.

The equivalent wetness for the purpose of this study is calculated by:

$$\theta_e = \theta_h + \sigma\theta_p \tag{20}$$

where

θ_h	=	component of wetness for the hygroscopic water under fully saturated conditions; is numerically identical to the porosity for hygroscopic water, and
σ	=	coefficient of equivalent wetness for pellicular water which should be greater than 0.5 and smaller than 1.0.

When the flow is predominated by vapor phase transport, the first and second terms on the right-hand side of Equation 15 drop out. Substituting the proper difference form of the dependent variables, Equation 15 becomes:

$$q_v = -\tau D_v(\rho_s - \rho_o)/Z_p \tag{21}$$

where

q_v	=	flux of moisture being transported in the vapor phase,
D_v	=	diffusivity of water vapor in the trench cap,
Z_p	=	deficit of pellicular water,
ρ_s	=	water vapor concentration at the front of pellicular water, and
ρ_o	=	water vapor concentrations at the top of trench cover.

The diffusion of water vapor from the top of the trench cover to the atmosphere, on the other hand, can be written based on Fick's Law as:

$$q_v' = -\tau D_a(\rho_o - \rho_a)/\delta \tag{22}$$

where

q_v'	=	flux of water vapor in the boundary layer of diffusion,
D_a	=	diffusivity of vapor in the boundary layer,
δ	=	equivalent thickness of the boundary layer, and
ρ_a	=	water vapor concentration in the atmosphere outside the boundary layer.

Since the vapor flux in the trench cover and in the boundary layer should be identical, Equations 21 and 22 may be combined to yield:

$$q_v = -\frac{\gamma D_a(\rho_s - \rho_o)/\delta}{1 + \dfrac{D_a}{\delta D_v} Z_p} \tag{23}$$

Furthermore, the ratio of diffusivities, D_a/D_v, may be obtained by introducing Penman's study [20] on the diffusion of vapor through a porous solid and Rohwer's study [17] on evaporation potentials. Substituting their results into Equation 23 and replacing its numerator with the evaporation potential, one obtains

$$q = -\frac{E_p - E_o}{1 + \dfrac{1 + 0.6V_w}{\delta}\dfrac{Z_p}{0.66(\theta_p + \theta_g)}} \tag{24}$$

For the purpose of this study, the coefficient, $(1+0.6V_w)/\delta$, is assumed to be a constant and equal to 0.5 m^{-1} (see next section on model testing). When this coefficient is used, Equation 24 becomes

$$q_v = -\frac{E_p - E_o}{1 + \dfrac{0.5Z_p}{0.66(\theta_p + \theta_g)}} \tag{25}$$

Now, the flux of moisture being lost through evaporation q_p can be computed by

$$q_p = -\mathrm{Max}(|q_L|, |q_v|) \tag{26}$$

where "Max" denotes a function designed to select the largest number of those values designated in the parentheses.

Again, by substituting the proper difference form of the dependent variables, Equation 16 becomes:

$$\frac{dZ_p}{dt} = -\frac{(q_p + q_t)}{\theta_p} \tag{27}$$

where q_t may be computed by

$$q_t = q_o \quad \text{when } Z_p > 0$$
$$q_t = 0, \quad \text{when } Z_p = 0. \tag{28}$$

Equations 8-10, 11, 17-19, and 25-28 are the basic equations for the practical infiltration model. There are 11 equations and 11 dependent variables in the system equations. Since all of the dependent variables are space independent and each pair of momentum and continuity equations can be solved in sequence, the computer coding for the mathematical model is greatly simplified from that of the original system equations. A computer model was developed for testing the proposed system equations and for the application of the model to the evaluation of a low-level waste disposal system.

MODEL TESTING

The overland flow system, using Equations 8 and 9 as basic equations, has been studied through laboratory studies and field observations by Takasao et al. [5-8]. They concluded that the space-independent system equations, as represented by Equations 8 and 9, can reasonably be used to characterize the nature of overland flow for flood routing purposes. Since the primary purpose of this study is the simulation of infiltration rates, the proposed overland flow system equations are judged to be adequate for the infiltration model. Testing of the model was therefore concentrated on the subsurface flow system.

To test the subsurface flow system submodel, three special cases with simplified boundary conditions were selected. The results of simulation were compared with existing studies having the similar boundary conditions. They are described in the following sections.

Gravity Water Drainage without Evaporation

A computer simulation of gravity water drainage by gravitational force without evaporation loss was conducted by Hillel and van Bavel [15]. This simulation was conducted by solving equations similar to the basic differential equations expressed in Equations 3 and 4 without the term representing the vapor phase transport. Their results of simulation for a sandy soil (1.16 m thick) were used to calculate the cumulative water volume being drained from the soil (see Figure 2).

By applying the same boundary conditions used in Hillel and van Bevels study to the model developed for this study, the cumulative water volume drained from the soil is simulated and plotted in Figure 2. The comparison of the two results indicates that the proposed model does not simulate the time variation of the drainage precisely, but the calculation of the cumulative water volume drained from the soil is reasonably close to the

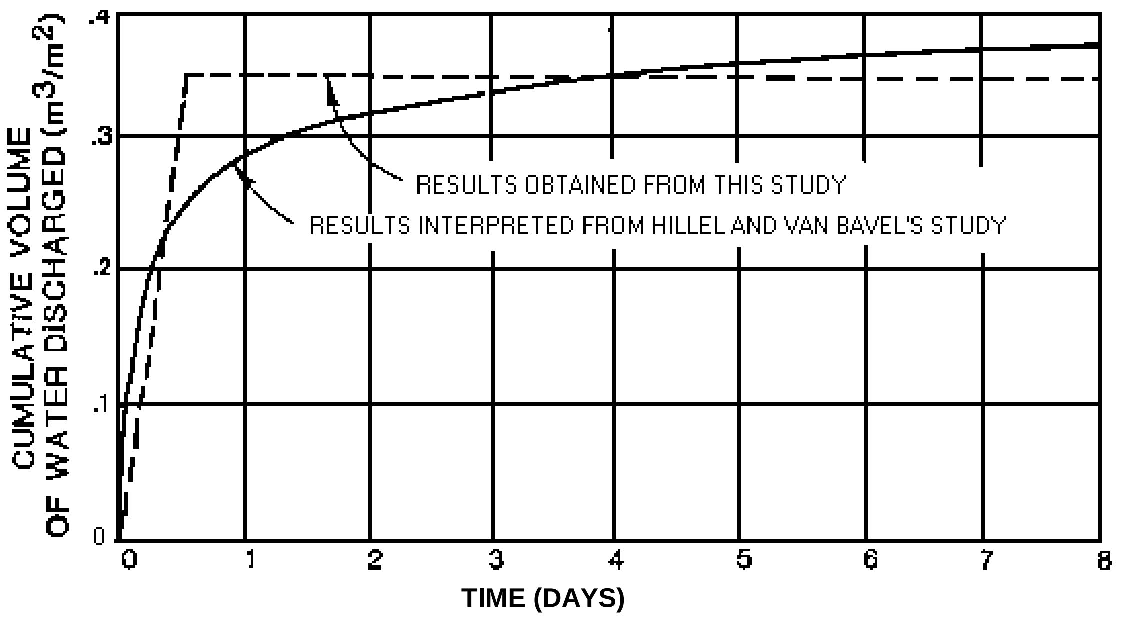

Figure 2. Comparison of the results of simulation for gravity drainage of a typical sand using the proposed model and the results interpreted from Hillel and Van Bevels study.

results obtained from Hillel and van Bevels simulation. Since the main purpose of the simulation described in this study is to obtain the cumulative volume of water infiltrated into the waste trench, the proposed model simulates the rate of infiltration with reasonable accuracy.

Steady-State Evaporation Rate

The steady-state evaporation rate from a clay soil system with a relatively high groundwater table has been analyzed by Ripple [21]. This study analyzed the evaporation rate by solving the system equation characterizing the water flux transported in the subsurface flow system and the vapor flux diffused into the atmosphere. The results of his analyses for the groundwater table at depths of 0.6, 0.9, 1.2 and 1.8 meters are shown in Figure 3. By applying similar parameter values and boundary conditions to the proposed model and reorganizing the results into the form corresponding to Ripple's results, one obtains the results as shown in Figure 3. The results of the simulation fit reasonably well with those obtained by Ripple.

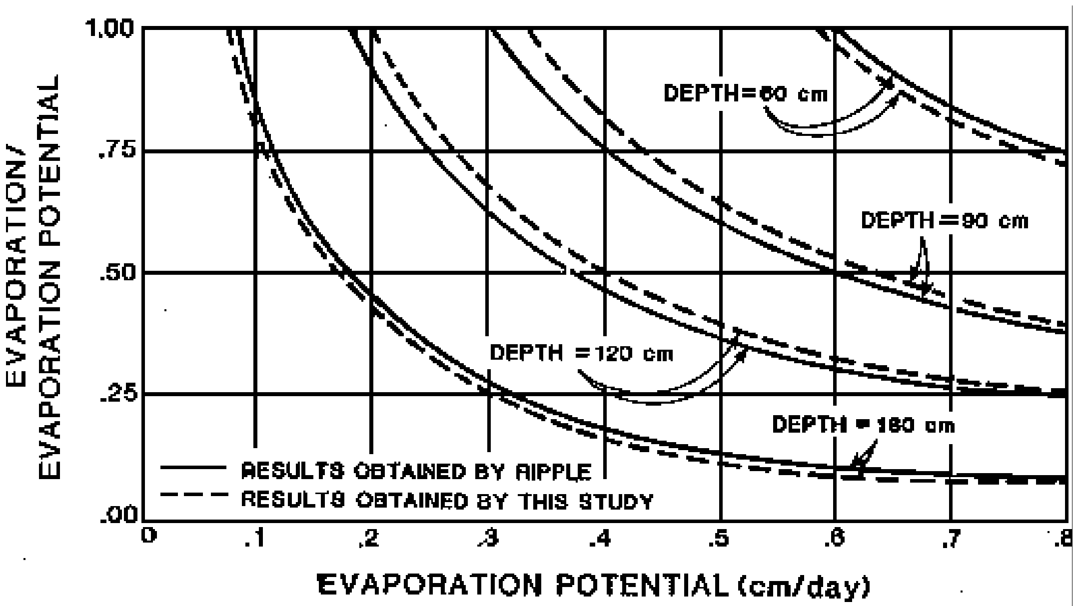

Figure 3. Comparison of the results of simulation for the steady-state evaporation of Chino clay by using the proposed model and that obtained by Ripple.

The above evaporation rate was simulated for a relatively shallow groundwater table. Therefore, the transport of soil moisture was predominated by liquid phase transport. However, when the groundwater table is very deep, the steady-state rate of evaporation may be predominated by the vapor phase transport. The computation of vapor transport in Equation 25 becomes important under this condition.

<u>Vapor Phase Transport</u>

There are no data available for evaluating the transport of pellicular water in a vapor phase. To compare the characteristics of vapor phase transport and liquid phase transport, the flux of moisture being transported by these two phases are computed for various depths of pellicular water deficit based on Equations 19, 25, and 26, using evaporation potentials of 0.3 and 0.6 cm/day. The results of analyses for both sandy and clay soils are plotted and presented in Figure 4. The author selected the coefficient represented by $(1.0 + 0.6V_w)/\delta$ as 0.5 m^{-1} to obtain the best transition from liquid phase transport to vapor phase transport for both soils and for the evaporation potentials which ranged from 0.3 to 0.6 cm/day. The trend of pellicular water flux variations with the increase in the pellicular water deficit agrees, in general, with the trend described by Philip [22].

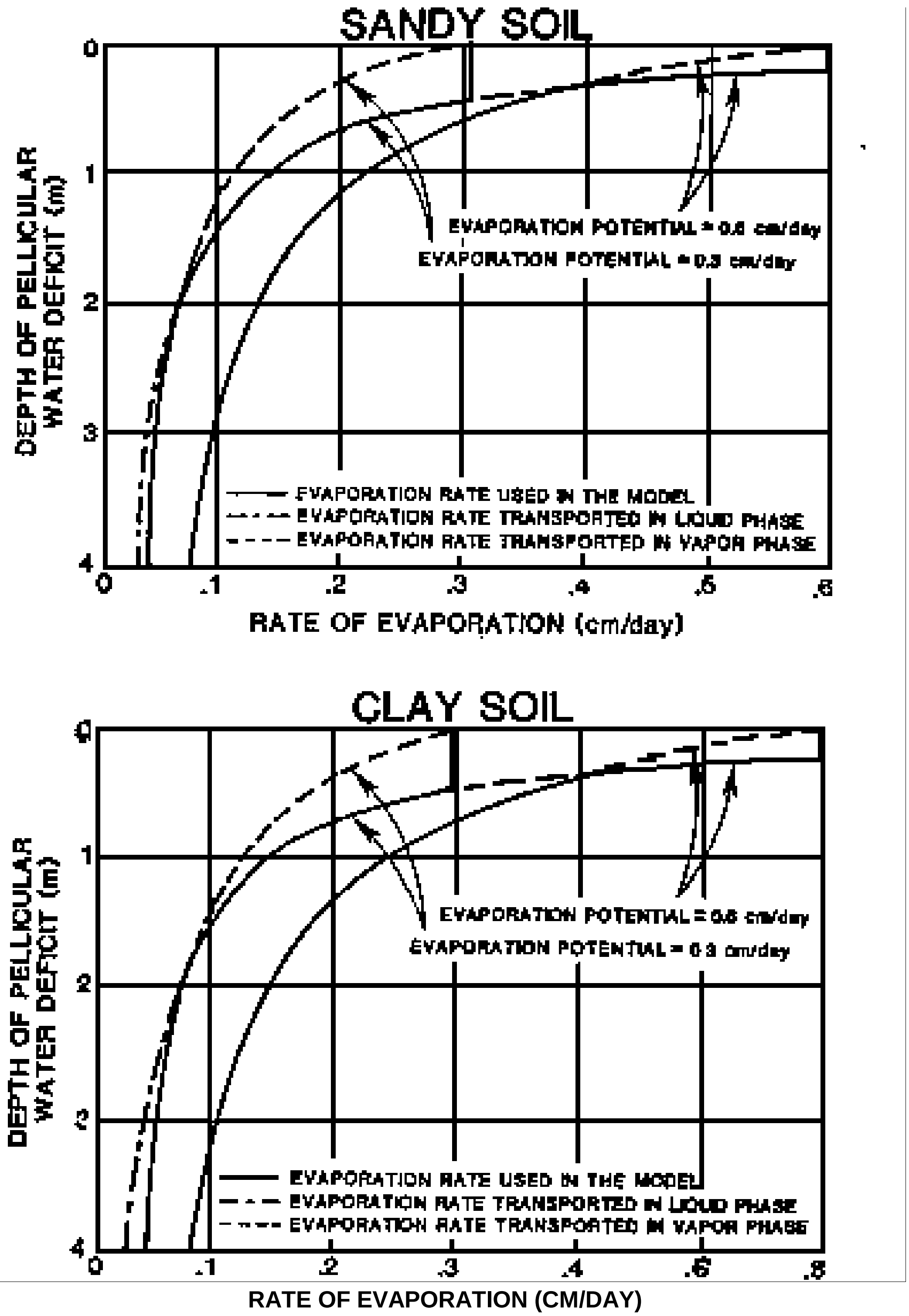

Figure 4. **Transitions in pellicular water transport from liquid phase to vapor phase calculated from Equations 19, 25, and 26 for sandy and clay soils.**

APPLICATION OF THE MODEL TO AN ACTUAL WASTE DISPOSAL SITE

The low-level radioactive waste disposal site located at Barnwell, South Carolina, was selected for an application of the model to an actual waste disposal site. The trench cover is constructed in two soil layers, loamy sand (120 cm thick) at the top and clay soil (80 cm thick) at the bottom. First, the analyses simulated the infiltration rates for a homogeneous trench cover for each of the soil types constituting the trench cover; then, the rate of infiltration for the composite trench section was interpreted from the results.

The soil characteristics for both layers were interpreted from basic data reported by Chem-Nuclear Systems, Inc. [23]. The results used for the computer simulation are listed in Table 1.

Using the annual rainfall of 118 cm/year and the rainfall distribution pattern observed in Augusta, Georgia, the simulation was conducted for the loamy sand and the clay soil. The results of simulation, presented in Figure 5, indicate that the infiltration rates are 45 cm/year for the loamy sand and 7 cm/year for the clay soil. It is obvious that the rate of infiltration will not be affected by the soil characteristics below the level of annual maximum deficit for pellicular water plus the allowance for gravity water storage.

Table 1. Soil Characteristics of the Trench Cover Used in Simulating the Annual Rainfall Infiltration, Barnwell Radioactive Waste Disposal Site.

Type	Saturat hydraul conduct (m/hr)	Equival upward diffus (m^2/hr)	Equival upward conduct (m/hr)	Total porosity	Pellicul water porosity	Gravity water porosity
Top layer Loamy sand	0.02	0.02×10^{2}	0.12×10^{-5}	0.51	0.24	0.25
Bottom layer Clay soil	0.005	0.13×10^{-3}	0.01×10^{-4}	0.54	0.44	0.08

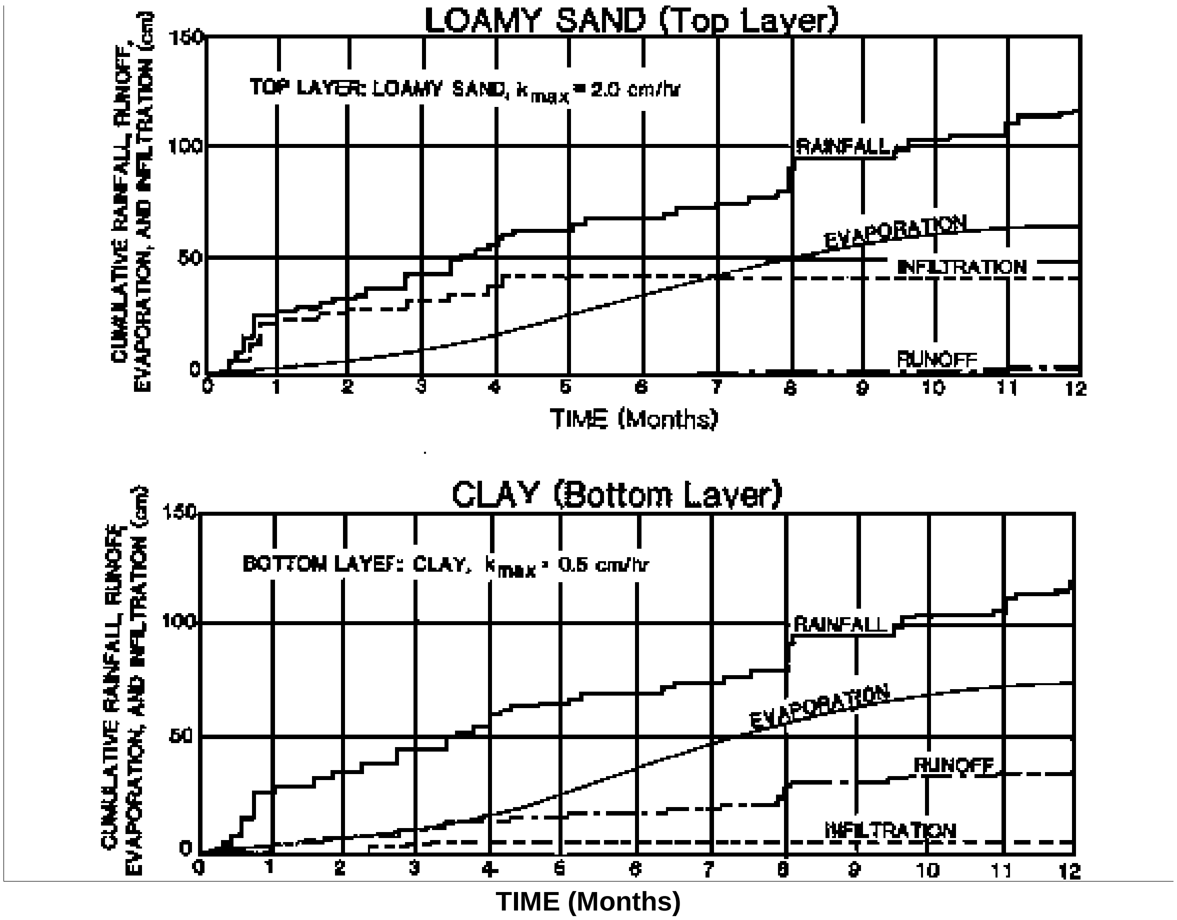

Figure 5. The results of simulation using the proposed model for loamy sand and clay soil, Barnwell radioactive waste disposal site.

The pellicular water deficit simulated for the loamy sand (Figure 6) indicated that the maximum pellicular water deficit reached the level of approximately 50 cm which is far above the upper boundary of the clay soil layer (120 cm below the top of trench cap). Thus, one may conclude that the infiltration rate for the Barnwell site is controlled by the characteristics of the top layer and the rate of infiltration is 45 cm/year or 17.7 in/year.

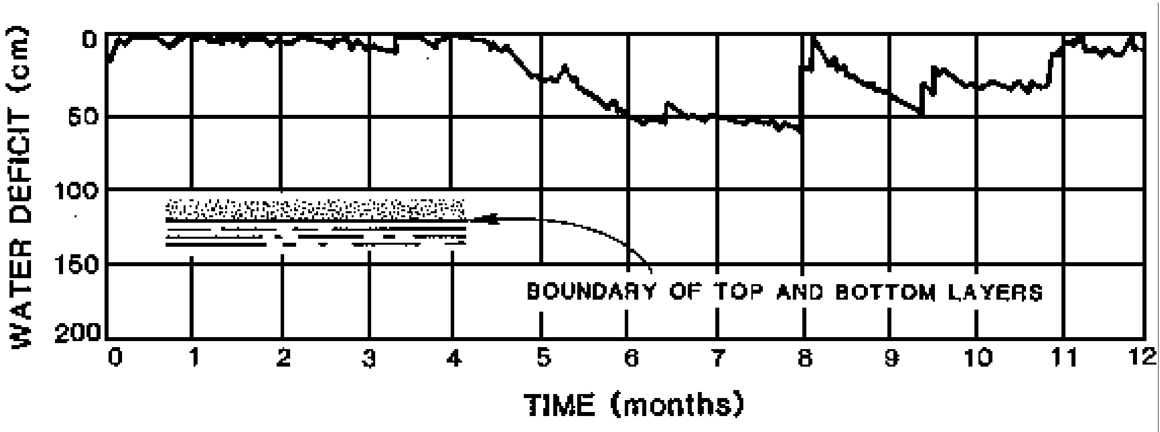

Figure 6. The results of simulation for pellicular water deficit, loamy sand, Barnwell radioactive waste disposal site.

The above analyses assumed a uniform rainfall distribution within the hourly period when the rainfall was recorded. However, the rainfall distribution within any hour in a real case is not necessarily uniform. By assuming a peak factor of two; i.e., all of the rainfall being recorded hourly is assumed to be concentrated in the second half of the recorded period, and reapplying the same input data to the infiltration model to rerun the case for the loamy sand (top layer), the rate of infiltration becomes 35 cm/year or 13.8 in/year. Therefore, one may conclude that the infiltration rate for the Barnwell site may vary between 13.8 and 17.7 in/year due to the nonuniform hourly rainfall distribution.

Independent studies have been conducted by the U.S. Nuclear Regulatory Commission (NRC) [24] and the U.S. Geological Survey (USGS) [25] on the rate of infiltration for the Barnwell site, based on an analysis of groundwater being discharged to a nearby creek. NRC's analyses indicated a rate of 14 in/year; USGS's, 14 to 17 in/year. The results of simulation using the infiltration model are in agreement with these two studies.

CONCLUSIONS

1. The space-dependent variables in the momentum and continuity equations of a subsurface flow system can be transformed into space-independent variables by breaking down the soil moisture into gravity water, pellicular water, and hygroscopic water components.

2. The results of transformations for the overland flow system, the subsurface flow system, and the atmospheric diffusion system have greatly simplified the computational procedures for simulating these systems and have improved the stability and efficiency of the numerical analysis.

3. Although the transformed system equations cannot simulate the dynamic response of soil moisture as precisely as the original partial differential equations, the derived system

equations can be used to simulate the long-term infiltration rates with reasonable accuracy.

4. When the model was applied to the Barnwell radioactive waste disposal site, the results of simulation fit very well with the results of analyses conducted by other investigators using the other methods. This fact implies that the proposed model can be usefully employed to simulate the infiltration of rainwater through the cap of a waste disposal trench.

5. The proposed practical infiltration model is suitable for integration into a larger system model for risk assessment of a low-level radioactive waste disposal site.

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APPENDIX B

THEORETICAL BACKGROUND OF THE GROUNDWATER TRANSPORT SUBMODEL

APPENDIX B

This appendix contains the background theory of the groundwater transport submodel (subroutine VERHOR) used in PRESTO-EPA-POP model as developed by Hung (HU86). The original article was published in the proceedings of Nuclear and Chemical Waste Management, Volume 6, 1986.

AN OPTIMUM GROUNDWATER TRANSPORT MODEL FOR APPLICATION TO THE ASSESSMENT OF HEALTH EFFECTS DUE TO LAND DISPOSAL OF RADIOACTIVE WASTES

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ABSTRACT

This paper presents a groundwater transport model for simulating radionuclide transport in an aquifer, using an approximate solution of the basic transport equation. The model is designed to avoid: (1) relatively high computer simulation costs normally experienced with numerical models and (2) the large errors sometimes introduced when the physical boundary conditions are converted to a mathematical form suitable for the analytical model. The model neglects initially the effect of radionuclide transport through dispersion and compensates for this effect subsequently with a health effects correction factor. This correction factor is found to be a function of the Peclet number, a dimensionless parameter expressing the relative importance of diffusion and convective transportation, and the "transport number," which has been defined and can be determined by using the parameters of the groundwater transport system. The model has a low cost of simulation and yet maintains reasonable accuracy of predicting the cumulative amount of radionuclides flowing through a section. This is the primary output expected from a groundwater transport model for health effects assessments. The model has been integrated into the PRESTO–EPA model which is designed to predict radiation effects due to a shallow–trench operation.

INTRODUCTION

Comprehensive studies on the evaluation of an optimum method of disposing radioactive wastes have been conducted by various government agencies [1, 2] and by an Interagency Review Group [3]. All of these studies have unanimously concluded that the geological disposal method is one of the most viable alternatives. Because the transport of radionuclides through an aquifer to the biosphere is a primary pathway, the groundwater transport model, which simulates the migration of radionuclides in an aquifer, becomes one of the important submodels required in a health effects assessment model.

To date, there are more than 108 groundwater transport models [4] available. However, some of the models fail to consider the process of radionuclide decay and/or sorption and are, therefore, not suitable for the assessment of a radioactive waste disposal site. The rest of the models, which may be suitable for health effects evaluation, can be subdivided into two groups: analytical and numerical. In general, the application of an analytical model is limited by its specific form of boundary conditions. Therefore, when the actual boundary conditions do not match the form that the model called for, some approximation of its actual boundary conditions would be required before the analytical solution can be applied. As a result, these models may suffer from considerable error due to the approximation of boundary conditions.

The application of a numerical model generally requires many more tedious computations than the analytical approach. Such as, the accuracy of simulation depends greatly on the adjustments of time and space increments. Severe errors may result if they are improperly adjusted. On the other hand, a proper adjustment of these increments, in some cases, may result in consuming excessive computer time for the simulation. Therefore, it is conceivable that the cost of simulation may become prohibitive when the model is applied to long–term simulations.

The basic groundwater transport model aiming for health effects assessment was developed by Hung [8] and was integrated into the PRESTO–EPA model [9], a model which is used to predict the radiation impacts on health effects from shallow-trench operations.

The purpose of this paper is to present the groundwater transport model used in the PRESTO–EPA model and its characteristics.

APPLICATION OF THE EXISTING MODEL IN HEALTH EFFECTS EVALUATION

The basic equations for a groundwater transport system include the momentum, the energy, and the continuity equations for the hydrodynamic system and for the solute. Using tensor notations, the equations take the form [10]

$$\underline{v} = -\frac{K}{\mu}\left(\nabla p - \rho g \nabla z\right) \tag{1}$$

$$\nabla\cdot[(\frac{\rho k}{\mu})H(\nabla p - \rho g \nabla z)] + \nabla\cdot\underline{D_h}\cdot\nabla T - q_L - q^{/}H = \frac{\partial}{\partial t}[n\rho U + (1 - n)(\rho c_p T)] \tag{2}$$

$$\nabla\rho\underline{v} + q^{/} = -\frac{\partial}{\partial t}(n\rho) \tag{3}$$

$$\nabla\cdot[\rho C\frac{k}{\mu}(\nabla p - \rho g\nabla z)] + n\nabla\cdot\rho\underline{D_c}\cdot\nabla C - q'C - \rho n\lambda_d RC = \frac{\partial}{\partial t}(\rho nRC) \qquad (4)$$

in which:

C	=	concentration of the radionuclide in the fluid phase;
$\underline{v}$	=	velocity vector;
k	=	permeability;
μ	=	viscosity of the fluid;
p	=	pressure;
ρ	=	mass density;
g	=	gravitational acceleration;
D	=	dispersivity tensor;
T	=	temperature;
q_L	=	rate of heat loss;
H	=	fluid enthalpy;
n	=	porosity;
z	=	height above the reference plane;
λ_d	=	radionuclide decay constant;
R	=	retardation factor;
U	=	internal energy;
c_p	=	specific heat;
q'	=	rate of fluid withdrawal; and
h,c	=	heat energy and component of mass, respectively.

The preceding non–linear equations characterize the transport of radionuclides in a groundwater system. Since each of the preceding equations are related through dependent variables, the direct solution of the system equation for any boundary and initial conditions is extremely difficult. A commonly used practice in solving the system equation is to assume that the flow of groundwater is steady and that there is no heat energy being generated or absorbed in the system. The system equation then reduces to a single equation:

$$R\frac{\partial C}{\partial t} - \nabla\cdot(\underline{D}\cdot\nabla C) + V\nabla C + \lambda_d RC = 0 \qquad (5)$$

in which V is the interstitial velocity (V = v/n). Equation 5 has been further simplified and solved by numerous investigators [10, 11, 12, and 13] employing numerical or analytical approaches. However, some difficulties are often encountered in applying these models for health effects assessments. They are described in the following sections.

Numerical Models

The existing multidimensional models are solved either by the finite–difference method [10] or by the finite–element method [11, 12, and 13]. A model employing the finite–element method is, in general, more efficient than one employing the finite–difference method [12]. However, the time required to execute a computer model employing the finite–element method is still far beyond the limitations of a normal project budget for risk assessment when numerous cases with long durations of simulation must be considered.

Analytical Models

Lester, Jansen, and Burkholder [6] developed an analytical groundwater transport model for a one–dimensional, semi–finite aquifer system having impulse release and decaying band release boundary conditions. These boundary conditions at x = 0 were expressed as:

$$\mathrm{C} = C_0 \delta(t) \tag{6}$$

and

$$\mathrm{C} = \frac{C_0}{t_d} EXP(-\lambda_d t) \tag{7}$$

for the impulse release and the decaying band release, respectively. In the preceding equation, x is the space coordinate, t is the time, t_d is the duration of radionuclide leaching, and C_0 is the concentration of radionuclides at t = 0.

Ford, Bacon, and Davis, Inc. employed an analytical model that assumed that the rate of radionuclide release at any time is proportional to the inventory of radionuclides remaining at the source point [7]. Mathematically, it is expressed as:

$$\mathrm{C} = \frac{\lambda_L I_m}{Q_w} EXP[-(\lambda_d + \lambda_L)t] \tag{8}$$

in which λ_L is the leaching constant, I_m is the initial inventory of the radionuclides in the waste depository, and Q_w is the rate of groundwater flow.

These analytical models have made considerable contributions in groundwater transport modeling by simplifying the simulation procedures. However, the application of these models to health effects assessments is limited because it requires converting the actual boundary condition to a form meeting the requirements of the analytical model. These approximations may result in considerable simulation error in some cases.

The preceding discussion implies that existing numerical and analytical groundwater models may either be too costly to compute or may introduce large errors when applied to health effects assessments. Therefore, a more accurate and more economic groundwater transport model has been developed for health risk assessment and is presented in this paper.

THEORETICAL BACKGROUND OF THE OPTIMUM GROUNDWATER TRANSPORT MODEL FOR HEALTH EFFECTS ASSESSMENTS

Derivation of the Basic Equation

The groundwater transport model to be discussed in this section simulates the transport of radionuclides from a disposal site to a point where radionuclides are pumped out to the biosphere for human uptake or discharged into a surface stream for another mode of transport. To simplify the model, it is assumed that the flow of the fluid carrying the radionuclides is steady, uniform, and one–dimensional. It is also assumed that the dissolved radionuclides are in equilibrium with those adsorbed by the solids in the aquifer formation and that decay is in progress for both dissolved and adsorbed radionuclides.

The basic one–dimensional groundwater transport equations simulating radionuclide migration in an aquifer may be reduced from Equation 5. This yields:

$$D\frac{\partial^2 C}{\partial x^2} - V\frac{\partial C}{\partial x} - R\frac{\partial C}{\partial t} - \lambda_d RC = 0 \tag{9}$$

which is to be solved by the following initial and boundary conditions:

$$C = 0, \quad at \quad all \quad x, \quad when \quad t = 0 \tag{10}$$

$$\begin{aligned} C &= C_0(t), \quad at \quad x = 0, \quad when \quad t > 0, \quad and \\ C &= finite, \quad at \quad x = \infty, \quad when \quad t > 0 \end{aligned} \tag{11}$$

For the convenience of analysis, one may transform the dependent variable from radionuclide concentration, C, into the rate of radionuclide transport by multiplying Equations 9, 10, and 11 by the rate of groundwater flow. When this transformation is completed, the preceding equations become:

$$D\frac{\partial^2 Q}{\partial x^2} - V\frac{\partial Q}{\partial x} - R\frac{\partial Q}{\partial t} - \lambda_d R Q = 0 \qquad (12)$$

$$\begin{array}{lll} Q = 0, & \text{at all } x, & \text{when } t = 0, \\ Q = Q_0(t), & \text{at } x = 0, & \text{when } t > 0, \text{ and} \\ Q = \text{finite}, & \text{at } x = \infty, & \text{when } t > 0 \end{array} \qquad (13)$$

where Q denotes the rate of radionuclide transport.

Since Equation 13 is an undefined boundary condition, the analytical solution for Equation 12 cannot be obtained. However, one may express its solution into a convolution form expressed by:

$$Q(t) = \int_0^t Q_0(t - \tau)u(\tau)d\tau \qquad (14)$$

in which u denotes the radionuclide release rate at the point of discharge end, x = L, which responds to the unit release of a radionuclide at x = 0 and $\tau = 0$. This function is normally known as a unit response function.

The preceding unit response function, $u(\tau)$, has been thoroughly studied by Burkholder et al. [6], with the following results:

$$u(\tau) = \frac{V}{2L}\sqrt{\frac{RP}{\pi\theta^3}} EXP\left[-N_d\theta - \frac{P\theta}{4R}\left(\frac{R}{\theta} - 1\right)^2\right] \qquad (15)$$

in which P is the Peclet number (= VL/D); θ is the dimensionless time (= τV/L); and N_d is the decay number (= λ_dL/V). By substituting Equation 15 into Equation 14, one obtains:

$$Q(t) = \int_0^t Q_0(t - \tau)\cdot\frac{V}{2L}\sqrt{\frac{RP}{\pi\theta^3}} EXP\left[-N_d\theta - \frac{P\theta}{4R}\left(\frac{R}{\theta} - 1\right)^2\right] d\tau \qquad (16)$$

Equation 16 cannot be integrated because $Q_0(t - \tau)$ is undefined. However, if the dispersion term, $D(\partial^2 Q/\partial x^2)$, in Equation 12 is neglected, then the unit response function, $u'(\tau)$, for the modified Equation 12 becomes [6]:

$$u'(\tau) = EXP \frac{-RL\lambda_d}{V} \delta\left(\tau - \frac{RL}{V}\right) \tag{17}$$

As a consequence, Equation 14 can be integrated, and the result is
In Equations 17 and 18, δ denotes the delta function, and the prime on u and Q denotes variables responding to the system with the dispersion term being neglected.

$$Q'(t) = Q_0\left(t - \frac{RL}{V}\right) EXP \frac{-\lambda_d RL}{V} \tag{18}$$

Although Equation 18 is easier to calculate than Equation 16, the results obtained from Equation 18 include an error resulting from neglecting the dispersion term in the basic transport equation. To compensate for this error, a correction factor defined by:

$$\xi\left(P, \frac{\lambda_d RL}{V}, t\right) = \frac{Q(t)}{Q'(t)} \tag{19}$$

has been introduced. After this correction factor has been characterized, the rate of radionuclide transport, Q(t), can be obtained by combining Equations 18 and 19. The result is:

$$Q(t) = \xi Q_0\left(t - \frac{RL}{V}\right) EXP\left(-\frac{\lambda_d RL}{V}\right) \tag{20}$$

In Equation 20, the correction factor, ξ, is expected to be a function of t, P, and $\lambda_d RL/V$. The complexity of this term prohibits its application. This correction factor is further transformed into a time-independent factor based on the grounds that the transport model is primarily for the purpose of risk assessment. The transformation is derived as follows.

The assessment of health effects due to direct and/or indirect ingestion of groundwater contaminated with radionuclides involves complicated simulation of the cumulative doses of organs. Such an assessment also requires the probabilistic analysis of the occurrence of fatal cancer effects following the simulation of radionuclide transport in the aquifer. Due to the complexity of the dose and health effects simulation, a linear model is generally employed in various risk assessment models. An example of this application is the PRESTO–EPA model [9].

