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**AT123D: Analytical Transient
One-, Two-, and Three-Dimensional
Simulation of Waste Transport
in the Aquifer System**

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ABSTRACT

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A generalized analytical transient, one-, two-, and/or three-dimensional (AT123D) computer code is developed for estimating the transport of wastes in a groundwater aquifer system. It contains 450 options: 288 for the three-dimensional case, 72 for the two-dimensional case in the x-y plane, 72 for the two-dimensional case in the x-z plane, and 18 for the one-dimensional case in the longitudinal direction. These are the combinations of three types of wastes, eight sets of source configurations, three kinds of source releases, and four variations of the aquifer dimensions. Three types of the wastes are radioactive waste, chemicals, and heat. The eight types of source configurations are a point source, a line source parallel to the x-axis, a line source parallel to the y-axis, a line source parallel to the z-axis, an area source perpendicular to the x-axis, an area source perpendicular to the y-axis, an area source perpendicular to the z-axis, and a volume source. Three kinds of source releases are instantaneous, continuous, and finite duration releases. Four variations of the aquifer dimensions are finite depth and finite width, finite depth and infinite width, infinite depth and finite width, and infinite depth and infinite width. The mechanisms of transport included in the analysis are advection, hydrodynamic dispersion, adsorption, decay/degeneration, and waste losses to the

atmosphere. Boundary conditions included Dirichlet, Neumann, mixed type, and/or radiation boundaries. Fifty sample cases are provided to illustrate the application of AT123D to various situations.

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I. INTRODUCTION

Since the early seventies there has been an accelerating interest in the area of groundwater pollution. In recent years, several vigorous environmental monitoring programs have resulted in the identification of hundreds of sites throughout the country where groundwater resources have been polluted by hazardous wastes or are in imminent danger of contamination. A particularly tragic example is the Love Canal case near Niagara Falls, New York, where a variety of discarded hazardous chemicals entered the basements of nearby homes after traveling through the ambient groundwater (ABC News Close Up: The Killing Ground, March 29, 1979). Many Federal EPA-sponsored studies of hazardous waste disposal sites throughout the United States have shown that potentially dangerous situations are not rare, as thousands of similar sites in the United States are simply waiting for public discovery (ABC News Close Up: The Killing Ground, March 29, 1979).

Increasing public concerns of the above problems and the legal provisions of the Resource Conservation and Recovery Act of 1976, the 1974 Safe Drinking Water Act, and the 1972 amendments to the Federal Pollution Control Act have compelled industry, the public sector, and private business to carefully formulate waste management plans and evaluate disposal sites for hazardous wastes. Adequate but less time-consuming techniques are therefore needed to provide good initial estimates of the dispersion, advection, and adsorption characteristics of a specific disposal site because waste management planning is becoming less conceptual and more quantitative as the volume of wastes

increases and concern is expressed of their environmental compatability. Complete analysis of a given site requires extensive investigation, including boring, pumping tests, physical model simulations, and sophisticated numerical models, which are considered too expensive and impractical during the preliminary disposal site-selection stage. More often than not, an adequate analytical model is highly desirable and useful not only for screening alternative waste disposal sites but also for detailed planning and design of field measurements and monitoring programs. It must be emphasized that a considerable amount of time and expense would undoubtedly be saved by utilizing analytical predictive models in planning field surveys and establishing monitoring programs.

Numerous analytical models for predicting the transport and migration of hazardous wastes in the subsurface media are available (Lapidus and Amundson 1952, Davidson et al. 1968, Lindstrom and Boersma 1971, Lai and Jurinak 1972, Warrick et al. 1972, Cleary et al. 1973, Lindstrom and Stone 1974, Marino 1974, Kuo 1976, Yeh and Tsai 1976, Van Genuchten and Wierenga 1976, Selim and Mansell 1976, Wang et al. 1977). Each of these deal with a particular problem. All of them involve more or less simplification in order to render possible analytical simulation of the governing equation. For example the simplification in the early analytical solution often involve the assumption of the infinite extent of the media. Recently, progress has been made to relax this assumption by allowing both the depth and width of the aquifer to be finite.

This report presents a generalized analytical transient, one-, two-, and/or three-dimensional model (AT123D) with the computer code to

compute the spatio-temporal distribution of wastes in the aquifer system. In the search for closed-form solution, the application of Green's function is utilized to optimum advantage. There are practically no limitations on the configuration and situation of source releases and types of boundary conditions. This results from the versatility of using Green's functions. The code in fact contains 450 options: 288 for the three-dimensional case, 72 for each of the two-dimensional cases in the x-y and x-z planes, respectively, and 18 for the one-dimensional case in the longitudinal direction. The attached computer program provides the engineering community a ready tool for the preliminary assessment of waste disposal sites.

II. MATHEMATICAL STATEMENTS

As pollutants are released into groundwater, several factors contribute to their migration and transport. First of all, the solutes in the porous media will move with the mean velocity of the solvent. This mechanism is termed advection. If this were the only mechanism governing the transport of solutes, it would behave as an aggregated solid particle traveling through the media without any lengthening or spreading. In reality, the body of solute will spread because the solution does not move uniformly in the porous media, though it does in the average sense. The flow parcel travels slower near the walls of the pore than in the center; it flows faster in larger pores than in small pores; it does not travel in a particular direction but meanders randomly. This mechanism of migration is called hydraulic dispersion. Another process causing the growth in size of the solute patches is molecular diffusion. This is caused by the random Brownian motion of molecules in the solution and occurs whether the solution in the porous media is stationary or has average motion. This diffusion process is normally small compared to the hydraulic dispersion and its effects are usually combined in the term of dispersion.

In addition to advection, hydraulic dispersion and molecular diffusion, the transport and concentration of the solute(s) are affected by reversible ion exchange with the soil grains; the chemical degeneration with other constituents; fluid compression and expansion; and, in the case of radioactive wastes, by the radioactive decay. Neglecting fluid compression and, expansion, the equations governing

the distribution of contaminant is (Robertson 1974, Duguid and Reeves 1976, Yeh and Ward 1981):

$$\begin{aligned} \frac{\partial n_e C}{\partial t} = & \underbrace{a}_{\text{a}} = \underbrace{\nabla \cdot (n_e \bar{D} \nabla C)}_{\text{b}} - \underbrace{\nabla \cdot C \vec{q}}_{\text{c}} + \underbrace{\dot{M}}_{\text{d}} - \underbrace{K n_e C}_{\text{e}} - \underbrace{\lambda n_e C}_{\text{f}} \\ & - \underbrace{\left\{ \frac{\partial (\rho_b C_s)}{\partial t} + \lambda \rho_b C_s \right\}}_{\text{g}} \end{aligned} \quad (1)$$

where

$\vec{q}$ = Darcy velocity vector (LT^{-1});

$\bar{D}$ = hydraulic dispersion coefficient tensor ($L^2 T^{-1}$)

C = dissolved concentration of the solute (ML^{-3})

C_s = absorbed concentration in the solid (MM^{-1})

ρ_b = bulk density of the media (ML^{-3});

$\dot{M}$ = rate of release of source ($ML^{-3} T^{-1}$)

n_e = effective porosity (L^0)

λ = radioactive decay constant (T^{-1})

K = degradation rate (T^{-1})

Term a in Eq. (1) is the time rate of change of waste solute mass per unit volume of the aquifer water; term b, the combined effect of hydraulic dispersion and molecular diffusion; term c, the effects of advective transport; term d, the contribution of waste source; term e, the effects of first order chemical and biological degradation; term f, the effects of radioactive decay; and term g, the effects of reversible ion exchange or sorption.

The initial condition of Eq. (1) is assumed to be known:

$$C = C_i(x, y, z, 0) \text{ at } t = 0 \text{ in } R, \quad (2)$$

where C_i is a given function of spatial coordinates, x , y , and z ; R is a region bounded by the curve, $S(x,y,z) = 0$, as shown in Fig. 1. This C_i may also be obtained by simulating the steady state version of Eq. (1) with steady boundary conditions and groundwater flow field. Three types of boundary conditions may be specified depending on the physical constraints. The first type is the Dirichlet boundary condition, according to which the concentration is prescribed:

$$C = C_1(x,y,z,t) \text{ on } S_1, \quad (3)$$

where S_1 is a portion of S and C_1 is a given function of time and the location on S_1 . The second type is the Neumann boundary condition, according to which the normal gradient of the concentration is prescribed:

$$-n_e \vec{\nabla} C \cdot \vec{n} = q_2(x,y,z,t) \text{ on } S_2, \quad (4)$$

where $\vec{n}$ is the unit vector normal to the S_2 portion of the surface S , $q_2(x,y,z,t)$ is the given function of time t , and space (x,y,z) on S_2 .

A third type or mixed type (Cauchy) boundary condition, which is applied to the flow-through boundaries with flows into the region, can be written as

$$-(n_e \vec{\nabla} C \cdot \vec{n} - \vec{q}C) = q_3(x,y,z,t) \text{ on } S_3, \quad (5)$$

where q_3 is a given function of time and the point (x,y,z) , on the S_3 portion of S . If the pollutant to be modelled is heat, another type of boundary condition, referred to as radiation condition, may be specified as

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Fig. 1. Spatial boundary of the region of interest.

where

$$R_d = \text{Retardation Factor} = 1 + \rho_b K_d / n_e$$

$$\bar{K} = \text{Retarded Dispersion Tensor} = \bar{D} / R_d$$

$$\vec{U} = \text{Retarded Seepage Velocity} = (\vec{q} / n_e) / R_d$$

$$K_d = \text{Distribution coefficient}$$

The solution of Eq. 7, subject to initial and boundary conditions of Eqs. (2) through (5), is

$$\begin{aligned} C(x,y,z,t) &= \int_0^t \int_R \frac{\dot{M}}{n_e R_d} G dR_0 d\tau + \int_R (G C_i)_{\tau=0} dR_0 \\ &= \int_0^t \int_{S_1} \bar{K} \cdot \nabla G \cdot \vec{n} C_1 dS_0 d\tau - \int_0^t \int_{S_2} \frac{G q_2}{n_e R_d} dS_0 d\tau \\ &\quad - \int_0^t \int_{S_3} \frac{G q_3}{n_e R_d} dS_0 d\tau \end{aligned} \quad (8)$$

if $G(x,y,z,t; \xi, \eta, \zeta, \tau)$ satisfies the following conditions:

$$\lim_{t \rightarrow \tau} G = \delta(x - \xi) \delta(y - \eta) \delta(z - \zeta) \quad (9a)$$

$$G = 0 \quad \text{for } t < \tau \quad (9b)$$

$$G = 0 \quad \text{on } S_1 \quad (10)$$

$$(n_e \bar{D} \cdot \nabla_0 G + \vec{q} G) \cdot \vec{n} = 0 \quad \text{on } S_2 \quad (11)$$

$$n_e \bar{D} \cdot \nabla_0 G \cdot \vec{n} = 0 \quad \text{on } S_3 \quad (12)$$

$$-\bar{D} \cdot \nabla G \cdot \vec{n} + K_d^* G = 0 \quad \text{on } S_4 \quad (13)$$

and

$$-\frac{\partial G}{\partial \tau} = \nabla_0 \cdot (\bar{K} \cdot \nabla_0 G) + U \cdot \nabla G - \left(\frac{K}{R_d} + \lambda\right) G \quad \text{for } t > \tau, \quad (14)$$

where δ is the Dirac Delta function. The subscript, "o", in Eqs. (8) through (14) refers to the operation with respect to ξ, η, ζ rather than x, y, z . Eq. (8) expresses the spatio-temporal distribution of the contaminant in terms of the source/sink, $\dot{M}$, the initial condition, C_i , the boundary conditions, C_1, q_2 , and q_3 , and Green's function, G . If G is known, the problem is solved. Thus, we have effectively reduced the initial-boundary value problem of Eqs. (2) through (6) to a homogeneous problem of Eqs. (9a) through (14).

It can be shown that for simple geometry such as separable coordinate system, Green's function, G , can be expressed as:

$$G(x, y, z, t; \xi, \eta, \zeta, \tau) = G_1(x, t; \xi, \tau) G_2(y, t; \eta, \tau) G_3(z, t; \zeta, \tau) \quad (15)$$

The derivation of G_1, G_2 , and G_3 can be found elsewhere (Yeh and Tsai 1976). If we further assume that no waste can flow across the impervious boundaries and the flows through open boundaries are located at infinity, then we obtain $C_1 = 0, q_2 = 0$, and $q_3 = 0$. Under this circumstance, Eq. (8) is reduced to:

for continuous source or finite duration release and $t < T$

$$C(x, y, z, t) = \int_0^t \frac{\dot{M}}{n_e R_d} F_{ijk}(x, y, z, t; \tau) d\tau \quad (16a)$$

for finite duration source and $t > T$

$$= \int_0^T \frac{\dot{M}}{n_e R_d} F_{ijk}(x, y, z, t; \tau) d\tau \quad (16b)$$

for instantaneous source

$$= \frac{M}{n_e R_d} F_{ijk}(x, y, z, t; \tau) \quad , \quad (16c)$$

where F_{ijk} is the integral of Green's function, G , over the source space; M is the instantaneous release of total mass; and T is the duration of waste release. F_{ijk} is given by:

$$F_{ijk} = X_i Y_j Z_k \quad , \quad (17)$$

where $i = 1$ or 2 , $j = 1, 2, 3$, or 4 , and $k = 1, 2, 3$, or 4 . Functions X_i , Y_j , and Z_k are given by Eqs. (18) through (27) for three-dimensional cases as follows:

for point source in the x-direction:

$$X_1 = \frac{1}{\sqrt{4\pi K_{xx}(t-\tau)}} \exp \left[- \frac{\{(x-x_s) - U(t-\tau)\}^2}{4K_{xx}(t-\tau)} - \left(\frac{K}{R_d} + \lambda\right)(t-\tau) \right] \quad (18)$$

for line source in the x-direction:

$$X_2 = \frac{1}{2} \left\{ \operatorname{erf}\left(\frac{x-L_1 - U(t-\tau)}{\sqrt{4K_{xx}(t-\tau)}}\right) - \operatorname{erf}\left(\frac{x-L_2 - U(t-\tau)}{\sqrt{4K_{xx}(t-\tau)}}\right) \right\} \cdot \exp \left[- \left(\frac{K}{R_d} + \lambda\right)(t-\tau) \right] \quad (19)$$

for finite width and point source in the y-direction:

$$Y_1 = \frac{1}{B} + \frac{2}{B} \sum_{i=1}^{\infty} \cos\left(\frac{i\pi y}{B}\right) \cdot \cos\left(\frac{i\pi y_s}{B}\right) \cdot \exp \left[- \left(\frac{i\pi}{B}\right)^2 K_{yy}(t-\tau) \right] \quad (20)$$

for finite width and line source in the y-direction:

$$Y_2 = \frac{B_2 - B_1}{B} + \frac{2}{B} \sum_{i=1}^{\infty} \cos\left(\frac{i\pi y}{B}\right) \cdot \frac{B}{\pi} \left\{ \sin\left(\frac{i\pi B_2}{B}\right) - \sin\left(\frac{i\pi B_1}{B}\right) \right\} \exp \left[- \left(\frac{i\pi}{B}\right)^2 K_{yy}(t-\tau) \right] \quad (21)$$

for infinite width and point source in the y-direction:

$$Y_3 = \frac{1}{\sqrt{4\pi K_{yy}(t-\tau)}} \exp \left[-\frac{(y-y_s)^2}{4K_{yy}(t-\tau)} \right] \quad (22)$$

for infinite width and line source in the y-direction:

$$Y_4 = \frac{1}{2} \left\{ \operatorname{erf} \left(\frac{y-B_1}{\sqrt{4K_{yy}(t-\tau)}} \right) - \operatorname{erf} \left(\frac{y-B_2}{\sqrt{4K_{yy}(t-\tau)}} \right) \right\} \quad (23)$$

for finite depth and point source in the z-direction:

$$Z_1 = \sum_{i=1}^{\infty} \Psi_i(z) \Psi_i(z_s) \cdot \exp \left[-\kappa_i^2 K_{zz}(t-\tau) \right] \quad (24)$$

for finite depth and line source in the z-direction:

$$Z_2 = \sum_{i=1}^{\infty} \Psi_i(z) \left(\frac{a_i}{\kappa_i} \right) \left\{ \sin(\kappa_i H_2) - \sin(\kappa_i H_1) - \frac{K_{zz}^*}{K_{zz} \kappa_i} [\cos(\kappa_i H_2) - \cos(\kappa_i H_1)] \right\} \cdot \exp \left[-\kappa_i^2 K_{zz}(t-\tau) \right] \quad (25)$$

for infinite depth and point source in the z-direction:

$$Z_3 = \frac{1}{\sqrt{4\pi K_{zz}(t-\tau)}} \left\{ \exp \left[-\frac{(z-z_s)^2}{4K_{zz}(t-\tau)} \right] + \exp \left[-\frac{(z+z_s)^2}{4K_{zz}(t-\tau)} \right] \right\} \\ - \frac{K_{zz}^*}{K_{zz}} \exp \left[K_{zz} \left(\frac{K_{zz}^*}{K_{zz}} \right)^2 (t-\tau) + \left(\frac{K_{zz}^*}{K_{zz}} \right) (z+z_s) \right] \cdot \\ \operatorname{erfc} \left[\frac{z+z_s}{\sqrt{4K_{zz}(t-\tau)}} + \frac{K_{zz}^*}{K_{zz}} \sqrt{K_{zz}(t-\tau)} \right] \quad (26)$$

for infinite depth and line source in the z-direction:

$$\begin{aligned}
 Z_4 = & \frac{1}{2} \left\{ \operatorname{erf} \left[\frac{z+H_2}{\sqrt{4K_{zz}(t-\tau)}} \right] - \operatorname{erf} \left[\frac{z+H_1}{\sqrt{4K_{zz}(t-\tau)}} \right] - \operatorname{erf} \left[\frac{z-H_2}{\sqrt{4K_{zz}(t-\tau)}} \right] \right. \\
 & \left. + \operatorname{erf} \left[\frac{z-H_1}{\sqrt{4K_{zz}(t-\tau)}} \right] \right\} - \exp \left[K_{zz} \left(\frac{K_e^*}{K_{zz}} \right)^2 (t-\tau) \right] \cdot \\
 & \left\{ \exp \left[\left(\frac{K_e^*}{K_{zz}} \right) (z+H_2) \right] \cdot \operatorname{erfc} \left[\frac{z+H_2}{\sqrt{4K_{zz}(t-\tau)}} + \left(\frac{K_e^*}{K_{zz}} \right) \sqrt{K_{zz}(t-\tau)} \right] \right. \\
 & \left. - \exp \left[\left(\frac{K_e^*}{K_{zz}} \right) (z+H_1) \right] \cdot \operatorname{erfc} \left[\frac{z+H_1}{\sqrt{4K_{zz}(t-\tau)}} + \left(\frac{K_e^*}{K_{zz}} \right) \sqrt{K_{zz}(t-\tau)} \right] \right\} \\
 & - \left\{ \operatorname{erf} \left[\frac{z+H_2}{\sqrt{4K_{zz}(t-\tau)}} \right] - \operatorname{erf} \left[\frac{z+H_1}{\sqrt{4K_{zz}(t-\tau)}} \right] \right\}
 \end{aligned} \quad (27)$$

where B and H are the width and depth of the aquifer; L_1, B_1, H_1 and L_2, B_2, H_2 are the beginning x, y, z and the ending x, y, z coordinates of the source; x_s, y_s , and z_s are the x, y, and z coordinates of the point source. In Eqs. (24) and (25), $\psi_i(z)$ denotes the function:

$$\psi_i(z) = a_i \left\{ \cos(\kappa_i z) + \frac{K_e^*}{K_{zz} \kappa_i} \sin(\kappa_i z) \right\}, \quad (28)$$

where κ_i and a_i are given by the following equations:

$$\tan(\kappa_i H) = \frac{K_e^*}{K_{zz} \kappa_i} \quad (29)$$

and

$$a_i^2 = \frac{2}{H \{1 + (K_e^*/K_{zz} \kappa_i)^2 + (K_e^*/K_{zz} \kappa_i)\}} \quad (30)$$

To apply the above equations to two-dimensional cases in the x-y plane, one has to set $Z_k = 1$ ($k = 1, 2, \dots, 4$). Similarly for the two-dimensional cases in the x-z plane, one has to set $Y_j = 1$ ($j = 1, 2, \dots, 4$) and for the one dimensional cases, say x-direction, one simply sets both i_j and Z_k equal to 1.

In practical computation, Eqs. (20) and (21) often converge very slowly when $K_{yy}(t-\tau)/B^2$ is small. Under such circumstances, the following equations, which are obtained by the method of image, are used:

$$\begin{aligned} Y_1 = \frac{1}{\sqrt{4 K_{yy}(t-\tau)}} & \left\{ \sum_{n=0}^{\infty} \exp \left[- \frac{\{(y-y_s)-2nB\}^2}{4K_{yy}(t-\tau)} \right] + \sum_{n=0}^{\infty} \exp \left[- \frac{\{(y-y_s)-2(n-1)B\}^2}{4K_{yy}(t-\tau)} \right] \right. \\ & \left. + \sum_{n=0}^{\infty} \exp \left[- \frac{\{(y+y_s)-2(n+1)B\}^2}{4K_{yy}(t-\tau)} \right] + \sum_{n=0}^{\infty} \exp \left[- \frac{\{(y+y_s)-2nB\}^2}{4K_{yy}(t-\tau)} \right] \right\} \end{aligned}$$

(31)

$$\begin{aligned}
Y_2 = & \frac{1}{2} \sum_{n=0}^{\infty} \left\{ \operatorname{erf} \left[\frac{(y-B_1)-2nB}{\sqrt{4K_{yy}(t-\tau)}} \right] - \operatorname{erf} \left[\frac{(y-B_2)-2nB}{\sqrt{4K_{yy}(t-\tau)}} \right] \right. \\
& + \operatorname{erf} \left[\frac{y-B_1-2(n-1)B}{\sqrt{4K_{yy}(t-\tau)}} \right] - \operatorname{erf} \left[\frac{y-B_2-2(n-1)B}{\sqrt{4K_{yy}(t-\tau)}} \right] \\
& + \operatorname{erf} \left[\frac{y+B_2-2(n+1)B}{\sqrt{4K_{yy}(t-\tau)}} \right] - \operatorname{erf} \left[\frac{y+B_1-2(n+1)B}{\sqrt{4K_{yy}(t-\tau)}} \right] \\
& \left. + \operatorname{erf} \left[\frac{y+B_2-2nB}{\sqrt{4K_{yy}(t-\tau)}} \right] - \operatorname{erf} \left[\frac{y+B_1-2nB}{\sqrt{4K_{yy}(t-\tau)}} \right] \right\}
\end{aligned} \tag{32}$$

It is seen that 32 equations may be obtained for the spatial integral of Green's function, F_{ijk} . These are F_{111} , F_{112} , ... and F_{244} . Substitution of each of those 32 equations into Eqs. (16a), (16b), and (16c) would yield 96 equations. Since each equation is applicable to any of three wastes, there would be 288 options when all three spatial dimensions are considered. Careful adoption of source distribution and media size would yield 72 two-dimensional options each in the x-y plane and x-z plane, respectively, and 18 options for the one-dimensional along the longitudinal direction. AT123D computer code is developed to perform the integration of Eqs. (16a), (16b) and (16c).

IV. PARAMETER SPECIFICATIONS

The applications of AT123D to practical problems require: (a) the geometry of the region of interest; (b) the dispersion coefficient tensor, $\bar{K}$, characterized by its components, K_{xx} , K_{yy} , K_{zz} ; (c) the soil properties, n_e , ρ_b , and the hydraulic conductivity, K_h ; (d) the source/sink strength and configuration, $\dot{M}$, and x_s , y_s , z_s , or L_1 , L_2 , B_1 , B_2 , H_1 , and H_2 ; (e) the parameter representing the waste-soil interaction, K_d ; and (f) the pressure field of the flow and the decay constant, λ . Among these inputs, K_{xx} , K_{yy} , and K_{zz} are perhaps the most difficult ones to determine. No effective way is currently practical to measure these coefficients in the field because of the aquifer inhomogeneities (Bredehoft and Pinder 1973, Robertson 1974). Tensor analysis indicates that they would be a linear function of the groundwater velocity (Bear 1972). For our case, we may write:

$$K_{xx} = \alpha_L U; K_{yy} = \alpha_T U; K_{zz} = \alpha_V U, \quad (18)$$

where α_L , α_T and α_V are the longitudinal, transverse, and vertical dispersivities, respectively. The distribution coefficient, K_d , should be determined by batch test or column test. The decay constant, λ , is a function of radwastes. The pressure field, which may be obtained either by numerical simulation of flow equation or by field mapping of well data, and hydraulic conductivity are used to compute the velocity.

Typical values of the effective porosity, hydraulic conductivity, and the dispersivities for sand, silt, and clay are listed in Table 1 (Eagleson 1970, Bredehoeft and Pinder 1973, Robertson 1974). These values are intended to provide guidelines for these parameters. For actual application, soil measurements should be made to determine the effective porosity and hydraulic conductivity. Dispersivities should be obtained by calibration against field data (Robertson 1974) or they may be extrapolated from values that have been calibrated from similar aquifer system. Based on the field experimental results, the dispersivity varies with aquifer materials, the more permeable an aquifer, the higher the dispersivity. Thus, the values of α_L , α_T , and α_y may be modified by the permeability factor from the calibrated values.

Table 1. Typical values of effective porosity, hydraulic conductivity, dispersivity, and bulk density

	Sand	Silt	Clay
Effective porosity, n_e	0.1 ~ 0.3	0.05 ~ 0.1	0.03 ~ 0.05
Hydraulic conductivity K_h (cm/sec)	$10^{-1} \sim 10^{-2}$	$10^{-3} \sim 10^{-4}$	$10^{-5} \sim 10^{-6}$
Longitudinal dispersivity α_L (m)	10 ~ 100	1 ~ 10	0.1 ~ 1.0
Transverse dispersivity α_T (m)	1 ~ 10	0.1 ~ 1.0	0.01 ~ 0.1
Vertical dispersivity α_V (m)	1 ~ 10	0.1 ~ 1.0	0.01 ~ 0.1
Bulk density, ρ_b gram/cm ³	1.18 ~ 1.58	1.29 ~ 1.8	1.4 ~ 2.2

V. SAMPLE PROBLEM

To illustrate the application of AT123D code, radwaste will be assumed to be released into an aquifer system continuously. For simplicity, the release rate will be assumed constant, although the code takes care of the time-dependent rate. Thirty-two (32) sample problems are performed for the three-dimensional application. In addition, 8 sample problems each for the two-dimensional cases in the x-y and x-z planes, respectively, and two sample problems for the one-dimensional case in the longitudinal direction are illustrated. These fifty cases are listed in Table 2. Inputs of these sample problems are given in Appendix B. Output of four sample cases are also included in Appendix B. Output of all fifty cases are given in the microfiche which is attached in the inside page of the back cover. Preparation of input data is given in Appendix A and a listing of FORTRAN source program is given in Appendix C.

For the sample problems, porosity, n_e , of the aquifer is assumed to be 0.2. The hydraulic conductivity, K_h , is assumed to be 0.5 mhr⁻¹. A hydraulic gradient of 0.05 is assumed along the longitudinal direction which results in a velocity of 0.025 m hr⁻¹. Typical values of longitudinal, transverse, and vertical dispersivities, α_L , α_T , and α_V , are assumed to be 30.0, 5.0, and 5.0 meters, respectively for silty sand. A distribution coefficient, K_d , of 10 cm³/gram is used to represent the absorption of strontium in the silty sand. Bulk density, ρ_b of the soil is assumed to be 1.4 gram/cm³. Decay constant, λ , of 2.83×10^{-6} hr⁻¹ is used. This decay constant is equivalent to a half life of 28 years. The source location is at $(x_s, y_s, z_s) = (0, 10, 1)$ in the example of point source.

Table 2. List of sample problems

Sample problem case	Aquifer geometry				Source Configuration					
	FW	IW	FD	ID	X-direction		Y-direction		Z-direction	
					PS	LS	PS	LS	PS	LS
1	x		x		x		x		x	
2	x		x			x	x		x	
3	x		x		x			x	x	
4	x		x		x		x			x
5	x		x		x			x		x
6	x		x			x	x			x
7	x		x			x		x	x	
8	x		x			x		x		x
9	x			x	x		x		x	
10	x			x		x	x		x	
11	x			x	x			x	x	
12	x			x	x		x			x
13	x			x	x			x		x
14	x			x		x	x			x
15	x			x		x		x	x	
16	x			x		x		x		x
17		x	x		x		x		x	
18		x	x			x	x		x	
19		x	x		x			x	x	
20		x	x		x		x			x
21		x	x		x			x		x
22		x	x			x	x			x
23		x	x			x		x	x	
24		x	x			x		x		x
25		x		x	x		x		x	
26		x		x		x	x		x	
27		x		x	x			x	x	
28		x		x	x		x			x
29		x		x	x			x		x
30		x		x		x	x			x
31		x		x		x		x	x	
32		x		x		x		x		x
33	x		x		x		x			x
34	x		x			x	x			x
35	x		x		x			x		x
36	x		x			x		x		x
37		x	x		x		x			x
38		x	x			x	x			x
39		x	x		x			x		x
40		x	x			x		x		x
41	x		x		x			x	x	
42	x		x			x		x	x	
43	x		x		x			x		x
44	x		x			x		x		x
45	x			x	x			x	x	
46	x			x		x		x	x	
47	x			x	x			x		x
48	x			x		x		x		x
49	x		x		x			x		x
50	x		x			x		x		x

FW = finite width, IW = infinite width, FD = finite depth, ID = infinite depth,
 PS = point source, LS = line source.

In the example of volume source, the following source dimensions are used: $L_1 = 0.0$ meter, $L_2 = 5.0$ meter, $B_1 = 0.0$ meter, $B_2 = 20.0$ meters, $H_1 = 0.0$ meters and $H_2 = 2.0$ meters. When the finite width is used, a width of $B = 200$ meters is assumed. If the finite depth option is used, a depth of $H = 10$ meters is assumed. These source dimensions are shown in Fig. 2.

It should be noted that if the code is applied for a two-dimensional problem in the x-y plane (sample cases 33-40), one has to input $H_1 = 0$ and $H_2 = H$. Similarly, if the model is employed for a two-dimensional problem in the x-z plane (sample cases 41-43), one just uses input $B_1 = 0$ and $B_2 = B$. For the reduction to one-dimensional problem in the longitudinal direction (sample cases 49 and 50), one has to input $B_1 = 0$ and $B_2 = B$ as well as $H_1 = 0$ and $H_2 = H$.

The following sample cases are intended to illustrate the effect of source configurations and sizes of the media on the distribution of the radionuclides. Sample case no. 1 in Appendix B presents the concentration distribution as a result of the continuous release of radwaste with a rate of 1.0 Ci/hr and lasting for 240 hours. A point source configuration is assumed and it is discharged into a three-dimensional media with finite depth and finite width. Initially, the media is clean and the concentration at time = 0 hour is zero everywhere. At the end of 1224 hours, the concentration at the point $(x,y,z) = (10,10,2)$ is 33300 pCi/liter. At the point $(x,y,z) = (60,10,2)$, the concentration has decreased to 0.0269 pCi/liter. Had

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Fig. 2. Schematization of source dimensions and the medium.

the dispersion not been included, the concentration at both points would have been zero since the retarded velocity is 0.176×10^{-2} m/hr, thus the mean front of the waste has traveled only to $x = 2.16$ m at the end of 1224 hours. It should be pointed out that at the end of 1224 hours, the decay mechanism would not significantly attenuate the concentration because the half life of 28 years is relatively much longer than the simulation time

Sample case no. 39 shows the concentration distribution of 240 hour continuous release with a rate of 1.0 Ci/hr. A line source configuration parallel to y-direction is assumed and it is discharged into the two-dimensional media in the x-y plane. At the end of 1224 hours, the concentration at points, $(x,y,z) = (10,10,2)$ and $(x,y,z) = (60,10,2)$, are 2310 pCi/liter and 0.0023 pCi/liter, respectively. These values are smaller than those in the above sample case because complete mixing is assumed in the vertical direction. It is noted that the concentration distribution in the vertical direction is uniform as expected. For example, the x-y distribution of the concentration on $z = 2$ m is identical to that on $z = 4$ m.

Sample case no. 48 illustrates the distribution as a result of continuous release into the two-dimensional media in the x-z plane. The release configuration is assumed to be an area source. At the end of 1224 hours, the concentration at points, $(x,y,z) = (10,10,2)$ and $(x,y,z) = (60,10,2)$, are 657.0 pCi/liter and 0.00218 pCi/liter, respectively. Finally, sample case no. 50 shows the concentration distribution resulting from a volume release into a one-dimensional media in the x-direction. As expected, the concentration in the y- and z-directions are uniform.