When a linear model is employed, the annual health effects due to the ingestion of a specific radionuclide, E_i, for a community with a population of P' can be expressed by [14]:

$$(H_e)_i = \left(\frac{P^{/}}{T_e}\right) \sum_{l=1}^{M} E_i (R_f)_{i,l} \tag{21}$$

in which R_f is the health risk conversion factor per unit rate of chronic ingestion, T_e is the number of years of life expectancy, E is the rate of radionuclide exposure, and I and l denote the order of radionuclides and human organs, respectively.   Furthermore, since a risk assessment involves the estimates of health effects for infinitive generations residing in the community of interest, the total health effects due to the exposure rate of E_i is calculated by the following generalized equation:

$$\begin{aligned}(H_t)_i &= \int_0^{\infty} \left(\frac{P^{/}}{T_e}\right) \sum_{l=1}^{M} E_i (R_f)_{i,l} dt \\ &= \left(\frac{P^{/}}{T_e}\right) \sum_{l=1}^{M} (R_f)_{i,l} \int_0^{\infty} E_i dt\end{aligned} \tag{22}$$

where H_t is the total health effects and t is the time.

Since the annual rate of radionuclides that will be ingested by humans from the drinking water pumped out of the aquifer is directly proportional to the rate of radionuclides being transported to the well point, one may write:

$$E_i = \frac{rQ_i}{P^{/}} \tag{23}$$

where r is the ratio of the rates of radioactivity expected to be ingested by the inhabitants of the community to the rate of radioactivity reaching the well point, and Q_i is the rate of radionuclides being transported to the well point.

Substituting Equation 23 into Equation 22, one obtains

$$(H_t)_i = \left(\frac{r}{T_e}\right) \sum_{l=1}^{M} (R_f)_{i,l} \int_0^{\infty} Q_i dt \tag{24}$$

Equation 24 indicates that the total health effects depend on the total cumulative activity of radionuclides reaching the well point and are independent of the time variation of the transport rate. Therefore, for the purpose of health effects assessment, <u>the key input required from a groundwater transport model is the cumulative amount of radionuclides reaching the well point over an infinite period of time.</u> This is the key concept used in developing the groundwater model presented in this paper.

Since the goal of health effects assessments is estimating fatal health effects, one may also introduce a long–term health effects correction factor, η, defined by:

$$\eta = \frac{H_t}{H'_t} \tag{25}$$

where H_t and H_t' represent the total health effects resulted from the groundwater pathway with and without considering the dispersion term, respectively.

For the purpose of developing a groundwater transport model, one may assume that the population affected by the well water remains constant and that the total health effects due to the released radionuclides are so small that they would not alter the size of the population at risk and the other factors affecting the health effects. If this is the case, there will be a linear relationship between the cumulative radionuclides reaching the well and the expected total health effects. Substituting Equation 24 into Equation 25 and lumping together all terms affecting the health effects conversion factors into a single health effects conversion factor, Equation 25 can then be rewritten as:

$$\eta = \frac{F_h \int_0^{\infty} Q(t) dt}{F_h \int_0^{\infty} Q'(t) dt} \tag{26}$$

where F_h denotes the conversion factor for health effect from cumulative radionuclide release.

Subsequent substitution of Equation 14 into Equation 26 yields:

$$\eta = \frac{\int_0^{\infty}\int_0^{t} Q_0(t - \tau)u(\tau)d\tau dt}{\int_0^{\infty}\int_0^{t} Q_0(t - \tau)u^{/}(\tau)d\tau dt} \tag{27}$$

When the order of integration of the double integral for both numerator and denominator is reversed, Equation 27 can be rewritten as:

$$\eta = \frac{\int_0^{\infty}\int_{\tau}^{\infty} Q_0(t - \tau)u(\tau)dt d\tau}{\int_0^{\infty}\int_{\tau}^{\infty} Q_0(t - \tau)u^{/}(\tau)dt d\tau} \tag{28}$$

Furthermore, when the independent variable, t, is transformed to σ such that σ = t – τ, Equation 28 becomes

$$\eta = \frac{\int_0^{\infty}\int_0^{\infty} Q_0(\sigma)u(\tau)d\sigma d\tau}{\int_0^{\infty}\int_0^{\infty} Q_0(\sigma)u^{/}(\tau)d\sigma d\tau} \tag{29}$$

Since Q_0 is independent of τ and u and u' are independent of σ, the double integral in the denominator and numerator can now be separated into products of single integral and yield:

$$\eta = \frac{\int_0^{\infty} Q_0(\sigma)d\sigma \int_0^{\infty} u(\tau)d\tau}{\int_0^{\infty} Q_0(\sigma)d\sigma \int_0^{\infty} u^{/}(\tau)d\tau}$$

This can be simplified to:

$$\eta = \frac{\int_0^{\infty} u(\tau)d\tau}{\int_0^{\infty} u^{/}(\tau)d\tau} \tag{30}$$

Equation 30 implies that the health effects correction factor, η, is independent of environmental time. Once the health effects correction factor is determined, the rate of radionuclides being discharged may be approximated by:

$$Q(t) = \eta Q_0\left(t - \frac{RL}{V}\right)EXP\left(-\frac{\lambda_d RL}{V}\right) \tag{31}$$

Equation 31 is the basic equation of this groundwater transport model.

<u>Characterization of the Health Effects Correction Factor</u>

To determine the characteristics of the health effects correction factor, one may first substitute Equations 15 and 17 into Equation 30 and then complete the integration of the denominator. This yields:

$$\eta = \frac{\int_0^\infty \frac{1}{2}\sqrt{\frac{RP}{\pi\theta^3}}EXP\left[-N_d\theta - \frac{P\theta}{4R}\left(\frac{R}{\theta} - 1\right)^2\right]d\theta}{EXP\left(-\frac{\lambda_d RL}{V}\right)} \tag{32}$$

The numerator of Equation 32 can also be integrated into a modified Bessel function of the second kind [15]. When the result of integration is substituted, Equation 32 becomes:

$$\eta = \frac{EXP\left(\frac{P}{2} - \frac{P}{2}\sqrt{1 + \frac{4\lambda_d RL}{PV}}\right)}{EXP\left(-\frac{\lambda_d RL}{V}\right)} \tag{33}$$

Equation 33 indicates that the health effect correction factor is a function of the Peclet number and the parameter expressed by $\lambda_d RL/V$. This parameter represents the ratio of the radioactive decay constant, λ_d and the "transport constant", V/RL, and is designated as the "transport number" for this study. The preceding results were plotted on a Peclet number vs. transport number plane, as shown in Figure 1. This figure indicates that the health effects conversion factor increases with the increase in transport number and decreases with the increase in Peclet number. Equation 33 also indicates that the health effects correction factor is always greater than 1.

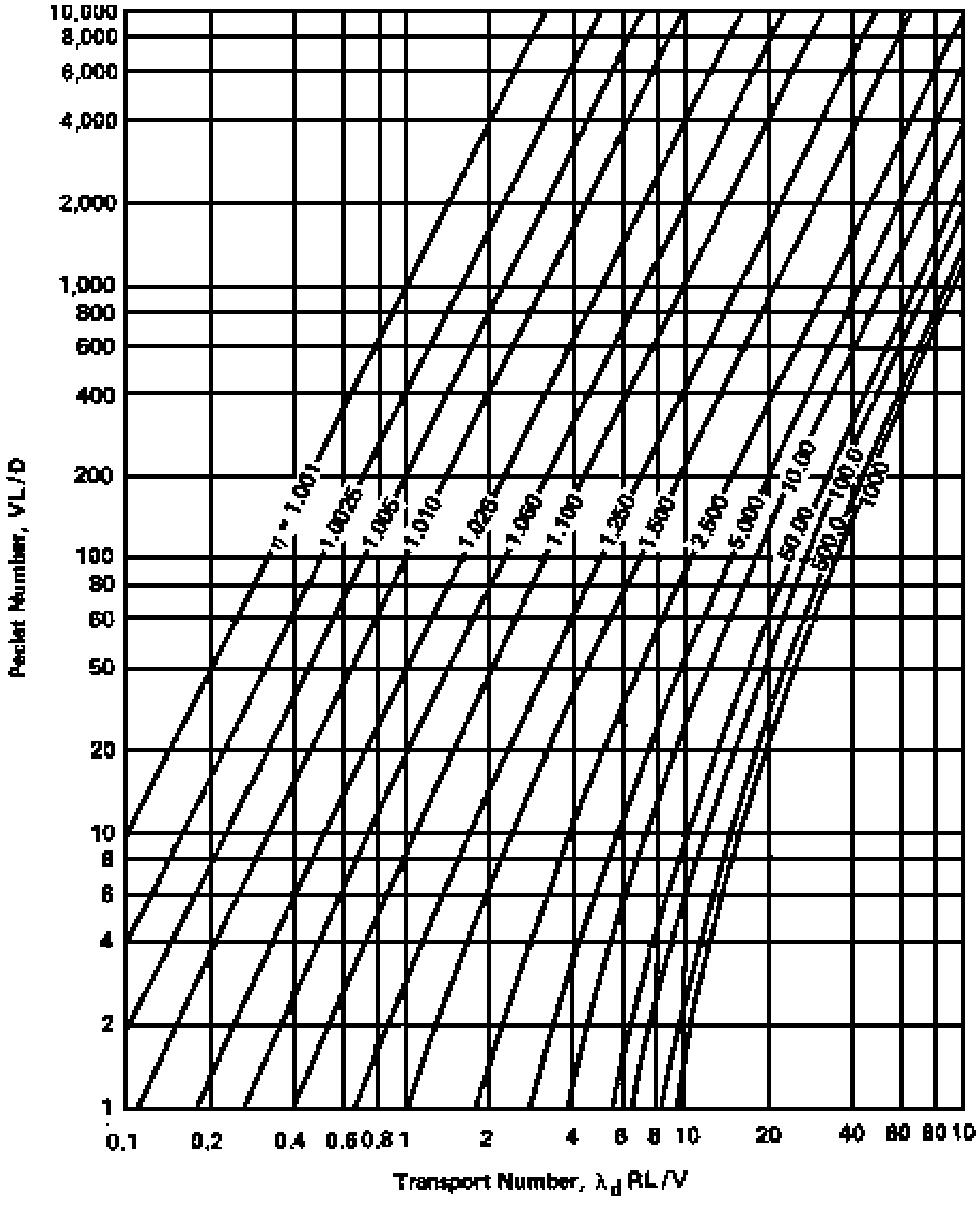

Figure 1. Results of Health Effect correction factor analysis, Equation 33.

Proposed Groundwater Transport Model for Health Effects Assessment

Based on the previous discussions, a groundwater system with initial and boundary conditions as shown in Equation 13 may be simulated by Equation 31, which is duplicated here:

$$Q(t) = \eta Q_0\left(t - \frac{RL}{V}\right) EXP\left(-\frac{\lambda_d RL}{V}\right) \tag{34}$$

Equation 34 represents an algebraic equation in which the constant, η, is determined from Equation 33; and the terms RL/V and λ_d are known constants determined from the characteristics of the groundwater system. Therefore, the proposed model described by Equation 34 is the simplest and most economical to process when it is integrated into a health effects assessment model.

It should be noted that when this model is employed in a health effects assessment model, there may be a slight error in the number of health effects for each individual generation, but the total health effects for all generations should remain the same as that obtained from the direct integration of Equation 14. The nature of this error is characterized in the following section.

CHARACTERIZATION OF THE POTENTIAL ERROR IN THE MODEL

Hypothetical Groundwater System

To characterize the nature of error incurred by the proposed model, a hypothetical groundwater transport system was established. In the hypothetical groundwater system, it was assumed that: the velocity of groundwater flow is 100 m/yr; the location of radionuclide discharge is 500 meters downstream from the source point where the radionuclide is released; the coefficient of dispersion is 300 m^2/yr; the rate of radionuclide release at the source point, x = 0, varies with time and is represented by

$$\begin{aligned} Q_0(t) &= Sin\left(\frac{\pi}{t_d}t\right) && for \quad 0 < t < t_d \\ Q_0(t) &= 0 && for \quad t > t_d \end{aligned} \tag{35}$$

where t_d is the duration of radionuclide release.

Three cases are assumed for the analysis. Case I represents a fast release, t_d = 200 yr, and long radionuclide half–life, λ_d = 0.000693. Case II represents a fast release, t_d = 200 yr, and short radionuclide half–life, λ_d = 0.0693. Case III represents a slower release, t_d = 400 yr, and long radionuclide half–life, λ_d = 0.000693. Each case is subdivided into three subcases with retardation factors equal to 1, 10, and 100, respectively.

Method and Results of Analysis

Two models were developed for the analysis. One of them was developed based on the numerical integration of Equation 16 and was designated as the "Exact Model." The other model was developed based on Equation 34 and was designated as the "Optimum Model." Each of these models was designed to compute the radionuclide discharge rate at the downstream end of the aquifer and the cumulative amount of radionuclides released at the discharging point over infinite time. The results of computer analyses using these two models are presented in Figures 2, 3, and 4.

Discussion of Results

For Cases I and III, i.e., those with long radionuclide half–lives, the rate of radionuclide release and the cumulative radionuclide release computed from the exact model and the optimum model agree very well for all three subcases. However, the results of the Case II analysis, where the radionuclide half–life is short, indicate that the rate of radionuclide discharge obtained from the optimum model deviates more and more from that obtained from the exact model as the retardation factor increases. Nevertheless, the major deviations are merely in the time–lag of radionuclide discharge, whereas the peak discharge showed little deviation (Figure 3). The results of this latter analysis also indicated that the deviation will be mitigated for those radionuclides with longer half-lives; i.e., with smaller transport numbers (Figure 2). Fortunately, a system with larger transport numbers results in a limited quantity of radionuclide discharge, as can be seen by comparing Case II-3 with Cases II-2 or II-l. This result implies that the discharge of radionuclides with high transport numbers, such as Case II-3, would not be a major concern from the point of view of health effects assessment. Besides, this deviation should further decrease with the increase in the duration of radionuclide release at the radionuclide source point, as shown in Figures 2 and 4.

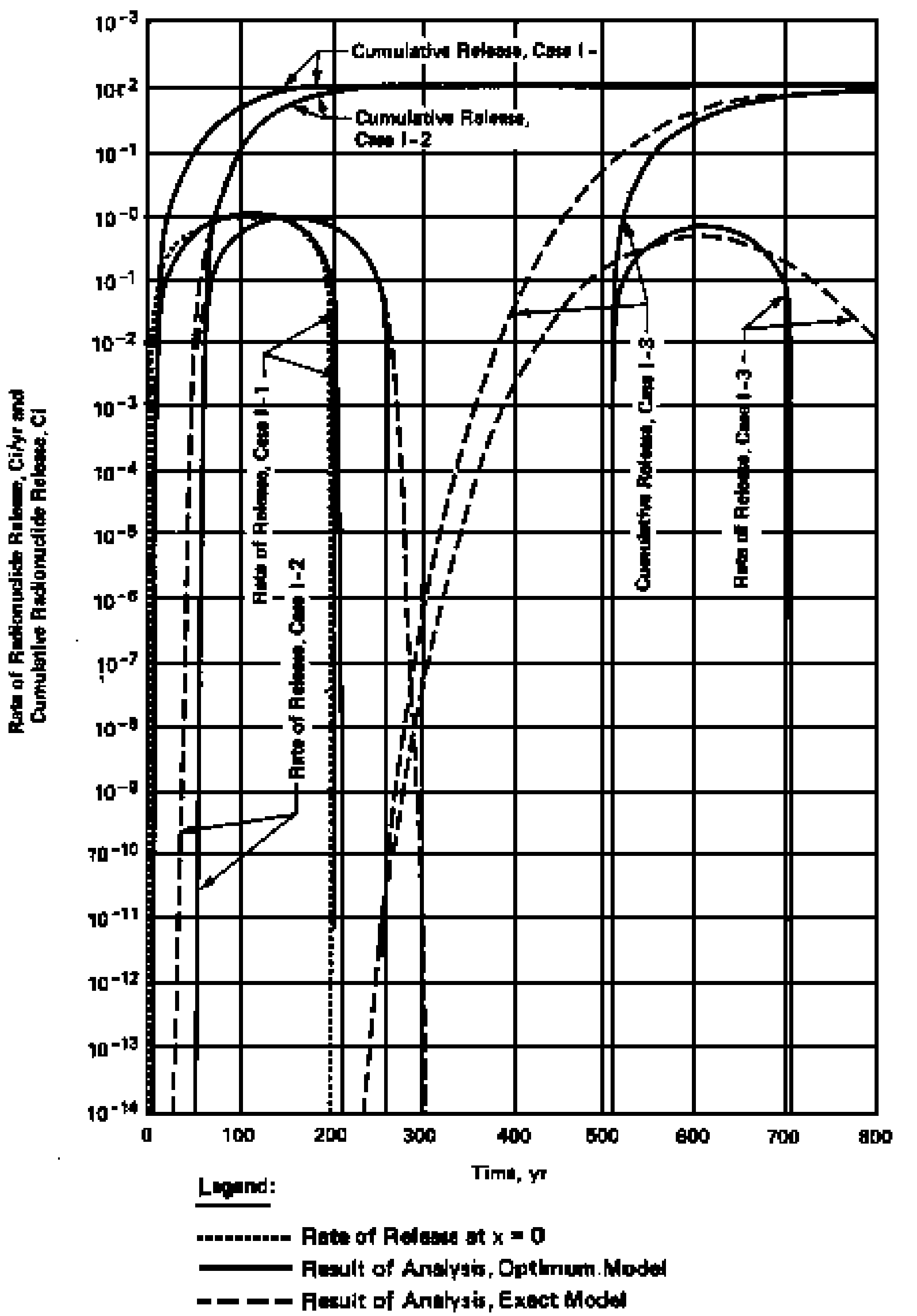

Figure 2. **Comparison of the Result of Analyses Obtained from the Optimum Model and the Exact Model, Case I, λ_d = 0.000693, t_d = 200 yrs**

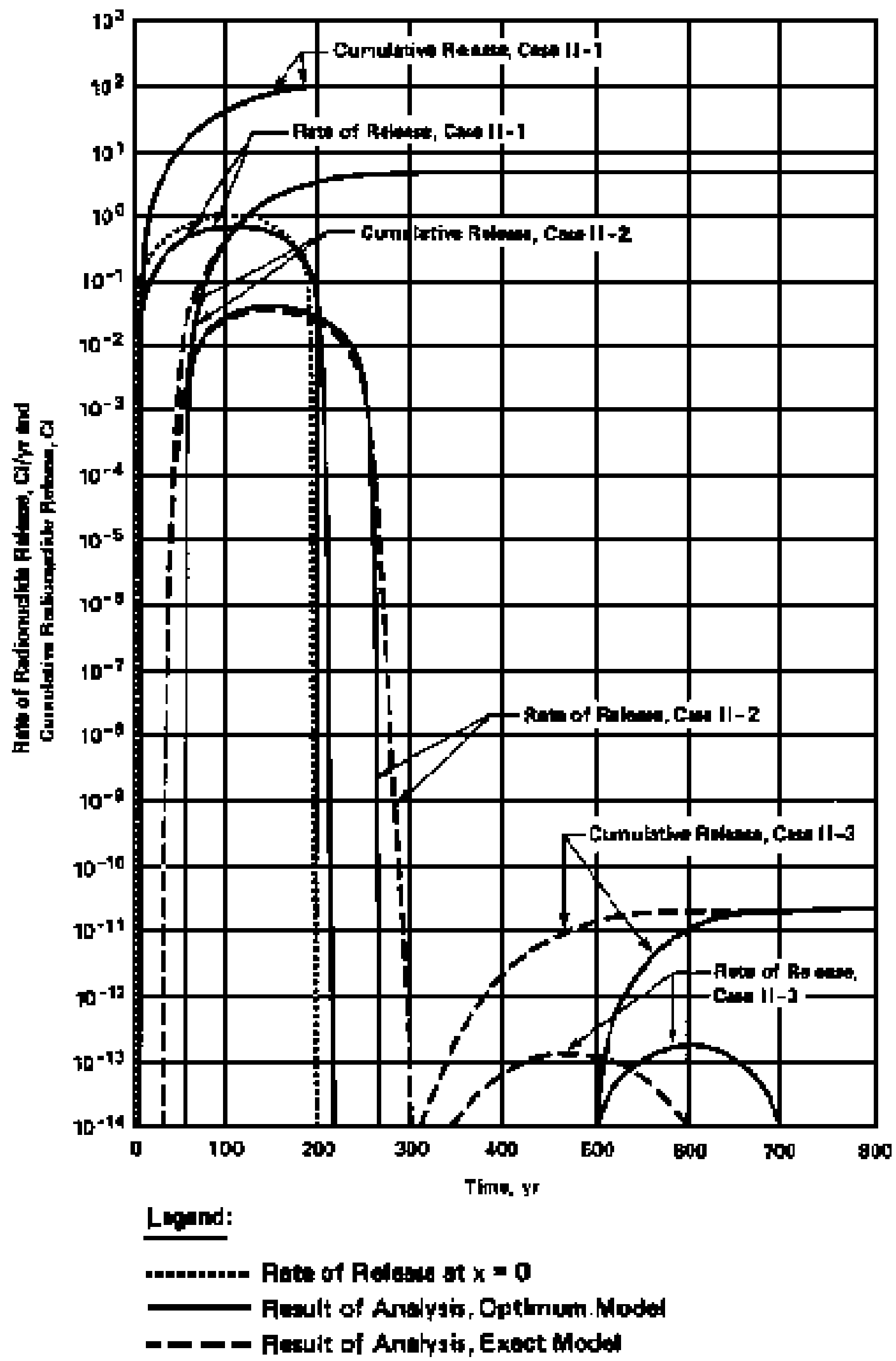

Figure 3. Comparison of the Result of Analyses Obtained from the Optimum Model and the Exact Model, Case II, λ_d = 0.0693, t_d = 200 yrs

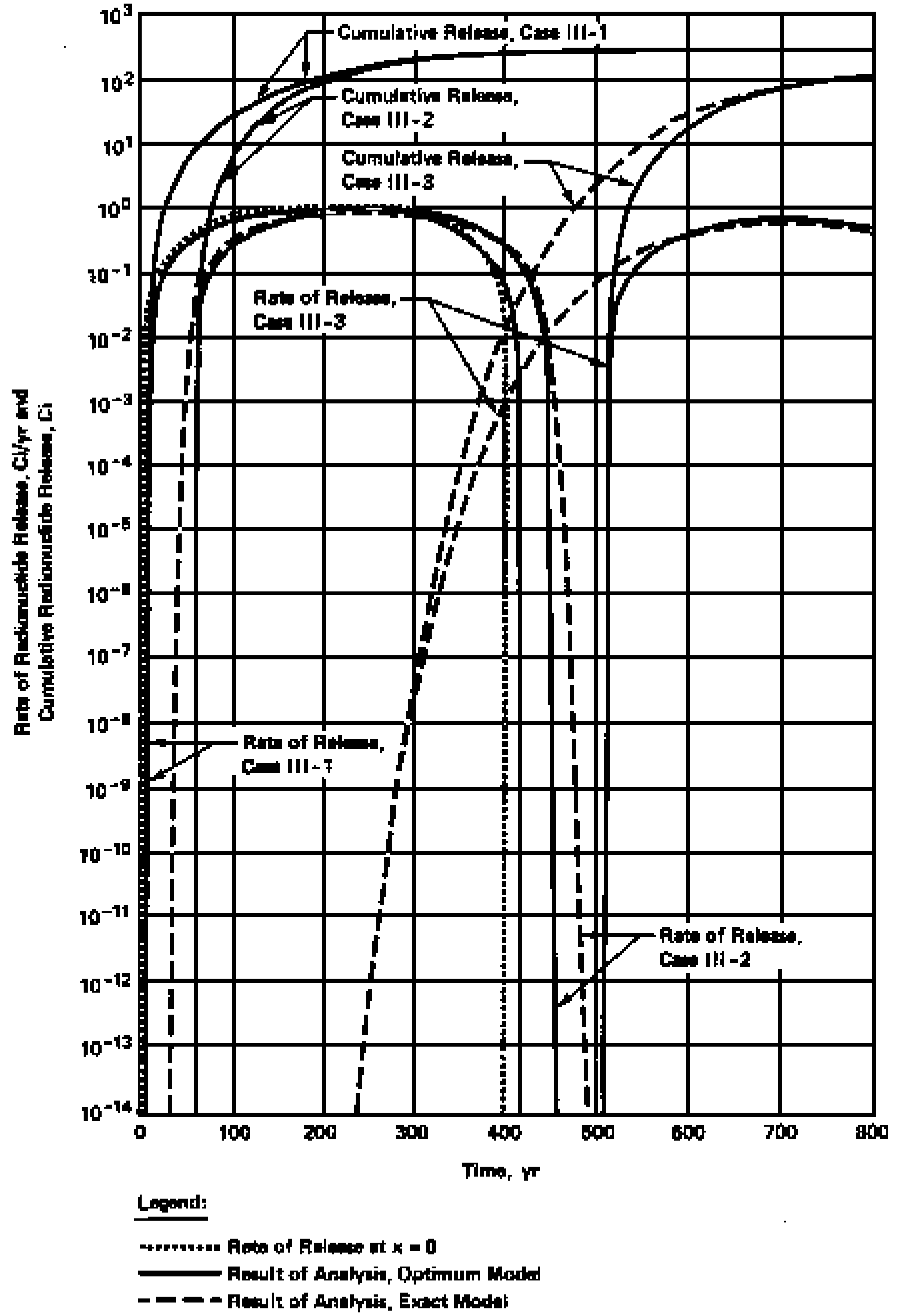

Figure 4. Comparison of the Result of Analyses Obtained from the Optimum Model and the Exact Model, Case II, λ_d = 0.000693, t_d = 400 yrs

Nevertheless, the cumulative radioactive discharge, which is the primary parameter in determining total health effects from a radioactive waste disposal site, remains the same for those obtained from the exact model and from the optimum model in all cases. This agreement implies that the proposed optimum model can be integrated into the health effects assessment model without introducing any significant error in the assessment of health effects.

APPLICATION TO A RISK ASSESSMENT MODEL

The optimum groundwater transport model has been integrated into the PRESTO–EPA model, a model designed to predict the radiological effects due to the disposal of radioactive wastes by a shallow trench operation. The PRESTO-EPA model is a complete risk assessment model. It includes the simulation of radionuclide transport from the wastes through hydrologic and atmospheric pathways to environmental receptors and from the environmental receptors to human organs through food–chain pathways and the estimation of the number of fatal health effects from the cumulative exposure of radionuclides to the organs. The model was developed by joint effort of the Oak Ridge National Laboratory and EPA.

The groundwater transport submodel receives output from the leaching submodel as its boundary conditions and calculates the rate of radionuclide transport at the well point. These outputs are then fed into the food-chain submodels for human-exposure evaluations and, subsequently, for health effects assessments.

The PRESTO–EPA model has been used to assess the health effects for over 400 different combinations of radionuclide source terms with various hydrogeological, demographic, and disposal conditions. The model interacts with other submodels smoothly, implying that the proposed optimum groundwater transport model can be integrated into a risk assessment model.

CONCLUSION

An optimum groundwater transport model for health effects assessment has been derived and characterized. The processing time required to simulate this model is significantly less than that for comparable models, because it requires only algebraic calculations.

The error from simulating the peak discharge of radionuclides using the "optimum " model, as compared with the results from that of the "exact" model; i.e., the numerical model represented by Equations 16 and 35, may be noticeable when the groundwater transport number is greater than 5. However, the cumulative amount of radionuclides released under the same conditions is normally only a small fraction of the cumulative radionuclides released at the source point. Therefore, the effect of this error should not be as important as that for those radionuclides with lower transport numbers.

The predicted cumulative radionuclides passing the point of interest obtained from the proposed "optimum" model agree very well with that obtained from the "exact" model in all cases. This implies that the proposed model can be integrated into a health effects assessment model with confidence, if one accepts a one–dimensional flow model.

The application of the proposed optimum groundwater transport model to the PRESTO–EPA model indicated that the model interacts with other submodels very smoothly, implying that the model can be easily integrated into a risk assessment model.

ACKNOWLEDGMENTS

The author is grateful to Mr. G. Lewis Meyer of EPA for his valuable suggestions and continuous encouragement throughout the development of this model. Special acknowledgments to Dr. Akio Ogata of USGS and Professor Donald S. Cohen of the California Institute of Technology are given for their suggestions and criticisms during the course of model review.

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NOMENCLATURE

C: concentration of radionuclide dissolved in fluid.
C_0: concentration of radionuclide at $t = 0$.
c_p: specific heat of fluid.
D: dispersivity of fluid.
E: rate of exposure from a radionuclide.
F_h: fatal health effect conversion factor.
g: acceleration due to gravitational force.
H: enthalpy of fluid.
H_e: number of fatal health effects.
h: subscript for heat energy.
I_m: initial inventory of radionuclide.
I: subscript for radionuclide.
k: permeability of porous medium.
L: distance from disposal site to well point.
l: subscript for organs.
M: total number of organs considered.
N_d: decay number ($=\lambda_d L/V$).
n: porosity of porous medium.
P: Peclet number ($=VL/D$).
P': population of community.
p: intensity of pressure.
Q: rate of radionuclide transport with dispersion effect considered.
Q': rate of radionuclide transport with dispersion effect neglected.
Q_0: rate of radionuclide transport at $x = 0$.
Q_w: rate of groundwater flow.
q': rate of fluid withdrawal from the transport system.
q_L: rate of heat loss from fluid.
R: retardation factor for porous medium.
R_f: risk conversion factor.
r: ratio of radioactivity being up taken to that reaching the well point.
T: temperature of fluid.
T_e: number of years of life expectancy.
t: time.
t_d: duration of radionuclide leaching.
U: internal energy.
u: unit response function with dispersion effects being considered.
u': unit response function with dispersion effects being neglected.
V: interstitial velocity of groundwater.
$\underline{v}$: velocity vector.
x: space coordinate in horizontal direction.
z: height above reference plane.
δ: unit impulse function.
η: long–term health effects conversion factor.

NOMENCLATURE (Continued)

θ: dimensionless time (=τV/L).
μ: viscosity of fluid.
λ_d: radioactive decay constant.
λ_L: radionuclide leaching factor.
ξ: instantaneous radionuclide transport correction factor.
ρ: mass density of fluid.
τ: dummy time variable.

APPENDIX C

THEORETICAL BACKGROUND OF
DAUGHTER NUCLIDE IN-GROWTH EFFECTS CORRECTION FACTOR

INTRODUCTION

The previous version of the PRESTO-EPA-POP model calculates only the health impacts resulting from the parent nuclide and ignores the health impacts contributed by its progeny. This simplification may, in some cases, incur significant error in the results of the assessment.

The mathematical relationships representing the transport of parent nuclides and their daughter products in an aquifer were well developed by Burkholder et al. [1 and 2]. However, these relationships are too complex to be incorporated into a screening model such as the PRESTO-EPA model. A separate attempt was made to develop a PRESTO-EPA model employing Burkholder's relationship to allow estimation of progeny effects. However, the time required to execute the model increased excessively [3]. Therefore, it was essential to simplify the mathematical relationships so that they can be integrated into the PRESTO-EPA model without unduly prolonging the execution time.

Since the existing model was designed to evaluate the health impacts without progeny effects, one of the simplest approaches to integrate the progeny effects into the existing model is to introduce a correction factor. This correction factor can be used to adjust the results obtained from the existing model to account for the progeny effects. This appendix presents the background theory of the correction factor developed by Hung [4].

METHOD OF CALCULATION

Basic Assumption

In order to avoid the complex model as developed by Burkholder, a crude assumption has to be imposed on the analysis. That is, one has to assume that the sorption characteristics of the parent nuclide and its progeny are identical throughout the processes of leaching and groundwater transport. This assumption seems unrealistic, but the error incurred from this crude assumption is not excessive and, in most cases, is on the conservative side. In addition, this assumption is widely adopted in screening risk assessment models.

When the above assumption is imposed, the mathematical relationships for nuclide transport in the geosphere can be greatly simplified. This is because a moving control volume concept with no flux transport across its boundary can be applied. As a result, the ratio of the activities between daughter and parent nuclides within a designated control volume at any given time can be calculated from the Bateman equation. This ratio can then be used to calculate the correction factor to account for the progeny in-growth effects. Detailed derivation of their mathematical formulation is described in the following sections.

<u>Decay Chains</u>

For the purpose of assessing the health impacts from contaminated soil sites, the following simplified decay chains are selected for incorporation into the PRESTO-EPA-CPG/POP model:

1. Am-243 $\longrightarrow$ Pu-239 $\longrightarrow$ U-235
2. Cm-244 $\longrightarrow$ Pu-240 $\longrightarrow$ U-236 $\longrightarrow$ Th-232
3. Pu-238 $\longrightarrow$ U-234 $\longrightarrow$ Th-230 $\longrightarrow$ Ra-226 $\longrightarrow$ Pb-210
4. Pu-241 $\longrightarrow$ Am-241 $\longrightarrow$ Np-237
5. Pu-242 $\longrightarrow$ U-238 $\longrightarrow$ U-234 $\longrightarrow$ Th-230 $\longrightarrow$ Ra-226 $\longrightarrow$ Pb-210

The decay chains depicted above assume that those progeny not shown in these chains can be ignored for the analysis. The error introduced from this simplification is considered to be insignificant for an application to a screening model such as the PRESTO-EPA model. It is obvious that the imposition of the above simplification can significantly reduce the complexity of progeny- effect analysis.

Altogether, 13 parent nuclides are considered and built into the model for calculating their progeny effects. They are Am-243, Pu-239, Cm-244, Pu-240, U-236, Pu-238, U-234, Th-230, Ra-226, Pu-241, Am-241, Pu-242, and U-238. The model evaluates the progeny in-growth effects up to the fourth member of the chains shown above. The effects contributed from the fifth and higher members are neglected because extending the analysis beyond the fourth member will considerably increase the complexity of the mathematical formulation and, thereby, the complexity of the analysis. Using Pu-242 as an example, the analysis calculates the health effects contributed from U-238, U-234, and Th-230 only; all other progeny are ignored.

In addition, the radionuclides that appear at the end of the decay chains above, namely, U-235, Th-232, Pb-210, and Np-237, are considered to have no significant progeny effects. Since the assessment of the health effects for these radionuclides is already built into the existing model, the correction factors for these radionuclides are not evaluated.

<u>Mathematical Formulation</u>

1. Derivation of Correction Factors

The progeny in-growth effect correction factors for four-, three-, and two-member decay chains are derived as follows:

A. 4-member Decay Chain

Since the purpose of the analysis is to analyze the progeny effect relative to the parent nuclide, an initial condition of no progeny is selected. Mathematically, it is expressed as:

$$Q_1 = Q_{01},$$

$$Q_2 = 0,$$

$$Q_3 = 0, \text{ and} \qquad (1)$$

$$Q_4 = 0,$$

when $t = 0$

Accordingly, one may write the Bateman equation for a four-member decay chain at any time t as:

$$Q_1 = Q_{01} EXP(-\lambda_1 t) \qquad (2)$$

$$Q_2 = \lambda_2 Q_{01}\left(\frac{EXP(-\lambda_1 t)}{(\lambda_2 - \lambda_1)} + \frac{EXP(-\lambda_2 t)}{(\lambda_1 - \lambda_2)}\right) \qquad (3)$$

$$Q_3 = \lambda_2 \lambda_3 Q_{01}\left(\frac{EXP(-\lambda_1 t)}{(\lambda_3 - \lambda_1)(\lambda_2 - \lambda_1)} \frac{EXP(-\lambda_2 t)}{(\lambda_3 - \lambda_2)(\lambda_1 - \lambda_2)} \frac{EXP(-\lambda_3 t)}{(\lambda_2 - \lambda_3)(\lambda_1 - \lambda_3)}\right) \qquad (4)$$

$$Q_4 = \lambda_2 \lambda_3 \lambda_4 Q_{01}\left(\frac{EXP(-\lambda_1 t)}{(\lambda_4 - \lambda_1)(\lambda_3 - \lambda_1)(\lambda_2 - \lambda_1)} + \frac{EXP(-\lambda_2 t)}{(\lambda_4 - \lambda_2)(\lambda_3 - \lambda_2)(\lambda_1 - \lambda_2)}\right.$$

$$\left. + \frac{EXP(-\lambda_3 t)}{(\lambda_4 - \lambda_3)(\lambda_2 - \lambda_3)(\lambda_1 - \lambda_3)} + \frac{EXP(-\lambda_4 t)}{(\lambda_3 - \lambda_4)(\lambda_2 - \lambda_4)(\lambda_1 - \lambda_4)}\right) \qquad (5)$$

respectively, for the first, second, third, and fourth member decay products. In the above equations, Q is the activity, λ is the decay constant, t is the time, the subscript 0 denotes the initial stage, and 1, 2, 3, and 4 denote parent, second, third, and fourth decay chain products, respectively.

On the other hand, the health effects expected from the intake of a parent nuclide and its progeny from time t to time t + Δt can be expressed by:

$$\Delta HE_1 = I \cdot Q_1 \cdot CF_1 \cdot \Delta t$$
$$\Delta HE_2 = I \cdot Q_2 \cdot CF_2 \cdot \Delta t$$
$$\Delta HE_3 = I \cdot Q_3 \cdot CF_3 \cdot \Delta t \qquad (6)$$
$$\Delta HE_4 = I \cdot Q_4 \cdot CF_4 \cdot \Delta t$$

where HE, I, and CF denote the number of health effects, the radionuclide intake factor, and the health effects conversion factor, respectively.