VI. NOTATION

a_i	A coefficient defined by Eq. (30)
B	Width of the aquifer
B_1	Beginning coordinate of the source in the y-direction
B_2	Ending coordinate of the source in the y-direction
C	Concentration
C_i	Initial concentration
C_1	Concentration on the boundary S_1
C_s	Absorbed concentration in the solid grain
D	Dispersion tension
FD	Finite depth
F_{ijk}	A function defined by Eq. (17)
FW	Finite width
g	gravity
G	Green's function
G_1	Subgreen's function
G_2	Subgreen's function
G_3	Subgreen's function
H	Depth of the aquifer
H_1	Beginning coordinate of the source in the z-direction
H_2	Ending coordinate of the source in the z-direction
ID	Infinity deep
IW	Infinity wide
K	Chemical degeneration rate
K_e^r	Modified heat exchange coefficient

K_d	Distribution coefficient
$\bar{K}$	Retarded dispersion tensor
K_{xx}	x-component of the retarded dispersion tensor
K_{yy}	y-component of the retarded dispersion tensor
K_{zz}	z-component of the retarded dispersion tensor
L_1	Beginning coordinate of the source in the x-direction
L_2	Ending coordinate of the source in the x-direction
LS	Line source
M	Source rate
M	Total source
n_e	Porosity
$\vec{n}$	An outward unit vector normal to a surface
PS	Point source
$\vec{q}$	Darcy's velocity vector
q_2	Flux through boundary S_2
q_3	Flux through boundary S_3
R	A region with respect to x, y, z
R_d	Retardation factor
R_0	A region with respect to ξ, η, ζ
S	The boundary of R
S_1	Part of S
S_2	Part of S
S_3	Part of S
S_4	Part of S
t	Time

$\vec{U}$	Retarded velocity vector
U	The magnitude of $\vec{U}$
x	Longitudinal coordinate
x_s	x -coordinate of a point source
x_i	Either function x_1 or x_2
x_1	A function defined by Eq. (18)
x_2	A function defined by Eq. (19)
y	Transfer coordinate
y_s	y -coordinate of a point source
y_j	Either function y_1, y_2, y_3, y_4
y_1	A function defined by Eq. (20)
y_2	A function defined by Eq. (21)
y_3	A function defined by Eq. (22)
y_4	A function defined by Eq. (23)
z	Vertical coordinate
z_s	z -coordinate of a point source
z_k	k -th Z -function
z_1	A function defined by Eq. (24)
z_2	A function defined by Eq. (25)
z_3	A function defined by Eq. (26)
z_4	A function defined by Eq. (27)
α_L	Longitudinal dispersivity
α_T	Transverse dispersivity
α_V	Vertical dispersivity
∇	Del operator with respect to x, y, z
∇_0	Del operator with respect to ξ, η, ζ

λ	Decay constant
ρ_b	Bulk density
τ	Time
ξ	Longitudinal coordinate
η	Transverse coordinate
ζ	Vertical coordinate
κ_i	i -th eigenvalue defined by Eq. (29)
ψ_i	i -th eigenfunction defined by Eq. (28)

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1. TITLE: Format (20A4) one card per problem

TITLE

TITLE = Array for the title of the problem. It may contain up to 80 characters.

2. Basic Integer Parameters: Format (16I5) one card

NX	NY	NZ	NROOT	NBGTI	NEDTI	NPRINT	INSTAN
5	10	15	20	25	30	35	40

NSOUS	INTER	ICASE	IDEP	IWID	IBUG		
45	50	55	60	65	70	75	80

NX = Number of points in the x-direction where the solution is desired.

NY = Number of points in the y-direction where the solution is desired.

NZ = Number of points in the z-direction where the solution is desired.

NROOT = Number of eigenvalues required for series evaluation.

NBGTI = Number of beginning time in terms of DT when the solution is desired.

NEDTI = Number of ending time in terms of DT when the solution is desired.

NPRINT = An integer parameter indicating that for every NPRINT time steps the solution is desired

INSTAN = An integer parameter indicating if the release is an instantaneous release or not; = 0 instantaneous release, = 1 continuous release.

NSOUS = An integer parameter indicating if the source is constant or changing with time: = 0 constant source, ≠ 0 NSOUS data points as function of time are required.

INTER = An integer parameter indicating if intermittent solutions between NBGTI and NEDTI are to be line-printed: = 0 No, = 1 yes

- ICASE = An integer parameter indicating what type of waste is being simulated: = 1 for heat, = 2 for chemical, = 3 for radwaste.
- IWID = An integer parameter indicating if the media is infinity or not in the y-direction; = 0 yes, = 1 no.
- IDEP = An integer parameter indicating if the aquifer is infinitely deep: = 0 yes, = 1 no.
- IBUG = An integer parameter indicating if the diagnostic check is desired or not: = 0 no, = 1 yes. For debugging, IBUG is normally set to 1. For production, IBUG is normally set to zero.

3. Aquifer Size and Source Size: Format (8F10.0)

DEPTH	WIDTH	RL1	RL2	RB1	RB2	RH1	RH2
10	20	30	40	50	60	70	80

- DEPTH = Aquifer depth, (L)
- WIDTH = Aquifer width, (L)
- RL1 = Beginning coordinate of the source in the x-direction, (L)
- RL2 = Ending coordinate of the source in the x-direction, (L)
- RB1 = Beginning coordinate of the source in the y-direction, (L)
- RB2 = Ending coordinate of the source in the y-direction, (L)
- RH1 = Beginning coordinate of the source in the z-direction, (L)
- RH2 = Ending coordinate of the source in the z-direction, (L)

4. Soil and Waste Properties: Format (8F10.0)

POR	HCOND	HGRAD	AELONG	ATRANV	AVERTI	AKD	AKE
10	20	30	40	50	60	70	80

- POR = Porosity of the soil
- HCOND = Hydraulic conductivity, (LT⁻¹)

HGRAD = Hydraulic gradient
 AELONG = Longitudinal dispersivity, (L)
 ATRANV = Transverse dispersivity, (L)
 AVERTI = Vertical dispersivity, (L)
 AKD = Distribution coefficient, (L^3M^{-1})
 AKE = Modified heat exchange coefficient, (LT^{-1})

5. More soil and waste properties and some real number parameters:
 FORMAT (3F10.0)

AMTAU	RAMADA	RHOB	RHOW	ACCU	DT	TDISP	Q
10	20	30	40	50	60	70	80

AMTAU = Molecular diffusion coefficient, (L^2T^{-1})
 RAMADA = Decay constant (T^{-1})
 RHOB = Bulk density of the soil, (ML^{-3})
 RHOW = Density of water, (ML^{-3})
 ACCU = Error tolerance if steady-state solution is desired
 DT = Time step size for which the solution is desired, (T)
 TDISP = Time duration of waste release, (T)
 Q = Constant waste release rate or total instantaneous release, (MT^{-1})

6. X-SPACE Coordinate: Format (8F10.0)

Number of cards depend on NX: READ (XDIM(I), I = 1, NX).

XDIM(1)	XDIM(2)	---	---	---	---	---	---
10	20	30	40	50	60	70	80

XDIM(I) = x-coordinate of I-th point in the x-direction, where the solution is desired, (L)

7. Y-Space Coordinate: FORMAT (8F10.0)

Number of cards depend on NY: READ (YDIM(I), I = 1, NY).

YDIM(1)	YDIM(2)	---	---	---	---	---	---
10	20	30	40	50	60	70	80

YDIM(I) = y-coordinate of I-th point in the y-direction where the solution is desired, (L)

8. Z-Space Coordinate: FORMAT (8F10.0)

Number of cards depends on NZ: READ (ZDIM(I), I = 1, NZ).

ZDIM(1)	ZDIM(2)	---	---	---	---	---	---
10	20	30	40	50	60	70	80

ZDIM(I) = z-coordinate of the I-th point in the z-direction where the solution is desired, (L)

9. Variably Source Release Rate: FORMAT (8F10.0)

The number of cards depends on NSORS. This group of cards is required only if NSORS > 0. READ (QS(I), I = 1, NSORS).

QS(1)	QS(2)	---	---	---	---	---	---
10	20	30	40	50	60	70	80

QS(1) = waste release rate at time = (I-1)*DT, (MT-1)

APPENDIX B INPUT AND OUTPUT OF SAMPLE CASES

B.1 INPUT DATA OF ALL FIFTY CASES

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 1									
6	2	1000	101	103	1	1	0	3	1
10.0	200.0	0.0	0.0	10.0	10.0	1.0	1.0		
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0		
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0		
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0		
0.0	5.0	10.0	15.0	20.0	25.0				
2.0	4.0								

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 2									
6	2	1000	101	103	1	1	0	3	1
10.0	200.0	0.0	0.0	10.0	10.0	1.0	1.0		
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0		
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0		
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0		
0.0	5.0	10.0	15.0	20.0	25.0				
2.0	4.0								

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 3									
6	2	1000	101	103	1	1	0	3	1
10.0	200.0	0.0	0.0	10.0	10.0	1.0	1.0		
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0		
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0		
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0		
0.0	5.0	10.0	15.0	20.0	25.0				
2.0	4.0								

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 4									
6	2	1000	101	103	1	1	0	3	1
10.0	200.0	0.0	0.0	10.0	10.0	0.0	2.0		
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0		
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0		
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0		
0.0	5.0	10.0	15.0	20.0	25.0				
2.0	4.0								

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 5									
6	2	1000	101	103	1	1	0	3	1
10.0	200.0	0.0	0.0	10.0	10.0	0.0	2.0		
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0		
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0		
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0		
0.0	5.0	10.0	15.0	20.0	25.0				
2.0	4.0								

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 6									
6	2	1000	101	103	1	1	0	3	1
10.0	200.0	0.0	0.0	10.0	10.0	0.0	2.0		
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0		
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0		
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0		
0.0	5.0	10.0	15.0	20.0	25.0				
2.0	4.0								

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 7									
6	2	1000	101	103	1	1	0	3	1
10.0	200.0	0.0	0.0	10.0	10.0	0.0	2.0		
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0		
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0		
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0		
0.0	5.0	10.0	15.0	20.0	25.0				
2.0	4.0								

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CARD 050

B.1 INPUT DATA OF ALL FIFTY CASES (continued)

10.0	200.0	0.0	5.0	0.0	20.0	1.0	1.0
0.2	0.5	0.05	10.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
6	RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 8						
10.0	200.0	0.0	5.0	0.0	20.0	0.0	2.0
0.2	0.5	0.05	10.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
6	RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 9						
10.0	200.0	0.0	5.0	10.0	10.0	1.0	1.0
0.2	0.5	0.05	10.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
6	RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 10						
10.0	200.0	0.0	5.0	10.0	10.0	1.0	1.0
0.2	0.5	0.05	10.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
6	RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 11						
10.0	200.0	0.0	0.0	0.0	20.0	1.0	1.0
0.2	0.5	0.05	10.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
6	RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 12						
10.0	200.0	0.0	0.0	10.0	10.0	0.0	2.0
0.2	0.5	0.05	10.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
6	RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 13						
10.0	200.0	0.0	0.0	0.0	20.0	0.0	2.0
0.2	0.5	0.05	10.0	5.0	5.0	0.01	0.0

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CARD 100

B.1 INPUT DATA OF ALL FIFTY CASES (continued)

0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0	CARD 101
10.0	30.0	10.0	40.0	50.0	60.0	70.0	80.0	CARD 102
0.0	5.0	10.0	15.0	20.0	25.0			CARD 103
2.0	4.0							CARD 104
6	6	6	6	6	6	6	6	CARD 105
10.0	200.0	101	103	1	10.0	0.0	0	CARD 106
0.0	0.5	0.05	30.0	5.0	5.0	0.01	2.0	CARD 107
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0	CARD 108
10.0	30.0	10.0	40.0	50.0	60.0	70.0	80.0	CARD 109
0.0	5.0	10.0	15.0	20.0	25.0			CARD 110
2.0	4.0							CARD 111
6	6	6	6	6	6	6	6	CARD 112
10.0	200.0	101	103	1	10.0	0.0	0	CARD 113
0.0	0.5	0.05	30.0	5.0	5.0	0.01	1.0	CARD 114
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0	CARD 115
10.0	30.0	10.0	40.0	50.0	60.0	70.0	80.0	CARD 116
0.0	5.0	10.0	15.0	20.0	25.0			CARD 117
2.0	4.0							CARD 118
6	6	6	6	6	6	6	6	CARD 119
10.0	200.0	101	103	1	10.0	0.0	0	CARD 120
0.0	0.5	0.05	30.0	5.0	5.0	0.01	1.0	CARD 121
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0	CARD 122
10.0	30.0	10.0	40.0	50.0	60.0	70.0	80.0	CARD 123
0.0	5.0	10.0	15.0	20.0	25.0			CARD 124
2.0	4.0							CARD 125
6	6	6	6	6	6	6	6	CARD 126
10.0	200.0	101	103	1	10.0	0.0	0	CARD 127
0.0	0.5	0.05	30.0	5.0	5.0	0.01	1.0	CARD 128
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0	CARD 129
10.0	30.0	10.0	40.0	50.0	60.0	70.0	80.0	CARD 130
0.0	5.0	10.0	15.0	20.0	25.0			CARD 131
2.0	4.0							CARD 132
6	6	6	6	6	6	6	6	CARD 133
10.0	200.0	101	103	1	10.0	0.0	0	CARD 134
0.0	0.5	0.05	30.0	5.0	5.0	0.01	1.0	CARD 135
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0	CARD 136
10.0	30.0	10.0	40.0	50.0	60.0	70.0	80.0	CARD 137
0.0	5.0	10.0	15.0	20.0	25.0			CARD 138
2.0	4.0							CARD 139
6	6	6	6	6	6	6	6	CARD 140
10.0	200.0	101	103	1	10.0	0.0	0	CARD 141
0.0	0.5	0.05	30.0	5.0	5.0	0.01	1.0	CARD 142
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0	CARD 143
10.0	30.0	10.0	40.0	50.0	60.0	70.0	80.0	CARD 144
0.0	5.0	10.0	15.0	20.0	25.0			CARD 145
2.0	4.0							CARD 146
6	6	6	6	6	6	6	6	CARD 147
10.0	200.0	101	103	1	10.0	0.0	0	CARD 148
0.0	0.5	0.05	30.0	5.0	5.0	0.01	1.0	CARD 149
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0	CARD 150
10.0	30.0	10.0	40.0	50.0	60.0	70.0	80.0	CARD 151

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CARD 200

B.1 INPUT DATA OF ALL FIFTY CASES (continued)

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 26										
	6	2	1000	101	103	1	1	0	3	0
10.0	200.0	0.0	5.0	10.0	10.0	1.0	1.0			
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0			
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0			
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0			
0.0	5.0	10.0	15.0	20.0	25.0					
2.0	4.0									

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 27										
	6	2	1000	101	103	1	1	0	3	0
10.0	200.0	0.0	5.0	10.0	10.0	1.0	1.0			
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0			
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0			
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0			
0.0	5.0	10.0	15.0	20.0	25.0					
2.0	4.0									

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 28										
	6	2	1000	101	103	1	1	0	3	0
10.0	200.0	0.0	5.0	10.0	10.0	0.0	2.0			
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0			
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0			
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0			
0.0	5.0	10.0	15.0	20.0	25.0					
2.0	4.0									

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 29										
	6	2	1000	101	103	1	1	0	3	0
10.0	200.0	0.0	5.0	10.0	10.0	0.0	2.0			
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0			
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0			
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0			
0.0	5.0	10.0	15.0	20.0	25.0					
2.0	4.0									

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 30										
	6	2	1000	101	103	1	1	0	3	0
10.0	200.0	0.0	5.0	10.0	10.0	0.0	2.0			
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0			
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0			
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0			
0.0	5.0	10.0	15.0	20.0	25.0					
2.0	4.0									

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 31										
	6	2	1000	101	103	1	1	0	3	0
10.0	200.0	0.0	5.0	10.0	10.0	1.0	1.0			
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0			
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0			
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0			
0.0	5.0	10.0	15.0	20.0	25.0					
2.0	4.0									

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 32										
	6	2	1000	101	103	1	1	0	3	0
10.0	200.0	0.0	5.0	10.0	10.0	1.0	1.0			
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0			
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0			
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0			
0.0	5.0	10.0	15.0	20.0	25.0					
2.0	4.0									

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CARD 250

B.1 INPUT DATA OF ALL FIFTY CASES (continued)

10.0	200.0	0.0	5.0	0.0	20.0	0.0	2.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 33							
10.0	200.0	0.0	5.0	0.0	20.0	0.0	2.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 34							
10.0	200.0	0.0	5.0	0.0	20.0	0.0	2.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 35							
10.0	200.0	0.0	5.0	0.0	20.0	0.0	2.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 36							
10.0	200.0	0.0	5.0	0.0	20.0	0.0	2.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 37							
10.0	200.0	0.0	5.0	0.0	20.0	0.0	2.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 38							
10.0	200.0	0.0	5.0	0.0	20.0	0.0	2.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0

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CARD 300

B.1 INPUT DATA OF ALL FIFTY CASES (continued)

0.0	0.00000293	1400.0	1000.0	0.021	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
	RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 39						
6	2 1000	101 103	1	1	0	3	0
10.0	200.0	0.0	0.0	0.0	20.0	0.0	10.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.021	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
	RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 40						
6	2 1000	101 103	1	1	0	3	0
10.0	200.0	0.0	5.0	0.0	20.0	0.0	10.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000293	1400.0	1000.0	0.021	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
	RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 41						
6	2 1000	101 103	1	1	0	3	1
10.0	200.0	0.0	0.0	0.0	200.0	1.0	1.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.021	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
	RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 42						
6	2 1000	101 103	1	1	0	3	1
10.0	200.0	0.0	5.0	0.0	200.0	1.0	1.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.021	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
	RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 43						
6	2 1000	101 103	1	1	0	3	1
10.0	200.0	0.0	0.0	0.0	200.0	0.0	2.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.021	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
	RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 44						
6	2 1000	101 103	1	1	0	3	1
10.0	200.0	0.0	5.0	0.0	200.0	0.0	2.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000293	1400.0	1000.0	0.021	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0

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CARD 350

B.1 INPUT DATA OF ALL FIFTY CASES (continued)

	0.0	5.0	10.0	15.0	20.0	25.0	
2.0	4.0						
10.0	6	200.0	0.0	0.0	0.0	200.0	1.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
10.0	6	200.0	0.0	5.0	0.0	200.0	1.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
10.0	6	200.0	0.0	0.0	0.0	200.0	0.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
10.0	6	200.0	0.0	5.0	0.0	200.0	0.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
10.0	6	200.0	0.0	0.0	0.0	200.0	0.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
10.0	6	200.0	0.0	5.0	0.0	200.0	0.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
10.0	6	200.0	0.0	0.0	0.0	200.0	0.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						
10.0	6	200.0	0.0	5.0	0.0	200.0	0.0
0.2	0.5	0.05	30.0	5.0	5.0	0.01	0.0
0.0	0.00000283	1400.0	1000.0	0.001	12.0	240.0	1.0
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
0.0	5.0	10.0	15.0	20.0	25.0		
2.0	4.0						

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B.2 OUTPUT OF SAMPLE CASE NO. 1

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 1

NO. OF POINTS IN X-DIRECTION	6
NO. OF POINTS IN Y-DIRECTION	6
NO. OF POINTS IN Z-DIRECTION	2
NO. OF ROOTS: NO. OF SERIES TERMS	1000
NO. OF BEGINNING TIME STEPS	101
NO. OF ENDING TIME STEP	103
NO. OF TIME INTERVALS FOR PRINTED OUT SOLUTION	1
INSTANTANEOUS SOURCE CONTROL = 0 FOR INSTANT SOURCE	1
SOURCE CONDITION CONTROL = 0 FOR STEADY SOURCE	0
INTERMITTENT OUTPUT CONTROL = 3 NO SUCH OUTPUT	1
CASE CONTROL = 1 THERMAL, = 2 FOR CHEMICAL, = 3 RAD	3
AQUIFER DEPTH, = 0.0 FOR INFINITE DEEP (METERS) ...	0.1000E 02
AQUIFER WIDTH, = 0.0 FOR INFINITE WIDE (METERS) ...	0.2000E 03
BEGIN POINT OF X-SOURCE LOCATION (METERS)	0.0
END POINT OF X-SOURCE LOCATION (METERS)	0.0
BEGIN POINT OF Y-SOURCE LOCATION (METERS)	0.1000E 02
END POINT OF Y-SOURCE LOCATION (METERS)	0.1000E 02
BEGIN POINT OF Z-SOURCE LOCATION (METERS)	0.1000E 01
END POINT OF Z-SOURCE LOCATION (METERS)	0.1000E 01
POROSITY	0.2000E 00
HYDRAULIC CONDUCTIVITY (METER/HOUR)	0.5000E 00
HYDRAULIC GRADIENT	0.5000E-01
LONGITUDINAL DISPERSIVITY (METER)	0.3000E 02
LATERAL DISPERSIVITY (METER)	0.5000E 01
VERTICAL DISPERSIVITY (METER)	0.5000E 01
DISTRIBUTION COEFFICIENT, KD (M**3/KG)	0.1000E-01
HEAT EXCHANGE COEFFICIENT (KCAL/HR-M**2-DEGREE C) ..	0.0
MOLECULAR DIFFUSION MULTIPLY BY POROSITY (M**2/HR)	0.0
DECAY CONSTANT (PER HOUR)	0.2030E-05
BULK DENSITY OF THE SOIL (GRAM/CM**3)	0.1400E 04
ACCURACY TOLERANCE FOR REACHING STEADY STATE	0.1000E-02
DENSITY OF WATER (KG/M**3)	0.1000E 04
TIME INTERVAL SIZE FOR THE DESIRED SOLUTION (HR) ..	0.1200E 02
DISCHARGE TIME (HR)	0.2400E 03
WASTE RELEASE RATE (KCAL/HR), (KG/HR), OR (CI/HR) ..	0.1000E 01
RETARDATION FACTOR	0.7100E 02
RETARDED DARCY VELOCITY (M/HR)	0.1761E-02
RETARDED LONGITUDINAL DISPERSION COEF. (M**2/HR) ..	0.5282E-01
RETARDED LATERAL DISPERSION COEFFICIENT (M**2/HR) ..	0.8803E-02
RETARDED VERTICAL DISPERSION COEFFICIENT (M**2/HR) ..	0.8803E-02

B.2 OUTPUT OF SAMPLE CASE NO. 1 (continued)

DISTRIBUTION OF RAD WASTE IN PCI AT 0.0 HRS						
Z = 2.00						
Y	10.	20.	30.	40.	X 50.	60.
0.	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0	0.0
Z = 4.00						
Y	10.	20.	30.	40.	X 50.	60.
0.	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0	0.0

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1200E 04 HRS						
Z = 2.00						
Y	10.	20.	30.	40.	X 50.	60.
0.	0.167E-00	0.522E-01	0.686E-02	0.387E-03	0.971E-05	0.112E-06
5.	0.274E-03	0.950E-02	0.146E-02	0.991E-00	0.301E-01	0.410E-03
10.	0.334E-05	0.104E-05	0.134E-04	0.743E-02	0.180E-01	0.198E-01
15.	0.274E-03	0.950E-02	0.146E-02	0.991E-00	0.301E-01	0.410E-03
20.	0.234E-00	0.733E-01	0.963E-02	0.543E-03	0.136E-04	0.158E-06
25.	0.505E-01	0.156E-01	0.200E-02	0.108E-03	0.250E-05	0.256E-07
Z = 4.00						
Y	10.	20.	30.	40.	X 50.	60.
0.	0.199E-01	0.673E-02	0.995E-03	0.651E-04	0.191E-05	0.255E-07
5.	0.719E-02	0.251E-02	0.388E-01	0.268E-00	0.826E-02	0.114E-03
10.	0.373E-04	0.125E-04	0.141E-03	0.115E-02	0.324E-00	0.409E-02
15.	0.719E-02	0.251E-02	0.388E-01	0.268E-00	0.826E-02	0.114E-03
20.	0.268E-01	0.907E-02	0.135E-02	0.895E-04	0.267E-05	0.363E-07
25.	0.536E-02	0.176E-02	0.247E-03	0.149E-04	0.392E-06	0.454E-08

B.2 OUTPUT OF SAMPLE CASE NO. 1 (continued)

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1212E 04 HRS

Z = 2.00				
Y	10.	20.	30.	40.
0.	0.167E 00	0.529E-01	0.712E-02	0.415E-03
5.	0.274E 03	0.960E 02	0.150E 02	0.105E 01
10.	0.332E 05	0.140E 04	0.140E 04	0.797E 02
15.	0.274E 03	0.960E 02	0.150E 02	0.105E 01
20.	0.274E 03	0.744E-01	0.100E-01	0.582E-03
25.	0.504E-01	0.158E-01	0.208E-02	0.116E-03

Z = 4.00				
Y	10.	20.	30.	40.
0.	0.192E-01	0.681E-02	0.102E-02	0.635E-04
5.	0.718E 02	0.253E 02	0.401E 01	0.285E 00
10.	0.372E 04	0.126E 04	0.187E 03	0.123E 02
15.	0.718E 02	0.253E 02	0.401E 01	0.285E 00
20.	0.267E-01	0.918E-02	0.140E-02	0.953E-04
25.	0.535E-02	0.178E-02	0.255E-03	0.159E-04

STEADY STATE SOLUTION HAS NOT BEEN REACHED BEFORE FINAL SIMULATING TIME

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1224E 04 HRS

Z = 2.00				
Y	10.	20.	30.	40.
0.	0.166E 00	0.537E-01	0.739E-02	0.444E-03
5.	0.273E 03	0.971E 02	0.155E 04	0.112E 02
10.	0.332E 05	0.107E 05	0.145E 04	0.854E 02
15.	0.273E 03	0.971E 02	0.155E 04	0.112E 02
20.	0.274E 00	0.754E-01	0.104E-01	0.423E-03
25.	0.504E-01	0.160E-01	0.216E-02	0.124E-03

Z = 4.00				
Y	10.	20.	30.	40.
0.	0.192E-01	0.689E-02	0.106E-02	0.737E-04
5.	0.717E 02	0.256E 02	0.413E 01	0.302E 00
10.	0.372E 04	0.128E 04	0.194E 03	0.131E 02
15.	0.717E 02	0.256E 02	0.413E 01	0.302E 00
20.	0.267E-01	0.920E-02	0.144E-02	0.101E-03
25.	0.535E-02	0.160E-02	0.244E-03	0.170E-04

X 50.				
0.	0.108E-04	0.130E-06	0.130E-06	0.130E-06
5.	0.322E-01	0.473E-03	0.473E-03	0.473E-03
10.	0.201E-01	0.273E-03	0.273E-03	0.273E-03
15.	0.322E-01	0.473E-03	0.473E-03	0.473E-03
20.	0.152E-04	0.164E-06	0.164E-06	0.164E-06
25.	0.280E-05	0.301E-07	0.301E-07	0.301E-07

X 50.				
0.	0.211E-05	0.294E-07	0.294E-07	0.294E-07
5.	0.910E-02	0.172E-02	0.172E-02	0.172E-02
10.	0.359E-00	0.474E-02	0.474E-02	0.474E-02
15.	0.910E-02	0.172E-02	0.172E-02	0.172E-02
20.	0.295E-05	0.419E-07	0.419E-07	0.419E-07
25.	0.436E-06	0.522E-08	0.522E-08	0.522E-08

X 50.				
0.	0.121E-06	0.152E-06	0.152E-06	0.152E-06
5.	0.324E-01	0.544E-03	0.544E-03	0.544E-03
10.	0.201E-01	0.269E-03	0.269E-03	0.269E-03
15.	0.324E-01	0.544E-03	0.544E-03	0.544E-03
20.	0.160E-04	0.214E-06	0.214E-06	0.214E-06
25.	0.313E-06	0.352E-07	0.352E-07	0.352E-07

X 50.				
0.	0.235E-05	0.359E-07	0.359E-07	0.359E-07
5.	0.100E-01	0.151E-03	0.151E-03	0.151E-03
10.	0.307E-00	0.548E-02	0.548E-02	0.548E-02
15.	0.100E-01	0.151E-03	0.151E-03	0.151E-03
20.	0.322E-05	0.482E-07	0.482E-07	0.482E-07
25.	0.483E-06	0.613E-08	0.613E-08	0.613E-08

B.3 OUTPUT OF SAMPLE CASE NO. 2

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 39

NO. OF POINTS IN X-DIRECTION	5
NO. OF POINTS IN Y-DIRECTION	6
NO. OF POINTS IN Z-DIRECTION	2
NO. OF ROOTS; NO. OF SERIES TERMS	1000
NO. OF BEGINNING TIME STEPS	101
NO. OF ENDING TIME STEPS	103
NO. OF TIME INTERVALS FOR PRINTED OUT SOLUTION	1
INSTANTANEOUS SOURCE CONTROL = 0 FOR INSTANT SOURCE	1
SOURCE CONDITION CONTROL = 0 FOR STEADY SOURCE	0
INTERMITTENT OUTPUT CONTROL = 0 NO SUCH OUTPUT	1
CASE CONTROL = 1 THERMAL, = 2 FOR CHEMICAL, = 3 RAD	3
AQUIFER DEPTH, = 0.0 FOR INFINITE DEEP (METERS) ...	0.1000E 02
AQUIFER WIDTH, = 0.0 FOR INFINITE WIDE (METERS) ...	0.0
BEGIN POINT OF X-SOURCE LOCATION (METERS)	0.0
END POINT OF X-SOURCE LOCATION (METERS)	0.0
BEGIN POINT OF Y-SOURCE LOCATION (METERS)	0.0
END POINT OF Y-SOURCE LOCATION (METERS)	0.2000E 02
BEGIN POINT OF Z-SOURCE LOCATION (METERS)	0.0
END POINT OF Z-SOURCE LOCATION (METERS)	0.1000E 02
POROSITY	0.2000E 00
HYDRAULIC CONDUCTIVITY (METER/HOUR)	0.5000E 00
HYDRAULIC GRADIENT	0.5000E-01
LONGITUDINAL DISPERSIVITY (METER)	0.3000E 02
LATERAL DISPERSIVITY (METER)	0.5000E 01
VERTICAL DISPERSIVITY (METER)	0.5000E 01
DISTRIBUTION COEFFICIENT, KD (M**3/KG)	0.1000E-01
HEAT EXCHANGE COEFFICIENT (KCAL/HR-M**2-DEGREE C) ..	0.0
MOLECULAR DIFFUSION MULTIPLY BY POROSITY (M**2/HR)	0.0
DECAY CONSTANT (PER HOUR)	0.2830E-05
BULK DENSITY OF THE SOIL (GRAM/CM**3)	0.1400E 04
ACCURACY TOLERANCE FOR REACHING STEADY STATE	0.1000E-02
DENSITY OF WATER (KG/M**3)	0.1000E 04
TIME INTERVAL SIZE FOR THE DESIRED SOLUTION (HR) ..	0.1200E 02
DISCHARGE TIME (HR)	0.2400E 03
WASTE RELEASE RATE (KCAL/HR), (KG/HR), OR (CI/HR) ..	0.1000E 01
RETARDATION FACTOR	0.7100E 02
RETARDED DARCY VELOCITY (M/HR)	0.1761E-02
RETARDED LONGITUDINAL DISPERSION COEF. (M**2/HR) ..	0.5282E-01
RETARDED LATERAL DISPERSION COEFFICIENT (M**2/HR)	0.8803E-02
RETARDED VERTICAL DISPERSION COEFFICIENT (M**2/HR)	0.8803E-02

B.3 OUTPUT OF SAMPLE CASE NO. 2 (continued)

DISTRIBUTION OF RAD WASTE IN PCI AT 0.0 MPS						
Z = 2.00						
Y	10.	20.	30.	40.	X 50.	60.
0.	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0	0.0

Z = 4.00						
Y	10.	20.	30.	40.	X 50.	60.
0.	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0	0.0

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1200E 04 MPS						
Z = 2.00						
Y	10.	20.	30.	40.	X 50.	60.
0.	0.110E 04	0.368E 03	0.493E 02	0.286E 01	0.732E-01	0.850E-02
5.	0.232E 04	0.735E 03	0.985E 02	0.570E 01	0.146E 00	0.169E-02
10.	0.232E 04	0.735E 03	0.985E 02	0.570E 01	0.146E 00	0.170E-02
15.	0.116E 04	0.168E 01	0.493E 02	0.286E 01	0.732E-01	0.169E-02
20.	0.352E 01	0.144E 01	0.189E 01	0.130E-01	0.432E-03	0.850E-03