The combined health effects resulting from the intake of the parent nuclide and its progeny can, therefore, be expressed as:

$$\Delta HE_c = \Delta HE_1 + \Delta HE_2 + \Delta HE_3 + \Delta HE_4$$

or

$$\Delta HE_c = Q_1 \cdot I \cdot CF_1 \cdot \Delta t + Q_2 \cdot I \cdot CF_2 \cdot \Delta t + Q_3 \cdot I \cdot CF_3 \cdot \Delta t + Q_4 \cdot I \cdot CF_4 \cdot \Delta t. \qquad (7)$$

Equation 7 can also be rewritten as:

$$\Delta HE_c = Q_1 \cdot I \cdot CF_1 \left(1 + \frac{Q_2 \cdot I \cdot CF_2}{Q_1 \cdot I \cdot CF_1} + \frac{Q_3 \cdot I \cdot CF_3}{Q_1 \cdot I \cdot CF_1} + \frac{Q_4 \cdot I \cdot CF_4}{Q_1 \cdot I \cdot CF_1} \right) \Delta t \qquad (8)$$

For the purpose of this analysis, one may define correction factors for the parent nuclide and its progeny as follows:

$$\eta_1 = \frac{Q_1 \cdot CF_1}{Q_1 \cdot CF_1} = 1 \tag{9}$$

$$\eta_2 = \frac{Q_2 \cdot CF_2}{Q_1 \cdot CF_1} \tag{10}$$

$$\eta_3 = \frac{Q_3 \cdot CF_3}{Q_1 \cdot CF_1} \tag{11}$$

$$\eta_4 = \frac{Q_4 \cdot CF_4}{Q_1 \cdot CF_1} \tag{12}$$

respectively, for the parent, second, third, and fourth decay chain members. In the above equations, η denotes the health effects correction factor. By substituting Equations 2, 3, 4, and 5 into Equations 9, 10, 11, and 12, one obtains:

$$\eta_2 = \lambda_2 \frac{CF_2}{CF_1}\left(\frac{1}{\lambda_2 - \lambda_1} + \frac{EXP(-(\lambda_2 - \lambda_1)t)}{\lambda_1 - \lambda_2} \right) \tag{13}$$

$$\eta_3 = \lambda_2 \lambda_3 \left(\frac{CF_3}{CF_1} \right) \left(\frac{1}{(\lambda_3 - \lambda_1)(\lambda_2 - \lambda_1)} + \frac{EXP(-(\lambda_2 - \lambda_1)t)}{(\lambda_3 - \lambda_2)(\lambda_1 - \lambda_2)} + \frac{EXP(-(\lambda_3 - \lambda_1)t)}{(\lambda_2 - \lambda_3)(\lambda_1 - \lambda_3)} \right) \tag{14}$$

$$\eta_4 = \lambda_2 \lambda_3 \lambda_4 \left(\frac{CF_4}{CF_1} \right) \left(\frac{1}{(\lambda_4 - \lambda_1)(\lambda_3 - \lambda_1)(\lambda_2 - \lambda_1)} + \frac{EXP(-(\lambda_2 - \lambda_1)t)}{(\lambda_4 - \lambda_2)(\lambda_3 - \lambda_2)(\lambda_1 - \lambda_2)} + \frac{EXP(-(\lambda_3 - \lambda_1)t)}{(\lambda_4 - \lambda_3)(\lambda_2 - \lambda_3)(\lambda_1 - \lambda_3)} + \frac{EXP(-(\lambda_4 - \lambda_1)t)}{\lambda_3 - \lambda_4)(\lambda_2 - \lambda_4)(\lambda_1 - \lambda_4)} \right) \tag{15}$$

On the other hand, one may define the combined progeny in-growth health effects correction factor, η_c, as the sum of health effects from all four members of the decay chain. That is:

$$\eta = 1 + \eta_2 + \eta_3 + + \eta_4. \quad (16)$$

For simplicity, the subscript c is dropped throughout the rest of this document. Substituting Equations 9, 10, 11, 12, and 16, into Equation 8, one obtains:

$$\Delta HE = I \cdot Q_1 \cdot CF_1 \cdot \eta \cdot \Delta t \quad (17)$$

Therefore, the cumulative health effects from the decay chain for the period of analysis can be written as:

$$I \cdot CF_1 \int_0^T Q_1 \cdot \eta \cdot dt \quad (18)$$

where T denotes the duration of the health effects analysis. Equation 18 implies that the combined health effects for a four-member decay chain can be calculated from the integration of the product of parent nuclide activity in the control volume and its combined correction factor over the duration of health effect analysis.

B. Three- and Two-Member Decay Chains

The combined health effects for three- and two-member decay chains can also be calculated in the same manner as described in the previous section (Equation 18). In applying this equation, the combined health effect correction factors for 3- and 2-member decay chains should be used. These correction factors can be reduced from the correction factor developed for the four-member decay chain as follows:

$$\eta = 1 + \eta_2 + \eta_3 \quad (19)$$

for a three-member decay chain, and

$$\eta = 1 + \eta_2 \quad (20)$$

for a two-member decay chain. The definition of each component of the correction factors, η_2 and η_3, remains the same as presented in Equations 13 and 14.

2. Health Effects Calculation

Two types of health effects calculations are built into the PRESTO-EPA-POP model. The first type is for local population health effects and the second type is for downstream basin population health effects.

The first type of calculation involves the estimation of health effects resulting from the exposure of radionuclides contaminating the environmental receptors. The radionuclide concentration in an environmental receptor is calculated annually and its average value is calculated at the end of the yearly loop analysis. The average human exposure rate and its subsequent health effects are calculated from this average value. The integration of the daughter knuckled in-growth simply involves the modification of the average concentration in a similar manner as expressed in Equation 18 as:

$$C_{ave} = (1/T)\int_0^T C \cdot \eta \cdot dt \qquad (21)$$

After the average radionuclide concentration in the environmental receptor is calculated, the number of health effects for the local population is calculated through the existing biological and human exposure pathways model without modification.

The health effects induced in the downstream basin population are calculated from the product of the cumulative release of radioactivity and the conversion factor. To integrate the daughter knuckled in-growth effect into the health effect assessment, the released parent knuckled activity should be corrected annually. The corrected cumulative radionuclide release is calculated by:

$$Q_T = \int_0^T Q \cdot \eta \cdot dt \qquad (22)$$

where QT denotes the corrected cumulative radionuclide release.

After the parent radionuclide released into the downstream basin is corrected for daughter knuckled in-growth effects, the total health effects calculated for the downstream basin population are calculated by multiplying the corrected cumulative radionuclide release with the precalculated conversion factor for the parent knuckled.

The cumulative health effects from the decay chain can then be calculated from Equation 18.

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APPENDIX D

DEVELOPMENT OF EQUIVALENT UPWARD DIFFUSIVITY AND CONDUCTIVITY

APPENDIX D

This appendix contains the background theory and calculations of the equivalent upward diffusivity and conductivity used as input parameters for the calculation of the infiltration rate using the INFIL subroutine. These values are calculated for three typical soils – sand, loam, and clay – which are intended for use as a guideline for collecting these input parameters. This guideline is developed because the equivalent upward diffusivity may not be measured easily in a soil test with simple equipment.

DEVELOPMENT OF EQUIVALENT UPWARD DIFFUSIVITY AND CONDUCTIVITY FOR TYPICAL SOILS

The value of hydraulic conductivity and diffusivity used in the mass balance equation for the pellicular water are theoretically functions of water content (see Equation 15, Appendix A, Part A). In order to simplify the calculation, the independent terms "equivalent upward hydraulic conductivity" and "equivalent upward hydraulic diffusivity" are introduced by Hung in conjunction with the development of the INFIL model. These values are used in the calculation of the upward movement of soil moisture, in liquid phase, during dry periods. They can be determined from the soil characteristics expressed in hydraulic diffusivity and conductivity.

The hydraulic diffusivity is an alternate form of expressing the flow equation (see Hillel's *Soil Physics*, p. 240, and Equation 3, Appendix A, Part A). As indicated in Hillel's *Soil Physics*, a hydraulic diffusivity is related to the hydraulic conductivity and suction head and can be expressed by:

$$D_L(\theta) = K(\theta)\,(d\,\psi/d\,\theta) \qquad (1)$$

Where

D_L	=	hydraulic diffusivity,
θ	=	soil moisture content,
K	=	hydraulic conductivity, and
ψ	=	suction head.

Therefore, the hydraulic diffusivity-moisture content relationship for a specific soil can be calculated from its soil characteristics, including suction head and hydraulic conductivity.

Since the basic equations used in the INFIL model were derived from the alternative form of the flow equation, the above moisture-dependent hydraulic diffusivity was used and transformed into a moisture-independent hydraulic diffusivity. This transformation involved the selection of a representative soil moisture content. The representative moisture content is determined by an average of the maximum and minimum moisture content of the pellicular water plus a positive correction factor. In matching the moisture content with the field data, a correction factor of 0.115 was found to be the most suitable. Mathematically it is determined by:

$$\theta_{rep} = (\theta_{max} + \theta_{min})\,(0.500 + 0.115) \qquad (2)$$

Once the representative moisture content is determined, the representative hydraulic diffusivity can be determined from the relationship shown in Equation 1. This representative hydraulic diffusivity was designated by Hung as "equivalent upward diffusivity."

In the same manner, the moisture content-dependent hydraulic conductivity was also transformed into a moisture content-independent hydraulic conductivity. The same representative moisture content was also used in this transformation. The transformed representative hydraulic conductivity was designated by Hung as "equivalent upward hydraulic conductivity."

For the sake of supplying basic data, three basic sod types – sand, loam, and clay – were selected. Based on the representative hydraulic conductivity and suction head characteristics of these soils cited by Hillel et al. (Exhibit 1), the hydraulic diffusivity – moisture content relationships were calculated and the results are presented in Exhibit 2.

Furthermore, using the results of Hillel's wetting and drying analysis, the maximum motisture contents for sand, loam, and clay were determined to be 0.11, 0.19, and 0.41, respectively, and the minimum moisture content for all soils was 0.02. Based on these data, the representative water contents were calculated from Equation 2 to be 0.0754, 0.1245, and 0.26 for sand, loam, and clay soils, respectively. Using these moisture contents, the equivalent upward diffusivities and hydraulic conductivities were determined from Exhibit 2 for diffusivity and Exhibit 1 for conductivity. The results are presented in Table 1.

Table 1. Results of Equivalent Upward Diffusivity and Conductivity Calculation

Variables	Sand	Loam	Clay
upward diffusivity, m^2/hr	7.2E-4	3.6E-4	1.4E-4
upward hydraulic conductivity, m/hr	3.6E-6	1.4E-6	1.1E-6

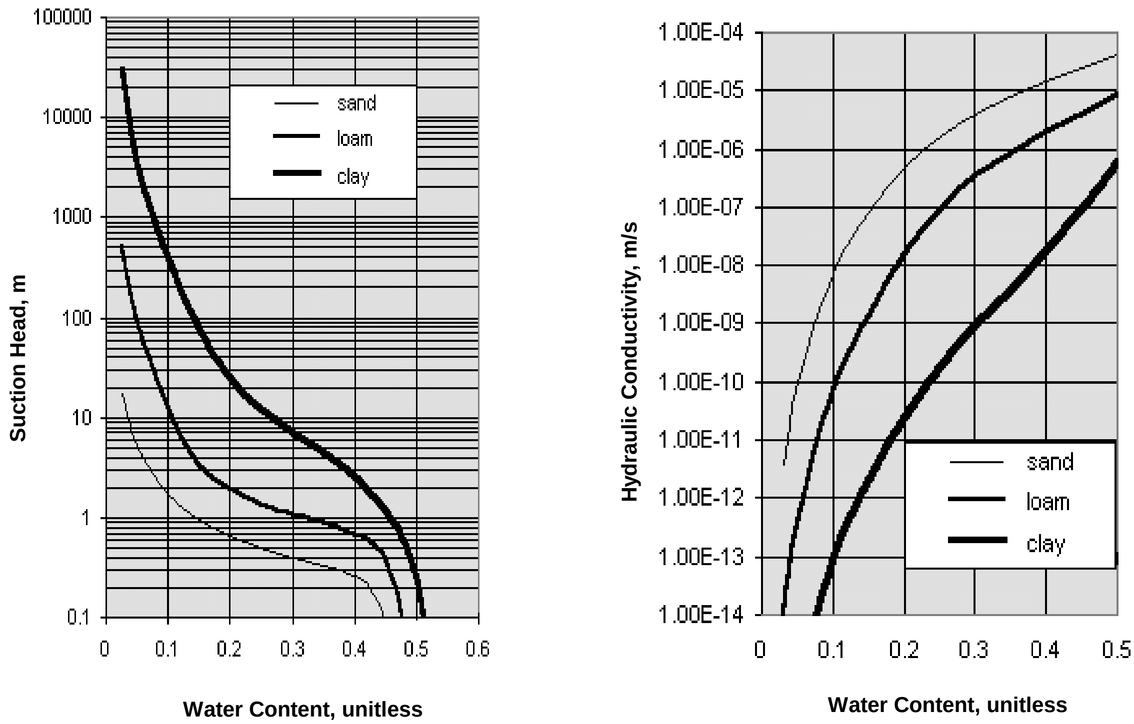

Exhibit 1. Soil Characteristics Used in the Analysis
(Cited from Hillel et al. Journal of Soil Science Society of America, Vol. 40, No 6, Nov., 1976)

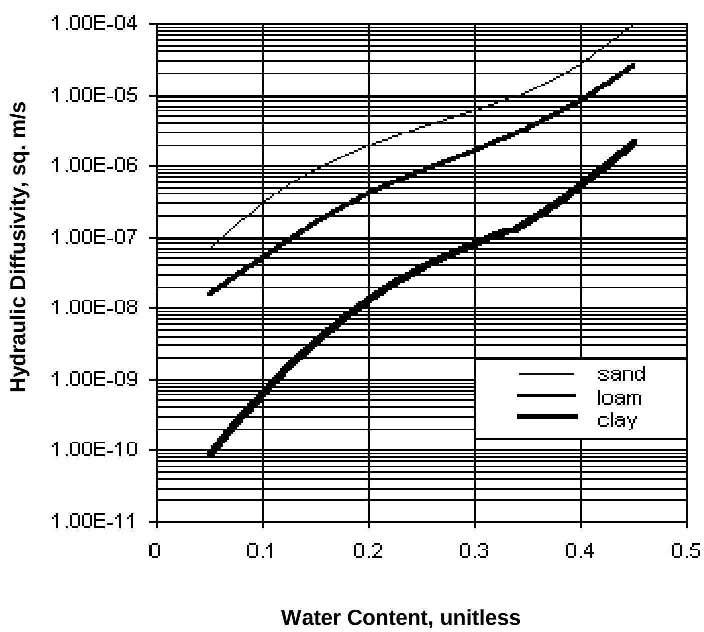

Exhibit 2. Calculated Hydraulic Diffusivity

APPENDIX E

BENCHMARK STUDY FOR THE DEGREE OF SATURATION FORMULA

APPENDIX E

This appendix contains a memorandum that Dr. Hung prepared for reporting the results of a benchmark study of the empirical formulas used in predicting the degree of saturation for various soils under dynamic infiltrating conditions. The study compares the results of predicted degree of saturation using Clap's formula used in the PRESTO model and another empirical formula used by other models.

Memorandum

Date: July 13, 1999

From: Cheng Hung

To: Ken Czyscinski
Dan Schultheisz
Shankar Ghose

Subject: Comparison of the Formulas Used for the Degree of Saturation Prediction

Per your request I have completed the comparison of the formulas for the degree of saturation prediction used in PRESTO and RESRAD models. The results of the calculations for typical sand, loam, and clay materials are used to compare both equations. The results are quite comparable, indicating that the equations are also comparable. Details of the comparisons are as follows:

1. Mathematical Formulations

A. PRESTO

$$R_s = \zeta + (1 - \zeta)\,(I/K)^{0.25} \qquad (1)$$

Where:

R_s = degree of saturation,
ζ = fraction of residual moisture content relative to saturated moisture content,
II = rate of infiltration, and
K = saturated hydraulic conductivity.

B. RESRAD

$$R_s = (I/K)^{(1/(2b+3))} \qquad (2)$$

Where:

b = soil-dependent constant given empirically.

2. Data Collected for Comparison

The soil characteristic data required for predicting both models are shown in Table 1. Only typical soils for sand, loam, and clay were selected because the soil characteristics for these soils are readily available without conducting tedious laboratory soil tests.

Table 1. Soil Characteristics Collected for the Analyses

Characteristics	Sand	Loam	Clay
residual water content	0.1[a]	0.2[a]	0.4[a]
saturated water content	0.4[a]	0.48[a]	0.52[a]
b	4.05[b]	5.39[b]	11.4[b]
ζ	0.25[c]	0.42[c]	0.769[c]

Note: a. from *Applications of Soil Physics*, Academic Press, p. 57.
b. from *Data Collection Handbook to Support Modeling the Impacts of Radionuclides Materials in Soil*, ANL, p. 77.
c. calculated from "residual water content" divided by "saturated water content."

3. Results of Prediction

The degrees of saturation, using both equations and the collected data above, are calculated for various infiltration-hydraulic conductivity ratios. The results are presented in Table 2.

Table 2. Results of Prediction

I/K	PRESTO			RESRAD		
	Sand	Loam	Clay	Sand	Loam	Clay
1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.75	0.948	0.960	0.984	0.974	0.979	0.989
0.5	0.880	0.908	0.963	0.939	0.951	0.973
0.25	0.780	0.830	0.932	0.880	0.904	0.947

4. Comparison of Results

From the above comparison of the results calculated from these two equations, one can conclude that the equations give comparable results. The PRESTO model has consistently given slightly lower values, which will result in higher groundwater velocities. This implies that PRESTO is slightly more conservative than RESRAD. However, there is no evidence that either model fits better with those empirical data. The judgment of the credibility of these equations was not pursued because it was not the intent of this study.

APPENDIX F

THEORETICAL BACKGROUND OF EXTERNAL EXPOSURE CALCULATION

APPENDIX F

This appendix contains the background theory of the external exposure calculation for outdoor and basement pathways. Because of the complexity of the calculation, crude assumptions are inevitably imposed to simplify the modeling. This appendix contains a memorandum prepared during the course of model development which states all crude assumptions and the derivation of pertinent basic equations used in PRESTO model. It is intended for documenting the crude assumptions and the processes of calculation for the convenience of model reviewers.

MEMORANDUM

Date: March 5, 1997

From: Cheng Hung

To: Craig Conklin
Jerome Puskin
Chris Nelson
Files

Subject: Method of Outdoor and Basement Gamma Exposure Calculations

This memorandum summarizes the proposed methodologies for calculating outdoor and basement external exposures to be used in the PRESTO-EPA model currently being developed.

I. Outdoor Exposure

Because the model handles three distinct layers of contamination, the outdoor external exposure should be calculated for three components: active-layer, nominal top-layer (gross top-layer less active layer), and bottom-layer.

It is commonly known that the simplest and most reliable method of calculating the external exposure is to employ the method proposed in the Federal Guideline Report No 12. Unfortunately, the Report listed the dose coefficients for the contaminate depths of 0.01 m, 0.05 m, 0.15 m, and infinite depth only. Therefore, It is necessary to predict the dose coefficient for an actual depth for use in a model application. The method of calculation is as follows.

Theoretical Background

A careful observation of the variation of dose coefficient with depth indicated that the simplest and best-fit mathematical formula is an exponential formula expressed

$$DC_y = DC_\infty(1.-Exp(-K_A Y)) \qquad (1)$$

where:

DC_y	=	the dose coefficient for contaminated soil thickness of Y meter,
DC_∞	=	the dose coefficient for infinite soil thickness,
K_A	=	the radionuclide specific attenuation coefficient, and
Y	=	the contaminated soil thickness.

The attenuation coefficient can then be solved in terms of the known dose coefficient at a contaminated depth of 0.15 meter and infinite depth. The solution can be expressed in:

$$K_A = -\left(\frac{1}{0.15}\right) Ln\left(1. - \frac{DC_{15}}{DC_{\infty}}\right) \quad (2)$$

Thus, the dose coefficient of a soil layer can be calculated if the dose coefficients for the 0.15 meter and infinite depth are given.

Method of Dose Rate Calculation

A. Active Layer

Since the active layer is always on the ground surface, its dose coefficient can be calculated directly from Equations 1 and 2 above once the depth of the active layer is known. That is, the dose rate can be calculated by:

$$DS_{AL} = \xi * C_{AL} * DC_{AL} \quad (3)$$

where:

DS_{AL}	=	dose rate from the active layer,
ξ	=	occupancy factor,
C_{AL}	=	radionuclide concentration in the active layer, and
DC_{AL}	=	dose coefficient calculated for its depth.

B. Nominal Top Layer and Bottom Layer

Both the nominal top layer and the bottom layer are shielded with a contaminated or uncontaminated soil layer above. For the purpose of this analysis, this layer is defined as the cover layer and the soil layer being considered as the contaminated layer. Since the exposure due to the cover layer is calculated separately, for the purpose of this analysis, this layer is assumed to be uncontaminated. The methods of calculation for the nominal top layer and the bottom layer are identical and can proceed as follows:

For the purpose of deriving the basic equation using Federal Guidance Report No. 13 methodology, it is assumed that the cover layer is also contaminated with the same radionuclide and concentration as existing in the contaminated soil layer first. The net dose coefficient for the contaminated soil layer can then be calculated from the difference between the dose coefficients for the combined layer, including the cover layer and the contaminated layer, and the cover layer. Mathematically, the dose to the onsite individual can be expressed by:

$$DS_{CSL} = \xi * C_{CSL}(DC_{CBL} - DC_{CVL}) \tag{4}$$

where the subscripts CSL, CBL, and CVL denote contaminated soil layer, combined soil layer, and cover layer, respectively.

II. Basement Exposure to an Onsite Resident

The basement gamma exposure to an onsite resident is a complicated calculation that should take into consideration the geometry and characteristics of construction materials and radionuclide in addition to the nature of the contaminated soil layer. Since this pathway will not, normally, be a dominant pathway, some crude assumptions can be imposed to simplify the model.

One of the simplifications is to fix the geometry of the basement: The basement is assumed to be 2 meters deep with a radius of 3 meters (assumed to be in a circular form) and to have 0.1 meter-thick concrete side walls and floor. The receptor of the dose is assumed to be concentrated at the center of the basement and at a height of 1 meter from the floor. Two components, one from the layer surrounding the side wall (defined as the side wall layer) and the other from the contaminated soil layer beneath the basement floor (designated as the floor layer) are considered. The concentrations of the radionuclide within the side wall layer and the floor layer are assumed to be uniform.

A. Side Wall Layer

1. Theoretical Development

A generalized equation for analyzing the dose rate to a receptor in the basement from the side wall layer having unit radionuclide concentration can be expressed as:

$$DC_{SWL} = \int_V \frac{B(\mu_{SWL}, \rho_{SWL})}{\rho^2} EXP\left[-\left(\mu_{SWL}\rho_{SWL} + \mu_{CON}\rho_{CON} + \mu_{AIR}\rho_{AIR}\right)\right] dv \tag{5}$$

where:

DC_{SWL}	=	the dose coefficient for the side wall layer,
B	=	the radionuclide build-up factor,
μ	=	the linear attenuation coefficient,
ρ	=	the length of the path in a medium measured in the direction connecting the source, dv, and the receptor, and the subscripts,
SWL	=	side wall layer,
CON	=	concrete material, and
AIR	=	air.

Equation 5 can also be expanded to analyze a cylindrical basement built in a uniformly contaminated side wall layer, which yields:

$$DC_{SWL} = 2\pi \int_0^{R+d} \int_0^H r \frac{B(\mu_{SWL}, \rho_{SWL})}{\rho^2} EXP\left[-\left(\mu_{SWL}\rho_{SWL} + \mu_{CON}\rho_{CON} + \mu_{AIR}\rho_{AIR}\right)\right] dz\,dr \qquad (6)$$

where:

R	=	the radius of the cylindrical basement,
H	=	the height of basement,
d	=	the cut-off thickness, which is recommended to use and approximately equals to $10/\mu_{SWL}$, and
r,z	=	the cylindrical coordinates.

The integration of the equation can be easily conducted by employing the existing software MICROSHIELD for a desired basement geometry.

2. Modeling Approach for the PRESTO Model

Since the dose coefficient for the side wall layer depends on the geometry of the basement, an accurate calculation of the dose coefficient may be accomplished by adding a subroutine similar to the MICROSHIELD code. However, this approach would considerably increase the complexity of the model. In order to avoid this complexity, some conservative crude assumptions are made to simplify the model, as stated below.

It is expected that the ratio of the overall dose coefficient for the side wall layer (Equation 6) and the dose coefficient for a 0.15 m contaminated depth should vary with the gamma energy of the radionuclide. However, since the range of variation is relatively small, a conservative fixed number can be assigned to simplify the modeling. If this factor is known, the dose rate to an individual living in the basement can be calculated by:

$$DS_{SWL} = \eta \cdot DC_{15} \cdot C_{SWL} \cdot (D/H) \qquad (7)$$

where:

η	=	the basement factor,
C_{SWL}	=	is the concentration of radionuclide in the side wall layer,
D	=	the thickness of the contaminated layer, and
H	=	the depth of the basement which is fixed at 2 meters.

Determination of the η Value

In order to determine the η value, a series of MICROSHIELD runs are conducted for a unit concentration and full basement depth contamination. The geometry of the basement is fixed to 2 m height, with 0.1 m thick wall and equivalent radius of 3 m. The results of the analysis indicated that the factor η varies from 0.766 to 1.514. A conservative number of 1.5 is recommended for all nuclides.

B. Floor Layer

The calculation of the component from floor layer can be conducted using a similar approach as that employed in the calculation of the outdoor external dose rate. That is, the dose coefficient for the basement floor layer can be calculated by:

$$DC_{BFL} = DC_{\infty}(l.- EXP(-K_A \cdot D_{BFL}) \quad (8)$$

where the subscript BFL denotes basement floor layer. The dose rate for this layer can be calculated by incorporating the attenuation effects from the concrete floor. The result yields:

$$DS_{BFL} = C_{BFL} \cdot DC_{BFL} \cdot EXP(-\mu_{CNF}\rho_{CNF}) \quad (9)$$

where:

ρ_{CNF} = the overall equivalent thickness of the concrete floor measured along the path of gamma ray, and subscript CNF denotes concrete floor, and

μ_{CNF} = the radionuclide specific concrete attenuation coefficient.

For the purpose of the screening model application, one may conservatively set the value of ρ_{CNF} to be equal to the thickness of the concrete floor, which is 0.1 m. When this approximation is made, Equation 9 becomes:

$$DS_{BFL} = C_{BFL} \cdot DC_{BFL} \cdot EXP(-0.10\mu_{CNF}) \quad (10)$$

The total external dose from residing in the basement is the sum of the above two components. Of course, the adjustment for the fraction of time spent in the basement should also be considered.

APPENDIX G

THEORETICAL BACKGROUND OF THE AREA FACTOR SUBMODEL

APPENDIX G

This appendix contains the background theory of the area factor submodel used in the PRESTO model. The area factor is used to adjust the gamer exposure for an infinite area to an actual area size. The factor is used in adjusting both outdoor and basement gamer exposure calculations.

MEMORANDUM

Date: January 18, 2000

From: Cheng Hung

To: Jerome Puskin
Chris Nelson
Anthony Wolbarst

Subject: Addition of Area Factor for Use in Outdoor External Exposure Correction

This memorandum summarizes the theoretical background of the area factor calculation proposed for outdoor and basement gamer exposure calculation correction.

Introduction

The calculation of external gamma radiation for a receptor standing on a contaminated site uses the volumetric nuclide concentrations in the soil layers and the corresponding conversion factors given in the Federal Guidance Report No. 12. The generic conversion factors were developed based on the assumption that the radionuclides are uniformly distributed over an infinite plane.

It is commonly known that the effect of the gamma exposure would be insensitive to the total dose if the source segment of interest is hundreds of meters away from the receptor. Thus, the application of these conversion factors on a relatively large area, for instance, a low-level waste disposal site, would not incur any significant error. However, significant error may be incurred if the model is applied to a relatively small contaminated area. Therefore, it is important to include an area factor to correct the external exposure calculation and to improve the model accuracy. For the purpose of modeling, this correction factor is defined as the area factor.

Theoretical Background

For the purpose of deriving the basic equations, it is assumed that (1) the multilayer soil contamination considered in the PRESTO model can be converted to an equivalent surface contamination, (2) no radioactive decay takes place for the contaminant, (3) the contamination is homogeneous, and (4) the energy absorption buildup effect can be ignored. Based on these assumptions, the dose rate at a height of 1 m above the ground surface for an infinite plane can be written as (reduced from Equations 8.39 and 8.40, *Radiological Assessment*, by John Till and H. Robert Meyer):

$$D_{\infty} = 2 \cdot CF \cdot C \int_0^{\infty} \int_0^{\infty} \left(1/r^2\right) Exp\left(-\mu_a r\right) dx\,dy \quad (1)$$

where:

D_∞	=	dose rate from an infinite plane contamination,
CF	=	unit transformation constant,
C	=	the concentration of radionuclide on the ground surface,
μ_a	=	linear attenuation coefficient of air, and
r	=	the distance from the receptor to the area segment of interest and is calculated by the square root of $x^2 + y^2 + 1$.

Similarly, the dose rate at the same height for the contaminated site can be written as:

$$D_a = 2 \cdot CF \cdot C \int_0^{L/2} \int_0^{B/2} \left(1/r^2\right) Exp\left(-\mu_a r\right) dx\,dy \tag{2}$$

where:

D_a	=	the dose rate from the actual contaminated area,
L	=	the length of the contaminated site, and
B	=	the width of the contaminated site.

Now, based on the definition of the area factor, one can express the same factor as:

$$F_a = \frac{\int_0^{L/2} \int_0^{B/2} \left(1/r^2\right) Exp\left(-\mu_a r\right) dx\,dy}{\int_0^{\infty} \int_0^{\infty} \left(1/r^2\right) Exp\left(-\mu_a r\right) dx\,dy} \tag{3}$$

where:

F_a	=	area factor.

Since the linear attenuation coefficient is a function of the photon energy level and the level of photon energy is radionuclide dependent, the area factor should also be radionuclide dependent. In order to simplify the procedures of calculation and yet to maintain the level of accuracy, a preliminary study is conducted to identify the variation of area factor with radionuclide. The results of the analysis indicate that the range of variation for a series of square sites is relatively small within the range of practical application (Exhibit A). Therefore, use of a lower-bound photon energy level or an upper-bound value of the linear attenuation coefficient to represent all nuclides would not accrue excessive error in the dose calculation.

Exhibit A is calculated based on the Fortran code (Equation 3) developed for this purpose. The upper- and lower-bound area factors are determined respectively from the lowest and highest weighted mean photon energy for those decay series considered in the PRESTO model. U-234 and Po-210 are selected for this analysis. The results of calculation for U-234 and Po-210 are plotted in Exhibit A.

Based on the above study, an area factor calculation subroutine for U-234 is built into the PRESTO codes and automatically calculates the area factor for the given contaminated rectangular site. The same area factor is also used for all other radionuclides.

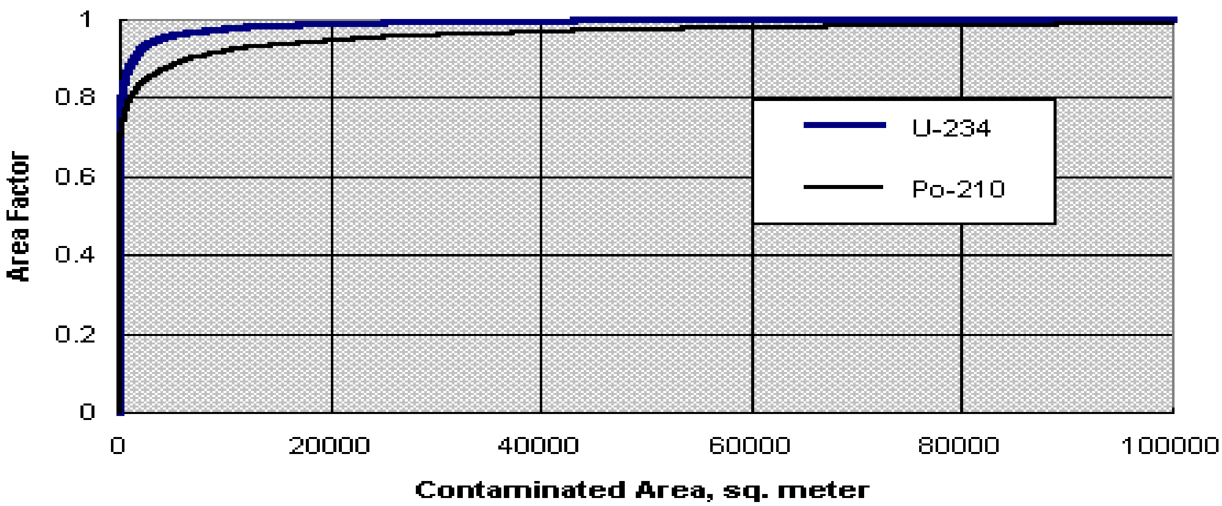

Exhibit A. Range of Area Factor Variation

APPENDIX H

THEORETICAL BACKGROUND OF THE WELL WATER CONCENTRATION CALCULATION

APPENDIX H

This appendix contains the theoretical background for the calculation of the radionuclide concentration in well water, which is used to calculate the individual uptake of drinking water and the concentration of the radionuclide in foods, including milk, meat, and vegetables. The original paper was presented in the NRC's Workshop on "Groundwater Modeling Related to Dose Assessments," June 23, 1999.

CONCEPTUALIZATION AND CALCULATION OF WELL WATER CONTAMINANT CONCENTRATIONS FOR A GIVEN PLUME

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ABSTRACT: This paper discusses the theoretical basis and practical models for calculating concentrations of contaminants in well water being pumped from an aquifer contaminated with radionuclides. The discussion includes two modeling approaches commonly used in screening-type risk assessments, the upper-bound calculation model and the semi-analytical model. A qualitative analysis is presented to demonstrate the enormous difference in the results between the two models. Finally the paper identifies the importance of model selection and encourages greater manager participation.

1 INTRODUCTION

This paper discusses the well-known theoretical basis and practical models for calculating the concentrations of contaminants in well water being pumped from an aquifer contaminated with radionuclides. The discussion includes two modeling approaches used in calculating these concentrations commonly employed in screening-type risk assessment models.

Since the results of the calculation are to be used to calculate the health impacts resulting from the construction, demolition, or cleanup of a site, for the purpose of regulatory analysis, a desirable model should conservatively calculate the concentrations without excessively increasing the complexity of calculation.

A regulatory analysis involves minimizing the cost of construction under the constraints of regulatory guidelines. Thus, the use of an overly conservative model may satisfy the constraint of protecting the environment, but it could considerably increase the cost of system construction. In order to minimize the costs, the ideal model should be designed to calculate the health impacts conservatively, but it should not be overly conservative. Since enormous difference can be seen in the results of these two types of models, the selection of the type of model is a very important subject in the field of risk assessment and should not be ignored.

2 THEORETICAL BACKGROUND

The generic governing mass balance equation for calculating the solute transport in an aquifer contaminated with radionuclides in a steady uniform background flow with pumping action as shown in the schematic drawing, Figure 1, was expressed by Dugguid et al. (Du76) and

Hung (Hu86) as:

$$R(\partial C/\partial t) - \nabla \cdot (\underline{\underline{D}} \cdot \nabla C) + V \nabla C + \lambda_d R C = 0 \tag{1}$$

which is to be solved with initial conditions:

$$C = 0 \qquad \text{for all x, y, and z} \tag{2}$$

and boundary conditions for the source strength:

$$\begin{aligned} q &= 0 \qquad \text{for all x, y, and z, except:} \\ q &= q_{x,t} \qquad \text{for all y, at x = 0, z = 0, and} \end{aligned} \tag{3}$$

well screen sink strength:

$$f_w = F_w \qquad \text{at } x = X_w,\ y = Y_w, \text{ and } Z_{scl} > z > Z_{scu} \tag{4}$$

In the equations above, R is the retardation factor, C is the radionuclide concentration in the groundwater, $\underline{D}$ is the dispersivity tensor, V is the interstitial velocity of the groundwater, λ_d is the radionuclide decay constant, q is the flux of the radionuclide, f_w is the rate of pumping per unit length of screen, and t, x, y, and z are the independent variables for the time and space coordinates, respectively.

The momentum and continuity equations for the fluid flow are neglected because simple flow conditions, steady and uniform flow, are assumed for this study. The concentration of the well water in the pumping well can be calculated from the weighted average concentrations analyzed for all the nods representing the well sink.

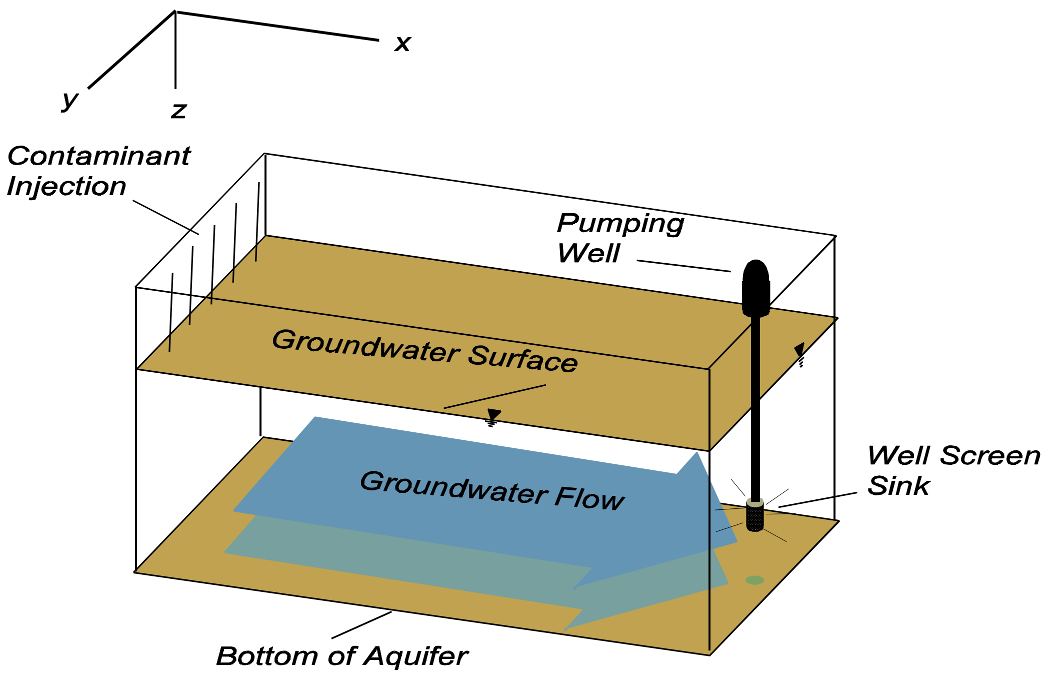

Figure 1. Schematic of Well Pumping in a Contaminated Groundwater System

Due to the fact that the function of the boundary conditions are undefined, an analytical solution for the above system equations is, in general, not obtainable. Therefore, a complex three-dimensional numerical model, such as MODFLOW-SURFACT (HG98), is required to solve this system of equations. The complexity of this approach is apparently much greater than the modeling scheme taken by most of the screening-type risk assessment models. Therefore, the above system of equations cannot be integrated into a risk assessment model, and a simplified practical model would be required to obtain the approximate solution. Details of practical models are discussed in the following sections.