Z = 4.00						
Y	10.	20.	30.	40.	X 50.	60.
0.	0.110E 04	0.368E 03	0.493E 02	0.286E 01	0.732E-01	0.850E-03
5.	0.232E 04	0.735E 03	0.985E 02	0.570E 01	0.146E 00	0.169E-02
10.	0.232E 04	0.735E 03	0.985E 02	0.570E 01	0.146E 00	0.170E-02
15.	0.116E 04	0.168E 01	0.493E 02	0.286E 01	0.732E-01	0.169E-02
20.	0.352E 01	0.144E 01	0.189E 01	0.130E-01	0.432E-03	0.850E-03

B.3 OUTPUT OF SAMPLE CASE NO. 2 (continued)

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1212E 04 HRS

		Z = 2.00					
Y		10.	20.	30.	40.	X 50.	60.
0.	0.116E 04	0.373E 03	0.512E 02	0.306E 01	0.815E-01	0.990E-03	
5.	0.231E 04	0.745E 03	0.102E 03	0.610E 01	0.162E 00	0.197E-02	
10.	0.232E 04	0.746E 03	0.102E 03	0.612E 01	0.163E 00	0.198E-02	
15.	0.231E 04	0.745E 03	0.102E 03	0.610E 01	0.162E 00	0.197E-02	
20.	0.116E 04	0.373E 03	0.512E 02	0.306E 01	0.815E-01	0.990E-03	
25.	0.351E 01	0.124E 01	0.196E 00	0.139E-01	0.443E-03	0.639E-05	

		Z = 4.00					
Y		10.	20.	30.	40.	X 50.	60.
0.	0.116E 04	0.373E 03	0.512E 02	0.306E 01	0.815E-01	0.990E-03	
5.	0.231E 04	0.745E 03	0.102E 03	0.610E 01	0.162E 00	0.197E-02	
10.	0.232E 04	0.746E 03	0.102E 03	0.612E 01	0.163E 00	0.198E-02	
15.	0.231E 04	0.745E 03	0.102E 03	0.610E 01	0.162E 00	0.197E-02	
20.	0.116E 04	0.373E 03	0.512E 02	0.306E 01	0.815E-01	0.990E-03	
25.	0.351E 01	0.124E 01	0.196E 00	0.139E-01	0.443E-03	0.639E-05	

STEADY STATE SOLUTION HAS NOT BEEN REACHED BEFORE FINAL SIMULATING TIME

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1224E 04 HRS

		Z = 2.00					
Y		10.	20.	30.	40.	X 50.	60.
0.	0.116E 04	0.378E 03	0.531E 02	0.327E 01	0.905E-01	0.115E-02	
5.	0.231E 04	0.755E 03	0.106E 03	0.652E 01	0.180E 00	0.229E-02	
10.	0.231E 04	0.756E 03	0.106E 03	0.654E 01	0.181E 00	0.230E-02	
15.	0.231E 04	0.755E 03	0.106E 03	0.652E 01	0.180E 00	0.229E-02	
20.	0.116E 04	0.378E 03	0.531E 02	0.327E 01	0.905E-01	0.115E-02	
25.	0.351E 01	0.125E 01	0.202E 00	0.147E-01	0.487E-03	0.735E-05	

		Z = 4.00					
Y		10.	20.	30.	40.	X 50.	60.
0.	0.116E 04	0.378E 03	0.531E 02	0.327E 01	0.905E-01	0.115E-02	
5.	0.231E 04	0.755E 03	0.106E 03	0.652E 01	0.180E 00	0.229E-02	
10.	0.231E 04	0.756E 03	0.106E 03	0.654E 01	0.181E 00	0.230E-02	
15.	0.231E 04	0.755E 03	0.106E 03	0.652E 01	0.180E 00	0.229E-02	
20.	0.116E 04	0.378E 03	0.531E 02	0.327E 01	0.905E-01	0.115E-02	
25.	0.351E 01	0.125E 01	0.202E 00	0.147E-01	0.487E-03	0.735E-05	

B.4 OUTPUT OF SAMPLE CASE NO. 3

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 48

NO. OF POINTS IN X-DIRECTION	6
NO. OF POINTS IN Y-DIRECTION	6
NO. OF POINTS IN Z-DIRECTION	2
NO. OF ROOTS: NO. OF SERIES TERMS	1000
NO. OF BEGINNING TIME STEPS	101
NO. OF ENDING TIME STEP	103
NO. OF TIME INTERVALS FOR PRINTED OUT SOLUTION	1
INSTANTANEOUS SOURCE CONTROL = 0 FOR INSTANT SOURCE	1
SOURCE CONDITION CONTROL = 0 FOR STEADY SOURCE	3
INTERMITTENT OUTPUT CONTROL = 0 NO SUCH OUTPUT	
CASE CONTROL = 1 THERMAL, = 2 FOR CHEMICAL, = 3 RAD	
AQUIFER DEPTH, = 0.0 FOR INFINITE DEEP (METERS) ...	0.0
AQUIFER WIDTH, = 0.0 FOR INFINITE WIDE (METERS) ...	0.2000E 03
BEGIN POINT OF X-SOURCE LOCATION (METERS)	0.0
END POINT OF X-SOURCE LOCATION (METERS)	0.5000E 01
BEGIN POINT OF Y-SOURCE LOCATION (METERS)	0.0
END POINT OF Y-SOURCE LOCATION (METERS)	0.2000E 03
BEGIN POINT OF Z-SOURCE LOCATION (METERS)	0.0
END POINT OF Z-SOURCE LOCATION (METERS)	0.2000E 01
POROSITY	0.2000E 00
HYDRAULIC CONDUCTIVITY (METER/HOUR)	0.5000E 00
HYDRAULIC GRADIENT	0.5000E-01
LONGITUDINAL DISPERSIVITY (METER)	0.3000E 02
LATERAL DISPERSIVITY (METER)	0.5000E 01
VERTICAL DISPERSIVITY (METER)	0.5000E 01
DISTRIBUTION COEFFICIENT, KD (M**3/KG)	0.1000E-01
HEAT EXCHANGE COEFFICIENT (KCAL/HR-M**2-DEGREE C) ..	0.0
MOLECULAR DIFFUSION MULTIPLY BY POROSITY (M**2/HR)	0.0
DECAY CONSTANT (PER HOUR)	0.2830E-05
BULK DENSITY OF THE SOIL (GRAM/CM**3)	0.1400E 04
ACCURACY TOLERANCE FOR REACHING STEADY STATE	0.1000E-02
DENSITY OF WATER (KG/M**3)	0.1000E 04
TIME INTERVAL SIZE FOR THE DESIRED SOLUTION (HR) ..	0.1200E 02
DISCHARGE TIME (HR)	0.2400E 03
WASTE RELEASE RATE (KCAL/HR), (KG/HR), OR (CI/HR) ..	0.1000E 01
RETARDATION FACTOR	0.7100E 02
RETARDED DARCY VELOCITY (M/HR)	0.1761E-02
RETARDED LONGITUDINAL DISPERSION COEF. (M**2/HR) ..	0.5282E-01
RETARDED LATERAL DISPERSION COEFFICIENT (M**2/HR) ..	0.8803E-02
RETARDED VERTICAL DISPERSION COEFFICIENT (M**2/HR) ..	0.8803E-02

B.4 OUTPUT OF SAMPLE CASE NO. 3 (continued)

DISTRIBUTION OF RAD WASTE IN PCI AT 0.0 HRS

		Z = 2.00				X 50.	
Y	10.	20.	30.	40.	50.	60.	
0.	0.0	0.0	0.0	0.0	0.0	0.0	
5.	0.0	0.0	0.0	0.0	0.0	0.0	
10.	0.0	0.0	0.0	0.0	0.0	0.0	
15.	0.0	0.0	0.0	0.0	0.0	0.0	
20.	0.0	0.0	0.0	0.0	0.0	0.0	
25.	0.0	0.0	0.0	0.0	0.0	0.0	

		Z = 4.00				X 50.	
Y	10.	20.	30.	40.	50.	60.	
0.	0.0	0.0	0.0	0.0	0.0	0.0	
5.	0.0	0.0	0.0	0.0	0.0	0.0	
10.	0.0	0.0	0.0	0.0	0.0	0.0	
15.	0.0	0.0	0.0	0.0	0.0	0.0	
20.	0.0	0.0	0.0	0.0	0.0	0.0	
25.	0.0	0.0	0.0	0.0	0.0	0.0	

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1200E 04 HRS

		Z = 2.00				X 50.	
Y	10.	20.	30.	40.	50.	60.	
0.	0.661E 03	0.265E 03	0.453E 02	0.337E 01	0.111E 00	0.166E -02	
5.	0.661E 03	0.265E 03	0.453E 02	0.337E 01	0.111E 00	0.166E -02	
10.	0.661E 03	0.265E 03	0.453E 02	0.337E 01	0.111E 00	0.166E -02	
15.	0.661E 03	0.265E 03	0.453E 02	0.337E 01	0.111E 00	0.166E -02	
20.	0.661E 03	0.265E 03	0.453E 02	0.337E 01	0.111E 00	0.166E -02	
25.	0.661E 03	0.265E 03	0.453E 02	0.337E 01	0.111E 00	0.166E -02	

		Z = 4.00				X 50.	
Y	10.	20.	30.	40.	50.	60.	
0.	0.107E 03	0.450E 02	0.830E 01	0.678E 00	0.248E -01	0.412E -03	
5.	0.107E 03	0.450E 02	0.830E 01	0.678E 00	0.248E -01	0.412E -03	
10.	0.107E 03	0.450E 02	0.830E 01	0.678E 00	0.248E -01	0.412E -03	
15.	0.107E 03	0.450E 02	0.830E 01	0.678E 00	0.248E -01	0.412E -03	
20.	0.107E 03	0.450E 02	0.830E 01	0.678E 00	0.248E -01	0.412E -03	
25.	0.107E 03	0.450E 02	0.830E 01	0.678E 00	0.248E -01	0.412E -03	

B.4 OUTPUT OF SAMPLE CASE NO. 3 (continued)

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1212E 04 HRS

Y	10.	20.	30.	40.	X 50.	60.
0.	0.659E 03	0.267E 03	0.466E 02	0.357E 01	0.122E 00	0.192E-02
5.	0.659E 03	0.267E 03	0.466E 02	0.357E 01	0.122E 00	0.192E-02
10.	0.659E 03	0.267E 03	0.466E 02	0.357E 01	0.122E 00	0.192E-02
15.	0.659E 03	0.267E 03	0.466E 02	0.357E 01	0.122E 00	0.192E-02
20.	0.659E 03	0.267E 03	0.466E 02	0.357E 01	0.122E 00	0.192E-02
25.	0.659E 03	0.267E 03	0.466E 02	0.357E 01	0.122E 00	0.192E-02

Z = 2.00

Y	10.	20.	30.	40.	X 50.	60.
0.	0.137E 03	0.453E 02	0.715E 01	0.715E 00	0.271E-01	0.471E-03
5.	0.137E 03	0.453E 02	0.715E 01	0.715E 00	0.271E-01	0.471E-03
10.	0.137E 03	0.453E 02	0.715E 01	0.715E 00	0.271E-01	0.471E-03
15.	0.137E 03	0.453E 02	0.715E 01	0.715E 00	0.271E-01	0.471E-03
20.	0.137E 03	0.453E 02	0.715E 01	0.715E 00	0.271E-01	0.471E-03
25.	0.137E 03	0.453E 02	0.715E 01	0.715E 00	0.271E-01	0.471E-03

STEADY STATE SOLUTION HAS NOT BEEN REACHED BEFORE FINAL SIMULATING TIME

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1224E 04 HRS

Y	10.	20.	30.	40.	X 50.	60.
0.	0.657E 03	0.269E 03	0.480E 02	0.377E 01	0.134E 00	0.218E-02
5.	0.657E 03	0.269E 03	0.480E 02	0.377E 01	0.134E 00	0.218E-02
10.	0.657E 03	0.269E 03	0.480E 02	0.377E 01	0.134E 00	0.218E-02
15.	0.657E 03	0.269E 03	0.480E 02	0.377E 01	0.134E 00	0.218E-02
20.	0.657E 03	0.269E 03	0.480E 02	0.377E 01	0.134E 00	0.218E-02
25.	0.657E 03	0.269E 03	0.480E 02	0.377E 01	0.134E 00	0.218E-02

Z = 2.00

Y	10.	20.	30.	40.	X 50.	60.
0.	0.137E 03	0.457E 02	0.754E 01	0.754E 00	0.296E-01	0.532E-03
5.	0.137E 03	0.457E 02	0.754E 01	0.754E 00	0.296E-01	0.532E-03
10.	0.137E 03	0.457E 02	0.754E 01	0.754E 00	0.296E-01	0.532E-03
15.	0.137E 03	0.457E 02	0.754E 01	0.754E 00	0.296E-01	0.532E-03
20.	0.137E 03	0.457E 02	0.754E 01	0.754E 00	0.296E-01	0.532E-03
25.	0.137E 03	0.457E 02	0.754E 01	0.754E 00	0.296E-01	0.532E-03

Z = 4.00

B.5 OUTPUT OF SAMPLE CASE NO. 4

RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 50

NO. OF POINTS IN X-DIRECTION	6
NO. OF POINTS IN Y-DIRECTION	6
NO. OF POINTS IN Z-DIRECTION	2
NO. OF ROOTS: NO. OF SERIES TERMS	1030
NO. OF BEGINNING TIME STEPS	101
NO. OF ENDING TIME STEP	103
NO. OF TIME INTERVALS FOR PRINTED OUT SOLUTION	1
INSTANTANEOUS SOURCE CONTROL = 0 FOR INSTANT SOURCE	1
SOURCE CONDITION CONTROL = 0 FOR STEADY SOURCE	0
INTERMITTENT OUTPUT CONTROL = 0 NO SUCH OUTPUT	1
CASE CONTROL = 1 THERMAL, = 2 FOR CHEMICAL, = 3 RAD	3
AQUIFER DEPTH, = 0.0 FOR INFINITE DEEP (METERS) ...	0.1000E 02
AQUIFER WIDTH, = 0.0 FOR INFINITE WIDE (METERS) ...	0.2000E 03
BEGIN POINT OF X-SOURCE LOCATION (METERS)	0.0
END POINT OF X-SOURCE LOCATION (METERS)	0.5000E 01
BEGIN POINT OF Y-SOURCE LOCATION (METERS)	0.0
END POINT OF Y-SOURCE LOCATION (METERS)	0.2000E 03
BEGIN POINT OF Z-SOURCE LOCATION (METERS)	0.0
END POINT OF Z-SOURCE LOCATION (METERS)	0.1000E 02
POROSITY	0.2000E 00
HYDRAULIC CONDUCTIVITY (METER/HOUR)	0.5000E 00
HYDRAULIC GRADIENT	0.5000E-01
LONGITUDINAL DISPERSIVITY (METER)	0.3000E 02
LATERAL DISPERSIVITY (METER)	0.5000E 01
VERTICAL DISPERSIVITY (METER)	0.5000E 01
DISTRIBUTION COEFFICIENT, KD (M**3/KG)	0.1000E-01
HEAT EXCHANGE COEFFICIENT (KCAL/HR-M**2-DEGREE C)..	0.0
MOLECULAR DIFFUSION MULTIPLY BY POROSITY (M**2/HR)	0.0
DECAY CONSTANT (PER HOUR)	0.2830E-05
BULK DENSITY OF THE SOIL (GRAM/CM**3)	0.1400E 04
ACCURACY TOLERANCE FOR REACHING STEADY STATE	0.1000E-02
DENSITY OF WATER (KG/M**3)	0.1000E 04
TIME INTERVAL SIZE FOR THE DESIRED SOLUTION (HR) ..	0.1200E 02
DISCHARGE TIME (HR)	0.2400E 03
WASTE RELEASE RATE (KCAL/HR), (KG/HR), OR (CI/HR) ..	0.1000E 01
RETARDATION FACTOR	0.7100E 02
RETARDED DARCY VELOCITY (M/HR)	0.1761E-02
RETARDED LONGITUDINAL DISPERSION COEF. (M**2/HR) ..	0.5282E-01
RETARDED LATERAL DISPERSION COEFFICIENT (M**2/HR)	0.8803E-02
RETARDED VERTICAL DISPERSION COEFFICIENT (M**2/HR).	0.8803E-02

B.5 OUTPUT OF SAMPLE CASE NO. 4 (continued)

DISTRIBUTION OF RAD WASTE IN PCI AT 0.0 HRS

		Z = 2.00					
Y		10.	20.	30.	40.	X 50.	60.
0.	3.3	0.0	0.0	0.0	0.0	0.0	0.0
5.	3.3	0.0	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0	0.0	0.0

		Z = 4.00					
Y		10.	20.	30.	40.	X 50.	60.
0.	3.3	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.	3.0	0.0	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.	3.3	0.0	0.0	0.0	0.0	0.0	0.0

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1200E 04 HRS

		Z = 2.00					
Y		10.	20.	30.	40.	X 50.	60.
0.	0.268E 03	0.107E 03	0.184E 02	0.137E 01	0.454E-01	0.683E-03	
5.	0.268E 03	0.107E 03	0.184E 02	0.137E 01	0.454E-01	0.683E-03	
10.	0.268E 03	0.107E 03	0.184E 02	0.137E 01	0.454E-01	0.683E-03	
15.	0.268E 03	0.107E 03	0.184E 02	0.137E 01	0.454E-01	0.683E-03	
20.	0.268E 03	0.107E 03	0.184E 02	0.137E 01	0.454E-01	0.683E-03	
25.	0.268E 03	0.107E 03	0.184E 02	0.137E 01	0.454E-01	0.683E-03	

		Z = 4.00					
Y		10.	20.	30.	40.	X 50.	60.
0.	0.268E 03	0.107E 03	0.184E 02	0.137E 01	0.454E-01	0.683E-03	
5.	0.268E 03	0.107E 03	0.184E 02	0.137E 01	0.454E-01	0.683E-03	
10.	0.268E 03	0.107E 03	0.184E 02	0.137E 01	0.454E-01	0.683E-03	
15.	0.268E 03	0.107E 03	0.184E 02	0.137E 01	0.454E-01	0.683E-03	
20.	0.268E 03	0.107E 03	0.184E 02	0.137E 01	0.454E-01	0.683E-03	
25.	0.268E 03	0.107E 03	0.184E 02	0.137E 01	0.454E-01	0.683E-03	

B.5 OUTPUT OF SAMPLE CASE NO. 4 (continued)

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1212E 04 HRS

Z = 2.00						
Y	10.	20.	30.	40.	X 50.	60.
0.	0.267E 03	0.108E 03	0.190E 02	0.145E 01	0.499E-01	0.788E-03
5.	0.267E 03	0.108E 03	0.190E 02	0.145E 01	0.499E-01	0.788E-03
10.	0.267E 03	0.108E 03	0.190E 02	0.145E 01	0.499E-01	0.788E-03
15.	0.267E 03	0.108E 03	0.190E 02	0.145E 01	0.499E-01	0.788E-03
20.	0.267E 03	0.108E 03	0.190E 02	0.145E 01	0.499E-01	0.788E-03
25.	0.267E 03	0.108E 03	0.190E 02	0.145E 01	0.499E-01	0.788E-03

Z = 4.00						
Y	10.	20.	30.	40.	X 50.	60.
0.	0.267E 03	0.108E 03	0.190E 02	0.145E 01	0.499E-01	0.788E-03
5.	0.267E 03	0.108E 03	0.190E 02	0.145E 01	0.499E-01	0.788E-03
10.	0.267E 03	0.108E 03	0.190E 02	0.145E 01	0.499E-01	0.788E-03
15.	0.267E 03	0.108E 03	0.190E 02	0.145E 01	0.499E-01	0.788E-03
20.	0.267E 03	0.108E 03	0.190E 02	0.145E 01	0.499E-01	0.788E-03
25.	0.267E 03	0.108E 03	0.190E 02	0.145E 01	0.499E-01	0.788E-03

STEADY STATE SOLUTION HAS NOT BEEN REACHED BEFORE FINAL SIMULATING TIME

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1224E 04 HRS

Z = 2.00						
Y	10.	20.	30.	40.	X 50.	60.
0.	0.266E 03	0.109E 03	0.195E 02	0.154E 01	0.547E-01	0.895E-03
5.	0.266E 03	0.109E 03	0.195E 02	0.154E 01	0.547E-01	0.895E-03
10.	0.266E 03	0.109E 03	0.195E 02	0.154E 01	0.547E-01	0.895E-03
15.	0.266E 03	0.109E 03	0.195E 02	0.154E 01	0.547E-01	0.895E-03
20.	0.266E 03	0.109E 03	0.195E 02	0.154E 01	0.547E-01	0.895E-03
25.	0.266E 03	0.109E 03	0.195E 02	0.154E 01	0.547E-01	0.895E-03

Z = 4.00						
Y	10.	20.	30.	40.	X 50.	60.
0.	0.266E 03	0.109E 03	0.195E 02	0.154E 01	0.547E-01	0.895E-03
5.	0.266E 03	0.109E 03	0.195E 02	0.154E 01	0.547E-01	0.895E-03
10.	0.266E 03	0.109E 03	0.195E 02	0.154E 01	0.547E-01	0.895E-03
15.	0.266E 03	0.109E 03	0.195E 02	0.154E 01	0.547E-01	0.895E-03
20.	0.266E 03	0.109E 03	0.195E 02	0.154E 01	0.547E-01	0.895E-03
25.	0.266E 03	0.109E 03	0.195E 02	0.154E 01	0.547E-01	0.895E-03

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MAIN	005
MAIN	010
MAIN	015
MAIN	020
MAIN	025
MAIN	030
MAIN	035
MAIN	040
MAIN	045
MAIN	050
MAIN	055
MAIN	060
MAIN	065
MAIN	070
MAIN	075
MAIN	080
MAIN	085
MAIN	0 0
MAIN	095
MAIN	100
MAIN	105
MAIN	110
MAIN	115
MAIN	120
MAIN	125
MAIN	130
MAIN	135
MAIN	140
MAIN	145
MAIN	150
MAIN	155
MAIN	160
MAIN	165
MAIN	170
MAIN	175
MAIN	180
MAIN	185
MAIN	190
MAIN	195
MAIN	200
MAIN	205
MAIN	210
MAIN	215
MAIN	220
MAIN	225
MAIN	230
MAIN	235
MAIN	240
MAIN	245
MAIN	250

APPENDIX C (continued)

```

C 300    QS(I)=1.0
C      DO 400 I=1,MAXRUT
C        RTY(I)=0.0
C        AIY(I)=0.0
C        RTZ(I)=0.0
C 400    AIZ(I)=0.0
C
C ----- PASS THE PROGRAM TO AT123D
C
C      CALL AT123D(TEMP,TEMPO,XDIM,YDIM,ZDIM,RTY,AIY,PSIS,FCTY,
C      > RTZ,AIZ,PHIS,FCTZ,OS,TITLE,MAXNX,MAXNY,MAXNZ,MAXNTI,MAXRUT)
C
C      STOP
C      END

```

```

MAIN 255
MAIN 260
MAIN 265
MAIN 270
MAIN 275
MAIN 280
MAIN 285
MAIN 290
MAIN 295
MAIN 300
MAIN 305
MAIN 310
MAIN 315
MAIN 320
MAIN 325
MAIN 330

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AT3D	005
AT3D	010
AT3D	010
AT3D	020
AT3D	025
AT3D	030
AT3D	035
AT3D	040
AT3D	045
AT3D	050
AT3D	055
A*3D	060
AT3D	065
AT3D	070
AT3D	075
AT3D	080
AT3D	085
AT3D	090
AT3D	095
AT3D	100
AT3D	105
AT3D	110
AT3D	115
AT3D	120
AT3D	125
AT3D	130
AT3D	135
AT3D	140
AT3D	145
AT3D	150
AT3D	155
AT3D	160
AT3D	165
AT3D	170
AT3D	175
AT3D	180
AT3D	185
AT3D	190
AT3D	195
AT3D	200
AT3D	205
AT3D	210
AT3D	215
AT3D	220
AT3D	225
AT3D	230
AT3D	235
AT3D	240
AT3D	245
AT3D	250

APPENDIX C (continued)

```

C      FACTOR=1.0/(CP*RHOW)
      IF(ICASE.EQ.2) FACTOR=1.0E3
      IF(ICASE.EQ.3) FACTOR=1.0E6
      RATIO=1.0
      IF(RL1.NE.RL2) RATIO=RATIO/(RL2-PL1)
      IF(RB1.NE.RB2) RATIO=RATIO/(RB2-RB1)
      IF(RH1.NE.RH2) RATIO=RATIO/(RH2-RH1)

C      ----- COMPUTE RETARDED VELOCITY, DISPERSION COEFFICIENTS, AND
C      ----- OTHER PARAMETERS
C
      RETARD=1.0 + RHOB*AKD/POR
      UF=HCOND*HGRAD/(POR*RETARD)
      AKX=AELONG*UF+AMTAU/(POR*RETARD)
      AKY=ATRAV*UF+AMTAU/(POR*RETARD)
      AKZ=AVERTI*UF+AMTAU/(POR*RETARD)
      RKE=(AKE/(POR*RETARD))/AKZ
      ROTPAR=1.0E50
      IF(IDEP.NE.0) ROTPAR=RKE*DEPTH

C      WRITE(6,1500) RETARD,UF,AKX,AKY,AKZ

C      ----- COMPUTE RTY(I) AND AIY(I) FOR FINITE WIDTH CASE
C
      IF(IWID.EQ.0) GO TO 180
      DO 130 I=1,NROOT
      RTY(I)=I*PAI/WIDTH
      130 AIY(I)=2.0/WIDTH

C      ----- WRITE OUT Y-EIGENVALUES AND Z-COEFFICIENTS
C
      IF(IBUG.EQ.0) GO TO 180
      WRITE(6,3100) (RTY(I),I=1,NROOT)
      WRITE(6,3200) (AIY(I),I=1,NROOT)

C      ----- COMPUTE RTZ(I) AND AIZ(I) FOR FINITE DEPTH CASE
C
      180 IF(IDEP.EQ.0) GO TO 290

C      ----- FOR THE THERMAL CASE, I.E. AKE NOT EQUAL TO 0.0
C
      IF(ICASE.NE.1) GO TO 250
      DO 200 I=1,NROOT
      200 CALL ROOT(RTZ,I,ROTPAR,MAXRUT)
      DO 210 I=1,NROOT
      RTZ(I) = RTZ(I)/DEPTH

```

AT30 255
 AT30 260
 AT30 265
 AT30 270
 AT30 275
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 AT30 460
 AT30 465
 AT30 470
 AT30 475
 AT30 480
 AT30 485
 AT30 490
 AT30 495
 AT30 500

APPENDIX C (continued)

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DENOMT=DEPTH*(1.0+RKE**2/RTZ(I)**2) + RKE/RTZ(I)**2
210 AIZ(I)=2.0/DENOMT
GO TO 285
C
C ----- FOR THE NON-THERMAL CASES
C
250 DO 260 I=1,NROOT
RTZ(I)=I*PAI/DEPTH
260 AIZ(I)=2.0/DEPTH
C
C ----- WRITE OUT Z-EIGENVALUES AND Z-COEFFICIENTS
C
285 IF(BUG.EQ.0) GO TO 290
WRITE(6,3300) (RTZ(I),I=1,NROOT)
WRITE(6,3400) (AIZ(I),I=1,NROOT)
C
C ----- COMPUTE SOURCE PART OF EACH OF THE SERIES TERMS
C
C ----- COMPUTE SOURCE PART OF EACH OF Y-SERIES
C
290 IF(IWID.EQ.0) GO TO 310
DO 300 I=1,NROOT
IF(RB1.EQ.RB2) PSIS(I)=COS(RTY(I)*YS)
IF(RB1.NE.RB2) PSIS(I)=(WIDTH/(I*PAI))*(SIN(RTY(I)*RB2) -
> SIN(RTY(I)*RB1))
300 CONTINUE
C
C ----- COMPUTE SOURCE PART OF EACH OF Z-SERIES
C
310 IF(IDEP.EQ.0) GO TO 330
DO 320 I=1,NROOT
IF(RH1.EQ.RH2) PHIS(I)=COS(RTZ(I)*ZS)+RKE/RTZ(I)*SIN(RTZ(I)*ZS)
IF(RH1.NE.RH2) PHIS(I)=(SIN(RTZ(I)*RH2)-SIN(RTZ(I)*RH1) -
> RKE/RTZ(I)*(COS(RTZ(I)*RH2)-COS(RTZ(I)*RH1)))/RTZ(I)
320 CONTINUE
C
C ----- WRITE OUT THE YS-SERIES AND ZS-SERIES
C
330 IF(BUG.EQ.0) GO TO 350
IF(IWID.NE.0) WRITE(6,3500) (PSIS(I),I=1,NROOT)
IF(IDEP.NE.0) WRITE(6,3600) (PHIS(I),I=1,NROOT)
C
C ----- COMPUTE THE Y- AND Z-PART OF THE INTEGRAND
C ----- FOR EACH SERIES TERM
C
350 DO 490 IT=1,NEDTI
TIMED=(IT-1)*DT

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AT3D 505
AT3D 510
AT3D 515
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AT3D 600
AT3D 605
AT3D 610
AT3D 615
AT3D 620
AT3D 625
AT3D 630
AT3D 635
AT3D 640
AT3D 645
AT3D 650
AT3D 655
AT3D 660
AT3D 665
AT3D 670
AT3D 675
AT3D 680
AT3D 685
AT3D 690
AT3D 695
AT3D 700
AT3D 705
AT3D 710
AT3D 715
AT3D 720
AT3D 725
AT3D 730
AT3D 735
AT3D 740
AT3D 745
AT3D 750

APPENDIX C (continued)

```

C      IF(IT.EQ.1) TIMED=DT
C      DO 440 IY=1,NY
C        Y=VDIM(IY)
C      ----- TO EVALUATE THE FUNCTION Y1(Y,T;TAU) OR Y2(Y,T;TAU)
C      IF(IWID.EQ.0) GO TO 420
C      IF(IT.NE.1) GO TO 410
C      FCTY(IY,IT)=0.0
C      IF(RB1.EQ.RB2 .AND. Y.EQ.YS) FCTY(IY,IT)=1.0
C      IF((RB1.NE.RB2) .AND. (Y.GE.RB1 .AND. Y.LE.RB2))
C      >      FCTY(IY,IT)=1.0
C      GO TO 440
410      CALL SERIEY(SERY,Y,YS,RB1,RB2,WIDTH,TIMED,AKY,RTY,AIY,
C      :      PS(S,MAXRUT,NROOT)
C      IF(RB1.EQ.RB2) FCTY(IY,IT)=1.0/WIDTH+SERY
C      IF(RB1.NE.RB2) FCTY(IY,IT)=(RB2-RB1)/WIDTH+SERY
C      IF(RB1.EQ.0.0 .AND. RB2.EQ.WIDTH) FCTY(IY,IT)=1.0
C      IF(FCTY(IY,IT).LT.0.0) FCTY(IY,IT)=0.0
C      GO TO 440
C      ----- TO EVALUATE THE FUNCTION Y3(Y,T;TAU) OR Y4(Y,T;TAU)
C      ----- TO COMPUTE FUNCTION Y3
420      IF(RB1.NE.RB2) GO TO 430
C      IF(IT.NE.1) GO TO 425
C      FCTY(IY,IT)=0.0
C      IF(Y.EQ.YS) FCTY(IY,IT)=1.0
C      GO TO 440
425      Y1=SQRT(4.0*PAI*AKY*TIMED)
C      EARG=(Y-YS)*(Y-YS)/(4.0*AKY*TIMED)
C      IF(ABS(EARG).GT.100.0) EARG=170.0
C      FCTY(IY,IT)=(1.0/Y1)*(EXP(-EARG))
C      GO TO 440
C      ----- TO COMPUTE FUNCTION Y4
C      IF(IT.NE.1) GO TO 435
C      FCTY(IY,IT)=0.0
C      IF(Y.GE.RB1 .AND. Y.LE.RB2) FCTY(IY,IT)=1.0
C      GO TO 440
435      SRT=SQRT(4.0*AKY*TIMED)
C      FCTY(IY,IT)=(ERF((Y-RB1)/SRT)-ERF((Y-RB2)/SRT))/2.0
440      CONTINUE
C      DO 480 IZ=1,NZ
C      Z=ZDIM(IZ)