3 PRACTICAL APPROACH MODELS

As stated earlier, a direct solution of the radionuclide concentration in well water, by applying Equation 1, is extremely complex and is not suitable for integrating into a screening type of risk assessment models. In order to further simplify the calculation, the calculation procedures for a screening-type model were normally divided into two major steps; (1) transport analysis through groundwater reach and (2) transport analysis through well pumping. The procedures of the analyses for each step are described as follows:

3.1 Transport Through Groundwater Reach

Up to date, dozens of solute transport models have been developed to calculate the transport of radionuclides in a groundwater reach or aquifer. They can be categorized as either a multi-dimensional model or a one-dimensional model. The goal of the model is to calculate the rate of transport through a section or the distribution of concentrations over the aquifer.

Because an indefinite form of the boundary conditions is involved in a general application, the use of a multi-dimensional model requires numerical integration even the Green's function approach is taken. The use of a 1-dimensional model, on the other hand, can simplify the processes of calculation, but a detailed distribution of radionuclides along a cross section cannot be obtained. Fortunately, the need for a concentration distribution can be avoided if one of the special procedures discussed in Section 3.2 is used. The discussion of the pro's and con's of these models and their standard procedures are beyond the scope of this study and, therefore, are neglected.

3.2 Transport Through Pumping Well

Because of a nonsymmetrical distribution of the radionuclide concentration, a dynamic analysis of the radionuclide concentration in the well water still requires a complex numerical solution that is not suitable for integrating into a screening- type model. Nevertheless, for the convenience of this discussion, the concentration of radionuclides in the well water may be expressed in a form of dimensional analysis. The result is expressed as:

$$C_w = f(Q_p, D_p, V, F_w, D_a, D_w, D_s) \tag{5}$$

where:

C_w	=	the radionuclide concentration in the well water,
Q_p	=	the rate of radionuclide transport through the section at the well,
D_p	=	the effective depth of the plume,
V	=	the Darcy velocity of the groundwater,
F_w	=	the pumping rate,
D_a	=	the total depth of the aquifer,
D_w	=	the depth the well penetrates into the aquifer, and
D_s	=	the length of the well screen.

Equation 5 simply defines the dependent parameters for the radionuclide concentration in the well, but its solution still requires further discussion. There are two types of models commonly used in the field of risk assessment, the upper-bound calculation type model and the semi-dynamic approach type model. The theoretical basis and assumptions are discussed in the following sections.

3.2.1 Upper-Bound Calculation Type Model

In order to avoid the complex procedures of calculation, this type of model is designed to calculate an approximated solution expressed in a maximum probable concentration. In order to reach this goal, this type of model assumes that the well screen length is shortened to a minimum and is penetrated to the depth that coincides with the axis of the plume. Therefore, the concentration of the well water is practically calculated from the maximum moving average of the concentration over the screen length by moving the well screen vertically and laterally to calculate the upper bound of the well water concentration.

This model approach is theoretically an acceptable model as long as the result is used to demonstrate compliance with certain regulatory guidelines. This is because the model always provides a concentration larger than the true value. However, if the result is to be used for minimization of the construction costs, this modeling approach may not be appropriate. This approach may result in an overly conservative estimate of the health impacts and may drive up costs to an unnecessary level.

3.2.2 Semi-Dynamic Type Model

Because of the complexity of this model, there are many ways of simplifying the original model. For the purpose of this study, the approach used in US EPA's PRESTO model is selected as an example. Because of the interconnection between the two major steps described above, the theoretical basis and its calculation procedures for these two steps are discussed below.

3.2.2.1 Rate of Radionuclide Transport

In order to simplify the process of calculation, Hung's one-dimensional groundwater transport model (Hu86) was selected for analyzing the rate of radionuclide transport through the section where the well is located. After this simplification, Equation 1 was reduced to:

$$D(\partial^2 q / \partial x^2) - V(\partial q / \partial x) - R(\partial q / \partial t) - R\lambda_d q = 0 \qquad (6)$$

The model calculates the rate of radionuclide transport through a section using the following boundary conditions:

$$\text{at } x = 0, \qquad q = q_0(t) \qquad (7)$$

in which $q_0(t)$ is the boundary condition expressed as a per-unit width rate of radionuclide transport passing through the section at x = 0.

The model introduces Hung's correction factor to obtain an analytical solution and to avoid numerical integration, which yielded the analytical solution:

$$q(t) = \eta q_0(t - RL / V) Exp(-RL\lambda_d / V) \qquad (8)$$

in which

$$\eta = \frac{Exp\left(\frac{P}{2} - \frac{P}{2}\sqrt{1 + \frac{4RL\lambda_d}{PV}}\right)}{Exp\left(-\frac{RL\lambda_d}{V}\right)} \qquad (9)$$

In the above equations, q(t) is the unit width rate of radionuclide transport in Ci per yr per meter, L is the x coordinate representing the location of the pumping well, η is Hung's transport rate correction factor, P is the Peclet number expressed in VL/D, and other notations are defined previously.

Because this is a one-dimensional model, the result of the analysis is expressed as a rate of radionuclide transport through the entire section, which is used for the follow-up step for analyzing the transport through the pumping well.

3.2.2.2 Transport Through Pumping Well

In order to simplify the analysis, the model assumes:

1. The well screen extends below the contaminated plume,
2. The depth of the well will extended to the depth calculated based on a reasonably probable scenario, and
3. The length of the well screen will extend from the groundwater surface to the bottom of the well.

Because the PRESTO model is specifically designed for the assessment of a system having its source of contamination in the vadose zone, it is conceivable that the plume of contamination will be located near the groundwater table at the well location where the critical population group resides. It is, therefore, reasonable to assume that the well will be extended below the plume.

Because a new well has to be drilled by a licensed well driller according to existing state regulations, it can be assumed that the well owner will be convinced by the well driller to drill the well deep enough to obtain better water quality and to secure water quality during drought season with minimal additional cost. It is reasonable to assume that the well will penetrate to a depth calculated based on a reasonably probable well drilling scenario.

The last assumption was made to simplify the analysis. This simplification could result in higher dose value, but is considered to be acceptable.

Based on the above assumptions, the generalized dimensional equation, Equation 5, can be greatly reduced and yields:

$$C_w = f(Q_p, V, D_w) \tag{10}$$

As a result, the concentration of radionuclides in the well water can be calculated by a simple algebraic equation expressed in:

$$C_w = \frac{Q_p}{V \cdot D_w} \tag{11}$$

The results of the calculation using this model are expected to be more conservative than those obtained from a three-dimensional model.

3.2.3 Differences in the Results of Analysis

In order to demonstrate the differences in the results of calculation between the upper-bound calculation model and the semi-dynamic model, the results of the solute transport analysis demonstrated in the VAM2D manual (Hg91) are selected as an example for comparison. The results of the analysis for the leachate migration from the disposal unit at certain time steps were copied and are shown in Figure 2.

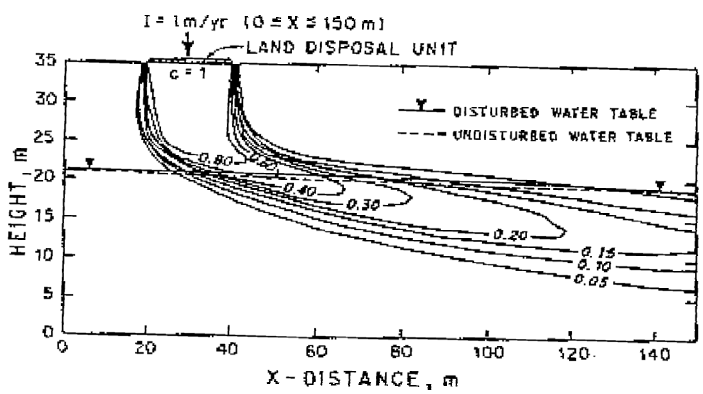

Figure 2. Example of Solute Transport Results

Now, if the well location is assumed to be at X = 80 meters and the well screen length is 1 meter, then the maximum probable concentration can be estimated to be approximately 0.31 unit/m^3 by using the upper-bound calculation model. On the other hand, the unit width rate of radionuclide transport can be calculated to be 10 unit/m/yr using the PRESTO model. If the well is constructed to the depth 2 meters above the bottom of the aquifer based on the well driller's recommendation then the total screen length will be approximately 18 meters. The concentration of the well water can now be calculated from Equation 7 to be approximately 0.056 unit/m^3. The difference in the results of calculation between the two models is as high as a factor of approximately 5.5.

A factor of 10 to 20 is frequently experienced in prototype low-level and mixed waste disposal sites analyses. It is apparent that the difference in the results of calculation between the two modeling approaches is enormous and, therefore, should not be overlooked.

4. CONCLUSION

Two different modeling approaches are being used to calculate the concentration in well water pumped from a given plume. They are the upper-bound calculation model and the semi-dynamic calculation model. The former model assumes that the well is designed under the worst possible condition to calculate the maximum probable concentration. The semi-dynamic model assumes that the well will be co-designed by the well owner and the well driller to secure better water quality and well productivity during a drought season.

The results of calculation from an upper-bound calculation model may be up to a factor of 5 higher than those calculated from a semi-dynamic model, and may go as high as a factor of 10 to 20 in some cases.

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Hu86 Hung, C.Y., An Optimum Groundwater Transport Model for Application to the Assessment of Health Effects Due to Land Disposal of Radioactive Wastes, proceeding of Nuclear and Chemical Waste Management, vol. 6, pp. 41-50, 1986.

APPENDIX I

INPUT PARAMETER LIST AND DESCRIPTION

SCREEN: TITLE

Parameter: TITLE
Description: Title
Definition: Identifies the run. Up to 80 characters are allowed.

Parameter: COMMENTS
Description: Comments
Definition: These records are available for comments and references pertaining to the data set. Up to 80 characters are allowed in each of seven records.

SCREEN: CONTROL

Parameter: MAXYR
Description: Number of Years to Simulate
Definition: The number of years for which the simulation will run (1 to 10,000 yr).

Parameter: ITMN
Description: Number of Years of Active Leachate Collection
Definition: Number of years of active leachate collection after site closure. No groundwater nuclide migration is initiated during the leachate collection period, although radioactive decay takes place.

Parameter: IRST
Description: Number of Years of Restricted Land Use after Site Closure
Definition: Same

Parameter: ICFT
Description: Number of Years before Waste Containers begin Failing
Definition: Same

Parameter: IDFT
Description: Number of Years to Complete Waste Container Failure
Definition: Number of years after site closure that containers fail completely.

Parameter: IAPP
Description: Number of Years of Agricultural Application
Definition: If IAPP is greater than 0 then the inventory is applied annually for IAPP years (Refer to the Source - Inventory screen).

Parameter: LEAOPT
Description: Leaching Option
Definition: Absorbing waste leaching option. Radionuclides will be removed from the absorbing waste contaminant in different manners depending on the value of LEAOPT. Must be one of the following calculation methods:

<u>Option Leach Calculation Method</u>
1. Chemical
2. Physico-chemical exchange with solubility limit control
3. Constant release fraction

Note: The leaching of radionuclides from solidified waste and activated metals is calculated by using the release fractions RELFCS and RELFCM assigned in Card No. 13.

Parameter: IORG
Description: Output Results by
Definition: Flag for dose equivalent output by organ. If IORG = 0, doses are not printed for each organ. If IORG = 1, doses are printed. (Not present for general population scenarios).

Parameter: IPRT1, IPRT2, IDELT
Description: Annual Summary - First Year, Last Year, Increment
Definition: An annual summary table will be produced for each year that is a multiple of IDELT and falls between the range of IPRT1 and IPRT2.

Parameter: NYR1, NYR2
Description: Trench Cap Failure - First Year, Last Year
Definition: Beginning and ending years of trench cap failure. Both values must be less than or equal to MAXYR. NYR2 must be greater than or equal to NYR1.

Parameter: PCT1, PCT2
Description: Trench Cap Failure - First Year Fraction, Last Year Fraction
Definition: Fraction of the cover assumed to fail between the years NYR1 and NYR2.

SCREEN - SUBSCREEN: SITE - CHARACTERISTICS

Parameter: PPN
Description: Total Annual Precipitation
Definition: Total annual precipitation (m). Calculated internally if SEEP = 0 and IDISP = 1.

Parameter: STFLOW
Description: Annual Flow Rate of Stream
Definition: Annual flow rate of the nearest stream (m^3/yr). Must be nonzero.

Parameter: DWELL
Description: Distance to Well in Meters
Definition: Distance from center of site to well (m). To trigger an onsite resident scenario, set WELLD equal to LENGTH/2. To trigger an adjacent resident, set WELLD greater than LENGTH/2 but less than LENGTH/2 + PD. To trigger an offsite an offsite scenario, WELLD must be greater than LENGTH/2 + PD.

Parameter: DWELL2*
Description: Distance from Site to Local Population
Definition: Distance from the site to the local population. Must be nonzero (m). Used only in the Population (POP) scenario.

Parameter: DWS*
Description: Distance between Well and Stream
Definition: Distance between the well and stream for basin effect calculations (m). Used only in the Population (POP) scenario.

Parameter: PD
Description: Distance to Surface Ditch (m)
Definition: Distance from edge of contaminated site to surface ditch (m). The area PD*WIDTH is the area occupied by the adjacent resident, if that scenario is selected.

Parameter: RAINF
Description: Rainfall Factor
Definition: The rainfall factor (R/yr).

Parameter: ERODF
Description: Soil-Erodiability Factor
Definition: Soil-erodiability factor has unit of tons/acre-R, where R = RAINF given below.

Parameter: COVER
Description: Crop Management Factor
Definition: Same

Parameter: CONTRL
Description: Erosion Control Practices Factor
Definition: Same

Parameter: SEDELR
Description: Sediment Delivery Ratio
Definition: This ratio is intended to apply to fouling of waterways from construction activity.

Parameter: STPLNG
Description: Slope Steepness-Length Factor
Definition: The slope steepness-length factor.

Parameter: RESAT
Description: Fraction of Residual Saturation
Definition: Same

Parameter: SEEP
Description: Fraction of Total Annual Precipitation for Infiltration Calculation
Definition: Fraction of the total annual precipitation (PPN) that will be used to calculate the rate of infiltration through trench cap. If a value of 0.0 is entered, the rate of infiltration will be calculated through INFIL subroutine.

Parameter: RUNOFF
Description: Top Soil Layer Precipitation Run-Off Fraction
Definition: Fraction of the annual precipitation that runs off from the top soil layer.

Parameter: RUNOF2
Description: Bottom Soil Layer Precipitation Run-Off Fraction
Definition: Fraction of the annual precipitation that runs off from the bottom soil layer.

Parameter: ADEPTH
Description: Active Depth of Soil in Surface-Contaminated Region
Definition: Used for the radionuclide transport analysis in the surface soil for both on and outside of the contamination area.

Parameter: WIDTH
Description: Width - Waste
Definition: Width of site perpendicular to groundwater flow (m).

Parameter: XLENGTH
Description: Length of the Contaminated Site
Definition: Length of contaminated site parallel to groundwater flow (m).

SCREEN - SUBSCREEN: SITE - PLANT & ANIMAL

Parameter: Y1, Y2
Description: Agriculture Productivity - Pasture Grass, Other Vegetation
Definition: Agricultural productivity for pasture grass and other consumed vegetation, respectively (kg/m).

Parameter: TE1, TE2
Description: Exposure Time in Contaminated Air - Pasture Grass, Crops
Definition: Period of time that pasture grass or crops and leafy vegetables, respectively, are exposed to contaminated air during each growing season (hr).

Parameter: QCW, QGW, QBW
Description: Amount of Daily Water Consumption - Dairy Cows, Dairy Goats, Beef Cattle
Definition: Values for the amount of water (L/d) consumed by milk cows, milk goats, and beef cattle, respectively.

Parameter: QFG, QFC
Description: Feed Consumption - Dairy Goats, Beef Cattle
Definition: The amount of feed consumed daily by dairy goats and beef cattle (kg).

Parameter: TH1 - TH4, TH5*, TH6*
Description: Delay Time between Harvest and Consumption - Pasture Grass, Stored Feed, Leafy Veg. (Ind.), Produce (Ind.), Leafy Veg. (Pop.), Produce (Pop.)
Definition: The delay time (hr) between harvest and consumption by animal or man of pasture grass (TH1), stored feed (TH2), leafy vegetables (TH3), produce (TH4) for the onsite population, and leafy vegetables (TH5) and produce (TH6) for the local population (TH6). <u>TH5 and TH6 are used in the population (POP) scenario only.</u>

Parameter: TF1
Description: Transport Time from Animal Feed to Human Receptor
Definition: The transport time (hr) from animal feed into the human consumer.

Parameter: TF2*
Description: Transport Time from Animal Feed to Local Population
Definition: The transport time (hr) from animal feed to the local population. <u>Used only in the Population (POP) scenario.</u>

Parameter: TS
Description: Time between Slaughter of Animals & Human Consumption
Definition: Length of time between slaughter of animals and human consumption of the resultant meat (hr).

Parameter: XAMBWE
Description: Weathering Removal Decay Constant
Definition: The weathering removal decay constant for atmospheric deposition onto food crops (hr^{-1}).

Parameter: P14
Description: Carbon-14 Fractional Equilibrium Value.
Definition: Carbon-14 fractional equilibrium value. Used for calculation of food chain specific activity for carbon-14 in foods.

Parameter: ABSH
Description: Absolute Humidity
Definition: Absolute humidity of the atmosphere (g/m^3). Used for calculation of food chain specific activity for tritium in foods. Must be nonzero.

Parameter: XRTM
Description: Root Depth for Onsite Farming Scenario
Definition: Root depth for onsite farming scenario (m).

Parameter: WIRATE
Description: Irrigation Rate
Definition: Irrigation rate (L/m-hr).

Parameter: SFRAC
Description: Fraction of Precipitation that Infiltrates through Outside of the Contaminated Area where the Irrigation Practice Takes Place.
Definition: Same

Parameter: FI
Description: Fraction of Year that Crops are Irrigated
Definition: Same

Parameter: FP
Description: Fraction of Year that Animals Graze on Pasture Grass
Definition: Same

Parameter: FS
Description: Fraction of Animal's Daily Feed that is Fresh Grass
Definition: Fraction of an animal's daily feed that is fresh grass for the period of time animals are in pasture.

SCREEN - SUBSCREEN: SITE - HUMAN UPTAKE

Parameter: ULEAFY
Description: Human Uptake of Leafy Vegetables
Definition: Human uptake of leafy vegetables on a wet weight basis (kg/yr).

Parameter: UPROD
Description: Human Uptake of Produce
Definition: Human uptake of produce on a wet weight basis(kg/yr).

Parameter: UCMILK
Description: Human Uptake of Cow Milk
Definition: Human uptake of cow milk (L/yr).

Parameter: UGMILK
Description: Human Uptake of Goat Milk
Definition: Human uptake of goat milk (L/yr).

Parameter: UMEAT
Description: Human Uptake of Meat
Definition: Human uptake of meat (kg/yr).

Parameter: UWAT
Description: Human Uptake of Drinking Water
Definition: Human uptake of drinking water (L/yr).

Parameter: UFISH
Description: Human Uptake of Fish
Definition: Human uptake of fish(kg/yr).

Parameter: USOIL
Description: Human Uptake of Soil
Definition: Human uptake of soil(kg/yr).

Parameter: UAIR
Description: Human Inhalation Rate
Definition: Inhalation rate (m^3/yr).

Parameter: POP*
Description: Onsite Population
Definition: Onsite population (number of people). Used only in the Population (POP) scenario.

Parameter: POPL*
Description: Offsite Population
Definition: Offsite population (number of people). Used only in the Population (POP) scenario.

Parameter: WWATH
Description: Fraction of Drinking Water Supplied from Well
Definition: Fraction of human drinking water supplied by contaminated water from well (1.0 if all water comes from well; 0.0 if none).

Parameter: SWATH
Description: Fraction of Drinking Water Supplied from Stream
Definition: Fraction of human drinking water supplied by contaminated water from stream (1.0 if all water comes from stream, 0.0 if none).

Parameter: WWATL
Description: Fraction of Irrigation Water Supplied from Well
Definition: Fraction of irrigation water supplied by contaminated water from well (1.0 if all water comes from well, 0.0 if none).

Parameter: SWATL
Description: Fraction of Irrigation Water Supplied by Stream
Definition: Fraction of irrigation water supplied by contaminated water from stream (1.0 if all water comes from stream, 0.0 if none).

Parameter: WWATA
Description: Fraction of Animal Drinking Water Supplied from Well
Definition: Fraction of animal drinking water supplied by contaminated water from well (1.0 if all water comes from well, 0.0 if none).

Parameter: SWATA
Description: Fraction of Animal Drinking Water Supplied from Stream
Definition: Fraction of animal drinking water supplied by contaminated water from stream (1.0 if all water comes from stream, 0.0 if none).

SCREEN - SUBSCREEN: SITE - COVER & WASTE

Parameter: OVER
Description: Thickness - Cover
Definition: Thickness of top contaminated layer (m).

Parameter: WDEPTH
Description: Thickness - Waste
Definition: Thickness of bottom contaminated layer (m).

Parameter: BDENS
Description: Density - Cover
Definition: Bulk density of top layer (g/cm^3). Must be nonzero.

Parameter: DENCON
Description: Density - Waste
Definition: Mean density of the contaminated soil (g/cm^3).

Parameter: PORS
Description: Porosity - Cover
Definition: Porosity of the top layer. Must be nonzero.

Parameter: PORT
Description: Porosity - Waste
Definition: Porosity of contaminated soil. This must be nonzero.

Parameter: XKI
Description: Permeability - Cover
Definition: The permeability of the top layer soil (m/hr).

Parameter: PERMT
Description: Permeability - Waste
Definition: Hydraulic conductivity of contaminated soil (m/yr).

Parameter: SLOP
Description: Average Slope - Cover
Definition: The average slope of cover (m/m).

Parameter: XL
Description: Width - Average Slope Length
Definition: Average length of site slope (m).

Parameter: YPI
Description: Pellicular Water Deficit - Cover
Definition: The initial pellicular water deficit of the trench cap (m).

Parameter: YGI
Description: Gravity Water Deficit - Cover
Definition: The initial gravity water deficit of the cover (m).

Parameter: EPSP
Description: Component of Porosity - Pellicular Water - Cover
Definition: The component of porosity for pellicular water in cover (unitless).

Parameter: EPSG
Description: Component of Porosity - Gravity Water - Cover
Definition: The component of porosity for gravity water in cover (unitless).

Parameter: XDE
Description: Equivalent Upward Diffusivity
Definition: The equivalent upward diffusivity (m/hr). Recommended values: 7.2E-4 (sand), 3.6E-4 (loam), and 1.4E-4 (clay).

Parameter: XKE
Description: Equivalent Upward Hydraulic Conductivity
Definition: The equivalent upward hydraulic conductivity (m/hr). Recommended values: 3.6E-6 (sand), 1.4E-6 (loam), and 1.1E-6 (clay).

Parameter: SPLA
Description: Spillage fraction for absorbing waste.
Definition: Fraction of initial absorbing waste inventory as spillage on the ground surface. Only if adjacent farming scenario is triggered. (LENGTH/2 < DWELL < PD + LENGTH/2)

Parameter: SPLS
Description: Spillage fraction for solidified waste.
Definition: Fraction of initial solidified waste inventory as spillage on ground surface. Only if adjacent farming scenario is triggered. (LENGTH/2 < DWELL < PD + LENGTH/2)

Parameter: SPLM
Description: Spillage fraction for activated metal.
Definition: Fraction of initial activated metal inventory as spillage on ground surface. Only if adjacent farming scenario is triggered. (LENGTH/2 < DWELL < PD + LENGTH/2)

Parameter: RELFCA
Description: Release Fraction for the Absorbing Waste
Definition: Same

Parameter: RELFCM
Description: Release Fraction for the Activated Metals
Definition: Same

Parameter: RELFCS
Description: Release Fraction for the Solidified Waste
Definition: Same

Parameter: FABS
Description: Fraction of Absorbing Waste that is Containerized
Definition: Same

SCREEN - SUBSCREEN: SITE - VERTICAL ZONE & AQUIFER

Parameter: DTRAQ
Description: Vertical Zone - Thickness
Definition: The distance from the bottom of the bottom layer of contamination to the nominal depth of the aquifer (m).

Parameter: WELLD
Description: Length of well screen.
Definition: Vertical penetration of well casing in aquifer (m). Used with AQDISP to calculate aquifer dilution volume.

Parameter: PORV
Description: Vertical Zone Porosity
Definition: Porosity below contaminated zone.

Parameter: PORA
Description: Aquifer - Porosity
Definition: Porosity of aquifer.

Parameter: BDENV
Description: Vertical Zone - Density
Definition: Density of material below contaminated zone (g/cm^3).

Parameter: PERMV
Description: Vertical Zone - Permeability
Definition: Hydraulic conductivity below contaminated zone.

Parameter: SSAT
Description: Vertical Zone - Fraction of Water Saturation
Definition: Fraction of water saturation in the ground formation beneath the buried waste. If SSAT is 0 or is left blank, the fraction of saturation is calculated internally by the code.

Parameter: GWV
Description: Aquifer - Groundwater Velocity
Definition: True velocity of the groundwater in the aquifer. Must be non zero (m/yr).

Parameter: AQDISP
Description: Aquifer - Dispersion Angle
Definition: Dispersion angle of the plume in the aquifer (in radians). Used with WELLD to calculate aquifer dilution volume.

Parameter: IAQSTF
Description: Aquifer - Allow Aquifer to Stream Flow
Definition: Flag for aquifer to stream flow. Selecting "Yes" triggers the discharge flow calculations.

SCREEN - SUBSCREEN: SITE - ATMOSPHERIC

Parameter: INF
Description: Site Environment
Definition: Flag for indicating which temperature and rainfall (INFIL) file will be used in calculating infiltration parameters.

1. Humid South (INFIL.HP)
2. Humid North (INFIL.HI)
3. Arid South (INFIL.AP)
4. Arid North (INFIL.AI)
5. User Defined (INFIL.INP)

Parameter: VD
Description: Deposition Velocity
Definition: Deposition velocity (m/s). Nominal generic value is 0.01 m/s.

Parameter: VG
Description: Gravitational Settling Velocity
Definition: Settling velocity of suspended dust particles due to gravity (m/s).

Parameter: RR
Description: Onsite Dust Loading from Mechanical Disturbance
Definition: Onsite dust loading in air (g/m^3).

Parameter: FTWIND
Description: Fraction of Time Wind Blows in Direction of Interest
Definition: Fraction of the time the wind blows in the direction from source to receptor.

Parameter: U
Description: Annual Average Wind speed in Direction of Interest
Definition: Annual average wind speed (m/s) in the direction of interest. Must be non zero.

Parameter: RE1, RE2, RE3
Description: Resuspension Equation Parameter #1, #2, #3
Definition: Factors (including algebraic signs) used in the resuspension rate equation.

Parameter: IS
Description: Stability Category Indicator
Definition: Atmospheric stability class indicator for most common atmospheric conditions at site. 1=Class A, 2=Class B, ..., 6=Class F.

Parameter: IT
Description: Pasquill-Gifford Atmospheric Stability Class Formation
Definition: Type of atmospheric stability formulation. Suggested formulation is Pasquill-Gifford, IT = 1.

Parameter: HLID
Description: Height of the Inversion Layer
Definition: Height of atmospheric inversion layer or lid height (m).

Parameter: ROUGH
Description: Hosker's Roughness Parameter
Definition: Hosker's ground surface roughness factor (m).

Parameter: CHIQ
Description: Atmospheric Transport Parameter
Definition: Atmospheric dispersion parameter (s/m^3). Equal to downwind atmospheric concentration (Bq/m^3) divided by the source strength (Bq/s).

SCREEN: BASEMENT

Parameter: EMANATE
Description: Rn-222 Emanation Fraction for Contaminated Soil
Definition: Same (unitless)

Parameter: BDEPTH
Description: Depth of Basement below Surface
Definition: Same (m)

Parameter: CTHICK
Description: Thickness of Concrete Floor in the Basement
Definition: Same (m)

Parameter: PORC
Description: Porosity of Concrete Floor in the Basement
Definition: Same (m)

Parameter: BASEP
Description: Length of Basement Perimeter
Definition: Same (m)

Parameter: HPRESS
Description: Negative Indoor House Pressure
Definition: Same (Pa)

Parameter: CRACKW
Description: Perimeter Shrinkage Crack Width
Definition: Same (m)

Parameter: VENT
Description: Basement Ventilation Rate
Definition: Same (air changes / s)

Parameter: BASEA
Description: Area of Basement Floor
Definition: Same (m)

Parameter: BSMTOC
Description: Basement Occupancy Fraction
Definition: Same (unitless)

Parameter: SITEOC
Description: Outdoor, Onsite Occupancy Fraction
Definition: Same (unitless)

SCREEN - SUBSCREEN: SOURCE - NUCLIDE LIST

Parameter: NONCLD
Description: (Calculated based on the number of radionuclides selected)
Definition: The number of radionuclides which are used in the simulation. Must be 40 or less.

Parameter: NUCLID(I)
Description: (Radionuclides are selected from the Nuclide List Screen)
Definition: Radionuclide name. Must be all upper-case, left-justified, have no embedded blanks, and have a hyphen separating the alphameric for the element and the numeric for the isotope. The names used must agree with the conventions used in dose and risk data below.

SCREEN - SUBSCREEN: SOURCE - UPTAKE

Parameter: RA(I)
Description: Retention Fraction - Air
Definition: Radionuclide retention fraction for air.

Parameter: RW(I)
Description: Retention Fraction - Irrigation
Definition: Radionuclide retention fraction for irrigation.

Parameter: BV(I)
Description: Soil-to-Plant - Veg
Definition: Radionuclide soil-to-plant uptake factor for vegetative parts.

Parameter: BR(I)
Description: Soil-to-Plant - Grain
Definition: Radionuclide soil-to-plant uptake factor for produce or grain.

Parameter: FMC(I)
Description: Transfer Factor - Cow Milk
Definition: Radionuclide forage-to-milk transfer factor for cows (d/l).

Parameter: FMG(I)
Description: Transfer Factor - Goat Milk
Definition: Radionuclide forage-to-milk transfer factor for goats (d/l).

Parameter: FF(I)
Description: Transfer Factor - Beef
Definition: Radionuclide forage-to-beef transfer factor (d/kg).

Parameter: FFIS(I)
Description: Transfer Factor - Fish
Definition: Radionuclide water-to-fish transfer factor (d/kg).

SCREEN - SUBSCREEN: SOURCE - TRANSPORT

Parameter: DECAY(I)
Description: Decay Constant
Definition: Radiological decay constant (yr^{-1}). Equal to 0.6931 divided by the radiological half-life in years.

Parameter: SOL(I)
Description: Solubility
Definition: Solubility of the radionuclide (mg/l). Used with the leaching option.

Parameter: XKD(1,I)
Description: Surface K_d
Definition: Surface K_d of radionuclide I (ml/g).

Parameter: XKD(2,I)
Description: Waste K_d
Definition: Waste K_d of radionuclide I (ml/g).

Parameter: XKD(3,I)
Description: Vertical Zone K_d
Definition: Vertical zone K_d of radionuclide I (ml/g).

Parameter: XKD(4,I)
Description: Aquifer K_d
Definition: Aquifer K_d of radionuclide I (ml/g).

SCREEN - SUBSCREEN: SOURCE - INVENTORY

Parameter: CIAW1(I)
Description: Absorbing Waste - Layer 1
Definition: Amount of the radionuclide in the absorbing waste of the first layer (Bq). If IAPP > 0, assumed to be applied annually for IAPP years. If IAPP > 0, subsequent data on this card are not read.

Parameter: CIAW2(I)
Description: Absorbing Waste - Layer 2
Definition: Amount of the radionuclide in the absorbing waste of the second layer (Bq).

Parameter: CISW1(I)
Description: Solidified Waste - Layer 1
Definition: Amount of the radionuclide in the solidified waste of the first layer (Bq).

Parameter: CISW2(I)
Description: Solidified Waste - Layer 2
Definition: Amount of the radionuclide in the solidified waste of the second layer (Bq).

Parameter: CIAM1(I)
Description: Activated Metals - Layer 1
Definition: Amount of the radionuclide in the activated metals of the first layer(Bq).

Parameter: CIAM2(I)
Description: Activated Metals - Layer 2
Definition: Amount of the radionuclide in the activated metals of the second layer(Bq).

Parameter: CON(I)*
Description: Conversion Factor
Definition: Conversion factor for the regional basin population health effects calculation (Health-Effects / Bq Released). Used only in the population (POP) scenario.

SCREEN - SUBSCREEN: SOURCE - DCF / HECF (INGESTION)
(Dose conversion factors are used only in the Individual (CPG) scenario)

Parameter: DCFCTR(I,1,1)
Description: Ingestion Dose Factor for Gonad
Definition: Gonad dose conversion factor for the ingestion exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,2,1)
Description: Ingestion Dose Factor for Breast
Definition: Breast dose conversion factor for the ingestion exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,3,1)
Description: Ingestion Dose Factor for Lung
Definition: Lung dose conversion factor for the ingestion exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,4,1)
Description: Ingestion Dose Factor for Red Marrow
Definition: Red Marrow dose conversion factor for the ingestion exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,5,1)
Description: Ingestion Dose Factor for Bone Surface
Definition: Bone Surface dose conversion factor for the ingestion exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,6,1)
Description: Ingestion Dose Factor for Thyroid
Definition: Thyroid dose conversion factor for the ingestion exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,7,1)
Description: Ingestion Dose Factor for Remainder
Definition: Remainder dose conversion factor for the ingestion exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,8,1)
Description: Ingestion Dose Factor for Effective
Definition: Effective dose conversion factor for the ingestion exposure pathway (Sv/Bq).

Parameter: XMRCF(I,1)
Description: Ingestion Risk Factor for Mortality
Definition: Mortality risk conversion factor for the ingestion exposure pathway (1/Bq).

Parameter: XIRCF(I,1)
Description: Ingestion Risk Factor for Incidence
Definition: Incidence risk conversion factor for the ingestion exposure pathway (1/Bq).

Parameter: HEFCTR(I,1)*
Description: Ingestion Risk Factor for Genetic
Definition: Genetic health-effect conversion factor for the ingestion exposure pathway (Risk/Bq).
Used only in the Population (POP) scenario.

SCREEN - SUBSCREEN: SOURCE - DCF / HECF (INHALATION)
(Dose conversion factors are used only in the Individual (CPG) scenario)

Parameter: DCFCTR(I,1,2)
Description: Inhalation Dose Factor for Gonad
Definition: Gonad dose conversion factor for the inhalation exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,2,2)
Description: Inhalation Dose Factor for Breast
Definition: Breast dose conversion factor for the inhalation exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,3,2)
Description: Inhalation Dose Factor for Lung
Definition: Lung dose conversion factor for the inhalation exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,4,2)
Description: Inhalation Dose Factor for Red Marrow
Definition: Red Marrow dose conversion factor for the inhalation exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,5,2)
Description: Inhalation Dose Factor for Bone Surface
Definition: Bone Surface dose conversion factor for the inhalation exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,6,2)
Description: Inhalation Dose Factor for Thyroid
Definition: Thyroid dose conversion factor for the inhalation exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,7,2)
Description: Inhalation Dose Factor for Remainder
Definition: Remainder dose conversion factor for the inhalation exposure pathway (Sv/Bq).

Parameter: DCFCTR(I,8,2)
Description: Inhalation Dose Factor for Effective
Definition: Effective dose conversion factor for the inhalation exposure pathway (Sv/Bq).

Parameter: XMRCF(I,2)
Description: Inhalation Risk Factor for Mortality
Definition: Mortality risk conversion factor for the inhalation exposure pathway (1/Bq).

Parameter: XIRCF(I,2)
Description: Inhalation Risk Factor for Incidence
Definition: Incidence risk conversion factor for the inhalation exposure pathway (1/Bq).

Parameter: HEFCTR(I,2)*
Description: Inhalation Risk Factor for Genetic
Definition: Genetic health-effect conversion factor for the ingestion exposure pathway (Risk/Bq).
Used only in the Population (POP) scenario.

SCREEN - SUBSCREEN: SOURCE - DCF / HECF (AIR IMMERSION)
(Dose conversion factors are used only in the Individual (CPG) scenario)

Parameter: DCFCTR(I,1,3)
Description: Air Immersion Dose Factor for Gonad
Definition: Gonad dose conversion factor for the air immersion exposure pathway [(Sv/sec)/(Bq/m^2)].

Parameter: DCFCTR(I,2,3)
Description: Air Immersion Dose Factor for Breast
Definition: Breast dose conversion factor for the air immersion exposure pathway [(Sv/sec)/(Bq/m^2)].

Parameter: DCFCTR(I,3,3)
Description: Air Immersion Dose Factor for Lung
Definition: Lung dose conversion factor for the air immersion exposure pathway [(Sv/sec)/(Bq/m^2)].

Parameter: DCFCTR(I,4,3)
Description: Air Immersion Dose Factor for Red Marrow
Definition: Red Marrow dose conversion factor for the air immersion exposure pathway [(Sv/sec)/(Bq/m^2)].

Parameter: DCFCTR(I,5,3)
Description: Air Immersion Dose Factor for Bone Surface
Definition: Bone Surface dose conversion factor for the air immersion exposure pathway [(Sv/sec)/(Bq/m^2)].

Parameter: DCFCTR(I,6,3)
Description: Air Immersion Dose Factor for Thyroid
Definition: Thyroid dose conversion factor for the air immersion exposure pathway [(Sv/sec)/(Bq/m^2)].

Parameter: DCFCTR(I,7,3)
Description: Air Immersion Dose Factor for Remainder
Definition: Remainder dose conversion factor for the air immersion exposure pathway [(Sv/sec)/(Bq/m^2)].

Parameter: DCFCTR(I,8,3)
Description: Air Immersion Dose Factor for Effective
Definition: Effective dose conversion factor for the air immersion exposure pathway [(Sv/sec)/(Bq/m^2)].

Parameter: XMRCF(I,3)
Description: Air Immersion Risk Factor for Mortality
Definition: Mortality risk conversion factor for the air immersion exposure pathway [(1/sec)/(Bq/m^2)].

Parameter: XIRCF(I,3)
Description: Air Immersion Risk Factor for Incidence
Definition: Incidence risk conversion factor for the air immersion exposure pathway [(1/sec)/(Bq/m^2)].

Parameter: HEFCTR(I,3)*
Description: Air Immersion Risk Factor for Genetic
Definition: Genetic health-effect conversion factor for the air immersion exposure pathway [(Risk/sec)/(Bq/m^2)]. <u>Used only in the Population (POP) scenario.</u>

SCREEN - SUBSCREEN: SOURCE - DCF / HECF (EXTERNAL)

Parameter: DCF15(I)
Description: External Dose Factor for 15 cm Soil Contamination
Definition: Dose conversion factor for the external exposure pathway contaminated to the depth of 15 cm [(Sv/sec)/(Bq/m^3)].

Parameter: DCFINF(I)
Description: External Dose Factor for Thick Soil Contamination
Definition: Dose conversion factor for the external exposure pathway contaminated to infinite thickness [(Sv/sec)/(Bq/m^3)].

Parameter: XMRCF(I,4)
Description: External Risk Factor for Mortality
Definition: Mortality risk conversion factor for the soil exposure pathway [Kg/Bq-s].

Parameter: XIRCF(I,4)
Description: External Risk Factor for Incidence
Definition: Incidence risk conversion factor for the soil exposure pathway [Kg/Bq-s].

Parameter: HEFCTR(I,4)*
Description: External Risk Factor for Genetic
Definition: Genetic health-effect conversion factor for the soil exposure pathway [Risk-Kg/Bq-sec]. Used only in the Population (POP) scenario.

APPENDIX J-1

REFERENCE INPUT FILE FORMAT FOR PRESTO-CPG

TABLE J-1

REFERENCE INPUT FILE FORMAT FOR PRESTO-CPG

(Note: Direct editing of this reference input file is highly discouraged.)

Card	Variable (Input Format)	Description
CARD 1	Run Identification (A80)	
	TITLE	Identifies the run. Up to 80 characters are allowed.
CARD 2	Time, Nuclides, and Farming Control Parameters (19I5)	
	MAXYR	Number of years for which the simulation will run (1 to 10,000 yr).
	NONCLD	Number of radionuclides used in the simulation. Must be 40 or less.
	LEAOPT	Absorbing waste leaching option. Radionuclides will be removed from the absorbing waste contaminant in different manners depending on the value of LEAOPT. Must be one of the following calculation methods: Option — Leach Calculation Method 1 — Chemical exchange 2 — Chemical exchange with solubility control 3 — Constant release fraction Note: The leaching of radionuclides from solidified waste and activated metals is calculated by using the release fractions RELFCS and RELFCM assigned in Card No. 13.
	NYR1, NYR2	Beginning and ending years of cap failure. Both values must be less than or equal to MAXYR. NYR2 must be greater than or equal to NYR1.
	IPRT1, IPRT2, IDELT	An annual summary table will be produced for each year that is a multiple of IDELT and falls between the range of IPRT1 and IPRT2.
	IRST	Number of years of restricted land use after site closure.
	ITMN	Number of years of active leachate collection after site closure. No groundwater nuclide migration is initiated during the leachate collection period, although radioactive decay takes place.
	IAPP	If IAPP > 0 then the inventory is applied annually for IAPP years (Refer to the Source - Inventory screen).
	IORG	Flag for dose equivalent output by organ. If IORG = 0, doses are not printed for each organ. If IORG = 1, doses are printed. (Not present for general pollution scenarios).
	INF	Flag for indicating which temperature and rainfall (INFIL) file will be used in calculating infiltration parameters. 1 — Humid South (INFIL.HS) 2 — Humid North (INFIL.HN) 3 — Arid South (INFIL.AS) 4 — Arid North (INFIL.AN)

TABLE J-1
(Continued)

Card	Variable (Input Format)	Description
		5 User Defined (INFIL.INP)
CARD 3	Control Parameters	
	IAQSTF	Control parameter for aquifer to stream flow. Selecting "Yes" defaults to calculations under the assumption that the flow takes place.
	ICFT	Number of years before waste containers begin failing.
	IDFT	Number of years after site closure that containers fail completely.
CARD 4	Water Infiltration and Use (8F10.0)	
	PCT1, PCT2	Fraction of the cover assumed to fail between the years NYR1 and NYR2.
	WWATL	Fraction of irrigation water supplied by contaminated water from well (1.0 if all water comes from well; 0.0 if none).
	WWATA	Fraction of animal drinking water supplied by contaminated water from well (1.0 if all water comes from well; 0.0 if none).
	WWATH	Fraction of human drinking water supplied by contaminated water from well (1.0 if all water comes from well; 0.0 if none).
	SWATL	Fraction of irrigation water supplied by contaminated water from stream (1.0 if all water comes from stream; 0.0 if none).
	SWATA	Fraction of animal drinking water supplied by contaminated water from stream (1.0 if all water comes from stream; 0.0 if none).
	SWATH	Fraction of human drinking water supplied by contaminated water from stream (1.0 if all water comes from stream; 0.0 if none).
CARDS 5-11	Comments and References (20A4)	
		These records are available for comments and references pertaining to data set. Up to 80 characters allowed in each of seven records.
CARD 12	Site Characteristics (7F10.0)	
	XLENGTH	Length of contaminated site parallel to groundwater flow (m). Must be nonzero.
	WIDTH	Width of site perpendicular to groundwater flow (m).
	WDEPTH	Thickness of bottom contaminated layer (m).
	OVER	Thickness of top contaminated layer (m).
	PORT	Porosity of contaminated soil. Must be nonzero.
	DENCON	Mean density of the contaminated soil (g/cm^3).

TABLE J-1
(Continued)

Card	Variable (Input Format)	Description
	SFRAC	Fraction of precipitation infiltrate through the surface soil outside of contaminated site where radionuclide transport analysis is required, such as irrigation area and overland flow area (unitless).
CARD 13 Groundwater Saturation (7F10.0)		
	SSAT	Fraction of water saturation in the ground formation beneath the buried waste. If SSAT is 0 or is left blank, the fraction of saturation is calculated internally by the code.
	RESAT	Fraction of residual saturation.
	PERMT	Hydraulic conductivity of contaminated soil (m/yr).
	SLOP	Average slope of cover (m/m).
	RELFCA	Release fraction for the absorbing waste.
	RELFCS	Release fraction for the solidified waste.
	RELFCM	Release fraction for the activated metals.
CARD 14 Waste Spillage Fractions (3F10.0)		
	SPLA	Fraction of initial absorbing waste inventory as spillage on the ground surface.
	SPLS	Fraction of initial solidified waste inventory as spillage on ground surface.
	SPLM	Fraction of initial activated metal inventory as spillage on ground surface.
CARD 15 Cover Infiltration Characteristics (8F10.0)		
	XKI	The permeability of the top layer soil (m/hr).
	XL	Average length of the site slop (m).
	EPSG	The component of porosity for gravity water in cover (unitless).
	EPSP	The component of porosity for pellicular water in cover (unitless).
	XDE	The equivalent upward diffusivity (m/hr).
	XKE	The equivalent upward hydraulic conductivity (m/hr).
	YPI	The initial pellicular water deficit of cover (m).
	YGI	The initial gravity water deficit of the cover (m).
CARD 16 Transport Parameters (7F10.0)		
	DTRAQ	Distance from the bottom of the bottom layer of contamination to the nominal depth of the aquifer (m).

TABLE J-1
(Continued)

Card	Variable (Input Format)	Description
	GWV	Velocity of the groundwater in the aquifer. Must be nonzero (m/yr).
	WELLD	Vertical penetration of well casing in aquifer (m). Used with AQDISP to calculate aquifer dilution volume.
	AQDISP	Dispersion angle of the pollutant plume in the aquifer (must be in radians). Used with WELLD to calculate aquifer dilution volume.
	PORA	Porosity of aquifer.
	PORV	Porosity below contaminated zone.
	PERMV	Hydraulic conductivity below contaminated zone.
CARD 17	Transport Properties (4F10.0)	
	BDENV	Density of material below contaminated zone (g/cm^3).
	FABS	Fraction of absorbing waste that is containerized.
	PD	Distance from edge of contaminated site to surface ditch (m). The area PD*WIDTH is the area occupied by the adjacent resident, if that scenario is selected.
	DWELL	Distance from center of site to well (m). To trigger an onsite resident scenario, set WELLD equal to LENGTH/2. To trigger an adjacent resident, set WELLD greater than LENGTH/2 but less than LENGTH/2 + PD. To trigger an offsite scenario, WELLD must be greater than LENGTH/2 and greater than PD.
CARD 18	Atmospheric Parameters (8F10.0)	
	VG	Settling velocity of suspended dust particles due to gravity (m/s).
	U	Annual average wind speed (m/s).
	VD	Deposition velocity (m/s). Nominal generic value is 0.01 m/s.
	FTWIND	Fraction of time the wind blows in the direction from source to receptor.
	RE1, RE2, RE3	Factors (including algebraic signs) used in the resuspension rate equation.
	RR	Onsite dust loading in air (g/m^3).
CARD 19	Basement Parameters (6F10.0)	
	EMANATE	Rn-222 emanation fraction for contaminated soil (unitless).
	BDEPTH	Depth of basement below surface (m).
	CTHICK	Thickness of concrete floor in the basement (m).
	PORC	Porosity of concrete floor (unitless).
	BASEP	Length of basement perimeter (m).

TABLE J-1
(Continued)

Card	Variable (Input Format)	Description
	HPRESS	Negative indoor house pressure (Pa).
CARD 20 Basement Parameters (5F10.0)		
	CRACKW	Perimeter shrinkage crack width (m).
	VENT	Basement ventilation rate (air changes/s).
	BASEA	Area of basement floor (m).
	BSMTOC	Basement occupancy fraction (unitless).
	SITEOC	Outdoor onsite occupancy fraction (unitless).
CARD 21 Universal Soil Loss Equation Parameters (6F10.0)		
	RAINF	Precipitation factor (R/yr).
	ERODF	Soil erosion factor. Has units of tons/acre-R where R = RAINF.
	STPLNG	Slope steepness-length factor.
	COVER	Crop management factor.
	CONTRL	Erosion control practices factor.
	SEDELR	Sediment delivery ratio. This ratio is intended to apply to fouling of waterways from construction activity.
CARD 22 Soil and Surface Water (4F10.0)		
	PORS	Porosity of the top layer. Must be nonzero.
	BDENS	Bulk density of the top layer (g/cm^3). Must be nonzero.
	STFLOW	Annual flow rate of the nearest stream (m^3/yr). Must be nonzero.
	ADEPTH	Active depth of soil in the surface-contaminated region. Used for the calculation of radionuclide concentration in both surface soil and surface water. Must be nonzero.
CARD 23 Surface Water Runoff (4F10.0)		
	PPN	Total annual precipitation (m).
	SEEP	Fraction of the total annual precipitation (PPN) that infiltrates through the soil (unitless). If a value of 0.0 is input, this rate of infiltration will be calculated through INFIL subroutine.
	RUNOFF	Fraction of the annual precipitation that runs off from the top layer soil (unitless). If SEEP = 0.0, this value will be calculated by INFIL subroutine.
	RUNOF2	Fraction of the annual precipitation that runs off from the bottom soil layer when the top soil layer has been eroded away. If SEEP = 0.0, this value will be calculated by INFIL subroutine. This value must be less than or equal to RUNOFF.

TABLE J-1
(Continued)

Card	Variable (Input Format)	Description
CARD 24 Agricultural Data (7F10.0)		
	Y1, Y2	Agricultural productivity for pasture grass and other consumed vegetation, respectively (kg/m).
	XAMBWE	The weathering removal decay constant for atmospheric deposition onto food crops (hr^{-1}).
	TE1, TE2	Period of time that pasture grass or crops and leafy vegetables, respectively, are exposed to contaminated air during each growing season (hr).
	XRTM	Root depth for on-site farming scenario (m).
CARD 25 Agricultural Delay Times and Fractions (6F10.0)		
	TH1, TH2, TH3, TH4	Represent the delay time (hr) between harvest and consumption by animal or man of pasture grass (TH1), stored feed (TH2), leafy vegetables (TH3), and produce (TH4).
	FP	Fraction of each year that animals graze on pasture grass.
	FS	Fraction of an animal's daily feed that is fresh grass for the period of time animals are in pasture.
CARD 26 Animal Feed Data 7F10.0)		
	QFC	Amount of feed consumed daily by cattle (kg).
	QFG	Amount of feed consumed daily by dairy goats (kg).
	TF1	Transport time (hr) from animal feed into milk and into human consumer.
	TS	Length of time between slaughter of animals and human consumption of the meat (hr).
	ABSH	Absolute humidity of the atmosphere (g/m^3). Used for calculation of food chain specific activity for tritium in foods. Must be nonzero.
	P14	Carbon-14 fractional equilibrium value. Used for calculation of food chain specific activity for carbon-14 in foods.
CARD 27 Irrigation Water Data (5F10.0)		
	FI	Fraction of the year that crops are irrigated.
	WIRATE	Irrigation rate (L/m-hr).
	QCW, QGW, QBW	Values for the amount of water (L/d) consumed by milk cows, milk goats, and beef cattle, respectively.
CARD 28 Human Food Uptake (8F10.0)		
	ULEAFY	Human uptake of leafy vegetables on a wet weight basis (kg/yr).
	UPROD	Human uptake of produce on a wet weight basis (kg/yr).

TABLE J-1
(Continued)

Card	Variable (Input Format)	Description
	UCMILK	Human uptake of cow milk (L/yr).
	UGMILK	Human uptake of goat milk (L/yr).
	UMEAT	Human uptake of meat (kg/yr).
	UWAT	Human uptake of drinking water (L/yr).
	UFISH	Human uptake of fish (kg/yr).
	USOIL	Human uptake of soil (kg/yr).
CARD 29 Human Respiration & Atmospheric (4F10.0,2I5)		
	UAIR	Inhalation rate (m^3/yr).
	HLID	Height of atmospheric inversion layer or lid height (m).
	ROUGH	Hosker's ground surface roughness factor (m).
	CHIQ	Atmospheric dispersion parameter (s/m^3). Equal to downwind atmospheric concentration (Bq/m^3) divided by the source strength (Bq/s).
	IT	Type of atmospheric stability formulation. Suggested formulation is Pasquill-Gifford (IT=1).
	IS	Atmospheric stability class indicator for most common atmospheric conditions at site. 1=Class A, 2=Class B, . . ., 6=Class F.
CARD 30[a] Nuclide Specific Data (A8, 2X, 4F10.0)		
	NUCLID(I)	Radionuclide name. Must be all upper-case, left-justified, have no embedded blanks, and have a hyphen separating the alphameric for the element and the numeric for the isotope. The names used must agree with the conventions used in dose and risk data below.
	CIAW1(I)	Amount of the radionuclide in the absorbing waste of the first layer (Bq). If IAPP > 0, assumed to be applied annually for IAPP years. If IAPP > 0, subsequent data on this card are not read.
	CIAW2(I)	Amount of the radionuclide in the absorbing waste of the second layer (Bq).
	CISW1(I)	Amount of the radionuclide in the solidified waste of the first layer (Bq).
	CISW2(I)	Amount of the radionuclide in the solidified waste of the second layer (Bq).
	CIAM1(I)	Amount of the radionuclide in the activated metals of the first layer (Bq).
	CIAM2(I)	Amount of the radionuclide in the activated metals of the second layer (Bq).

a: This card is repeated for each radionuclide.

TABLE J-1
(Continued)

Card	Variable (Input Format)	Description
CARD 31[a] Nuclide Specific Data (8A1, 2X, 4F10.0)		
	NUCL(I,K), K=1,8	Radionuclide name (same as on Card 31).
	DECAY(I)	Radiological decay constant (yr^{-1}). Equal to 0.6931 divided by the radiological half-life in years.
	SOL(I)	Solubility of the radionuclide (mg/l). Used with leaching option 2.
	RA(I)	Radionuclide retention fraction for air.
	RW(I)	Radionuclide retention fraction for irrigation.
CARD 32[a] Nuclide Transport Parameters (A8, 2X, 4F10.0)		
	NUCLID(I)	Radionuclide name (same as on Card 31).
	XKD(1,I)	Surface soil K_d of radionuclide I (ml/g).
	XKD(2,I)	Waste K_d of radionuclide I (ml/g).
	XKD(3,I)	Vertical zone K_d of radionuclide I (ml/g).
	XKD(4,I)	Aquifer K_d of radionuclide I (ml/g).
CARD 33[a] Agricultural Data for Nuclides (A8, 2X, 6F10.0)		
	NUCLID(I)	Radionuclide name (same as Card 31).
	BV(I)	Radionuclide soil-to-plant uptake factor for leafy vegetables.
	BR(I)	Radionuclide soil-to-plant uptake factor for produce or grain.
	FMC(I)	Radionuclide forage-to-milk transfer factor for cows (d/L).
	FMG(I)	Radionuclide forage-to-milk transfer factor for goats (d/L).
	FF(I)	Radionuclide forage-to-beef transfer factor (d/kg).
	FFIS(I)	Radionuclide water-to-fish transfer factor (d/L).
CARD 34 Gonad DCF[(a)] (A8, 3X, 3(1PE11.4.2X)		
	NUCLID(I)	The name of the radionuclide.
	DCFCTR (I,1,1)	Dose conversion factor for the ingestion exposure pathway (Sv/Bq).
	DCFCTR (I,1,2)	Dose conversion factor for the inhalation exposure pathway (Sv/Bq).
	DCFCTR (I,1,3)	Dose conversion factor for the air immersion exposure pathway ($Sv{\cdot}m^3/Bq{\cdot}s$).

a: This card is repeated for each radionuclide.

TABLE J-1
(Continued)

Card	Variable (Input Format)	Description
CARD 35	Breast DCF[a] (A8, 3X, 3(1PE11.4.2X)	
	NUCLID(I)	The name of the radionuclide.
	DCFCTR (I,2,1)	Dose conversion factor for the ingestion exposure pathway (Sv/Bq).
	DCFCTR (I,2,2)	Dose conversion factor for the inhalation exposure pathway (Sv/Bq).
	DCFCTR (I,2,3)	Dose conversion factor for the air immersion exposure pathway (Sv·m^3/Bq·s).
CARD 36	Lung DCF (A8, 3X, 3(1PE11.4.2X)	
	NUCLID (I)	The name of the radionuclide.
	DCFCTR (I,3,1)	Dose conversion factor for the ingestion exposure pathway (Sv/Bq).
	DCFCTR (I,3,2)	Dose conversion factor for the inhalation exposure pathway (Sv/Bq).
	DCFCTR (I,3,3)	Dose conversion factor for the air immersion exposure pathway (Sv·m^3/Bq·s).
CARD 37	Red Marrow DCF (A8, 3X, 3(1PE11.4.2X)	
	NUCLID (I)	The name of the radionuclide.
	DCFCTR (I,4,1)	Dose conversion factor for the ingestion exposure pathway (Sv/Bq).
	DCFCTR (I,4,2)	Dose conversion factor for the inhalation exposure pathway (Sv/Bq).
	DCFCTR (I,4,3)	Dose conversion factor for the air immersion exposure pathway (Sv·m^3/Bq·s).
CARD 38	Bone surface DCF (A8, 3X, 3(1PE11.4.2X)	
	NUCLID (I)	The name of the radionuclide.
	DCFCTR (I,5,1)	Dose conversion factor for the ingestion exposure pathway (Sv/Bq).
	DCFCTR (I,5,2)	Dose conversion factor for the inhalation exposure pathway (Sv/Bq).
	DCFCTR (I,5,3)	Dose conversion factor for the air immersion exposure pathway (Sv·m^3/Bq·s).
CARD 39	Thyroid DCF (A8, 3X, 3(1PE11.4.2X)	
	NUCLID (I)	The name of the radionuclide.

a: This card is repeated for each radionuclide.

TABLE J-1
(Continued)

Card	Variable (Input Format)	Description
	DCFCTR (I,6,1)	Dose conversion factor for the ingestion exposure pathway (Sv/Bq).
	DCFCTR (I,6,2)	Dose conversion factor for the inhalation exposure pathway (Sv/Bq).
	DCFCTR (I,6,3)	Dose conversion factor for the air immersion exposure pathway ($Sv{\cdot}m^3/Bq{\cdot}s$).

CARD 40 Remainder DCF (A8, 3X, 3(1PE11.4.2X)

	NUCLID (I)	The name of the radionuclide.
	DCFCTR (I,7,1)	Dose conversion factor for the ingestion exposure pathway (Sv/Bq).
	DCFCTR (I,7,2)	Dose conversion factor for the inhalation exposure pathway (Sv/Bq).
	DCFCTR (I,7,3)	Dose conversion factor for the air immersion exposure pathway ($Sv{\cdot}m^3/Bq{\cdot}s$).

CARD 41 Effective DCF (A8, 3X, 3(1PE11.4.2X)

	NUCLID (I)	The name of the radionuclide.
	DCFCTR (I,8,1)	Dose conversion factor for the ingestion exposure pathway (Sv/Bq).
	DCFCTR (I,8,2)	Dose conversion factor for the inhalation exposure pathway (Sv/Bq).
	DCFCTR (I,8,3)	Dose conversion factor for the air immersion exposure pathway ($Sv{\cdot}m^3/Bq{\cdot}s$).

CARD 42 External DCF (A8, 3X, 3(1PE11.4.2X)

	NUCLID (I)	The name of the radionuclide.
	DCF15 (I)	Dose conversion factor for the external exposure pathway contaminated to the depth of 15 cm ($Sv{\cdot}m^3/Bq{\cdot}s$).
	DCFINF (I)	Dose conversion factor for the external exposure pathway contaminated to infinite thickness ($Sv{\cdot}m^3/Bq{\cdot}s$).

CARD 43 Mortality Risk Conversion Factor (A8, 3X, 4(1PE11.4.2X)

	NUCLID (I)	The name of the radionuclide.
	XMRCF (I,1)	Mortality risk conversion factor for the ingestion exposure pathway (1/Bq).
	XMRCF (I,2)	Mortality risk conversion factor for the inhalation exposure pathway (1/Bq).
	XMRCF (I,3)	Mortality risk conversion factor for the air-immersion exposure pathway ($1{\cdot}m^3/Bq{\cdot}s$).

TABLE J-1
(Continued)

Card	Variable (Input Format)	Description
	XMRCF (I,4)	Mortality risk conversion factor for the ground-surface exposure pathway (1·kg/Bq·s).

CARD 44 Incidence Risk Conversion Factor (A8, 3X, 4(1PE11.4.2X)

NUCLID (I)	The name of the radionuclide.
XIRCF (I,1)	Incidence risk conversion factor for the ingestion exposure pathway (1/Bq).
XIRCF (I,2)	Incidence risk conversion factor for the inhalation exposure pathway (1/Bq).
XIRCF (I,3)	Incidence risk conversion factor for the air-immersion exposure pathway (1·m^3/Bq·s).
XIRCF (I,4)	Incidence risk conversion factor for the ground-surface exposure pathway (1·kg/Bq·s).

APPENDIX J-2

REFERENCE INPUT FILE FORMAT FOR PRESTO-POP

TABLE J-2

REFERENCE INPUT FILE FORMAT FOR PRESTO-POP
(Note: Direct editing of this reference input file is highly discouraged.)

Card	Variable (Input Format)	Description
CARD 1	Run Identification (A80)	
	TITLE	Identifies the run. Up to 80 characters are allowed.
CARD 2	Time, Nuclides, and Farming Control Parameters (19I5)	
	MAXYR	Number of years for which the simulation will run (1 to 10,000 yr).
	NONCLD	Number of radionuclides used in the simulation. Must be 40 or less.
	LEAOPT	Absorbing waste leaching option. Radionuclides will be removed from the absorbing waste contaminant in different manners depending on the value of LEAOPT. Must be one of the following calculation methods:

Option	Leach Calculation Method
1	Chemical exchange
2	Chemical exchange with solubility control
3	Constant release fraction

Note: The leaching of radionuclides from solidified waste and activated metals is calculated by using the release fractions RELFCS and RELFCM assigned in Card No. 13.

Card	Variable (Input Format)	Description
	NYR1, NYR2	Beginning and ending years of cap failure. Both values must be less than or equal to MAXYR. NYR2 must be greater than or equal to NYR1.
	IPRT1, IPRT2, IDELT	An annual summary table will be produced for each year that is a multiple of IDELT and falls between the range of IPRT1 and IPRT2.
	IRST	Number of years of restricted land use after site closure.
	ITMN	Number of years of active leachate collection after site closure. No groundwater nuclide migration is initiated during the leachate collection period, although radioactive decay takes place.
	IAPP	If IAPP > 0 then the inventory is applied annually for IAPP years (Refer to the Source - Inventory screen).
	INF	Flag for indicating which temperature and rainfall (INFIL) file will be used in calculating infiltration parameters.

1	Humid South (INFIL.HS)
2	Humid North (INFIL.HN)
3	Arid South (INFIL.AS)
4	Arid North (INFIL.AN)
5	User Defined (INFIL.INP)

TABLE J-2
(Continued)

Card	Variable (Input Format)	Description
CARD 3	Control Parameters	
	IAQSTF	Control parameter for aquifer to stream flow. Selecting "Yes" defaults to calculations under the assumption that the flow takes place.
	ICFT	Number of years before waste containers begin failing.
	IDFT	Number of years after site closure that containers fail completely.
CARD 4	Water Infiltration and Use (8F10.0)	
	PCT1, PCT2	Fraction of the cover assumed to fail between the years NYR1 and NYR2.
	WWATL	Fraction of irrigation water supplied by contaminated water from well (1.0 if all water comes from well; 0.0 if none).
	WWATA	Fraction of animal drinking water supplied by contaminated water from well (1.0 if all water comes from well; 0.0 if none).
	WWATH	Fraction of human drinking water supplied by contaminated water from well (1.0 if all water comes from well; 0.0 if none).
	SWATL	Fraction of irrigation water supplied by contaminated water from stream (1.0 if all water comes from stream; 0.0 if none).
	SWATA	Fraction of animal drinking water supplied by contaminated water from stream (1.0 if all water comes from stream; 0.0 if none).
	SWATH	Fraction of human drinking water supplied by contaminated water from stream (1.0 if all water comes from stream; 0.0 if none).
CARDS 5-11	Comments and References (20A4)	
		These records are available for comments and references pertaining to data set. Up to 80 characters allowed in each of seven records.
CARD 12	Site Characteristics (7F10.0)	
	XLENGTH	Length of contaminated site parallel to groundwater flow (m). Must be nonzero.
	WIDTH	Width of site perpendicular to groundwater flow (m).
	WDEPTH	Thickness of bottom contaminated layer (m).
	OVER	Thickness of top contaminated layer (m).
	PORT	Porosity of contaminated soil. Must be nonzero.
	DENCON	Mean density of the contaminated soil (g/cm^3).
	SFRAC	Fraction of precipitation that infiltrates through the surface soil outside of contaminated site where radionuclide transport analysis is required, such as irrigation area and overland flow area (unitless).

TABLE J-2
(Continued)

Card	Variable (Input Format)	Description
CARD 13 Groundwater Saturation (7F10.0)		
	SSAT	Fraction of water saturation in the ground formation beneath the buried waste. If SSAT is 0 or is left blank, the fraction of saturation is calculated internally by the code.
	RESAT	Fraction of residual saturation.
	PERMT	Hydraulic conductivity of contaminated soil (m/yr).
	SLOP	Average slope of cover (m/m).
	RELFCA	Release fraction for the absorbing waste.
	RELFCS	Release fraction for the solidified waste.
	RELFCM	Release fraction for the activated metals.
CARD 14 Cover Infiltration Characteristics (8F10.0)		
	XKI	The permeability of the top layer soil (m/hr).
	XL	Average length of the site slop (m).
	EPSG	The component of porosity for gravity water in cover (unitless).
	EPSP	The component of porosity for pellicular water in cover (unitless).
	XDE	The equivalent upward diffusivity (m/hr).
	XKE	The equivalent upward hydraulic conductivity (m/hr).
	YPI	The initial pellicular water deficit of cover (m).
	YGI	The initial gravity water deficit of the cover (m).
CARD 15 Transport Parameters (7F10.0)		
	DTRAQ	Distance from the bottom of the bottom layer of contamination to the nominal depth of the aquifer (m).
	GWV	Velocity of the groundwater in the aquifer. Must be nonzero (m/yr).
	WELLD	Vertical penetration of well casing in aquifer (m). Used with AQDISP to calculate aquifer dilution volume.
	AQDISP	Dispersion angle of the pollutant plume in the aquifer (must be in radians). Used with WELLD to calculate aquifer dilution volume.
	PORA	Porosity of aquifer.
	PORV	Porosity below contaminated zone.
	PERMV	Hydraulic conductivity below contaminated zone.
CARD 16 Transport Properties (4F10.0)		
	BDENV	Density of material below contaminated zone (g/cm^3).

TABLE J-2
(Continued)

Card	Variable (Input Format)	Description
	FABS	Fraction of absorbing waste that is containerized.
	DWS	Distance between the well and stream for basin effects calculations (m).
	DWELL2	Distance from the site to the local population. Must be nonzero (m).
CARD 17	Atmospheric Parameters (8F10.0)	
	VG	Settling velocity of suspended dust particles due to gravity (m/s).
	U	Annual average wind speed (m/s).
	VD	Deposition velocity (m/s). Nominal generic value is 0.01 m/s.
	FTWIND	Fraction of time the wind blows in the direction from source to receptor.
	RE1, RE2, RE3	Factors (including algebraic signs) used in the resuspension rate equation.
	RR	Onsite dust loading in air (g/m^3).
CARD 18	Basement Parameters (6F10.0)	
	EMANATE	Rn-222 emanation fraction for contaminated soil (unitless).
	BDEPTH	Depth of basement below surface (m).
	CTHICK	Thickness of concrete floor in the basement (m).
	PORC	Porosity of concrete floor (unitless).
	BASEP	Length of basement perimeter (m).
	HPRESS	Negative indoor house pressure (Pa).
CARD 19	Basement Parameters (5F10.0)	
	CRACKW	Perimeter shrinkage crack width (m).
	VENT	Basement ventilation rate (air changes/s).
	BASEA	Area of basement floor (m).
	BSMTOC	Basement occupancy fraction (unitless).
	SITEOC	Outdoor onsite occupancy fraction (unitless).
CARD 20	Universal Soil Loss Equation Parameters (6F10.0)	
	RAINF	Precipitation factor (R/yr).
	ERODF	Soil erosion factor. Has units of tons/acre-R where R = RAINF.
	STPLNG	Slope steepness-length factor.
	COVER	Crop management factor.

TABLE J-2
(Continued)

Card	Variable (Input Format)	Description
	CONTRL	Erosion control practices factor.
	SEDELR	Sediment delivery ratio. This ratio is intended to apply to fouling of waterways from construction activity.
CARD 21 Soil and Surface Water (4F10.0)		
	PORS	Porosity of the top layer. Must be nonzero.
	BDENS	Bulk density of the top layer (g/cm^3). Must be nonzero.
	STFLOW	Annual flow rate of the nearest stream (m^3/yr). Must be nonzero.
	ADEPTH	Active depth of soil in the surface-contaminated region. Used for the calculation of radionuclide concentration in both surface soil and surface water. Must be nonzero.
CARD 22 Surface Water Runoff (4F10.0)		
	PPN	Total annual precipitation (m).
	SEEP	Fraction of the total annual precipitation (PPN) that infiltrates through the soil (unitless). If a value of 0.0 is input, this rate of infiltration will be calculated through INFIL subroutine.
	RUNOFF	Fraction of the annual precipitation that runs off from the top layer soil (unitless). If SEEP = 0.0, this value will be calculated by INFIL subroutine.
	RUNOF2	Fraction of the annual precipitation that runs off from the bottom soil layer when the top soil layer has been eroded away. If SEEP = 0.0, this value will be calculated by INFIL subroutine. This value must be less than or equal to RUNOFF.
CARD 23 Agricultural Data (7F10.0)		
	Y1, Y2	Agricultural productivity for pasture grass and other consumed vegetation, respectively (kg/m).
	XAMBWE	The weathering removal decay constant for atmospheric deposition onto food crops (hr^{-1}).
	TE1, TE2	Period of time that pasture grass or crops and leafy vegetables, respectively, are exposed to contaminated air during each growing season (hr).
	XRTM	Root depth for on-site farming scenario (m).
CARD 24 Agricultural Delay Times and Fractions (6F10.0)		
	TH1, TH2, TH3, TH4, TH5, TH6	Represent the delay time (hr) between harvest and consumption by animal or man of pasture grass (TH1), stored feed (TH2), leafy vegetables for the onsite population (TH3), produce for the onsite population (TH4), leafy vegetables for the local population (TH5), and produce for the local population (TH6).
	FP	Fraction of each year that animals graze on pasture grass.

TABLE J-2
(Continued)

Card	Variable (Input Format)	Description
	FS	Fraction of an animal's daily feed that is fresh grass for the period of time animals are in pasture.
CARD 25 Animal Feed Data 7F10.0)		
	QFC	Amount of feed consumed daily by cattle (kg).
	QFG	Amount of feed consumed daily by dairy goats (kg).
	TF1	Transport time (hr) from animal feed into milk and into human consumer for the onsite population.
	TF2	Transport time (hr) from animal feed into milk and into human consumer for the local population.
	TS	Length of time between slaughter of animals and human consumption of the meat (hr).
	ABSH	Absolute humidity of the atmosphere (g/m^3). Used for calculation of food chain specific activity for tritium in foods. Must be nonzero.
	P14	Carbon-14 fractional equilibrium value. Used for calculation of food chain specific activity for carbon-14 in foods.
CARD 26 Irrigation Water Data (5F10.0)		
	FI	Fraction of the year that crops are irrigated.
	WIRATE	Irrigation rate (L/^{m}-hr).
	QCW, QGW, QBW	Values for the amount of water (L/d) consumed by milk cows, milk goats, and beef cattle, respectively.
CARD 27 Human Food Uptake (8F10.0)		
	ULEAFY	Human uptake of leafy vegetables on a wet weight basis (kg/yr).
	UPROD	Human uptake of produce on a wet weight basis (kg/yr).
	UCMILK	Human uptake of cow milk (L/yr).
	UGMILK	Human uptake of goat milk (L/yr).
	UMEAT	Human uptake of meat (kg/yr).
	UWAT	Human uptake of drinking water (L/yr).
	UFISH	Human uptake of fish (kg/yr).
	USOIL	Human uptake of soil (kg/yr).
CARD 28 Human Respiration, Population, & Atmospheric (6F10.0, 2I5)		
	UAIR	Inhalation rate (m^3/yr).
	POP	Onsite population (number of people).
	POPL	Offsite local population (number of people).
	HLID	Height of atmospheric inversion layer or lid height (m).

TABLE J-2
(Continued)

Card	Variable (Input Format)	Description
	ROUGH	Hosker's ground surface roughness factor (m).
	CHIQ	User specified atmospheric dispersion parameter, which may be calculated by an external atmospheric dispersion code (s/m^3). A nonzero value will override the internal calculation in PRESTO.
	IT	Type of atmospheric stability formulation. Suggested formulation is Pasquill-Gifford (IT=1).
	IS	Atmospheric stability class indicator for most common atmospheric conditions at site. 1=Class A, 2=Class B, . . ., 6=Class F.
CARD 29[a] Nuclide Specific Data (A8, 2X, 4F10.0)		
	NUCLID(I)	Radionuclide name. Must be all upper-case, left-justified, have no embedded blanks, and have a hyphen separating the alphameric for the element and the numeric for the isotope. The names used must agree with the conventions used in dose and risk data below.
	CIAW1(I)	Amount of the radionuclide in the absorbing waste of the first layer (Bq). If IAPP > 0, assumed to be applied annually for IAPP years. If IAPP > 0, subsequent data on this card are not read.
	CIAW2(I)	Amount of the radionuclide in the absorbing waste of the second layer (Bq).
	CISW1(I)	Amount of the radionuclide in the solidified waste of the first layer (Bq).
	CISW2(I)	Amount of the radionuclide in the solidified waste of the second layer (Bq).
	CIAM1(I)	Amount of the radionuclide in the activated metals of the first layer (Bq).
	CIAM2(I)	Amount of the radionuclide in the activated metals of the second layer (Bq).
CARD 30[a] Nuclide Specific Data (8A1, 2X, 4F10.0)		
	NUCL(I,K), K=1,8	Radionuclide name (same as on Card 31).
	DECAY(I)	Radiological decay constant (yr^{-1}). Equal to 0.6931 divided by the radiological half-life in years.
	SOL(I)	Solubility of the radionuclide (mg/l). Used with leaching option 2.
	RA(I)	Radionuclide retention fraction for air.
	RW(I)	Radionuclide retention fraction for irrigation.
	CON(I)	Conversion factor for the regional basin population health effects calculation (Health-Effects / Bq Released).

a: This card is repeated for each nuclide.