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AT3D 755
 AT3D 760
 AT3D 765
 AT3D 770
 AT3D 775
 AT3D 780
 AT3D 785
 AT3D 790
 AT3D 795
 AT3D 800
 AT3D 805
 AT3D 810
 AT3D 815
 AT3D 820
 AT3D 825
 AT3D 830
 AT3D 835
 AT3D 840
 AT3D 845
 AT3D 850
 AT3D 855
 AT3D 860
 AT3D 865
 AT3D 870
 AT3D 875
 AT3D 880
 AT3D 885
 AT3D 890
 AT3D 895
 AT3D 900
 AT3D 905
 AT3D 910
 AT3D 915
 AT3D 920
 AT3D 925
 AT3D 930
 AT3D 935
 AT3D 940
 AT3D 945
 AT3D 950
 AT3D 955
 AT3D 960
 AT3D 965
 AT3D 970
 AT3D 975
 AT3D 980
 AT3D 985
 AT3D 990
 AT3D 995
 AT3D1000

APPENDIX C (continued)

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C ----- TO EVALUATE THE FUNCTION Z1(Z,T;TAU) OR Z2(Z,T;TAU)
C
      IF(IDEP.EQ.0) GO TO 460
      IF(IT.NE.1) GO TO 450
      FCTZ(IZ,IT)=0.0
      IF(RH1.EQ.RH2 .AND. Z.EQ.ZS) FCTZ(IZ,IT)=1.0
      IF((RH1.NE.RH2) .AND. (Z.GE.RH1 .AND. Z.LE.RH2))
        > FCTZ(IZ,IT)=1.0
      GO TO 480
450 CALL SERIZ(SERZ,Z,TIMED,AKZ,PKE,PTZ,AIZ,PHIS,MAXRUT,NROOT)
      FCTZ(IZ,IT)=SERZ
      IF(AKE.EQ.0.0 .AND. RH1.EQ.RH2) FCTZ(IZ,IT)=1.0/DEPTH+SERZ
      IF(AKE.EQ.0.0 .AND. RH1.NE.RH2) FCTZ(IZ,IT)=(RH2-RH1)/DEPTH+
        > SERZ
      IF(RH1.EQ.0.0 .AND. RH2.EQ.DEPTH) FCTZ(IZ,IT)=1.0
      GO TO 480

C ----- TO EVALUATE THE FUNCTION Z3(Z,T;TAU) OR Z4(Z,T;TAU)
C
C ----- TO COMPUTE FUNCTION Z3
C
460 IF(RH1.NE.RH2) GO TO 470
      IF(IT.NE.1) GO TO 465
      FCTZ(IZ,IT)=0.0
      IF(Z.EQ.ZS) FCTZ(IZ,IT)=1.0
      GO TO 480
C
465 AKZT=4.0*AKZ*TIMED
      AKZTP1=AKZT*PA1
      AKZT4S=AKZT/4.0
      EARG1=(Z-ZS)*(Z-ZS)/AKZT
      EARG2=(Z+ZS)*(Z+ZS)/AKZT
      EARG3=AKZ*RKE*RKE*TIMED+RKE*(Z+ZS)
      ARG=(Z+ZS)/SORT(AKZT) + RKE*SORT(AKZT4S)
      TERM1=0.0
      IF(EARG1.LT.100.0) TERM1=EXP(-EARG1)/SORT(AKZTP1)
      TERM2=0.0
      IF(EARG2.LE.100.0) TERM2=EXP(-EARG2)/SORT(AKZTP1)
      TERM3=0.0
      IF(EARG3.LT.100.0) TERM3=-RKE*EXP(EARG3)*(1.0-ERF(ARG))
      FCTZ(IZ,IT)=TERM1+TERM2+TERM3
      GO TO 480

C ----- TO COMPUTE FUNCTION Z4
C
470 IF(IT.NE.1) GO TO 475
      FCTZ(IZ,IT)=0.0
      IF(Z.GE.RH1 .AND. Z.LE.RH2) FCTZ(IZ,IT)=1.0

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AT3D1005
 AT3D1010
 AT3D1015
 AT3D1020
 AT3D1025
 AT3D1030
 AT3D1035
 AT3D1040
 AT3D1045
 AT3D1050
 AT3D1055
 AT3D1060
 AT3D1065
 AT3D1070
 AT3D1075
 AT3D1080
 AT3D1085
 AT3D1090
 AT3D1095
 AT3D1100
 AT3D1105
 AT3D1110
 AT3D1115
 AT3D1120
 AT3D1125
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 AT3D1250

APPENDIX C (continued)

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C          GO TO 480
C 475      AKZT1=SQRT(4.0*AKZ*TIMED)
          AKZT2=AKZT1/2.0
          ARG1=(Z+RH2)/AKZT1
          ARG2=(Z+RH1)/AKZT1
          ARG3=(Z-RH2)/AKZT1
          ARG4=(Z-RH1)/AKZT1
          ARG5=AKZ*RKE*RKE*TIMED + RKE*(Z+RH2)
          ARG6=AKZ*RKE*RKE*TIMED + RKE*(Z+RH1)
          TERMS4=0.5*(ERF(ARG1)-ERF(ARG2)-ERF(ARG3)+ERF(ARG4))
          TERMS5=0.0
          IF(ARG5.LT.100.) TERM5=-EXP(ARG5)*(1.0-ERF(ARG1+RKE*AKZT2))
          TERM6=0.0
          IF(ARG6.LT.100.) TERM6=EXP(ARG6)*(1.0-ERF(ARG2+RKE*AKZT2))
          TERM78=-(ERF(ARG1)-ERF(ARG2))
          FCTZ(IJ,IT)=TERMS4+TERMS5+TERM6+TERM78
C
C 480      CONTINUE
C 490 CONTINUE
C
C ----- START TRANSIENT LOOP COMPUTATION
C
C      TIME=0.0
C      DO 600 ITT=NBGTI,NEDTI,NPRINT
C
C          DO 710 IX=1,NX
C              DO 710 IY=1,NY
C                  DO 710 IZ=1,NZ
C                      TEMPO(IX,IY,IZ)=TEMP(IX,IY,IZ)
C 710
C          IF(INTER.EQ.0) GO TO 725
C
C          IF(ICASE.EQ.1) WRITE(6,5100) TIME
C          IF(ICASE.EQ.2) WRITE(6,5200) TIME
C          IF(ICASE.EQ.3) WRITE(6,5300) TIME
C
C          DO 720 IZOUT=1,NZ
C              WRITE(6,6000) ZDIM(IZOUT)
C              CALL ALLOUT(TEMP,XDIM,YDIM,ZDIM,IZOUT,NX,NY,NZ,
C 720 >                MAXNX,MAXNY,MAXNZ)
C
C 725      TIME=(ITT-1)*DT
C
C          DO 760 IXX=1,NX
C              X=XDIM(IXX)
C              DO 750 IYY=1,NY
C                  Y=YDIM(IYY)
C                  DO 740 IZZ=1,NZ

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AT3D1500

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APPENDIX C (continued)

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C          Z=ZDIM( IZZ )
C ----- BRANCH TO INSTANTANEOUS SOURCE OR CONTINUOUS SOURCE
C          IF( INSTAN ) 731,732,731
C ----- FOR THE CASE OF CONTINUOUS SOURCE FOR THE DURATION OF NTDISP
C          731      IF( ITT.LE. NTDISP ) CALL TINTEG( S,X,XS,RL1,RL2,
>          >          FCTY,FCTZ,TIME,IYY,IZZ,ITT,UF,DT,AKX,RAMADA,OS,
>          >          MAXNY,MAXNZ,MAXNTI,INSTAN )
>          >          IF( ITT.GT. NTDISP ) CALL TINTEG( S,X,XS,RL1,RL2,
>          >          FCTY,FCTZ,TIME,IYY,IZZ,NTDISP,UF,DT,AKX,RAMADA,OS,
>          >          MAXNY,MAXNZ,MAXNTI,INSTAN )
C          GO TO 733
C ----- FOR THE CASE OF INSTANTANEOUS SOURCE RELEASE
C          732      CALL TINTEG( S,X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,ITT,
>          >          UF,DT,AKX,RAMADA,OS,MAXNY,MAXNZ,MAXNTI,INSTAN )
C          S=S*2.0/DT
C          733      TEMP( IXX,IYY,IZZ )=S*Q*Ratio*FACTOR/(POR*RETARD)
C          740      CONTINUE
C          750      CONTINUE
C          760      CONTINUE
C          IF( ITT.EQ. NBTI ) GO TO 800
C          IF( NSOURS.NE.0 ) GO TO 800
C ----- CHECK IF STEADY STATE SOLUTION HAS BEEN OBTAINED
C ----- BEFORE THE FINAL SIMULATING TIME
C          DIFMAX=0.0
C          DO 770 IX=1,NX
C            DO 770 IY=1,NY
C              DO 770 IZ=1,NZ
C                IF( TEMPO( IX,IY,IZ ).EQ.0.0 ) GO TO 770
C                DIF=ABS( TEMP( IX,IY,IZ )/TEMPO( IX,IY,IZ )-1.0 )
C                IF( DIF.LE. DIFMAX ) GO TO 770
C                DIFMAX=DIF
C          770      CONTINUE
C          IF( DIFMAX.LE. ACCU ) GO TO 910
C          900 CONTINUE
C          WRITE( 6,7000 )
C          GO TO 920
C          910 WRITE( 6,9000 )
C          920 CONTINUE

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 AT3D1745
 AT3D1750

APPENDIX C (continued)

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      IF(ICASE.EQ.1) WRITE(6,5100) TIME
      IF(ICASE.EQ.2) WRITE(6,5200) TIME
      IF(ICASE.EQ.3) WRITE(6,5300) TIME
      DO 930 IZOUT=1,NZ
        WRITE(6,6000) ZDIM(IZOUT)
930    CALL ALLOUT(TEMP,XDIM,YDIM,ZDIM,IZOUT,NX,NY,NZ,
      >      MAXNX,MAXNY,MAXNZ)
C
      DO 950 IX=1,NX
        DO 950 IY=1,NY
          DO 950 IZ=1,NZ
            TEMP(IX,IY,IZ)=0.0
950      GO TO 999
C
9999 CONTINUE
C
      10 FORMAT(20A4)
      20 FORMAT(16I5)
      30 FORMAT(8F10.0)
      1000 FORMAT(1H1.////.5X,20A4,/)
      1100 FORMAT(1H. /5X,
      > 'NO. OF POINTS IN X-DIRECTION .....',I4/5X,
      > 'NO. OF POINTS IN Y-DIRECTION .....',I5/5X,
      > 'NO. OF POINTS IN Z-DIRECTION .....',I5/5X,
      > 'NO. OF ROOTS: NO. OF SERIES TERMS .....',I5/5X,
      > 'NO. OF BEGINNING TIME STEPS .....',I5/5X,
      > 'NO. OF ENDING TIME STEP .....',I5/5X,
      > 'NO. OF TIME INTERVALS FOR PRINTED OUT SOLUTION .....',I5/5X,
      > 'INSTANTANEOUS SOURCE CONTROL = 0 FOR INSTANT SOURCE',I5/5X,
      > 'SOURCE CONDITION CONTROL = 0 FOR STEADY SOURCE .....',I5/5X,
      > 'INTERMITTENT OUTPUT CONTROL = 0 NO SUCH OUTPUT .....',I5/5X,
      > 'CASE CONTROL =1 THERMAL, = 2 FOR CHEMICAL, = 3 RAD',I5/)
      1200 FORMAT(1H. /5X,
      > 'AQUIFER DEPTH, = 0.0 FOR INFINITE DEEP (METERS) ...',E12.4/5X,
      > 'AQUIFER WIDTH, = 0.0 FOR INFINITE WIDE (METERS) ...',E12.4/5X,
      > 'BEGIN POINT OF X-SOURCE LOCATION (METERS) .....',E12.4/5X,
      > 'END POINT OF X-SOURCE LOCATION (METERS) .....',E12.4/5X,
      > 'BEGIN POINT OF Y-SOURCE LOCATION (METERS) .....',E12.4/5X,
      > 'END POINT OF Y-SOURCE LOCATION (METERS) .....',E12.4/5X,
      > 'BEGIN POINT OF Z-SOURCE LOCATION (METERS) .....',E12.4/5X,
      > 'END POINT OF Z-SOURCE LOCATION (METERS) .....',E12.4/)
      1300 FORMAT(1H. /5X,
      > 'POROSITY .....',E12.4/5X,
      > 'HYDRAULIC CONDUCTIVITY (METER/HOUR) .....',E12.4/5X,
      > 'HYDRAULIC GRADIENT .....',E12.4/5X,
      > 'LONGITUDINAL DISPERSIVITY (METER) .....',E12.4/5X,
      > 'LATERAL DISPERSIVITY (METER) .....',E12.4/5X,
      > 'VERTICAL DISPERSIVITY (METER) .....',E12.4/5X,
      > 'DISTRIBUTION COEFFICIENT, KD (M**3/KG) .....',E12.4/5X,
      > 'HEAT EXCHANGE COEFFICIENT (KCAL/HR-M**2-DEGREE C)...',E12.4/)

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AT3D1755
 AT3D1760
 AT3D1765
 AT3D1770
 AT3D1775
 AT3D1780
 AT3D1785
 AT3D1790
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 AT3D1800
 AT3D1805
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 AT3D1950
 AT3D1955
 AT3D1960
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 AT3D1970
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 AT3D1980
 AT3D1985
 AT3D1990
 AT3D1995
 AT3D2000

APPENDIX C (continued)

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1400 FORMAT(1H,/,5X,
> 'MOLECULAR DIFFUSION MULTIPLY BY TCROSSITY (M**2/HR) ',E12.4/5X,
> 'DECAY CONSTANT (PER HOUR) .....',E12.4/5X,
> 'BULK DENSITY OF THE SOIL (GRAM/CM**3) .....',E12.4/5X,
> 'ACCURACY TOLERANCE FOR REACHING STEADY STATE .....',E12.4/5X,
> 'DENSITY OF WATER (KG/M**3) .....',E12.4/5X,
> 'TIME INTERVAL SIZE FOR THE DESIRED SOLUTION (HR) .....',E12.4/5X,
> 'DISCHARGE TIME (HR) .....',E12.4/5X,
> 'WASTE RELEASE RATE (KCAL/HR), (KG/HR), OR (CI/HR) ',E12.4/)
1500 FORMAT(1H0,/,5X,
> 'RETARDATION FACTOR .....',E12.4/5X,
> 'RETARDED DARCY VELOCITY (M/HR) .....',E12.4/5X,
> 'RETARDED LONGITUDINAL DISPERSION COEF. (M**2/HR) .....',E12.4/5X,
> 'RETARDED LATERAL DISPERSION COEFFICIENT (M**2/HR) ',E12.4/5X,
> 'RETARDED VERTICAL DISPERSION COEFFICIENT (M**2/HR) ',E12.4/)
2000 FORMAT(1H0,4X,'LIST OF TRANSIENT SOURCE RELEASE RATE'/(5X,10E12.3)
> )
3100 FORMAT(1H1,4X,'LIST OF Y-EIGENVALUES'/(5X,10E12.4))
3200 FORMAT(1H0,4X,'LIST OF Y-COEFFICIENT'/(5X,10E12.4))
3300 FORMAT(1H1,4X,'LIST OF Z-EIGENVALUES'/(5X,10E12.4))
3400 FORMAT(1H0,4X,'LIST OF Z-COEFFICIENTS'/(5X,10E12.4))
3500 FORMAT(1H1,4X,'LIST OF YS-SERIES'/(5X,10E12.4))
3600 FORMAT(1H0,4X,'LIST OF ZS-SERIES'/(5X,10E12.4))
5100 FORMAT(1H1,4X,'TEMPERATURE DISTRIBUTION IN DEGREE C AT ',E12.4,'
> HOURS')
5200 FORMAT(1H1,4X,'DISTRIBUTION OF CHEMICALS IN PPB AT ',E12.4,' HRS')
5300 FORMAT(1H1,4X,'DISTRIBUTION OF RAD WASTE IN PCI AT ',E12.4,' HRS')
6000 FORMAT(1H0,20X,'Z = ',F10.2)
7000 FORMAT(1H0,'STEADY STATE SOLUTION HAS NOT BEEN REACHED BEFORE FINA
> L SIMULATING TIME'//)
8000 FORMAT(1H0,'STEADY STATE SOLUTION HAS BEEN OBTAINED BEFORE FINAL
> SIMULATING TIME'//)
      RETURN
      END