TABLE J-2
(Continued)

Card	Variable (Input Format)	Description
CARD 31[a] Nuclide Transport Parameters (A8, 2X, 4F10.0)		
	NUCLID(I)	Radionuclide name (same as on Card 31).
	XKD(1,I)	Surface soil K_d of radionuclide I (ml/g).
	XKD(2,I)	Waste K_d of radionuclide I (ml/g).
	XKD(3,I)	Vertical zone K_d of radionuclide I (ml/g).
	XKD(4,I)	Aquifer K_d of radionuclide I (ml/g).
CARD 32[a] Agricultural Data for Nuclides (A8, 2X, 6F10.0)		
	NUCLID(I)	Radionuclide name (same as Card 31).
	BV(I)	Radionuclide soil-to-plant uptake factor for leafy vegetables.
	BR(I)	Radionuclide soil-to-plant uptake factor for produce or grain.
	FMC(I)	Radionuclide forage-to-milk transfer factor for cows (d/L).
	FMG(I)	Radionuclide forage-to-milk transfer factor for goats (d/L).
	FF(I)	Radionuclide forage-to-beef transfer factor (d/kg).
	FFIS(I)	Radionuclide water-to-fish transfer factor (d/L).
CARD 33 Mortality Risk Conversion Factor (A8, 3X, 4(1PE11.4.2X)		
	NUCLID (I)	The name of the radionuclide.
	HEFCTR (I,1,1)	Mortality risk conversion factor for the ingestion exposure pathway (1/Bq).
	HEFCTR (I,1,2)	Mortality risk conversion factor for the inhalation exposure pathway (1/Bq).
	HEFCTR (I,1,3)	Mortality risk conversion factor for the air-immersion exposure pathway ($1 \cdot m^3/Bq \cdot s$).
	HEFCTR (I,1,4)	Mortality risk conversion factor for the ground-surface exposure pathway (1·kg/Bq·s).
CARD 34 Incidence Risk Conversion Factor (A8, 3X, 4(1PE11.4.2X)		
	NUCLID (I)	The name of the radionuclide.
	HEFCTR (I,2,1)	Incidence risk conversion factor for the ingestion exposure pathway (1/Bq).
	HEFCTR (I,2,2)	Incidence risk conversion factor for the inhalation exposure pathway (1/Bq).
	HEFCTR (I,2,3)	Incidence risk conversion factor for the air-immersion exposure pathway ($1 \cdot m^3/Bq \cdot s$).
	HEFCTR (I,2,4)	Incidence risk conversion factor for the ground-surface exposure pathway (1·kg/Bq·s).

a: This card is repeated for each nuclide.

TABLE J-2
(Continued)

Card	Variable (Input Format)	Description
CARD 35 Genetic Effects Conversion Factor (A8, 3X, 4(1PE11.4.2X)		
	NUCLID (I)	The name of the radionuclide.
	HEFCTR (I,3,1)	Genetic effects conversion factor for the ingestion exposure pathway (1/Bq).
	HEFCTR (I,3,2)	Genetic effects conversion factor for the inhalation exposure pathway (1/Bq).
	HEFCTR (I,3,3)	Genetic effects conversion factor for the air-immersion exposure pathway (1·m^3/Bq·s).
	HEFCTR (I,3,4)	Genetic effects conversion factor for the ground-surface exposure pathway (1·kg/Bq·s).
CARD 36 External DCF (A8, 3X, 3(1PE11.4.2X)		
	NUCLID (I)	The name of the radionuclide.
	DCF15 (I)	Dose conversion factor for the external exposure pathway contaminated to the depth of 15 cm (Sv·m^3/Bq·s).
	DCFINF (I)	Dose conversion factor for the external exposure pathway contaminated to infinite thickness (Sv·m^3/Bq·s).

APPENDIX K

SAMPLE OUTPUT FILE

APPENDIX K

This appendix contains a sample output file obtained from the execution of an agricultural land application of TENORM (technologically enhanced naturally occurring radioactive materials). Although the program can handle a total of 40 radionuclides, only five radionuclides are selected to shorten the output file. Radium-226 is included as one of the source radionuclides because it is the only radionuclide in the decay series that would trigger the analysis of radon gas effects. In addition, a continuous application scenario is selected to demonstrate that the water pathway could dominate the total dose in a long-term analysis.

** PRESTO-EPA-CLNCPG 4.2 **

** INPUT DATA AS READ IN **

```
Mississippi state oil and gas scale post disposal application
1000 5    1    1    1000 0    1000 100  0    0    1000 0    1    1
0    0    0
0.0       0.0       1.0       1.0       1.0       0.0       0.0       0.0
C  Run 24
C Source concentration :  1pCi/g
C Farm size = 2 acres = 90 m x 90 m
C plawdepth = 0.20 m
C Run 1, outdoor occ fac. = 0.3;  basement occupancy fac. = 0.4
C Continuous application
C Scenario: Radium-226 with associated radionuclides
90.       90.       0.2       0.2       0.45      1.6       0.36
0.0       0.17      0.03      0.01      1.0E-1    1.0E-1    1.0E-1
0.0       0.0       0.0
0.03      20.0      0.05      0.38      8.0E-5    9.0E-5    0.1       0.3
1.6       17.9      6.1       0.3       0.39      0.45      260.
1.6       0.0       45.       45.
0.01      2.01      0.01      .4458     1.0E-6    -0.15     1.0E-11   5.00e-5
0.3       2.0       0.10      0.18      40.       2.4
0.001     2.78E-4   100.      0.4       0.3
50.0      0.13      0.27      0.30      0.1       1.0
0.45      1.6       3.57E+5   0.15
1.40      0.00      0.00      0.00
0.67      0.65      0.0021    1401.6    1401.6    1.0
0.0       2160.0    24.0      1440.0    1.0       0.83
50.0      6.0       48.0      480.0     9.9       1.0
0.10      0.015     60.0      8.0       50.0
```

```
14.0    102.4   77.0    0.0     77.0    730.0   6.9     0.0365
7300.0  2.0     0.01    5.186e-8 1  4
RA-226  0.958E+08
PB-210  0.958E+08
PO-210  0.958E+08
RA-228  0.958E+08
TH-228  0.958E+08
RA-226  4.33E-4  .0     0.2     0.25
RA-226  70      70      70      70
RA-226  1.5E-2  1.5E-3  4.5E-4  5.0E-6  2.5E-4  5.0E+01
PB-210  3.11E-2  .0     0.2     0.25
PB-210  70      70      70      70
PB-210  1.5E-2  1.5E-3  4.5E-4  5.0E-6  2.5E-4  1.0E+02
PO-210  1.83E+0  .0     0.2     0.25
PO-210  70      70      70      70
PO-210  1.5E-2  1.5E-3  4.5E-4  5.0E-6  2.5E-4  5.0E+02
RA-228  1.21E-1  .0     0.2     0.25
RA-228  70      70      70      70
RA-228  1.5E-2  1.5E-3  4.5E-4  5.0E-6  2.5E-4  5.0E+01
TH-228  3.62E-01 .0     .20     .25
TH-228  70      70      70      70
TH-228  8.5E-03  4.0E-03  6.0E-04  5.0E-04  2.0E-04  3.0E+01
RA-226   9.1600E-08  1.0200E-07  3.0800E-16
RA-226   9.1700E-08  1.0200E-07  3.5400E-16
RA-226   9.1600E-08  1.6100E-05  2.9500E-16
RA-226   5.9800E-07  6.6400E-07  2.7000E-16
RA-226   6.8300E-06  7.5900E-06  7.9500E-16
RA-226   9.1500E-08  1.0200E-07  3.0900E-16
RA-226   1.0300E-07  1.0700E-07  2.7900E-16
RA-226   3.5800E-07  2.3200E-06  3.1500E-16
RA-226   5.05E-17    5.99E-17
PB-210   1.2500E-07  3.1800E-07  6.1900E-17
PB-210   1.2500E-07  3.1800E-07  8.1800E-17
PB-210   1.2500E-07  3.1800E-07  4.2500E-17
PB-210   1.4800E-06  3.7500E-06  3.1400E-17
PB-210   2.1600E-05  5.4700E-05  1.9500E-16
```

PB-210	1.2500E-07	3.1800E-07	5.4200E-17	
PB-210	1.8500E-06	4.6900E-06	4.0900E-17	
PB-210	1.4500E-06	3.6700E-06	5.6400E-17	
PB-210	1.31E-20	1.31E-20		
PO-210	8.2300E-08	4.0400E-07	4.0800E-19	
PO-210	8.2300E-08	4.0400E-07	4.6300E-19	
PO-210	8.2300E-08	7.2900E-07	4.0600E-19	
PO-210	8.2300E-08	4.0400E-07	3.9700E-19	
PO-210	8.2300E-08	4.0400E-07	6.3900E-19	
PO-210	8.2300E-08	4.0400E-07	4.1800E-19	
PO-210	1.5200E-06	7.4000E-06	3.8900E-19	
PO-210	5.1400E-07	2.5400E-06	4.1600E-19	
PO-210	2.45E-22	2.80E-22		
RA-228	1.5800E-07	1.8300E-07	0.0000E+00	
RA-228	1.5700E-07	1.8400E-07	0.0000E+00	
RA-228	1.5700E-07	7.2200E-06	0.0000E+00	
RA-228	6.5300E-07	7.3800E-07	0.0000E+00	
RA-228	5.8200E-06	6.5100E-06	0.0000E+00	
RA-228	1.5700E-07	1.8300E-07	0.0000E+00	
RA-228	1.6300E-07	1.8700E-07	0.0000E+00	
RA-228	3.8800E-07	1.2900E-06	0.0000E+00	
RA-228	2.76E-17	3.20E-17		
TH-228	2.5300E-09	2.2600E-07	9.1200E-17	
TH-228	2.3300E-09	2.3200E-07	1.0900E-16	
TH-228	2.3100E-09	6.9100E-04	8.3300E-17	
TH-228	1.9300E-07	1.8700E-05	7.3200E-17	
TH-228	2.3700E-06	2.2900E-04	2.6400E-16	
TH-228	2.3000E-09	2.3000E-07	8.8800E-17	
TH-228	3.8600E-08	6.0500E-07	7.8400E-17	
TH-228	1.0700E-07	9.2300E-05	9.2000E-17	
TH-228	4.38E-17	5.42e-17		
RA-226	5.3200E-09	7.2300E-07	1.5100E-17	1.3300E-17
RA-226	7.7500E-09	7.6100E-07	2.2300E-17	1.9600E-19
PB-210	1.7500E-08	4.0600E-07	2.1100E-18	8.0600E-19
PB-210	2.3800E-08	4.2800E-07	3.2200E-18	1.2100E-18
PO-210	3.5300E-08	3.7100E-07	2.1300E-20	2.3000E-20

PO-210	4.7900E-08	3.9100E-07	3.1300E-20	3.3800E-20
RA-228	2.0000E-08	1.1200E-06	0.0000E+00	0.0000E+00
RA-228	2.8100E-08	1.1800E-06	0.0000E+00	0.0000E+00
TH-228	1.8200E-09	3.4000E-06	4.2400E-18	3.2500E-18
TH-228	2.9000E-09	3.5800E-06	6.2900E-18	4.7900E-18

PRESTO-EPA-CLNCPG 4.2 - A MODEL FOR PREDICTING THE MAXIMUM INDIVIDUAL DOSE RESULTING FROM
RADIONUCLIDE-CONTAMINATED SOIL SITES

Mississippi state oil and gas scale post disposal application

*** CONTROL INFORMATION ***
THE SITE IS LOCATED IN THE HUMID SOUTH
THE SIMULATION WILL RUN FOR 1000 YEARS AND WILL INCLUDE 5 NUCLIDES
LEACHING OPTION NUMBER 1 WILL BE USED
IN YEAR 1, 0.% OF THE CAP WILL BE ASSUMED TO FAIL
THIS WILL CONTINUE UNTIL 0.% HAS FAILED IN YEAR 1000
CAP MAY ALSO FAIL BY SURFACE EROSION
HYDRAULIC CONDUCTIVITY WILL BE USED TO CALCULATE VERTICAL WATER VELOCITY
ONSITE INDIVIDUAL EXPOSURE WILL BE USED TO CALCULATE DOSES
100.% OF IRRIGATION WATER WILL BE GOTTEN FROM WELL
100.% OF DRINKING WATER FOR ANIMALS WILL BE GOTTEN FROM WELL
100.% OF DRINKING WATER FOR HUMANS WILL BE GOTTEN FROM WELL
0.% OF IRRIGATION WATER WILL BE GOTTEN FROM STREAM
0.% OF DRINKING WATER FOR ANIMALS WILL BE GOTTEN FROM STREAM
0.% OF DRINKING WATER FOR HUMANS WILL BE GOTTEN FROM STREAM

*** SITE INFORMATION ***
ANNUAL INFILTRATION FRACTION FOR THE WATERSHED IS .3600

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*** AQUIFER INFORMATION ***
   GROUNDWATER VELOCITY IS                      17.900 M/YR
   WASTE-TO-AQUIFER DISTANCE IS                   1.6 M
   DISTANCE TO WELL FROM CENTER OF WASTE IS          45.00 M
   AQUIFER THICKNESS IS                      6.10 M
   AQUIFER DISPERSION ANGLE IS                  .3000 RADIANS
   POROSITY OF AQUIFER REGION IS                 .39000
   POROSITY BENEATH WASTE IS                   .45000
   PERMEABILITY BENEATH WASTE IS                 2.60E+02 M/YR


*** ATMOSPHERIC INFORMATION ***
   VELOCITY OF GRAVITATIONAL FALL IS    .010 METERS/SECOND
   WIND VELOCITY IS   2.010 M/S
   DEPOSITION VELOCITY IS    .01 M/S
   FRACTION OF TIME WIND BLOWS TOWARD INDIVIDUAL IS   .445800
   RESUSPENSION FACTOR PARAMETERS       .1000E-05     -.1500E+00      .1000E-10
   THE DUST LOADING FOR ONSITE RESIDENT DUE TO MECHANICAL DISTURBANCE WILL BE  5.0000E-05 G/M^3
   MECHANICAL DISTURBANCE OCCURS FROM YEAR


*** SURFACE INFORMATION ***
   PARAMETERS FOR UNIVERSAL SOIL LOSS EQUATION
       RAINFALL         50.00
       ERODIBILITY         .13
       STEEPNESS-SLOPE     .27
       TOP LAYER           .30
       EROSION CONTROL     .10
       DELIVERY RATIO     1.00
   SOIL POROSITY IS   .45000
   SOIL BULK DENSITY IS  1.60000 G/CC
   CAPPED RUNOFF FRACTION IS   .00000
   NATURAL SOIL AND NONCAPPED RUNOFF FRACTION IS   .00000
   THE ANNUAL PRECIPITATION IS   1.40000
   STREAM FLOW RATE IS            3.5700E+05 M^3/YR
   ACTIVE SOIL DEPTH IS                  .15 M
```

*** AIR-FOODCHAIN INFORMATION ***

AGRICULTURAL PRODUCTIVITY FOR GRASS .67 KG/M**2
AGRICULTURAL PRODUCTIVITY FOR VEGETATION .65 KG/M**2
WEATHER DECAY CONSTANT .0021 1/HOURS
PERIOD PASTURE GRASS EXPOSURE GROWING SEASON 1401.60 HOURS
PERIOD CROP/VEGETATION EXPOSURE GROWING SEASON 1401.60 HOURS
DEPTH TO MAXIMUM ROOT DENSITY 1.0000 M
PERIOD BETWEEN HARVEST PASTURE GRASS AND INGESTION BY ANIMAL .00 HR
PERIOD BETWEEN STORED FEED AND INGESTION BY ANIMAL 2160.00 HR
PERIOD BETWEEN LEAFY VEG. HARVEST AND INGESTION BY INDIVIDUAL 24.00 HR
PERIOD BETWEEN PRODUCE HARVEST AND INGESTION BY INDIVIDUAL 1440.00 HR
FRACTION OF YEAR ANIMALS GRAZE ON PASTURE 1.00
FRACTION OF DAILY FEED THAT IS FRESH GRASS .83
AMOUNT OF FEED CONSUMED BY CATTLE 50.00 KG
AMOUNT OF FEED CONSUMED BY GOATS 6.00 KG
TRANSPORT TIME FEED-MILL-RECEPTOR FOR ONSITE INDIVIDUAL 48.00 HR
TIME FROM SLAUGHTER OF MEAT TO CONSUMPTION 480.00 HR
ABSOLUTE HUMIDITY OF THE ATMOSPHERE 9.90 G/M**3
FRACTIONAL EQUILIBRIUM RATIO FOR C-14 1.00

*** WATER-FOODCHAIN INFORMATION ***

FRACTION OF YEAR CROPS ARE IRRIGATED .10
IRRIGATION RATE .015 L/M^2-H
AMOUNT OF WATER CONSUMED BY COWS 60.00 L/D
AMOUNT OF WATER CONSUMED BY GOATS 8.00 L/D
AMOUNT OF WATER CONSUMED BY BEEF CATTLE 50.00 L/D

*** HUMAN INGESTION AND INHALATION RATE INFORMATION ***

ANNUAL INTAKE OF LEAFY VEG 14.00 KG/YR
ANNUAL INTAKE OF PRODUCE 102.40 KG/YR
ANNUAL INTAKE OF COW'S MILK 77.00 L/YR
ANNUAL INTAKE OF GOAT'S MILK .00 L/YR
ANNUAL INTAKE OF MEAT 77.00 KG/YR

ANNUAL INTAKE OF DRINKING WATER 730.00 L/YR
ANNUAL INTAKE OF FISH 6.90 KG/YR
ANNUAL INTAKE OF SOIL .04 KG/YR
ANNUAL INHALATION RATE OF AIR 7300.00 M^3/YR

*** NUCLIDE INFORMATION ***

NUCLIDE	AMT IN WASTE	DECAY CONST	SOLUBILITY
	BQ	1/Y	MG/L
RA-226	9.5800E+07	4.3300E-04	0.0000E+00
PB-210	9.5800E+07	3.1100E-02	0.0000E+00
PO-210	9.5800E+07	1.8300E+00	0.0000E+00
RA-228	9.5800E+07	1.2100E-01	0.0000E+00
TH-228	9.5800E+07	3.6200E-01	0.0000E+00

ANNUAL AGRICULTURAL APPLICATION RATE (Bq/yr) FOR 1000 YEARS

NUCLIDE	SURFACE
RA-226	9.58E+07
PB-210	9.58E+07
PO-210	9.58E+07
RA-228	9.58E+07
TH-228	9.58E+07

DISTRIBUTION COEFFICIENTS ML/G

NUCLIDE	SURFACE	WASTE	VERTICAL	AQUIFER
RA-226	7.00E+01	7.00E+01	7.00E+01	7.00E+01
PB-210	7.00E+01	7.00E+01	7.00E+01	7.00E+01
PO-210	7.00E+01	7.00E+01	7.00E+01	7.00E+01
RA-228	7.00E+01	7.00E+01	7.00E+01	7.00E+01
TH-228	7.00E+01	7.00E+01	7.00E+01	7.00E+01

SOLIDIFIED WASTE RELEASE FRACTION : 1.00E-01
ACTIVATED METALS WASTE RELEASE FRACTION : 1.00E-01

NUCLIDE	RETENTION FROM AIR	RETENTION FROM WATER	TRANS COEFF SOIL-V CROP	TRANS COEFF SOIL-R CROP	TRANS COEFF VEG-COW MILK	TRANS COEFF VEG-GOAT MILK	TRANS COEFF VEG-MEAT	TRANS COEFF WATER-FISH
			D/L	D/L	D/KG	L/KG		
RA-226	2.00E-01	2.50E-01	1.50E-02	1.50E-03	4.50E-04	5.00E-06	2.50E-04	5.00E+01
PB-210	2.00E-01	2.50E-01	1.50E-02	1.50E-03	4.50E-04	5.00E-06	2.50E-04	1.00E+02
PO-210	2.00E-01	2.50E-01	1.50E-02	1.50E-03	4.50E-04	5.00E-06	2.50E-04	5.00E+02
RA-228	2.00E-01	2.50E-01	1.50E-02	1.50E-03	4.50E-04	5.00E-06	2.50E-04	5.00E+01
TH-228	2.00E-01	2.50E-01	8.50E-03	4.00E-03	6.00E-04	5.00E-04	2.00E-04	3.00E+01

INFILTRATION CALCULATIONS
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INFIL FILE: HUMID SOUTH

DAILY SUNSHINE BY MONTH (HOURS)

10.8 11.2 12.0 12.8 13.4 13.7 13.6 13.0 12.3 11.6 10.9 10.6

DAILY TEMPERATURES (DEGREES CELSIUS):

MONTH= DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	8.88	10.16	6.00	20.92	17.80	25.34	26.30	24.99	21.89	13.96	19.89	19.77
2	8.48	6.81	8.76	19.34	19.45	26.79	25.79	25.92	22.43	19.38	19.56	19.15
3	7.05	7.79	12.65	20.61	20.04	25.34	27.73	25.28	22.71	20.17	19.56	19.73
4	15.27	13.93	14.35	16.68	20.37	23.45	28.48	26.23	18.00	18.79	19.56	19.23
5	6.13	12.14	17.74	11.78	11.90	25.40	25.39	23.77	16.67	20.95	19.56	20.96
6	8.84	13.12	16.25	12.02	20.78	24.17	22.78	23.78	15.04	22.37	19.56	13.86
7	15.54	6.94	10.90	8.20	20.90	23.86	18.01	25.78	15.87	22.63	19.56	11.56
8	15.54	9.23	4.41	8.60	21.38	26.07	12.58	25.85	16.54	21.47	19.56	11.70
9	15.54	13.06	7.93	12.57	20.27	27.60	21.33	25.12	18.09	22.77	19.56	13.60

10	15.54	8.44	13.33	11.21	20.66	25.60	24.66	25.61	19.68	21.45	19.56	8.13
11	15.54	8.13	17.32	12.79	21.81	24.10	25.09	24.93	21.19	17.03	19.56	9.71
12	15.54	4.59	18.87	15.35	22.07	23.99	25.93	24.71	21.44	19.06	19.56	7.16
13	15.54	7.46	21.13	17.93	15.08	23.10	23.91	24.22	24.27	19.10	19.56	.08
14	15.54	8.97	19.19	20.56	25.52	23.70	24.89	25.27	24.12	15.71	19.56	4.30
15	15.54	14.71	19.25	20.36	25.06	26.20	24.26	24.69	25.82	12.18	19.56	13.68
16	15.54	19.33	12.33	20.93	24.61	26.46	24.17	25.35	25.74	12.97	19.56	13.17
17	15.54	16.27	17.60	21.36	23.36	21.95	24.74	24.29	25.48	10.93	19.56	4.78
18	8.78	8.03	17.04	16.86	22.95	22.49	25.83	22.87	24.45	12.78	19.56	1.99
19	12.54	10.02	20.02	14.26	21.02	25.70	25.59	24.17	23.35	17.31	19.56	2.85
20	16.73	11.90	23.06	19.05	22.92	26.07	26.55	25.24	21.76	18.55	15.42	6.18
21	15.27	14.61	23.56	20.29	23.55	26.62	27.56	26.62	21.76	18.82	17.86	5.16
22	6.46	8.04	17.91	16.27	24.74	24.69	27.67	25.99	21.76	13.71	16.34	4.64
23	8.41	10.49	15.05	11.65	23.82	24.88	24.88	27.02	21.76	10.64	16.61	8.33
24	5.96	16.75	13.29	13.41	23.58	23.50	25.21	27.62	21.76	8.38	16.83	14.85
25	7.04	12.71	16.55	16.35	24.17	24.63	26.21	25.31	21.76	9.97	9.64	17.31
26	2.14	1.94	13.24	20.59	24.16	24.98	28.02	18.80	21.76	13.11	12.35	15.14
27	-1.54	2.03	6.57	18.13	23.39	24.05	29.36	20.31	21.76	11.43	15.29	16.79
28	5.18	3.65	6.58	17.02	25.76	25.13	27.35	25.31	21.76	12.19	13.85	18.56
29	7.55	.00	11.19	15.51	27.44	25.97	24.49	20.37	21.76	12.27	19.11	13.72
30	11.00	.00	16.00	15.75	23.84	27.27	25.53	20.49	20.81	14.62	15.48	7.34
31	16.16	.00	16.25	.00	24.13	.00	24.50	20.24	.00	17.46	.00	5.07

MONTH,DAY,& RAINFALL AS READ IN (0.1MM/HR):

1	1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	3	0.	0.	0.	0.	23.	0.	23.	23.	70.	23.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	4	0.	0.	0.	0.	23.	47.	23.	23.	47.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	13	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	23.	0.	0.
1	14	23.	23.	23.	23.	0.	0.	23.	0.	0.	0.	47.	23.	23.	0.	0.	23.	0.	0.	0.	0.	0.	0.	0.	0.
1	19	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	23.	0.	23.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	20	0.	0.	0.	0.	0.	0.	0.	0.	0.	23.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1	23	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	23.	47.	47.	0.	0.	0.	0.	0.	0.
1	31	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	23.	23.	23.	0.	0.	0.	0.
2	1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

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2  2   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.
2  3   0.  0. 23.  0.  0.  0.  0. 47.  0.  0.  0. 47. 23. 23.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.
2  9   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.
2 12   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 93.  0. 47. 23.  0.  0.  0.
2 16   0.  0.  0.  0.  0.  0. 23.  0.  0.  0. 23.  0.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.
2 17   0. 23.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
2 26   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
2 27   0.  0. 23.  0.  0. 23.  0.  0.  0.  0.  0. 23.  0.  0.  0. 23.  0.  0.  0.  0. 23.  0.  0.  0.
3  1   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
3  7  23.  0.  0.  0.  0.  0.  0.  0. 47.  0. 23. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
3 17   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23. 23. 23.  0.  0.  0.  0.  0.  0.
3 24   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
4  1   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
4  3   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
4  5   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23. 23. 70. 23.  0.  0.  0.  0.  0.  0.  0.  0.
4  8   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23.  0. 23.  0. 23. 47.  0. 23.  0.  0.  0.  0.  0.
4 12   0.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
4 17   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 47.  0.  0.140.  0.  0.  0. 23.  0.  0.
4 20   0.  0.  0.  0.  0.  0. 23. 93. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
4 25   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23. 70. 93. 93. 23. 23.  0.  0.  0.  0.
4 26   0.  0.  0.  0. 23. 23. 47. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.350.  0.  0.  0.  0.  0.
4 27   0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.
5  1   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
5 17   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 70. 23.  0.  0. 23.  0. 23.  0.
5 19   0.  0.  0.  0.  0.  0.  0.  0.  0. 47. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
5 24   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 47.117. 23.  0.  0.  0.  0.  0.
5 27   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.326.186. 23.  0.  0.  0.  0.
5 30   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 47.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
6  1   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
6  3   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23. 23.  0.  0.  0.  0.  0.
6 12   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.163.  0.  0.  0.  0.
6 13   0.  0.  0.  0.  0. 23.  0.  0. 93. 47.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
6 16   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 93.  0.  0.  0.
6 17   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 47. 23.  0.  0.  0.  0.  0.  0.  0.  0.
6 22   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23. 47.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
6 26   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
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6 27 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 70. 0. 0. 0. 23. 0. 0. 0.
6 28 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 70. 0. 0. 0. 0. 0. 0. 0. 0. 0.
7 1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
7 4 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
7 5 0. 23. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
7 7 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 23. 0. 0. 0. 0. 0. 0. 0. 0.
7 9 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.117. 70. 23. 0. 0. 0. 0. 0. 0. 0. 0. 0.
7 13 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 23. 0. 0. 47.210. 0. 0. 0. 0. 0. 0. 0. 0. 0.
7 14 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 23. 23. 0. 0. 0. 0. 0.
7 15 0. 0. 0. 0. 0. 23. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 23. 0. 23. 0. 0. 0. 0. 0.
7 16 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 70. 23. 0. 0. 0. 0. 0. 0. 0.
7 19 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.280.163. 0. 0. 0. 0. 0. 0.
7 20 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.117. 0. 0. 0.
7 23 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.210. 23. 23. 0. 0.
7 24 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 23. 0. 0. 0. 0. 0. 0.
7 27 0. 0. 0. 0. 0. 0. 0. 0. 0. 23. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
7 29 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 23. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
8 1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
8 5 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.419. 93. 0. 0.
8 6 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
8 7 23. 0. 23. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
8 8 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 23. 0.
8 9 0. 0. 0. 23. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
8 12 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 23. 0. 0. 0. 0. 0. 0.
8 18 23. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 93. 47. 23. 0. 0. 0. 23. 0. 0.
9 1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
9 10 0. 0. 0. 0. 0. 0. 0. 0. 23. 23. 23. 0. 0. 0. 0. 0. 0. 0. 0. 0. 23. 0. 0. 0.
9 18 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.140.233. 0. 0. 0.
9 19 0. 0. 0. 0. 0. 0. 23. 0. 0. 0. 0. 0. 0. 0. 0. 0. 47. 0. 0. 0. 0. 0. 0. 0.
9 21 0. 0. 0. 0. 0. 0. 0. 0. 0. 47. 0. 23. 0. 23. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
9 26 0. 0. 0. 0. 0. 0. 0. 23. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
10 1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
10 9 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 23. 0.
10 10 23. 0. 0. 23. 23. 0. 23. 0. 0. 0. 0. 0. 23. 23. 23. 23. 23. 0. 0. 0. 0. 0. 0. 0.
10 24 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 23. 23. 23. 0. 0. 0.
10 25 0. 23. 0. 0. 0. 0. 0. 0. 0. 23. 0. 23. 70. 47. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.

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10 26   0.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
10 27   0.  0.  0.  0. 47.  0.  0. 47.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
11  1   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
11 16   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0. 47.  0.
11 20   0.  0.  0.  0.  0.  0. 23. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
11 24   0.  0.  0.  0.  0. 23.  0.  0. 23.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.
11 30   0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23. 23.  0. 23.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.
12  1   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23.  0. 23. 70. 93.  0.  0. 23.  0.
12  2   0.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
12  6   0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
12 14   0.  0.  0.  0.  0.  0.  0.  0. 23. 23. 47. 47. 23.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.
12 15   0.  0.  0.  0.  0. 23. 23. 23. 93.117. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
12 18   0. 23. 23. 47.  0. 23.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
12 24   0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0. 23.  0.
12 25   0.  0.  0. 23. 47. 23. 23. 23.  0. 23. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
12 27   0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 23.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
12 28   0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0. 47.163.  0.
12 29   0. 23. 47.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
12 31   0.  0.  0. 47. 23. 23. 47. 70. 47. 70. 47. 47. 70. 47. 47. 23.  0.  0.  0.  0.  0.  0.  0.  0.
```

TRENCH CHARACTERISTICS:

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    SNOWMELT COEFFICIENT =                          3.05 MM/DEG-DAY
    THICKNESS OF TOP LAYER =                        1.00 M
    AVERAGE XLENGTH OF SLOPE =                     10.00 M
    AVERAGE SLOPE OF TOP LAYER =                     .01 M/M
    PERMEABLITY OF TOP LAYER =                    .300E-01 M/HR
    POROSITY FOR PELLIC WATER =                      .38
    POROSITY FOR GRAVITY WATER =                     .05
    EQUIVALENT UPWARD DIFFUSIVITY =                .80E-04 M**2/HR
    EQUIVALENT UPWARD HYDRAULIC CONDUCTIVITY =     .90E-04 M/HR
    TIME STEP FOR MODEL =                           1.00 HR
```

************CUMULATIVE ANNUAL VALUES (M) FOR YEAR 1************

PRECIP	EVAP	RUNOFF	INFIL
1.40E+00	8.79E-01	2.68E-02	4.92E-01

PELLICULAR DEFICIT	GRAVITY DEFICIT	SNOW
6.53E-04	1.00E+00	0.00E+00

CHANGE OF TOTAL ANNUAL INFILTRATION= 4.92E-01

************CUMULATIVE ANNUAL VALUES (M) FOR YEAR 2************

PRECIP	EVAP	RUNOFF	INFIL
1.40E+00	8.79E-01	2.68E-02	4.94E-01

PELLICULAR DEFICIT	GRAVITY DEFICIT	SNOW
6.53E-04	1.00E+00	0.00E+00

CHANGE OF TOTAL ANNUAL INFILTRATION= 2.75E-03
DEGREE OF SATURATION = .343
RESIDUAL SATURATION = .170

INITIAL TRAVEL CALCULATIONS

NUCLIDE	VERTICAL RETARDATION	VERTICAL TIME Y	VERTICAL DDETA	HORIZONTAL RETARDATION	HORIZONTAL TIME Y	HORIZONTAL DDETA	DDETA	BREAK THRU TIME Y
RA-226	7.2597E+02	3.6306E+02	1.0014E+00	2.8818E+02	7.2447E+02	1.0000E+00	1.0014E+00	1.0875E+03
PB-210	7.2597E+02	3.6306E+02	3.4126E+01	2.8818E+02	7.2447E+02	1.2044E+00	4.1100E+01	1.0875E+03
PO-210	7.2597E+02	3.6306E+02	1.0000E+00	2.8818E+02	7.2447E+02	1.0000E+00	1.0000E+00	1.0875E+03
RA-228	7.2597E+02	3.6306E+02	1.0000E+00	2.8818E+02	7.2447E+02	1.0000E+00	1.0000E+00	1.0875E+03
TH-228	7.2597E+02	3.6306E+02	1.0000E+00	2.8818E+02	7.2447E+02	1.0000E+00	1.0000E+00	1.0875E+03

RADIONUCLIDE BREAKTHROUGH TIME IS ONLY SLIGHTLY GREATER THAN
SIMULATION TIME AND LEADING EDGE OF PULSE MAY BE MISSED

ANNUAL SOIL LOSS IS 1.1800E-02 KG/M^2, OR
SURFACE EROSION RATE IS 7.3749E-06 M/YR
ANNUAL INFILTRATION THROUGH WASTE IS .4943 M
VERTICAL WATER VELOCITY IS 3.1993 M/YR
AREA FACTOR (OUTDOOR EXPOSURE) IS .975

NUCLIDE DOSE CONVERSION FACTORS

NUCLIDE	INGESTION	INHALATION	AIR IMMERS.	GRND-15CM	GRND-INF
RA-226	3.5800E-07	2.3200E-06	3.1500E-16	5.0500E-17	5.9900E-17
PB-210	1.4500E-06	3.6700E-06	5.6400E-17	1.3100E-20	1.3100E-20
PO-210	5.1400E-07	2.5400E-06	4.1600E-19	2.4500E-22	2.8000E-22
RA-228	3.8800E-07	1.2900E-06	0.0000E+00	2.7600E-17	3.2000E-17
TH-228	1.0700E-07	9.2300E-05	9.2000E-17	4.3800E-17	5.4200E-17

NUCLIDE INCIDENT RISK CONVERSION FACTORS

NUCLIDE	INGESTION	INHALATION	AIR IMMERS.	SURFACE
RA-226	5.3200E-09	7.2300E-07	1.5100E-17	8.3125E-21
PB-210	1.7500E-08	4.0600E-07	2.1100E-18	5.0375E-22
PO-210	3.5300E-08	3.7100E-07	2.1300E-20	1.4375E-23
RA-228	2.0000E-08	1.1200E-06	0.0000E+00	0.0000E+00
TH-228	1.8200E-09	3.4000E-06	4.2400E-18	2.0312E-21

NUCLIDE MORTALITY RISK CONVERSION FACTORS

NUCLIDE	INGESTION	INHALATION	AIR IMMERS.	SURFACE
RA-226	7.7500E-09	7.6100E-07	2.2300E-17	1.2250E-22
PB-210	2.3800E-08	4.2800E-07	3.2200E-18	7.5625E-22

PO-210	4.7900E-08	3.9100E-07	3.1300E-20	2.1125E-23
RA-228	2.8100E-08	1.1800E-06	0.0000E+00	0.0000E+00
TH-228	2.9000E-09	3.5800E-06	6.2900E-18	2.9937E-21

DAUGHTER NUCLIDE EFFECT CORRECTION FACTORS
(AT YEAR 500)

NUCLIDE	INGESTION	INHALATION	AIR IMMERS.	SURFACE
RA-226	5.1075E+00	2.6042E+00	1.1818E+00	1.3902E+00
PB-210	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00
PO-210	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00
RA-228	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00
TH-228	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

DAUGHTER NUCLIDE EFFECT CORRECTION FACTORS
(AT YEAR 1000)

NUCLIDE	INGESTION	INHALATION	AIR IMMERS.	SURFACE
RA-226	5.1075E+00	2.6042E+00	1.1818E+00	1.3902E+00
PB-210	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00
PO-210	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00
RA-228	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00
TH-228	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

WATER OUTFLOW FROM THE WASTE IS APPROACHING DILUTION VOLUME IN AQUIFER FOR YEAR 1

****
* YEAR 1 ANNUAL SUMMARY *
****

ACTIVE LAYER DEPTH (m) = .15

TOP LAYER THICKNESS (m) = .00
BOTTOM LAYER THICKNESS (m) = .00

FAILURE IN TOP LAYER (%) = 100.00
MAXIMUM WATER DEPTH IN LAYERS (m) = .15
VOLUME OF RUNOFF TO STREAM (m^3) = 0.00E+00
VOLUME OF WATER INFILTRATING DOWN TO AQUIFER (m^3) = 4.08E+03
VOLUME OF WATER OVERFLOWING SITE (m^3) = 0.00E+00

NUCLIDE TRANSPORT INFORMATION

NUCLIDE	AMOUNT IN ACTIVE LYR BQ	AMOUNT IN LAYER 1 BQ	AMOUNT IN LAYER 2 BQ	SITE OVERFLOW BQ	SITE DRAINAGE BQ	AMOUNT AT WELL BQ	SITE RUNOFF BQ
RA-226	9.3005E+07	0.0000E+00	0.0000E+00	0.0000E+00	2.7903E+06	0.0000E+00	4.5729E+03
PB-210	9.3005E+07	0.0000E+00	0.0000E+00	0.0000E+00	2.7903E+06	0.0000E+00	4.5729E+03
PO-210	9.3005E+07	0.0000E+00	0.0000E+00	0.0000E+00	2.7903E+06	0.0000E+00	4.5729E+03
RA-228	9.3005E+07	0.0000E+00	0.0000E+00	0.0000E+00	2.7903E+06	0.0000E+00	4.5729E+03
TH-228	9.3005E+07	0.0000E+00	0.0000E+00	0.0000E+00	2.7903E+06	0.0000E+00	4.5729E+03

ENVIRONMENTAL CONCENTRATIONS

NUCLIDE	SURFACE SOIL CONC BQ/KG	PORE WATER CONC BQ/M**3	ATMOSPHERE ONSITE BQ/M**3	WELL WATER CONC BQ/M**3	STREAM WATER CONC BQ/M**3
RA-226	4.7842E+01	6.8349E+02	2.7159E-06	0.0000E+00	1.2656E-02
PB-210	4.7842E+01	6.8349E+02	2.7159E-06	0.0000E+00	1.2656E-02
PO-210	4.7842E+01	6.8349E+02	2.7159E-06	0.0000E+00	1.2656E-02
RA-228	4.7842E+01	6.8349E+02	2.7159E-06	0.0000E+00	1.2656E-02
TH-228	4.7842E+01	6.8349E+02	2.7159E-06	0.0000E+00	1.2656E-02
RN-222	0.0000E+00	0.0000E+00	1.6119E-01	0.0000E+00	0.0000E+00

RADON TRANSPORT RESULTS

OUTDOOR RADON SURFACE FLUX = 7.200E-03 Bq/m^2/s
INDOOR RN DIFFUSIVE FLUX = 0.000E+00 Bq/m^2/s
INDOOR RN ADVECTIVE FLOW = 6.821E-07 Bq/s
TOTAL INDOOR RN CONCENTRATION = 1.227E-05 Bq/m^3

ORGAN DOSE/EXPOSURE SUMMARY

*** MAXIMUM INDIVIDUAL ***

DOSE RATES: ORGANS:	GONADS	BREAST	LUNG	R MARR	B SURF	THYROID	REMAIND	EFFECT
DOSE EQUIVALENT (µSV/YR)	90.1	90.1	97.4	103.	270.	90.1	105.	102.

*** ANNUAL MORTALITY RISK IS 4.279E-07
*** ANNUAL INCIDENCE RISK IS 5.807E-07

****
* YEAR 100 ANNUAL SUMMARY *
****

ACTIVE LAYER DEPTH (m) = .15
TOP LAYER THICKNESS (m) = .00
BOTTOM LAYER THICKNESS (m) = .00

FAILURE IN TOP LAYER (%) = 100.00
MAXIMUM WATER DEPTH IN LAYERS (m) = .15
VOLUME OF RUNOFF TO STREAM (m^3) = 0.00E+00
VOLUME OF WATER INFILTRATING DOWN TO AQUIFER (m^3) = 4.08E+03
VOLUME OF WATER OVERFLOWING SITE (m^3) = 0.00E+00

NUCLIDE TRANSPORT INFORMATION

NUCLIDE	AMOUNT IN ACTIVE LYR BQ	AMOUNT IN LAYER 1 BQ	AMOUNT IN LAYER 2 BQ	SITE OVERFLOW BQ	SITE DRAINAGE BQ	AMOUNT AT WELL BQ	SITE RUNOFF BQ
RA-226	2.9868E+09	0.0000E+00	0.0000E+00	0.0000E+00	8.9610E+07	0.0000E+00	1.4686E+05
PB-210	1.5753E+09	0.0000E+00	0.0000E+00	0.0000E+00	4.7262E+07	0.0000E+00	7.7457E+04
PO-210	1.1016E+08	0.0000E+00	0.0000E+00	0.0000E+00	3.3050E+06	0.0000E+00	5.4165E+03
RA-228	6.6520E+08	0.0000E+00	0.0000E+00	0.0000E+00	1.9957E+07	0.0000E+00	3.2707E+04
TH-228	2.8703E+08	0.0000E+00	0.0000E+00	0.0000E+00	8.6112E+06	0.0000E+00	1.4113E+04

ENVIRONMENTAL CONCENTRATIONS

NUCLIDE	SURFACE SOIL CONC BQ/KG	PORE WATER CONC BQ/M**3	ATMOSPHERE ONSITE BQ/M**3	WELL WATER CONC BQ/M**3	STREAM WATER CONC BQ/M**3
RA-226	1.5364E+03	2.1950E+04	7.7648E-05	0.0000E+00	4.0643E-01
PB-210	8.1036E+02	1.1577E+04	4.0953E-05	0.0000E+00	2.1436E-01
PO-210	5.6667E+01	8.0957E+02	2.8638E-06	0.0000E+00	1.4990E-02
RA-228	3.4218E+02	4.8885E+03	1.7293E-05	0.0000E+00	9.0517E-02
TH-228	1.4765E+02	2.1093E+03	7.4617E-06	0.0000E+00	3.9057E-02
RN-222	0.0000E+00	0.0000E+00	5.1765E+00	0.0000E+00	0.0000E+00

RADON TRANSPORT RESULTS

OUTDOOR RADON SURFACE FLUX = 2.312E-01 Bq/m^2/s
INDOOR RN DIFFUSIVE FLUX = 0.000E+00 Bq/m^2/s
INDOOR RN ADVECTIVE FLOW = 2.190E-05 Bq/s
TOTAL INDOOR RN CONCENTRATION = 3.940E-04 Bq/m^3

ORGAN DOSE/EXPOSURE SUMMARY

*** MAXIMUM INDIVIDUAL ***

DOSE RATES:	ORGANS: GONADS	BREAST	LUNG	R MARR	B SURF	THYROID	REMAIND	EFFECT
DOSE EQUIVALENT (µSV/YR)	1.918E+03	1.918E+03	1.970E+03	2.417E+03	8.798E+03	1.918E+03	2.070E+03	2.236E+03

*** ANNUAL MORTALITY RISK IS 7.155E-06
*** ANNUAL INCIDENCE RISK IS 1.005E-05

****
* YEAR 200 ANNUAL SUMMARY *
****

ACTIVE LAYER DEPTH (m) = .15
TOP LAYER THICKNESS (m) = .00
BOTTOM LAYER THICKNESS (m) = .00

FAILURE IN TOP LAYER (%) = 100.00
MAXIMUM WATER DEPTH IN LAYERS (m) = .15
VOLUME OF RUNOFF TO STREAM (m^3) = 0.00E+00
VOLUME OF WATER INFILTRATING DOWN TO AQUIFER (m^3) = 4.08E+03
VOLUME OF WATER OVERFLOWING SITE (m^3) = 0.00E+00

NUCLIDE TRANSPORT INFORMATION

NUCLIDE	AMOUNT IN ACTIVE LYR BQ	AMOUNT IN LAYER 1 BQ	AMOUNT IN LAYER 2 BQ	SITE OVERFLOW BQ	SITE DRAINAGE BQ	AMOUNT AT WELL BQ	SITE RUNOFF
RA-226	3.1349E+09	0.0000E+00	0.0000E+00	0.0000E+00	9.4053E+07	0.0000E+00	1.5414E+05
PB-210	1.5790E+09	0.0000E+00	0.0000E+00	0.0000E+00	4.7371E+07	0.0000E+00	7.7636E+04
PO-210	1.1016E+08	0.0000E+00	0.0000E+00	0.0000E+00	3.3050E+06	0.0000E+00	5.4165E+03

RA-228	6.6520E+08	0.0000E+00	0.0000E+00	0.0000E+00	1.9957E+07	0.0000E+00	3.2707E+04
TH-228	2.8703E+08	0.0000E+00	0.0000E+00	0.0000E+00	8.6112E+06	0.0000E+00	1.4113E+04

ENVIRONMENTAL CONCENTRATIONS

NUCLIDE	SURFACE SOIL CONC BQ/KG	PORE WATER CONC BQ/M**3	ATMOSPHERE ONSITE BQ/M**3	WELL WATER CONC BQ/M**3	STREAM WATER CONC BQ/M**3
RA-226	1.6126E+03	2.3039E+04	8.1498E-05	0.0000E+00	4.2659E-01
PB-210	8.1223E+02	1.1604E+04	4.1048E-05	0.0000E+00	2.1486E-01
PO-210	5.6667E+01	8.0957E+02	2.8638E-06	0.0000E+00	1.4990E-02
RA-228	3.4218E+02	4.8885E+03	1.7293E-05	0.0000E+00	9.0517E-02
TH-228	1.4765E+02	2.1093E+03	7.4617E-06	0.0000E+00	3.9057E-02
RN-222	0.0000E+00	0.0000E+00	5.4331E+00	0.0000E+00	0.0000E+00

RADON TRANSPORT RESULTS

OUTDOOR RADON SURFACE FLUX = 2.427E-01 Bq/m^2/s
INDOOR RN DIFFUSIVE FLUX = 0.000E+00 Bq/m^2/s
INDOOR RN ADVECTIVE FLOW = 2.299E-05 Bq/s
TOTAL INDOOR RN CONCENTRATION = 4.135E-04 Bq/m^3

ORGAN DOSE/EXPOSURE SUMMARY

*** MAXIMUM INDIVIDUAL ***

DOSE RATES: ORGANS:	GONADS	BREAST	LUNG	R MARR	B SURF	THYROID	REMAIND	EFFECT
DOSE EQUIVALENT (μSV/YR)	2.024E+03	2.024E+03	2.079E+03	2.556E+03	9.346E+03	2.024E+03	2.178E+03	2.360E+03

*** ANNUAL MORTALITY RISK IS 7.560E-06
*** ANNUAL INCIDENCE RISK IS 1.062E-05

****
* YEAR 300 ANNUAL SUMMARY *
****

ACTIVE LAYER DEPTH (m) = .15
TOP LAYER THICKNESS (m) = .00
BOTTOM LAYER THICKNESS (m) = .00

FAILURE IN TOP LAYER (%) = 100.00
MAXIMUM WATER DEPTH IN LAYERS (m) = .15
VOLUME OF RUNOFF TO STREAM (m^3) = 0.00E+00
VOLUME OF WATER INFILTRATING DOWN TO AQUIFER (m^3) = 4.08E+03
VOLUME OF WATER OVERFLOWING SITE (m^3) = 0.00E+00

NUCLIDE TRANSPORT INFORMATION

NUCLIDE	AMOUNT IN ACTIVE LYR BQ	AMOUNT IN LAYER 1 BQ	AMOUNT IN LAYER 2 BQ	SITE OVERFLOW BQ	SITE DRAINAGE BQ	AMOUNT AT WELL BQ	SITE RUNOFF
RA-226	3.1423E+09	0.0000E+00	0.0000E+00	0.0000E+00	9.4273E+07	0.0000E+00	1.5450E+05
PB-210	1.5790E+09	0.0000E+00	0.0000E+00	0.0000E+00	4.7372E+07	0.0000E+00	7.7636E+04
PO-210	1.1016E+08	0.0000E+00	0.0000E+00	0.0000E+00	3.3050E+06	0.0000E+00	5.4165E+03
RA-228	6.6520E+08	0.0000E+00	0.0000E+00	0.0000E+00	1.9957E+07	0.0000E+00	3.2707E+04
TH-228	2.8703E+08	0.0000E+00	0.0000E+00	0.0000E+00	8.6112E+06	0.0000E+00	1.4113E+04

ENVIRONMENTAL CONCENTRATIONS

NUCLIDE	SURFACE SOIL CONC BQ/KG	PORE WATER CONC BQ/M**3	ATMOSPHERE ONSITE BQ/M**3	WELL WATER CONC BQ/M**3	STREAM WATER CONC BQ/M**3

```
RA-226   1.6164E+03  2.3093E+04  8.1689E-05  0.0000E+00  4.2759E-01
PB-210   8.1223E+02  1.1604E+04  4.1048E-05  0.0000E+00  2.1486E-01
PO-210   5.6667E+01  8.0957E+02  2.8638E-06  0.0000E+00  1.4990E-02
RA-228   3.4218E+02  4.8885E+03  1.7293E-05  0.0000E+00  9.0517E-02
TH-228   1.4765E+02  2.1093E+03  7.4617E-06  0.0000E+00  3.9057E-02
RN-222   0.0000E+00  0.0000E+00  5.4458E+00  0.0000E+00  0.0000E+00


                 RADON TRANSPORT RESULTS
                 -----------------------

  OUTDOOR RADON SURFACE FLUX    = 2.432E-01 Bq/m^2/s
  INDOOR RN DIFFUSIVE FLUX      = 0.000E+00 Bq/m^2/s
  INDOOR RN ADVECTIVE FLOW      = 2.304E-05 Bq/s
  TOTAL INDOOR RN CONCENTRATION = 4.145E-04 Bq/m^3


                 ORGAN DOSE/EXPOSURE SUMMARY
                 ---------------------------

*** MAXIMUM INDIVIDUAL ***
DOSE RATES:    ORGANS:  GONADS    BREAST    LUNG     R MARR    B SURF    THYROID   REMAIND   EFFECT
DOSE EQUIVALENT (╡SV/YR) 2.029E+03 2.029E+03 2.084E+03 2.563E+03 9.373E+03 2.029E+03 2.183E+03 2.366E+03

*** ANNUAL MORTALITY RISK IS  7.580E-06
*** ANNUAL INCIDENCE RISK IS  1.065E-05


                 *****************************
                 * YEAR   400 ANNUAL SUMMARY *
                 *****************************

               ACTIVE LAYER DEPTH (m) =        .15
              TOP LAYER THICKNESS (m) =        .00
           BOTTOM LAYER THICKNESS (m) =        .00
```

FAILURE IN TOP LAYER (%) = 100.00

MAXIMUM WATER DEPTH IN LAYERS (m) = .15

VOLUME OF RUNOFF TO STREAM (m^3) = 0.00E+00

VOLUME OF WATER INFILTRATING DOWN TO AQUIFER (m^3) = 4.08E+03

VOLUME OF WATER OVERFLOWING SITE (m^3) = 0.00E+00

NUCLIDE TRANSPORT INFORMATION

NUCLIDE	AMOUNT IN ACTIVE LYR BQ	AMOUNT IN LAYER 1 BQ	AMOUNT IN LAYER 2 BQ	SITE OVERFLOW BQ	SITE DRAINAGE BQ	AMOUNT AT WELL BQ	SITE RUNOFF BQ
RA-226	3.1428E+09	0.0000E+00	0.0000E+00	0.0000E+00	9.4289E+07	7.6020E+05	1.5453E+05
PB-210	1.5790E+09	0.0000E+00	0.0000E+00	0.0000E+00	4.7372E+07	2.2904E+02	7.7636E+04
PO-210	1.1016E+08	0.0000E+00	0.0000E+00	0.0000E+00	3.3050E+06	0.0000E+00	5.4165E+03
RA-228	6.6520E+08	0.0000E+00	0.0000E+00	0.0000E+00	1.9957E+07	7.1719E-15	3.2707E+04
TH-228	2.8703E+08	0.0000E+00	0.0000E+00	0.0000E+00	8.6112E+06	0.0000E+00	1.4113E+04

ENVIRONMENTAL CONCENTRATIONS

NUCLIDE	SURFACE SOIL CONC BQ/KG	PORE WATER CONC BQ/M**3	ATMOSPHERE ONSITE BQ/M**3	WELL WATER CONC BQ/M**3	STREAM WATER CONC BQ/M**3
RA-226	1.6167E+03	2.3097E+04	8.1703E-05	1.7528E+02	2.5315E+00
PB-210	8.1223E+02	1.1604E+04	4.1048E-05	5.2810E-02	2.1549E-01
PO-210	5.6667E+01	8.0957E+02	2.8638E-06	0.0000E+00	1.4990E-02
RA-228	3.4218E+02	4.8885E+03	1.7293E-05	1.6536E-18	9.0517E-02
TH-228	1.4765E+02	2.1093E+03	7.4617E-06	0.0000E+00	3.9057E-02
RN-222	0.0000E+00	0.0000E+00	5.4468E+00	0.0000E+00	0.0000E+00

RADON TRANSPORT RESULTS

```
   OUTDOOR RADON SURFACE FLUX    = 2.433E-01 Bq/m^2/s
   INDOOR RN DIFFUSIVE FLUX      = 0.000E+00 Bq/m^2/s
   INDOOR RN ADVECTIVE FLOW      = 2.305E-05 Bq/s
   TOTAL INDOOR RN CONCENTRATION = 4.145E-04 Bq/m^3


                        ORGAN DOSE/EXPOSURE SUMMARY
                        ---------------------------

*** MAXIMUM INDIVIDUAL ***
DOSE RATES:     ORGANS:  GONADS    BREAST    LUNG     R MARR    B SURF    THYROID   REMAIND   EFFECT
DOSE EQUIVALENT (µSV/YR) 2.096E+03 2.096E+03 2.151E+03 2.995E+03 1.430E+04 2.096E+03 2.258E+03 2.625E+03

*** ANNUAL MORTALITY RISK IS  1.142E-05
*** ANNUAL INCIDENCE RISK IS  1.625E-05


                        *****************************
                        * YEAR   500 ANNUAL SUMMARY *
                        *****************************

                      ACTIVE LAYER DEPTH (m) =        .15
                     TOP LAYER THICKNESS (m) =        .00
                  BOTTOM LAYER THICKNESS (m) =        .00

                     FAILURE IN TOP LAYER (%) =     100.00
             MAXIMUM WATER DEPTH IN LAYERS (m) =        .15
              VOLUME OF RUNOFF TO STREAM (m^3) =   0.00E+00
VOLUME OF WATER INFILTRATING DOWN TO AQUIFER  (m^3) =   4.08E+03
          VOLUME OF WATER OVERFLOWING SITE (m^3) =   0.00E+00


                        NUCLIDE TRANSPORT INFORMATION
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NUCLIDE	AMOUNT IN ACTIVE LYR BQ	AMOUNT IN LAYER 1 BQ	AMOUNT IN LAYER 2 BQ	SITE OVERFLOW BQ	SITE DRAINAGE BQ	AMOUNT AT WELL BQ	SITE RUNOFF BQ
RA-226	3.1460E+09	0.0000E+00	0.0000E+00	0.0000E+00	9.4379E+07	5.5205E+06	1.5468E+05
PB-210	1.5790E+09	0.0000E+00	0.0000E+00	0.0000E+00	4.7372E+07	5.0214E+02	7.7636E+04
PO-210	1.1016E+08	0.0000E+00	0.0000E+00	0.0000E+00	3.3050E+06	0.0000E+00	5.4165E+03
RA-228	6.6520E+08	0.0000E+00	0.0000E+00	0.0000E+00	1.9957E+07	7.5914E-15	3.2707E+04
TH-228	2.8703E+08	0.0000E+00	0.0000E+00	0.0000E+00	8.6112E+06	0.0000E+00	1.4113E+04

ENVIRONMENTAL CONCENTRATIONS

NUCLIDE	SURFACE SOIL CONC BQ/KG	PORE WATER CONC BQ/M**3	ATMOSPHERE ONSITE BQ/M**3	WELL WATER CONC BQ/M**3	STREAM WATER CONC BQ/M**3
RA-226	1.6183E+03	2.3119E+04	8.1780E-05	1.2729E+03	1.5706E+01
PB-210	8.1223E+02	1.1604E+04	4.1048E-05	1.1578E-01	2.1625E-01
PO-210	5.6667E+01	8.0957E+02	2.8638E-06	0.0000E+00	1.4990E-02
RA-228	3.4218E+02	4.8885E+03	1.7293E-05	1.7504E-18	9.0517E-02
TH-228	1.4765E+02	2.1093E+03	7.4617E-06	0.0000E+00	3.9057E-02
RN-222	0.0000E+00	0.0000E+00	5.4520E+00	0.0000E+00	0.0000E+00

RADON TRANSPORT RESULTS

OUTDOOR RADON SURFACE FLUX = 2.435E-01 Bq/m^2/s
INDOOR RN DIFFUSIVE FLUX = 0.000E+00 Bq/m^2/s
INDOOR RN ADVECTIVE FLOW = 2.307E-05 Bq/s
TOTAL INDOOR RN CONCENTRATION = 4.149E-04 Bq/m^3

ORGAN DOSE/EXPOSURE SUMMARY

*** MAXIMUM INDIVIDUAL ***

DOSE RATES: ORGANS:	GONADS	BREAST	LUNG	R MARR	B SURF	THYROID	REMAIND	EFFECT
DOSE EQUIVALENT (μSV/YR)	2.511E+03	2.512E+03	2.566E+03	5.700E+03	4.517E+04	2.511E+03	2.725E+03	4.245E+03

*** ANNUAL MORTALITY RISK IS 3.547E-05
*** ANNUAL INCIDENCE RISK IS 5.127E-05

****
* YEAR 600 ANNUAL SUMMARY *
****

ACTIVE LAYER DEPTH (m) = .15
TOP LAYER THICKNESS (m) = .00
BOTTOM LAYER THICKNESS (m) = .00

FAILURE IN TOP LAYER (%) = 100.00
MAXIMUM WATER DEPTH IN LAYERS (m) = .15
VOLUME OF RUNOFF TO STREAM (m^3) = 0.00E+00
VOLUME OF WATER INFILTRATING DOWN TO AQUIFER (m^3) = 4.08E+03
VOLUME OF WATER OVERFLOWING SITE (m^3) = 0.00E+00

NUCLIDE TRANSPORT INFORMATION

NUCLIDE	AMOUNT IN ACTIVE LYR BQ	AMOUNT IN LAYER 1 BQ	AMOUNT IN LAYER 2 BQ	SITE OVERFLOW BQ	SITE DRAINAGE BQ	AMOUNT AT WELL BQ	SITE RUNOFF BQ
RA-226	3.1501E+09	0.0000E+00	0.0000E+00	0.0000E+00	9.4500E+07	1.0605E+07	1.5487E+05
PB-210	1.5790E+09	0.0000E+00	0.0000E+00	0.0000E+00	4.7372E+07	5.1686E+02	7.7636E+04
PO-210	1.1016E+08	0.0000E+00	0.0000E+00	0.0000E+00	3.3050E+06	0.0000E+00	5.4165E+03
RA-228	6.6520E+08	0.0000E+00	0.0000E+00	0.0000E+00	1.9957E+07	7.5914E-15	3.2707E+04
TH-228	2.8703E+08	0.0000E+00	0.0000E+00	0.0000E+00	8.6112E+06	0.0000E+00	1.4113E+04

ENVIRONMENTAL CONCENTRATIONS

NUCLIDE	SURFACE SOIL CONC BQ/KG	PORE WATER CONC BQ/M**3	ATMOSPHERE ONSITE BQ/M**3	WELL WATER CONC BQ/M**3	STREAM WATER CONC BQ/M**3
RA-226	1.6204E+03	2.3148E+04	8.1885E-05	2.4453E+03	2.9779E+01
PB-210	8.1223E+02	1.1604E+04	4.1048E-05	1.1917E-01	2.1629E-01
PO-210	5.6667E+01	8.0957E+02	2.8638E-06	0.0000E+00	1.4990E-02
RA-228	3.4218E+02	4.8885E+03	1.7293E-05	1.7504E-18	9.0517E-02
TH-228	1.4765E+02	2.1093E+03	7.4617E-06	0.0000E+00	3.9057E-02
RN-222	0.0000E+00	0.0000E+00	5.4590E+00	0.0000E+00	0.0000E+00

RADON TRANSPORT RESULTS

OUTDOOR RADON SURFACE FLUX = 2.438E-01 Bq/m^2/s
INDOOR RN DIFFUSIVE FLUX = 0.000E+00 Bq/m^2/s
INDOOR RN ADVECTIVE FLOW = 2.310E-05 Bq/s
TOTAL INDOOR RN CONCENTRATION = 4.155E-04 Bq/m^3

ORGAN DOSE/EXPOSURE SUMMARY

*** MAXIMUM INDIVIDUAL ***

DOSE RATES: ORGANS:	GONADS	BREAST	LUNG	R MARR	B SURF	THYROID	REMAIND	EFFECT
DOSE EQUIVALENT (╡SV/YR)	2.956E+03	2.957E+03	3.011E+03	8.589E+03	7.815E+04	2.955E+03	3.225E+03	5.976E+03

*** ANNUAL MORTALITY RISK IS 6.115E-05
*** ANNUAL INCIDENCE RISK IS 8.869E-05

****

* YEAR 700 ANNUAL SUMMARY *
****

ACTIVE LAYER DEPTH (m) = .15
TOP LAYER THICKNESS (m) = .00
BOTTOM LAYER THICKNESS (m) = .00

FAILURE IN TOP LAYER (%) = 100.00
MAXIMUM WATER DEPTH IN LAYERS (m) = .15
VOLUME OF RUNOFF TO STREAM (m^3) = 0.00E+00
VOLUME OF WATER INFILTRATING DOWN TO AQUIFER (m^3) = 4.08E+03
VOLUME OF WATER OVERFLOWING SITE (m^3) = 0.00E+00

NUCLIDE TRANSPORT INFORMATION

NUCLIDE	AMOUNT IN ACTIVE LYR BQ	AMOUNT IN LAYER 1 BQ	AMOUNT IN LAYER 2 BQ	SITE OVERFLOW BQ	SITE DRAINAGE BQ	AMOUNT AT WELL BQ	SITE RUNOFF BQ
RA-226	3.1542E+09	0.0000E+00	0.0000E+00	0.0000E+00	9.4620E+07	1.5522E+07	1.5507E+05
PB-210	1.5790E+09	0.0000E+00	0.0000E+00	0.0000E+00	4.7372E+07	5.1753E+02	7.7636E+04
PO-210	1.1016E+08	0.0000E+00	0.0000E+00	0.0000E+00	3.3050E+06	0.0000E+00	5.4165E+03
RA-228	6.6520E+08	0.0000E+00	0.0000E+00	0.0000E+00	1.9957E+07	7.5914E-15	3.2707E+04
TH-228	2.8703E+08	0.0000E+00	0.0000E+00	0.0000E+00	8.6112E+06	0.0000E+00	1.4113E+04

ENVIRONMENTAL CONCENTRATIONS

NUCLIDE	SURFACE SOIL CONC BQ/KG	PORE WATER CONC BQ/M**3	ATMOSPHERE ONSITE BQ/M**3	WELL WATER CONC BQ/M**3	STREAM WATER CONC BQ/M**3
RA-226	1.6225E+03	2.3178E+04	8.1989E-05	3.5789E+03	4.3386E+01
PB-210	8.1223E+02	1.1604E+04	4.1048E-05	1.1933E-01	2.1629E-01
PO-210	5.6667E+01	8.0957E+02	2.8638E-06	0.0000E+00	1.4990E-02

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RA-228     3.4218E+02   4.8885E+03   1.7293E-05   1.7504E-18   9.0517E-02
TH-228     1.4765E+02   2.1093E+03   7.4617E-06   0.0000E+00   3.9057E-02
RN-222     0.0000E+00   0.0000E+00   5.4659E+00   0.0000E+00   0.0000E+00


                    RADON TRANSPORT RESULTS
                    -----------------------

   OUTDOOR RADON SURFACE FLUX    = 2.441E-01 Bq/m^2/s
   INDOOR RN DIFFUSIVE FLUX      = 0.000E+00 Bq/m^2/s
   INDOOR RN ADVECTIVE FLOW      = 2.313E-05 Bq/s
   TOTAL INDOOR RN CONCENTRATION = 4.160E-04 Bq/m^3


                    ORGAN DOSE/EXPOSURE SUMMARY
                    ---------------------------

*** MAXIMUM INDIVIDUAL ***
DOSE RATES:     ORGANS:  GONADS    BREAST    LUNG     R MARR    B SURF    THYROID   REMAIND   EFFECT
DOSE EQUIVALENT (µSV/YR) 3.386E+03 3.387E+03 3.441E+03 1.138E+04 1.100E+05 3.384E+03 3.708E+03 7.649E+03

*** ANNUAL MORTALITY RISK IS  8.598E-05
*** ANNUAL INCIDENCE RISK IS  1.249E-04



                    *****************************
                    * YEAR   800 ANNUAL SUMMARY *
                    *****************************

                  ACTIVE LAYER DEPTH (m) =        .15
                 TOP LAYER THICKNESS (m) =        .00
              BOTTOM LAYER THICKNESS (m) =        .00