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AT3D2005
 AT3D2010
 AT3D2015
 AT3D2020
 AT3D2025
 AT3D2030
 AT3D2035
 AT3D2040
 AT3D2045
 AT3D2050
 AT3D2055
 AT3D2060
 AT3D2065
 AT3D2070
 AT3D2075
 AT3D2080
 AT3D2085
 AT3D2090
 AT3D2095
 AT3D2100
 AT3D2105
 AT3D2110
 AT3D2115
 AT3D2120
 AT3D2125
 AT3D2130
 AT3D2135
 AT3D2140
 AT3D2145
 AT3D2150
 AT3D2155
 AT3D2160
 AT3D2165
 AT3D2170

APPENDIX C (continued)

```

C      SUBROUTINE ROOT(RT,ROTPAR,MAXRUT)
C      DIMENSION RTZ(MAXRU)
C
      ZL=RTZ(I)
      IF(I.GT.1) ZL=RTZ(I-1)+0.01
100    ZL=ZL+0.01
      FZL=ZL*SIN(ZL)-ROTPAR*COS(ZL)
      ZR=ZL+0.01
      FZR=ZR*SIN(ZR)-ROTPAR*COS(ZR)
      IF(FZL*FZR.LT.0.0) GO TO 200
      GO TO 100
200    FZL=ZL*SIN(ZL)-ROTPAR*CCS(ZL)
      DO 300 J=1,6
      ZH=(ZL+ZR)/2.0
      FZH=ZH*SIN(ZH)-ROTPAR*COS(ZH)
      IF(FZH*FZL.LE.0.0) GO TO 400
      ZL=ZH
      FZL=FZH
      GO TO 300
400    ZR=ZH
300    CONTINUE
      RTZ(I)=(ZL+ZR)/2.0
      RETURN
      END

```

```

ROOT 005
ROOT 010
ROOT 015
ROOT 020
ROOT 025
ROOT 030
ROOT 035
ROOT 040
ROOT 045
ROOT 050
ROOT 055
ROOT 060
ROOT 065
ROOT 070
ROOT 075
ROOT 080
ROOT 085
ROOT 090
ROOT 095
ROOT 100
ROOT 105
ROOT 110
ROOT 115
ROOT 120
ROOT 125

```

APPENDIX C (continued)

```

      SUBROUTINE SERIEY(SER,Y,YS,RB1,RB2,B,TIMED,AKY,RTY,AIY,
> PSIS,MAXRUT,NROOT)
      DIMENSION RTY(MAXRUT),AIY(MAXRUT),PSIS(MAXRUT)
      DIMENSION YTEUL(15)
      EPS=0.0001
      IER=1
      I=1
      M=1
      N=1
      ASSIGN 100 TO IFC
      GO TO 500
100  YTEUL(1)=FCT
      SUM=YTEUL(1)*0.5
      J=0
      I=I+1
      IF(I-NROOT) 5,5,12
      N=1
      ASSIGN 200 TO IFC
      GO TO 500
200  AMN=FCT
      DO 6 K=1,M
      AMP=(AMN+YTEUL(K))*0.5
      YTEUL(K)=AMN
      6  AMN=AMP
      IF(ABS(AMN)-ABS(YTEUL(M))) 7,9,9
      7  IF(M-15) 9,9,9
      8  M=M+1
      YTEUL(M)=AMN
      AMN=0.5*AMN
      9  SUM=SUM+AMN
      IF(ABS(AMN)-EPS*ABS(SUM)) 10,10,3
      10 J=J+1
      IF(J-5) 4,11,11
      11 IER=0
      12 SER=SUM
      IF(IER.NE.0) WRITE(6,1000) Y,TIMED
      RETURN
C
C ----- TO EVALUATE N-TH TERM OF Y1(Y,T;TAU) OR Y2(Y,T;TAU)
C
500  AKYTB=AKY*TIMED/(B*B)
      IF(AKYTB.LE.0.0000014) GO TO 510
      EARG=RTY(N)*RTY(N)*AKY*TIMED
      IF(EARG.GT.100.0) FCT=0.0
      IF(EARG.LE.100) FCT=AIY(N)*(COS(RTY(N)*Y))*PSIS(N)*EXP(-EARG)
      GO TO 590
510  IF(RB1.NE.RB2) GO TO 520
      AKYTP[=4.0*3.141593*AKY*TIMED

```

```

SERY 003
SERY 010
SERY 013
SERY 020
SERY 028
SERY 030
SERY 035
SERY 040
SERY 048
SERY 050
SERY 055
SERY 060
SERY 065
SERY 070
SERY 075
SERY 080
SERY 085
SERY 090
SERY 095
SERY 100
SERY 105
SERY 110
SERY 115
SERY 120
SERY 125
SERY 130
SERY 135
SERY 140
SERY 145
SERY 150
SERY 155
SERY 160
SERY 165
SERY 170
SERY 175
SERY 180
SERY 185
SERY 190
SERY 195
SERY 200
SERY 205
SERY 210
SERY 215
SERY 220
SERY 225
SERY 230
SERY 235
SERY 240
SERY 245
SERY 250

```

APPENDIX C (continued)

```

      AKYT=4.0*AKY*TIMED
      EARG1=((Y-YS)-2.0*N*B)*((Y-YS)-2.0*N*B)/AKYT
      EARG2=((Y-YS)-2.0*(N-1)*B)*((Y-YS)-2.0*(N-1)*B)/AKYT
      EARG3=((Y+YS)-2.0*(N+1)*B)*((Y+YS)-2.0*(N+1)*B)/AKYT
      EARG4=((Y+YS)-2.0*N*B)*((Y+YS)-2.0*N*B)/AKYT
      FCT=(EXP(-EARG1)+EXP(-EARG2)+EXP(-EARG3)+EXP(-EARG4))/SQRT(AKYTP1)
      GO TO 590
520  AKY=SQRT(4.0*AKY*TIMED)
      ARG1=Y-RB1-2.0*N*B
      ARG2=Y-RB2-2.0*N*B
      ARG3=Y-RB1-2.0*(N-1)*B
      ARG4=Y-RB2-2.0*(N-1)*B
      ARG5=Y+RB1-2.0*(N+1)*B
      ARG6=Y+RB2-2.0*(N+1)*B
      ARG7=Y+RB1-2.0*N*B
      ARG8=Y+RB2-2.0*N*B
      FCT=0.5*(ERF(ARG1)-ERF(ARG2)+ERF(ARG3)-ERF(ARG4)
> -ERF(ARG5)+ERF(ARG6)-ERF(ARG7)+ERF(ARG8))
590  GO TO IFC. (100,200)
C
1000 FORMAT(1H0,10X,'WARNING: SERIES AT Y =',F8.2,'  TIMED=',F8.2,'
      1 NEEDS MORE TERMS')
      END

```

```

SERV 255
SERV 260
SERV 265
SERV 270
SERV 275
SERV 280
SERV 285
SERV 290
SERV 295
SERV 300
SERV 305
SERV 310
SERV 315
SERV 320
SERV 325
SERV 330
SERV 335
SERV 340
SERV 345
SERV 350
SERV 355
SERV 360
SERV 365

```


APPENDIX C (continued)

```

C      SUBROUTINE SERIEZ(SER,Z,TIMED,AKZ,RKE,RTZ,AIZ,PHIS,MAXRUT,NROOT)
C      DIMENSION RTZ(MAXRUT),AIZ(MAXRUT),PHIS(MAXRUT)
C      DIMENSION YTEUL(15)
C      EPS=0.0001
C      IER=1
C      I=1
C      M=1
C      N=1
C      ASSIGN 100 TO IFC
C      GO TO 500
100  YTEUL(1)=FCT
C      SUM=YTEUL(1)*0.5
C      J=0
C      I=I+1
C      IF(I-NROOT) 5,5,12
C      N=I
C      ASSIGN 200 TO IFC
C      GO TO 500
200  AMN=FCT
C      DO 6 K=1,M
C      AMP=(AMN+YTEUL(K))*0.5
C      YTEUL(K)=AMP
C      6 AMN=AMP
C      IF(ABS(AMN)-ABS(YTEUL(M))) 7,9,9
C      7 IF(M-15) 8,9,9
C      8 M=M+1
C      YTEUL(M)=AMN
C      AMN=0.5*AMN
C      9 SUM=SUM+AMN
C      IF(ABS(AMN)-EPS*ABS(SUM)) 10,10,3
C      10 J=J+1
C      IF(J-5) 4,11,11
C      11 IER=0
C      12 SER=SUM
C      IF(IER.NE.0) WRITE(6,1000) Z,TIMED
C      RETURN
C      ----- TO EVALUATE THE N-TH TERM OF Z1(Z,T;TAU) OR Z2(Z,T;TAU)
C      500 EARG=RTZ(N)**2*AKZ*TIMED
C      IF(EARG.GT.100.0) FCT=0.0
C      IF(EARG.LE.100) FCT=AIZ(N)*(COS(RTZ(N)*Z)+RKE/RTZ(N)*
C      1 SIN(RTZ(N)*Z))*PHIS(N)*EXP(-EARG)
C      GO TO IFC, (100,200)
C      1000 FORMAT(1H0,10X,'WARNING: SERIESZ AT Z =',F8.2,' TIMED=',F8.2,'
C      1 NEEDS MORE TERMS')
C      END

```

SERZ 005
SERZ 010
SERZ 015
SERZ 020
SERZ 025
SERZ 030
SERZ 035
SERZ 040
SERZ 045
SERZ 050
SERZ 055
SERZ 060
SERZ 065
SERZ 070
SERZ 075
SERZ 080
SERZ 085
SERZ 090
SERZ 095
SERZ 100
SERZ 105
SERZ 110
SERZ 115
SERZ 120
SERZ 125
SERZ 130
SERZ 135
SERZ 140
SERZ 145
SERZ 150
SERZ 155
SERZ 160
SERZ 165
SERZ 170
SERZ 175
SERZ 180
SERZ 185
SERZ 190
SERZ 195
SERZ 200
SERZ 205
SERZ 210
SERZ 215
SERZ 220
SERZ 225
SERZ 230
SERZ 235
SERZ 240
SERZ 245
SERZ 250

APPENDIX C (continued)

```

      SUBROUTINE TINTG(S,X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,ITT,
      > UF,DT,AKX,RAMADA,OS, MAXNY,MAXNZ,MAXNTI,INSTAN)
      DIMENSION FCTY(MAXNY,MAXNTI),FCTZ(MAXNZ,MAXNTI),QS(MAXNTI)
      PAI=3.1415927
      ITTM1=ITT-1
      N=ITTM1/2
      SUMEND=0.0
      SUMMID=0.0
      S=0.0
      ITAU=1
      ASSIGN 100 TO M
      GO TO 800
100  FIT1=FIT
      C
      C ----- IF N .LT. 1, THEN THERE IS ONLY ONE INTERVAL
      C
      IF(INSTAN.EQ.0) GO TO 700
      IF(N.LT.1) GO TO 700
      DO 400 K=1,N
      ASSIGN 200 TO M
      ITAU=K+K-1
      GO TO 800
200  SUMEND=SUMEND+FIT
      ASSIGN 300 TO M
      ITAU=K+K
      GO TO 800
300  SUMMID=SUMMID+FIT
400  CONTINUE
      C
      C ----- IF N#2 .NE. ITTM1, THEN THERE ARE ODD NUMBERS OF INTERVALS
      C
      IF(N#2 .NE. ITTM1) GO TO 500
      S=(2.0*SUMEND+4.0*SUMMID-FIT1)*DT/3.0
      GO TO 900
500  ASSIGN 600 TO M
      ITAU=ITTM1
      GO TO 800
600  S=(2.0*SUMEND+4.0*SUMMID-FIT1+FIT)*DT/3.0
700  S=S+(FIT)*DT/2.0
      GO TO 900
      C
      C ----- COMPUTE FUNCTION VALUE OF THE INTEGRAND
      C ----- FUNCTION F(ITAU)
      C
      C ----- TO EVALUATE THE FUNCTION X1(X,T:TAU) OR X2(X,T:TAU)
      C

```

```

TINT 005
TINT 010
TINT 015
TINT 020
TINT 025
TINT 030
TINT 035
TINT 040
TINT 045
TINT 050
TINT 055
TINT 060
TINT 065
TINT 070
TINT 075
TINT 080
TINT 085
TINT 090
TINT 095
TINT 100
TINT 105
TINT 110
TINT 115
TINT 120
TINT 125
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TINT 170
TINT 175
TINT 180
TINT 185
TINT 190
TINT 195
TINT 200
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TINT 210
TINT 215
TINT 220
TINT 225
TINT 230
TINT 235
TINT 240
TINT 245
TINT 250

```

APPENDIX C (continued)

```

900 XPART=0.0
    TIND=TIME-(ITAU-1)*DT
    IF(ITAU.EQ.ITT) TIND=0.01*DT
C
C ---- POINT SOURCE IN THE X-DIRECTION
C
    IF(RL1.NE.RL2) GO TO 820
    IF(ITAU.NE.ITT) GO TO 810
    XPART=0.0
    IF(X.EQ.XS) XPART=1.0
    GO TO 850
810 EARG=((X-XS)-UF*TIND)**2/(4.0*AKX*TIND)
    IF(ABS(EARG).GT.150.) GO TO 850
    XPART=(1.0/(SORT(4.0*PAI*AKX*TIND)))*EXP(-EARG)
    GO TO 850
C
C ---- LINE SOURCE IN THE X-DIRECTION
C
820 IF(ITAU.NE.ITT) GO TO 830
    XPART=0.0
    IF(X.GE.RL1 .AND. X.LE.RL2) XPART=0.0
    GO TO 850
830 SRT=SQRT(4.0*AKX*TIND)
    EAR=-UF*TIND
    EARG1=(X-RL1+EAR)/SRT
    EARG2=(X-RL2+EAR)/SRT
    XPART=(ERF(EARG1)-ERF(EARG2))/2.0
C
C ---- TO EVALUATE THE INTEGRAND, FIJK(X,Y,Z,T;TAU), IN EQ. 14
C
850 IT=ITT-ITAU + 1
    FIT=XPART*FCTZ(IZZ,IT)*FCTY(IYY,IT)*OS(ITAU)*EXP(-RAMADA*TIND)
    GO TO M.(100,200,300,400)
900 RETURN
    END

```

```

TINT 255
TINT 260
TINT 265
TINT 270
TINT 275
TINT 280
TINT 285
TINT 290
TINT 295
TINT 300
TINT 305
TINT 310
TINT 315
TINT 320
TINT 325
TINT 330
TINT 335
TINT 340
TINT 345
TINT 350
TINT 355
TINT 360
TINT 365
TINT 370
TINT 375
TINT 380
TINT 385
TINT 390
TINT 395
TINT 400
TINT 405
TINT 410
TINT 415
TINT 420
TINT 425

```

APPENDIX C (continued)

```

      SUBROUTINE ALLOUT(FTV,XDIM,YDIM,ZDIM,IZ,NX,NY,NZ,
      > MAXNX,MAXNY,MAXNZ)
C
      DIMENSION FTV(MAXNX,MAXNY,MAXNZ)
      DIMENSION XDIM(MAXNX),YDIM(MAXNY),ZDIM(MAXNZ)
C
      JOUT=(NX-1)/10+1
      DO 96 MM=1,JOUT
      JAA=10*(MM-1)+1
      JZZ=10*MM
      IF(MM.EQ.JOUT) JZZ=NX
      IF(MM.GT.1) WRITE(6,225)
225  FORMAT(1H0,50X,'CONTINUE')
      WRITE(6,222) (XDIM(J),J=JAA,JZZ)
222  FORMAT(1H,60X,'X'/1X,' Y ',10F12.0)
      WRITE(6,223)
223  FORMAT(1H,,' ',10(1X,' '))
      DO 97 NN=1,NY
      Y=YDIM(NN)
      WRITE(6,224) Y, (FTV(J,NN,IZ),J=JAA,JZZ)
224  FORMAT(1H,F5.0,10E12.3)
      97 CONTINUE
      96 CONTINUE
      RETURN
      END

```

IHC0021 STOP 0

```

      ALLO 005
      ALLO 010
      ALLO 015
      ALLO 020
      ALLO 025
      ALLO 030
      ALLO 035
      ALLO 040
      ALLO 045
      ALLO 050
      ALLO 055
      ALLO 060
      ALLO 065
      ALLO 070
      ALLO 075
      ALLO 080
      ALLO 085
      ALLO 090
      ALLO 095
      ALLO 100
      ALLO 105
      ALLO 110
      ALLO 115
      ALLO 120
      ALLO 125

```