                FAILURE IN TOP LAYER (%) =     100.00
       MAXIMUM WATER DEPTH IN LAYERS (m) =        .15
```

VOLUME OF RUNOFF TO STREAM (m^3) = 0.00E+00
VOLUME OF WATER INFILTRATING DOWN TO AQUIFER (m^3) = 4.08E+03
VOLUME OF WATER OVERFLOWING SITE (m^3) = 0.00E+00

NUCLIDE TRANSPORT INFORMATION

NUCLIDE	AMOUNT IN ACTIVE LYR BQ	AMOUNT IN LAYER 1 BQ	AMOUNT IN LAYER 2 BQ	SITE OVERFLOW BQ	SITE DRAINAGE BQ	AMOUNT AT WELL BQ	SITE RUNOFF
RA-226	3.1582E+09	0.0000E+00	0.0000E+00	0.0000E+00	9.4735E+07	2.0222E+07	1.5526E+05
PB-210	1.5790E+09	0.0000E+00	0.0000E+00	0.0000E+00	4.7372E+07	5.1756E+02	7.7636E+04
PO-210	1.1016E+08	0.0000E+00	0.0000E+00	0.0000E+00	3.3050E+06	0.0000E+00	5.4165E+03
RA-228	6.6520E+08	0.0000E+00	0.0000E+00	0.0000E+00	1.9957E+07	7.5914E-15	3.2707E+04
TH-228	2.8703E+08	0.0000E+00	0.0000E+00	0.0000E+00	8.6112E+06	0.0000E+00	1.4113E+04

ENVIRONMENTAL CONCENTRATIONS

NUCLIDE	SURFACE SOIL CONC BQ/KG	PORE WATER CONC BQ/M**3	ATMOSPHERE ONSITE BQ/M**3	WELL WATER CONC BQ/M**3	STREAM WATER CONC BQ/M**3
RA-226	1.6246E+03	2.3206E+04	8.2089E-05	4.6626E+03	5.6393E+01
PB-210	8.1223E+02	1.1604E+04	4.1048E-05	1.1933E-01	2.1629E-01
PO-210	5.6667E+01	8.0957E+02	2.8638E-06	0.0000E+00	1.4990E-02
RA-228	3.4218E+02	4.8885E+03	1.7293E-05	1.7504E-18	9.0517E-02
TH-228	1.4765E+02	2.1093E+03	7.4617E-06	0.0000E+00	3.9057E-02
RN-222	0.0000E+00	0.0000E+00	5.4725E+00	0.0000E+00	0.0000E+00

RADON TRANSPORT RESULTS

OUTDOOR RADON SURFACE FLUX = 2.444E-01 Bq/m^2/s

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   INDOOR RN DIFFUSIVE FLUX      = 0.000E+00 Bq/m^2/s
   INDOOR RN ADVECTIVE FLOW      = 2.316E-05 Bq/s
   TOTAL INDOOR RN CONCENTRATION = 4.165E-04 Bq/m^3


                         ORGAN DOSE/EXPOSURE SUMMARY
                         ---------------------------

*** MAXIMUM INDIVIDUAL ***
DOSE RATES:     ORGANS:  GONADS    BREAST    LUNG     R MARR    B SURF    THYROID   REMAIND   EFFECT
DOSE EQUIVALENT (µSV/YR) 3.797E+03 3.799E+03 3.852E+03 1.405E+04 1.405E+05 3.795E+03 4.169E+03 9.248E+03

*** ANNUAL MORTALITY RISK IS  1.097E-04
*** ANNUAL INCIDENCE RISK IS  1.594E-04


                         ******************************
                         * YEAR   900 ANNUAL SUMMARY *
                         ******************************

                     ACTIVE LAYER DEPTH (m) =        .15
                    TOP LAYER THICKNESS (m) =        .00
                 BOTTOM LAYER THICKNESS (m) =        .00

                    FAILURE IN TOP LAYER (%) =     100.00
             MAXIMUM WATER DEPTH IN LAYERS (m) =        .15
             VOLUME OF RUNOFF TO STREAM (m^3) =   0.00E+00
VOLUME OF WATER INFILTRATING DOWN TO AQUIFER  (m^3) =   4.08E+03
         VOLUME OF WATER OVERFLOWING SITE (m^3) =   0.00E+00


                         NUCLIDE TRANSPORT INFORMATION
                         -----------------------------

NUCLIDE    AMOUNT IN    AMOUNT IN    AMOUNT IN      SITE        SITE      AMOUNT AT     SITE
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	ACTIVE LYR	LAYER 1	LAYER 2	OVERFLOW	DRAINAGE	WELL	RUNOFF
	BQ	BQ	BQ	BQ	BQ	BQ	BQ
RA-226	3.1620E+09	0.0000E+00	0.0000E+00	0.0000E+00	9.4845E+07	2.4733E+07	1.5544E+05
PB-210	1.5790E+09	0.0000E+00	0.0000E+00	0.0000E+00	4.7372E+07	5.1756E+02	7.7636E+04
PO-210	1.1016E+08	0.0000E+00	0.0000E+00	0.0000E+00	3.3050E+06	0.0000E+00	5.4165E+03
RA-228	6.6520E+08	0.0000E+00	0.0000E+00	0.0000E+00	1.9957E+07	7.5914E-15	3.2707E+04
TH-228	2.8703E+08	0.0000E+00	0.0000E+00	0.0000E+00	8.6112E+06	0.0000E+00	1.4113E+04

ENVIRONMENTAL CONCENTRATIONS

NUCLIDE	SURFACE SOIL CONC	PORE WATER CONC	ATMOSPHERE ONSITE	WELL WATER CONC	STREAM WATER CONC
	BQ/KG	BQ/M**3	BQ/M**3	BQ/M**3	BQ/M**3
RA-226	1.6265E+03	2.3233E+04	8.2184E-05	5.7027E+03	6.8878E+01
PB-210	8.1223E+02	1.1604E+04	4.1048E-05	1.1933E-01	2.1629E-01
PO-210	5.6667E+01	8.0957E+02	2.8638E-06	0.0000E+00	1.4990E-02
RA-228	3.4218E+02	4.8885E+03	1.7293E-05	1.7504E-18	9.0517E-02
TH-228	1.4765E+02	2.1093E+03	7.4617E-06	0.0000E+00	3.9057E-02
RN-222	0.0000E+00	0.0000E+00	5.4789E+00	0.0000E+00	0.0000E+00

RADON TRANSPORT RESULTS

OUTDOOR RADON SURFACE FLUX = 2.447E-01 Bq/m^2/s
INDOOR RN DIFFUSIVE FLUX = 0.000E+00 Bq/m^2/s
INDOOR RN ADVECTIVE FLOW = 2.318E-05 Bq/s
TOTAL INDOOR RN CONCENTRATION = 4.170E-04 Bq/m^3

ORGAN DOSE/EXPOSURE SUMMARY

*** MAXIMUM INDIVIDUAL ***

DOSE RATES:	ORGANS: GONADS	BREAST	LUNG	R MARR	B SURF	THYROID	REMAIND	EFFECT
DOSE EQUIVALENT (-|SV/YR)	4.191E+03	4.193E+03	4.246E+03	1.662E+04	1.698E+05	4.189E+03	4.613E+03	1.078E+04

*** ANNUAL MORTALITY RISK IS 1.325E-04

*** ANNUAL INCIDENCE RISK IS 1.926E-04

****

* YEAR 1000 ANNUAL SUMMARY *

****

ACTIVE LAYER DEPTH (m) = .15

TOP LAYER THICKNESS (m) = .00

BOTTOM LAYER THICKNESS (m) = .00

FAILURE IN TOP LAYER (%) = 100.00

MAXIMUM WATER DEPTH IN LAYERS (m) = .15

VOLUME OF RUNOFF TO STREAM (m^3) = 0.00E+00

VOLUME OF WATER INFILTRATING DOWN TO AQUIFER (m^3) = 4.08E+03

VOLUME OF WATER OVERFLOWING SITE (m^3) = 0.00E+00

NUCLIDE TRANSPORT INFORMATION

NUCLIDE	AMOUNT IN ACTIVE LYR BQ	AMOUNT IN LAYER 1 BQ	AMOUNT IN LAYER 2 BQ	SITE OVERFLOW BQ	SITE DRAINAGE BQ	AMOUNT AT WELL BQ	SITE RUNOFF BQ
RA-226	3.1656E+09	0.0000E+00	0.0000E+00	0.0000E+00	9.4951E+07	2.9046E+07	1.5561E+05
PB-210	1.5790E+09	0.0000E+00	0.0000E+00	0.0000E+00	4.7372E+07	5.1756E+02	7.7636E+04
PO-210	1.1016E+08	0.0000E+00	0.0000E+00	0.0000E+00	3.3050E+06	0.0000E+00	5.4165E+03
RA-228	6.6520E+08	0.0000E+00	0.0000E+00	0.0000E+00	1.9957E+07	7.5914E-15	3.2707E+04
TH-228	2.8703E+08	0.0000E+00	0.0000E+00	0.0000E+00	8.6112E+06	0.0000E+00	1.4113E+04

ENVIRONMENTAL CONCENTRATIONS

NUCLIDE	SURFACE SOIL CONC BQ/KG	PORE WATER CONC BQ/M**3	ATMOSPHERE ONSITE BQ/M**3	WELL WATER CONC BQ/M**3	STREAM WATER CONC BQ/M**3
RA-226	1.6284E+03	2.3259E+04	8.2276E-05	6.6971E+03	8.0815E+01
PB-210	8.1223E+02	1.1604E+04	4.1048E-05	1.1933E-01	2.1629E-01
PO-210	5.6667E+01	8.0957E+02	2.8638E-06	0.0000E+00	1.4990E-02
RA-228	3.4218E+02	4.8885E+03	1.7293E-05	1.7504E-18	9.0517E-02
TH-228	1.4765E+02	2.1093E+03	7.4617E-06	0.0000E+00	3.9057E-02
RN-222	0.0000E+00	0.0000E+00	5.4850E+00	0.0000E+00	0.0000E+00

RADON TRANSPORT RESULTS

OUTDOOR RADON SURFACE FLUX = 2.450E-01 Bq/m^2/s
INDOOR RN DIFFUSIVE FLUX = 0.000E+00 Bq/m^2/s
INDOOR RN ADVECTIVE FLOW = 2.321E-05 Bq/s
TOTAL INDOOR RN CONCENTRATION = 4.175E-04 Bq/m^3

ORGAN DOSE/EXPOSURE SUMMARY

*** MAXIMUM INDIVIDUAL ***

DOSE RATES: ORGANS:	GONADS	BREAST	LUNG	R MARR	B SURF	THYROID	REMAIND	EFFECT
DOSE EQUIVALENT (╡SV/YR)	4.568E+03	4.571E+03	4.623E+03	1.907E+04	1.977E+05	4.565E+03	5.036E+03	1.225E+04

*** ANNUAL MORTALITY RISK IS 1.543E-04
*** ANNUAL INCIDENCE RISK IS 2.244E-04

THE MAXIMUM INDIVIDUAL DOSE COMMITMENT IS 1.23E+04 ╡SV OCCURING IN YEAR 1000

****
* YEAR 1000 ANNUAL SUMMARY *
****

ACTIVE LAYER DEPTH (m) = .15
TOP LAYER THICKNESS (m) = .00
BOTTOM LAYER THICKNESS (m) = .00

FAILURE IN TOP LAYER (%) = 100.00
MAXIMUM WATER DEPTH IN LAYERS (m) = .15
VOLUME OF RUNOFF TO STREAM (m^3) = 0.00E+00
VOLUME OF WATER INFILTRATING DOWN TO AQUIFER (m^3) = 4.08E+03
VOLUME OF WATER OVERFLOWING SITE (m^3) = 0.00E+00

NUCLIDE TRANSPORT INFORMATION

NUCLIDE	AMOUNT IN ACTIVE LYR BQ	AMOUNT IN LAYER 1 BQ	AMOUNT IN LAYER 2 BQ	SITE OVERFLOW BQ	SITE DRAINAGE BQ	AMOUNT AT WELL BQ	SITE RUNOFF
RA-226	3.1656E+09	0.0000E+00	0.0000E+00	0.0000E+00	9.4951E+07	2.9046E+07	1.5561E+05
PB-210	1.5790E+09	0.0000E+00	0.0000E+00	0.0000E+00	4.7372E+07	5.1756E+02	7.7636E+04
PO-210	1.1016E+08	0.0000E+00	0.0000E+00	0.0000E+00	3.3050E+06	0.0000E+00	5.4165E+03
RA-228	6.6520E+08	0.0000E+00	0.0000E+00	0.0000E+00	1.9957E+07	7.5914E-15	3.2707E+04
TH-228	2.8703E+08	0.0000E+00	0.0000E+00	0.0000E+00	8.6112E+06	0.0000E+00	1.4113E+04

ENVIRONMENTAL CONCENTRATIONS

NUCLIDE	SURFACE SOIL CONC BQ/KG	PORE WATER CONC BQ/M**3	ATMOSPHERE ONSITE BQ/M**3	WELL WATER CONC BQ/M**3	STREAM WATER CONC BQ/M**3
RA-226	1.6284E+03	2.3259E+04	8.2276E-05	6.6971E+03	8.0815E+01

PB-210	8.1223E+02	1.1604E+04	4.1048E-05	1.1933E-01	2.1629E-01
PO-210	5.6667E+01	8.0957E+02	2.8638E-06	0.0000E+00	1.4990E-02
RA-228	3.4218E+02	4.8885E+03	1.7293E-05	1.7504E-18	9.0517E-02
TH-228	1.4765E+02	2.1093E+03	7.4617E-06	0.0000E+00	3.9057E-02
RN-222	0.0000E+00	0.0000E+00	5.4850E+00	0.0000E+00	0.0000E+00

RADON TRANSPORT RESULTS

OUTDOOR RADON SURFACE FLUX = 2.450E-01 Bq/m^2/s
INDOOR RN DIFFUSIVE FLUX = 0.000E+00 Bq/m^2/s
INDOOR RN ADVECTIVE FLOW = 2.321E-05 Bq/s
TOTAL INDOOR RN CONCENTRATION = 4.175E-04 Bq/m^3

UPTAKE/CONCENTRATIONS PASSED TO DOSTAB

NUCLIDE	INGESTION	INHALATION	AIR IMMERS.	SURFACE
	BQ/YR	BQ/YR	PBQ/M**3	BQ/M**3
RA-226	5.5562E+03	2.7628E-01	8.2276E-05	7.7523E+05
PB-210	7.8867E+01	1.3784E-01	4.1048E-05	1.7024E-14
PO-210	4.9682E+00	9.6167E-03	2.8638E-06	2.6847E+04
RA-228	3.2955E+01	5.8070E-02	1.7293E-05	1.6244E+05
TH-228	1.9270E+01	2.5056E-02	7.4617E-06	7.0591E+04
RN-222	0.0000E+00	0.0000E+00	5.4850E+00	0.0000E+00

ORGAN DOSE/EXPOSURE SUMMARY

*** MAXIMUM INDIVIDUAL ***

DOSE RATES:	ORGANS: GONADS	BREAST	LUNG	R MARR	B SURF	THYROID	REMAIND	EFFECT
DOSE EQUIVALENT (µSV/YR)	4.568E+03	4.571E+03	4.623E+03	1.907E+04	1.977E+05	4.565E+03	5.036E+03	1.225E+04

*** ANNUAL MORTALITY RISK IS 1.543E-04
*** ANNUAL INCIDENCE RISK IS 2.244E-04

PATHWAY DOSE/EXPOSURE SUMMARY

*** MAXIMUM INDIVIDUAL ***
DOSE RATES:
EFFECTIVE DOSE EQUIVALENT (WEIGHTED)

PATHWAYS:	INGESTION	INHALATION	AIR IMMERSION	GROUND SURFACE	INTERNAL	EXTERNAL	TOTAL
DOSE EQUIVALENT (µSV/YR)	1.029E+04	7.69	1.354E-10	1.953E+03	1.030E+04	1.953E+03	1.225E+04
DOSE EQUIV. (% OF TOT.)	84.0	6.279E-02	1.105E-12	15.9	84.0	15.9	100.

NUCLIDE DOSE/EXPOSURE SUMMARY

*** MAXIMUM INDIVIDUAL ***
DOSE RATES:
EFFECTIVE DOSE EQUIVALENT

NUCLIDES:	RA-226	PB-210	PO-210	RA-228	TH-228	TOTAL
DOSE EQUIVALENT (µSV/YR)	1.188E+04	115.	2.58	154.	102.	1.225E+04
DOSE EQUIV. (% OF TOT.)	96.9	.937	2.103E-02	1.26	.831	100.
RN DOSE EQ. (% OF TOT.)	2.617E-02	.000	.000	.000	.000	2.537E-02

INDIVIDUAL DOSE EQUIVALENT RATES (µSV/YR)

***SUMMED OVER ALL ORGANS
NUCLIDES RA-226 PB-210 PO-210 RA-228 TH-228 TOTAL

PATHWAYS

- INGESTION	1.016E+04	114.	2.55	12.8	2.07	1.029E+04
% OF INTERNAL	100.	99.6	99.1	99.4	47.2	99.9
% OF ALL PATHWAYS	85.5	99.6	99.0	8.31	2.03	84.0
- DRINKING WATER	1.750E+03	.126	.000	4.958E-19	.000	1.750E+03
% OF INTERNAL	17.2	.110	.000	3.850E-18	.000	17.0
% OF ALL PATHWAYS	14.7	.110	.000	3.217E-19	.000	14.3
- NON-DRINKING WATER	8.408E+03	114.	2.55	12.8	2.07	8.539E+03
% OF INTERNAL	82.7	99.4	99.1	99.4	47.2	82.9
% OF ALL PATHWAYS	70.8	99.4	99.0	8.31	2.03	69.7
- INHALATION	4.77	.506	2.444E-02	7.463E-02	2.31	7.69
% FROM RN-222	65.1	.000	.000	.000	.000	40.4
% OF INTERNAL	4.698E-02	.441	.949	.580	52.8	7.471E-02
% OF ALL PATHWAYS	4.020E-02	.441	.949	4.843E-02	2.27	6.279E-02
- AIR IMMERSION	1.233E-10	9.322E-12	4.803E-15	.000	2.767E-12	1.354E-10
% OF EXTERNAL	7.193E-12	100.	2.318E-09	.000	2.841E-12	6.933E-12

% OF ALL PATHWAYS	1.038E-12	8.120E-12	1.864E-13	.000	2.719E-12	1.105E-12		
- GROUND SURFACE	1.714E+03	7.025E-21	2.072E-04	141.	97.4	1.953E+03		
% OF EXTERNAL	100.	7.536E-08	100.	100.	100.	100.		
% OF ALL PATHWAYS	14.4	6.119E-21	8.042E-03	91.6	95.7	15.9		
- INTERNAL	1.016E+04	115.	2.58	12.9	4.38	1.030E+04		
% OF ALL PATHWAYS	85.6	100.	100.	8.36	4.30	.000		
- EXTERNAL	1.714E+03	9.322E-12	2.072E-04	141.	97.4	1.953E+03		
% OF ALL PATHWAYS	14.4	8.120E-12	8.042E-03	91.6	95.7	15.9		
TOTAL OVER ALL PATHWAYS	1.188E+04	115.	2.58	154.	102.	1.225E+04		
% OF TOTAL	96.9	.937	2.103E-02	1.26	.831			

***SUMMED OVER ALL NUCLIDES

ORGANS PATHWAYS	GONADS	BREAST	LUNG	R MARR	B SURF	THYROID	REMAIND	EFFECT
- INGESTION	2.615E+03	2.618E+03	2.615E+03	1.711E+04	1.958E+05	2.612E+03	3.082E+03	1.029E+04
% OF INTERNAL	100.	100.	97.9	100.	100.	100.	100.	99.9
% OF ALL PATHWAYS	57.2	57.3	56.6	89.7	99.0	57.2	61.2	84.0

- INHALATION	.137	.138	55.3	1.51	19.1	.137	.821	7.69
% OF INTERNAL	5.254E-03	5.256E-03	2.07	8.823E-03	9.766E-03	5.264E-03	2.662E-02	7.471E-02
% OF ALL PATHWAYS	3.008E-03	3.011E-03	1.20	7.919E-03	9.670E-03	3.012E-03	1.629E-02	6.279E-02
- AIR IMMERSION	1.337E-10	1.555E-10	1.251E-10	1.132E-10	3.517E-10	1.327E-10	1.184E-10	1.354E-10
% OF EXTERNAL	6.844E-12	7.963E-12	6.407E-12	5.796E-12	1.801E-11	6.795E-12	6.065E-12	6.933E-12
% OF ALL PATHWAYS	2.926E-12	3.402E-12	2.706E-12	5.936E-13	1.779E-13	2.907E-12	2.352E-12	1.105E-12
- GROUND SURFACE	1.953E+03	1.953E+03	1.953E+03	1.953E+03	1.953E+03	1.953E+03	1.953E+03	1.953E+03
% OF EXTERNAL	100.	100.	100.	100.	100.	100.	100.	100.
% OF ALL PATHWAYS	42.8	42.7	42.2	10.2	.988	42.8	38.8	15.9
- INTERNAL	2.615E+03	2.618E+03	2.670E+03	1.711E+04	1.958E+05	2.612E+03	3.083E+03	1.030E+04
% OF ALL PATHWAYS	57.2	57.3	57.8	89.8	99.0	57.2	61.2	84.0
- EXTERNAL	1.953E+03	1.953E+03	1.953E+03	1.953E+03	1.953E+03	1.953E+03	1.953E+03	1.953E+03
% OF ALL PATHWAYS	42.8	42.7	42.2	10.2	.988	42.8	38.8	15.9
TOTAL OVER ALL PATHWAYS	4.568E+03	4.571E+03	4.623E+03	1.907E+04	1.977E+05	4.565E+03	5.036E+03	1.225E+04

MAXIMUM ANNUAL EXPOSURE BY NUCLIDE AND PATHWAY

NUCLIDE	AIR CONCENTRATION BQ/M**3	YEAR	SURFACE CONCENTRATION BQ/M**3	YEAR	INGESTION RATE BQ/Y	YEAR	INHALATION RATE BQ/Y	YEAR	BSMT SURFACE CONCENTRATION BQ/M**2	YEAR
RA-226	8.2276E-05	1000	7.7523E+05	1000	5.5562E+03	1000	2.7628E-01	1000	0.0000E+00	0
PB-210	4.1048E-05	221	1.7024E-14	221	7.8867E+01	828	1.3784E-01	221	3.9443E+04	221
PO-210	3.2169E-06	9	2.6847E+04	9	5.0066E+00	9	1.0802E-02	9	0.0000E+00	0
RA-228	1.7293E-05	99	1.6244E+05	99	3.2955E+01	99	5.8070E-02	99	1.1879E+04	99
TH-228	8.2146E-06	10	7.0591E+04	39	1.9270E+01	32	2.7585E-02	10	5.9823E+03	39
RN-222	5.4850E+00	1000	0.0000E+00	0	0.0000E+00	0	4.8758E-01	1000	1.6698E-04	1000

(IN BQ/M**3)

MAXIMUM AND AVERAGE CONCENTRATIONS OVER THE 1000 YEARS OF THE SIMULATION

NUCLIDE	ATMOSPHERE ONSITE			IN WELL			IN STREAM		
	AVERAGE BQ/M**3	MAXIMUM BQ/M**3	YEAR	AVERAGE BQ/M**3	MAXIMUM BQ/M**3	YEAR	AVERAGE BQ/M**3	MAXIMUM BQ/M**3	YEAR
RA-226	7.9214E-05	8.2276E-05	1000	2.1170E+03	6.6971E+03	1000	2.5824E+01	8.0815E+01	1000
PB-210	4.0411E-05	4.1048E-05	221	7.0129E-02	1.1933E-01	913	2.1227E-01	2.1629E-01	798
PO-210	2.8675E-06	3.2169E-06	9	0.0000E+00	0.0000E+00	0	1.4987E-02	1.4990E-02	9
RA-228	1.7201E-05	1.7293E-05	99	1.0847E-18	1.7504E-18	529	8.9959E-02	9.0517E-02	99
TH-228	7.4553E-06	8.2146E-06	10	0.0000E+00	0.0000E+00	0	3.8976E-02	3.9057E-02	39
RN-222	5.2794E+00	5.4850E+00	1000	0.0000E+00	0.0000E+00	0	0.0000E+00	0.0000E+00	0

AVERAGE RADIONUCLIDE CONCENTRATION IN FOODS DUE TO ATMOSPHERIC DEPOSITION

PICO BEQUERELS PER KILOGRAM

NUCLIDE	LEAFY VEG	PRODUCE	COW'S MILK	GOAT'S MILK	BEEF MEAT
RA-226	3.9581E+11	3.9578E+10	7.3179E+09	9.7572E+06	4.0654E+09
PB-210	2.0163E+11	2.0061E+10	3.7269E+09	4.9692E+06	2.0673E+09
PO-210	1.3150E+10	9.7824E+08	2.4014E+08	3.2019E+05	1.2190E+08
RA-228	8.5452E+10	8.3797E+09	1.5784E+09	2.1046E+06	8.7169E+08
TH-228	3.6612E+10	3.4531E+09	9.0010E+08	9.0010E+07	2.9472E+08

AVERAGE RADIONUCLIDE CONCENTRATION IN FOODS DUE TO IRRIGATION
PICO BEQUERELS PER KILOGRAM

NUCLIDE	LEAFY VEG	PRODUCE	COW'S MILK	GOAT'S MILK	BEEF MEAT
RA-226	7.1218E+12	1.0078E+12	3.1179E+11	4.2419E+08	1.6792E+11
PB-210	8.0422E+11	2.2669E+11	7.6030E+10	1.0137E+08	4.2174E+10
PO-210	5.5820E+10	1.1766E+10	4.7386E+09	6.3181E+06	2.4054E+09
RA-228	3.3865E+11	9.4092E+10	3.1821E+10	4.2428E+07	1.7573E+10
TH-228	8.2748E+10	1.0406E+11	1.0756E+10	1.0756E+09	3.5220E+09

NUCLIDE	AVG. ANNUAL INTAKE BY INGESTION BQ/Y	AVG. ANNUAL INTAKE BY INHALATION BQ/Y
RA-226	1.8641E+03	2.6600E-01
PB-210	7.8741E+01	1.3570E-01
PO-210	4.9686E+00	9.6289E-03
RA-228	3.2943E+01	5.7761E-02
TH-228	1.9269E+01	2.5035E-02
RN-222	0.0000E+00	1.2190E+00

AGGREGATED VALUES OF RADIOACTIVITY:

NUCLIDE	PUMPED OUT THE WELL	PUMPED OUT THE STREAM	LEFT BOTTOM OF SITE	OVERFLOWED SITE	RELEASED TO THE ATMOSPHERE
RA-226	1.5826E+08	0.0000E+00	9.1392E+10	0.0000E+00	9.0381E+08
PB-210	5.2425E+03	0.0000E+00	4.6615E+10	0.0000E+00	4.6109E+08
PO-210	0.0000E+00	0.0000E+00	3.3044E+09	0.0000E+00	3.2717E+07
RA-228	8.1090E-14	0.0000E+00	1.9834E+10	0.0000E+00	1.9626E+08
TH-228	0.0000E+00	0.0000E+00	8.5933E+09	0.0000E+00	8.5063E+07
RN-222	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	6.0237E+13

FRACTION OF INGESTION DUE TO WATER

NUCLIDE	FRACTION
RA-226	.8290
PB-210	.0007
PO-210	.0000
RA-228	.0000
TH-228	.0000

ORGAN DOSE/EXPOSURE SUMMARY

*** AVERAGE INDIVIDUAL ***

DOSE RATES: ORGANS:	GONADS	BREAST	LUNG	R MARR	B SURF	THYROID	REMAIND	EFFECT
DOSE EQUIVALENT (µSV/YR)	1.202E+03	1.203E+03	1.257E+03	6.151E+03	6.730E+04	1.201E+03	1.455E+03	3.862E+03

*** ANNUAL MORTALITY RISK IS 5.370E-05
*** ANNUAL INCIDENCE RISK IS 7.821E-05

PATHWAY DOSE/EXPOSURE SUMMARY

*** AVERAGE INDIVIDUAL ***
DOSE RATES:
EFFECTIVE DOSE EQUIVALENT (WEIGHTED)

PATHWAYS:	INGESTION	INHALATION	AIR IMMERSION	GROUND SURFACE	INTERNAL	EXTERNAL	TOTAL
DOSE EQUIVALENT (µSV/YR)	3.539E+03	7.62	1.307E-10	314.	3.547E+03	314.	3.862E+03
DOSE EQUIV. (% OF TOT.)	91.7	.197	3.384E-12	8.14	91.9	8.14	100.

NUCLIDE DOSE/EXPOSURE SUMMARY

*** AVERAGE INDIVIDUAL ***
DOSE RATES:
EFFECTIVE DOSE EQUIVALENT

NUCLIDES:	RA-226	PB-210	PO-210	RA-228	TH-228	TOTAL
DOSE EQUIVALENT (╡SV/YR)	3.568E+03	115.	2.58	74.1	102.	3.862E+03
DOSE EQUIV. (% OF TOT.)	92.4	2.97	6.673E-02	1.92	2.63	100.
RN DOSE EQ. (% OF TOT.)	8.710E-02	.000	.000	.000	.000	8.049E-02

INDIVIDUAL DOSE EQUIVALENT RATES (╡SV/YR)

***SUMMED OVER ALL ORGANS

NUCLIDES PATHWAYS	RA-226	PB-210	PO-210	RA-228	TH-228	TOTAL
- INGESTION	3.408E+03	114.	2.55	12.8	2.07	3.539E+03
% OF INTERNAL	99.9	99.6	99.1	99.4	47.2	99.8
% OF ALL PATHWAYS	95.5	99.5	99.0	17.3	2.03	91.7
- DRINKING WATER	1.750E+03	.126	.000	4.958E-19	.000	1.750E+03
% OF INTERNAL	51.3	.110	.000	3.852E-18	.000	49.3
% OF ALL PATHWAYS	49.0	.110	.000	6.689E-19	.000	45.3
- NON-DRINKING WATER	1.658E+03	114.	2.55	12.8	2.07	1.789E+03
% OF INTERNAL	48.6	99.5	99.1	99.4	47.2	50.4
% OF ALL PATHWAYS	46.5	99.4	99.0	17.3	2.03	46.3

- INHALATION	4.71	.498	2.447E-02	7.424E-02	2.31	7.62
% FROM RN-222	66.0	.000	.000	.000	.000	40.8
% OF INTERNAL	.138	.435	.950	.577	52.8	.215
% OF ALL PATHWAYS	.132	.435	.950	.100	2.28	.197
- AIR IMMERSION	1.187E-10	9.178E-12	4.809E-15	.000	2.765E-12	1.307E-10
% OF EXTERNAL	7.621E-11	3.157E-08	8.846E-10	.000	2.845E-12	4.158E-11
% OF ALL PATHWAYS	3.327E-12	8.005E-12	1.866E-13	.000	2.722E-12	3.384E-12
- GROUND SURFACE	156.	2.907E-02	5.437E-04	61.2	97.2	314.
% OF EXTERNAL	100.	100.	100.	100.	100.	100.
% OF ALL PATHWAYS	4.37	2.535E-02	2.110E-02	82.6	95.7	8.14
- INTERNAL	3.413E+03	115.	2.58	12.9	4.38	3.547E+03
% OF ALL PATHWAYS	95.6	100.	100.	17.4	4.31	.000
- EXTERNAL	156.	2.907E-02	5.437E-04	61.2	97.2	314.
% OF ALL PATHWAYS	4.37	2.535E-02	2.110E-02	82.6	95.7	8.14
TOTAL OVER ALL PATHWAYS	3.568E+03	115.	2.58	74.1	102.	3.862E+03
% OF TOTAL	92.4	2.97	6.673E-02	1.92	2.63	

***SUMMED OVER ALL NUCLIDES

ORGANS PATHWAYS	GONADS	BREAST	LUNG	R MARR	B SURF	THYROID	REMAIND	EFFECT
- INGESTION	888.	889.	888.	5.836E+03	6.696E+04	887.	1.140E+03	3.539E+03
% OF INTERNAL	100.	100.	94.2	100.	100.	100.	99.9	99.8
% OF ALL PATHWAYS	73.8	73.9	70.6	94.9	99.5	73.8	78.3	91.7
- INHALATION	.134	.134	54.8	1.48	18.8	.134	.808	7.62
% OF INTERNAL	1.509E-02	1.509E-02	5.82	2.542E-02	2.806E-02	1.511E-02	7.081E-02	.215
% OF ALL PATHWAYS	1.114E-02	1.115E-02	4.36	2.412E-02	2.793E-02	1.116E-02	5.552E-02	.197
- AIR IMMERSION	1.290E-10	1.501E-10	1.207E-10	1.092E-10	3.396E-10	1.281E-10	1.143E-10	1.307E-10
% OF EXTERNAL	4.105E-11	4.778E-11	3.841E-11	3.474E-11	1.081E-10	4.075E-11	3.636E-11	4.158E-11
% OF ALL PATHWAYS	1.073E-11	1.248E-11	9.606E-12	1.775E-12	5.046E-13	1.066E-11	7.853E-12	3.384E-12
- GROUND SURFACE	314.	314.	314.	314.	314.	314.	314.	314.
% OF EXTERNAL	100.	100.	100.	100.	100.	100.	100.	100.
% OF ALL PATHWAYS	26.1	26.1	25.0	5.11	.467	26.2	21.6	8.14
- INTERNAL	888.	889.	942.	5.837E+03	6.698E+04	887.	1.141E+03	3.547E+03

% OF ALL PATHWAYS	73.9	73.9	75.0	94.9	99.5	73.8	78.4	91.9
- EXTERNAL	314.	314.	314.	314.	314.	314.	314.	314.
% OF ALL PATHWAYS	26.1	26.1	25.0	5.11	.467	26.2	21.6	8.14
TOTAL OVER ALL PATHWAYS	1.202E+03	1.203E+03	1.257E+03	6.151E+03	6.730E+04	1.201E+03	1.455E+03	3.862E+03

Mississippi state oil and gas scale post disposal application

1.023E+02	1.887E+02	2.646E+02	3.329E+02	3.954E+02	4.536E+02	5.084E+02	5.603E+02	6.098E+02	6.575E+02	10
7.029E+02	7.469E+02	7.897E+02	8.312E+02	8.716E+02	9.109E+02	9.492E+02	9.865E+02	1.023E+03	1.058E+03	20
1.093E+03	1.127E+03	1.160E+03	1.192E+03	1.223E+03	1.254E+03	1.284E+03	1.313E+03	1.341E+03	1.369E+03	30
1.396E+03	1.423E+03	1.448E+03	1.473E+03	1.498E+03	1.522E+03	1.545E+03	1.568E+03	1.590E+03	1.611E+03	40
1.632E+03	1.653E+03	1.673E+03	1.692E+03	1.711E+03	1.729E+03	1.747E+03	1.765E+03	1.782E+03	1.798E+03	50
1.814E+03	1.830E+03	1.845E+03	1.860E+03	1.875E+03	1.889E+03	1.902E+03	1.915E+03	1.928E+03	1.941E+03	60
1.953E+03	1.965E+03	1.977E+03	1.988E+03	1.999E+03	2.009E+03	2.020E+03	2.030E+03	2.039E+03	2.049E+03	70
2.058E+03	2.067E+03	2.076E+03	2.084E+03	2.092E+03	2.100E+03	2.108E+03	2.116E+03	2.123E+03	2.130E+03	80
2.137E+03	2.144E+03	2.150E+03	2.157E+03	2.163E+03	2.169E+03	2.175E+03	2.180E+03	2.186E+03	2.191E+03	90
2.196E+03	2.201E+03	2.206E+03	2.211E+03	2.215E+03	2.220E+03	2.224E+03	2.228E+03	2.232E+03	2.236E+03	100
2.240E+03	2.244E+03	2.247E+03	2.251E+03	2.254E+03	2.258E+03	2.261E+03	2.264E+03	2.267E+03	2.270E+03	110
2.273E+03	2.276E+03	2.278E+03	2.281E+03	2.284E+03	2.286E+03	2.288E+03	2.291E+03	2.293E+03	2.295E+03	120
2.297E+03	2.299E+03	2.301E+03	2.303E+03	2.305E+03	2.307E+03	2.309E+03	2.310E+03	2.312E+03	2.314E+03	130
2.315E+03	2.317E+03	2.318E+03	2.320E+03	2.321E+03	2.322E+03	2.324E+03	2.325E+03	2.326E+03	2.328E+03	140
2.329E+03	2.330E+03	2.331E+03	2.332E+03	2.333E+03	2.334E+03	2.335E+03	2.336E+03	2.337E+03	2.338E+03	150
2.339E+03	2.339E+03	2.340E+03	2.341E+03	2.342E+03	2.343E+03	2.343E+03	2.344E+03	2.345E+03	2.345E+03	160
2.346E+03	2.347E+03	2.347E+03	2.348E+03	2.348E+03	2.349E+03	2.349E+03	2.350E+03	2.350E+03	2.351E+03	170
2.351E+03	2.352E+03	2.352E+03	2.353E+03	2.353E+03	2.354E+03	2.354E+03	2.354E+03	2.355E+03	2.355E+03	180
2.355E+03	2.356E+03	2.356E+03	2.356E+03	2.357E+03	2.357E+03	2.357E+03	2.358E+03	2.358E+03	2.358E+03	190
2.358E+03	2.359E+03	2.359E+03	2.359E+03	2.359E+03	2.360E+03	2.360E+03	2.360E+03	2.360E+03	2.360E+03	200

2.361E+03	2.361E+03	2.361E+03	2.361E+03	2.361E+03	2.361E+03	2.362E+03	2.362E+03	2.362E+03	2.362E+03	210
2.362E+03	2.362E+03	2.362E+03	2.363E+03	2.363E+03	2.363E+03	2.363E+03	2.363E+03	2.363E+03	2.363E+03	220
2.363E+03	2.363E+03	2.364E+03	2.364E+03	2.364E+03	2.364E+03	2.364E+03	2.364E+03	2.364E+03	2.364E+03	230
2.364E+03	2.364E+03	2.364E+03	2.365E+03	2.365E+03	2.365E+03	2.365E+03	2.365E+03	2.365E+03	2.365E+03	240
2.365E+03	2.365E+03	2.365E+03	2.365E+03	2.365E+03	2.365E+03	2.365E+03	2.365E+03	2.365E+03	2.365E+03	250
2.365E+03	2.365E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	260
2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	270
2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	280
2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	290
2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	2.366E+03	300
2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	310
2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	320
2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	330
2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	340
2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	350
2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	360
2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	2.367E+03	370
2.367E+03	2.375E+03	2.382E+03	2.390E+03	2.397E+03	2.404E+03	2.411E+03	2.417E+03	2.424E+03	2.430E+03	380
2.436E+03	2.442E+03	2.447E+03	2.453E+03	2.458E+03	2.471E+03	2.484E+03	2.496E+03	2.508E+03	2.519E+03	390
2.531E+03	2.541E+03	2.552E+03	2.562E+03	2.572E+03	2.582E+03	2.591E+03	2.600E+03	2.609E+03	2.625E+03	400
2.641E+03	2.657E+03	2.671E+03	2.686E+03	2.700E+03	2.714E+03	2.727E+03	2.740E+03	2.752E+03	2.764E+03	410
2.776E+03	2.787E+03	2.798E+03	2.809E+03	2.827E+03	2.845E+03	2.862E+03	2.878E+03	2.895E+03	2.910E+03	420
2.925E+03	2.940E+03	2.954E+03	2.968E+03	2.982E+03	2.995E+03	3.007E+03	3.019E+03	3.039E+03	3.058E+03	430
3.077E+03	3.094E+03	3.112E+03	3.129E+03	3.145E+03	3.161E+03	3.176E+03	3.191E+03	3.206E+03	3.220E+03	440
3.234E+03	3.247E+03	3.267E+03	3.287E+03	3.307E+03	3.325E+03	3.343E+03	3.361E+03	3.378E+03	3.395E+03	450
3.411E+03	3.427E+03	3.442E+03	3.457E+03	3.471E+03	3.485E+03	3.498E+03	3.519E+03	3.539E+03	3.558E+03	460
3.577E+03	3.596E+03	3.613E+03	3.631E+03	3.647E+03	3.664E+03	3.679E+03	3.695E+03	3.710E+03	3.724E+03	470
3.738E+03	3.759E+03	3.780E+03	3.800E+03	3.819E+03	3.838E+03	3.856E+03	3.873E+03	3.890E+03	3.907E+03	480
3.923E+03	3.939E+03	3.954E+03	3.969E+03	3.983E+03	4.004E+03	4.025E+03	4.045E+03	4.065E+03	4.084E+03	490
4.102E+03	4.120E+03	4.137E+03	4.154E+03	4.170E+03	4.186E+03	4.202E+03	4.216E+03	4.231E+03	4.245E+03	500
4.266E+03	4.287E+03	4.306E+03	4.326E+03	4.344E+03	4.362E+03	4.380E+03	4.397E+03	4.414E+03	4.430E+03	510
4.445E+03	4.460E+03	4.475E+03	4.489E+03	4.511E+03	4.531E+03	4.551E+03	4.571E+03	4.590E+03	4.608E+03	520
4.626E+03	4.643E+03	4.660E+03	4.676E+03	4.691E+03	4.707E+03	4.722E+03	4.736E+03	4.750E+03	4.771E+03	530
4.791E+03	4.811E+03	4.830E+03	4.848E+03	4.866E+03	4.884E+03	4.901E+03	4.917E+03	4.933E+03	4.949E+03	540
4.964E+03	4.978E+03	4.992E+03	5.013E+03	5.034E+03	5.054E+03	5.073E+03	5.092E+03	5.110E+03	5.127E+03	550
5.144E+03	5.161E+03	5.177E+03	5.192E+03	5.208E+03	5.222E+03	5.236E+03	5.258E+03	5.278E+03	5.298E+03	560

5.317E+03	5.336E+03	5.354E+03	5.372E+03	5.389E+03	5.405E+03	5.421E+03	5.437E+03	5.452E+03	5.467E+03	570
5.481E+03	5.495E+03	5.516E+03	5.536E+03	5.555E+03	5.574E+03	5.592E+03	5.610E+03	5.627E+03	5.644E+03	580
5.660E+03	5.676E+03	5.692E+03	5.706E+03	5.721E+03	5.735E+03	5.756E+03	5.776E+03	5.795E+03	5.814E+03	590
5.833E+03	5.850E+03	5.868E+03	5.885E+03	5.901E+03	5.917E+03	5.932E+03	5.947E+03	5.961E+03	5.976E+03	600
5.996E+03	6.016E+03	6.036E+03	6.055E+03	6.073E+03	6.091E+03	6.109E+03	6.125E+03	6.142E+03	6.158E+03	610
6.173E+03	6.188E+03	6.202E+03	6.216E+03	6.230E+03	6.250E+03	6.270E+03	6.289E+03	6.308E+03	6.326E+03	620
6.343E+03	6.360E+03	6.377E+03	6.393E+03	6.408E+03	6.423E+03	6.438E+03	6.452E+03	6.466E+03	6.486E+03	630
6.506E+03	6.525E+03	6.544E+03	6.562E+03	6.580E+03	6.597E+03	6.613E+03	6.629E+03	6.645E+03	6.660E+03	640
6.674E+03	6.689E+03	6.702E+03	6.723E+03	6.743E+03	6.762E+03	6.781E+03	6.799E+03	6.816E+03	6.833E+03	650
6.850E+03	6.866E+03	6.881E+03	6.896E+03	6.911E+03	6.925E+03	6.939E+03	6.953E+03	6.973E+03	6.992E+03	660
7.011E+03	7.029E+03	7.047E+03	7.064E+03	7.080E+03	7.097E+03	7.112E+03	7.128E+03	7.142E+03	7.157E+03	670
7.171E+03	7.184E+03	7.204E+03	7.224E+03	7.242E+03	7.261E+03	7.279E+03	7.296E+03	7.312E+03	7.329E+03	680
7.344E+03	7.360E+03	7.375E+03	7.389E+03	7.403E+03	7.416E+03	7.437E+03	7.456E+03	7.475E+03	7.493E+03	690
7.511E+03	7.528E+03	7.545E+03	7.561E+03	7.577E+03	7.592E+03	7.607E+03	7.621E+03	7.635E+03	7.649E+03	700
7.662E+03	7.682E+03	7.701E+03	7.719E+03	7.737E+03	7.754E+03	7.771E+03	7.788E+03	7.803E+03	7.819E+03	710
7.834E+03	7.848E+03	7.862E+03	7.876E+03	7.889E+03	7.909E+03	7.928E+03	7.947E+03	7.965E+03	7.982E+03	720
7.999E+03	8.015E+03	8.031E+03	8.047E+03	8.062E+03	8.076E+03	8.090E+03	8.104E+03	8.117E+03	8.137E+03	730
8.156E+03	8.175E+03	8.193E+03	8.210E+03	8.227E+03	8.243E+03	8.259E+03	8.275E+03	8.290E+03	8.304E+03	740
8.319E+03	8.332E+03	8.346E+03	8.358E+03	8.378E+03	8.396E+03	8.414E+03	8.432E+03	8.449E+03	8.466E+03	750
8.482E+03	8.497E+03	8.512E+03	8.527E+03	8.541E+03	8.555E+03	8.569E+03	8.582E+03	8.601E+03	8.620E+03	760
8.638E+03	8.655E+03	8.673E+03	8.689E+03	8.705E+03	8.721E+03	8.736E+03	8.751E+03	8.765E+03	8.779E+03	770
8.792E+03	8.806E+03	8.825E+03	8.844E+03	8.862E+03	8.879E+03	8.896E+03	8.913E+03	8.929E+03	8.945E+03	780
8.960E+03	8.975E+03	8.989E+03	9.003E+03	9.016E+03	9.029E+03	9.042E+03	9.061E+03	9.079E+03	9.097E+03	790
9.114E+03	9.131E+03	9.147E+03	9.163E+03	9.178E+03	9.193E+03	9.208E+03	9.222E+03	9.235E+03	9.248E+03	800
9.261E+03	9.280E+03	9.299E+03	9.316E+03	9.334E+03	9.351E+03	9.367E+03	9.383E+03	9.398E+03	9.413E+03	810
9.427E+03	9.441E+03	9.455E+03	9.468E+03	9.481E+03	9.500E+03	9.518E+03	9.536E+03	9.554E+03	9.570E+03	820
9.587E+03	9.603E+03	9.618E+03	9.633E+03	9.647E+03	9.661E+03	9.675E+03	9.688E+03	9.701E+03	9.713E+03	830
9.732E+03	9.750E+03	9.767E+03	9.784E+03	9.801E+03	9.817E+03	9.832E+03	9.847E+03	9.862E+03	9.876E+03	840
9.890E+03	9.903E+03	9.916E+03	9.929E+03	9.947E+03	9.965E+03	9.983E+03	1.000E+04	1.002E+04	1.003E+04	850
1.005E+04	1.006E+04	1.008E+04	1.009E+04	1.011E+04	1.012E+04	1.013E+04	1.014E+04	1.016E+04	1.018E+04	860
1.020E+04	1.022E+04	1.023E+04	1.025E+04	1.026E+04	1.028E+04	1.029E+04	1.031E+04	1.032E+04	1.033E+04	870
1.035E+04	1.036E+04	1.037E+04	1.039E+04	1.041E+04	1.043E+04	1.044E+04	1.046E+04	1.047E+04	1.049E+04	880
1.050E+04	1.052E+04	1.053E+04	1.055E+04	1.056E+04	1.057E+04	1.058E+04	1.060E+04	1.062E+04	1.064E+04	890
1.065E+04	1.067E+04	1.069E+04	1.070E+04	1.072E+04	1.073E+04	1.074E+04	1.076E+04	1.077E+04	1.078E+04	900
1.080E+04	1.081E+04	1.083E+04	1.084E+04	1.086E+04	1.088E+04	1.089E+04	1.091E+04	1.092E+04	1.094E+04	910
1.095E+04	1.097E+04	1.098E+04	1.099E+04	1.100E+04	1.102E+04	1.103E+04	1.105E+04	1.107E+04	1.109E+04	920

1.110E+04	1.112E+04	1.113E+04	1.115E+04	1.116E+04	1.117E+04	1.119E+04	1.120E+04	1.121E+04	1.123E+04	930
1.124E+04	1.126E+04	1.128E+04	1.129E+04	1.131E+04	1.133E+04	1.134E+04	1.136E+04	1.137E+04	1.138E+04	940
1.140E+04	1.141E+04	1.142E+04	1.143E+04	1.145E+04	1.146E+04	1.148E+04	1.150E+04	1.151E+04	1.153E+04	950
1.154E+04	1.156E+04	1.157E+04	1.159E+04	1.160E+04	1.161E+04	1.163E+04	1.164E+04	1.165E+04	1.167E+04	960
1.169E+04	1.170E+04	1.172E+04	1.173E+04	1.175E+04	1.176E+04	1.178E+04	1.179E+04	1.181E+04	1.182E+04	970
1.183E+04	1.184E+04	1.186E+04	1.187E+04	1.189E+04	1.191E+04	1.192E+04	1.194E+04	1.196E+04	1.197E+04	980
1.198E+04	1.200E+04	1.201E+04	1.203E+04	1.204E+04	1.205E+04	1.206E+04	1.207E+04	1.209E+04	1.211E+04	990
1.212E+04	1.214E+04	1.216E+04	1.217E+04	1.219E+04	1.220E+04	1.221E+04	1.223E+04	1.224E+04	1.225E+04	1000