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

G. T. Yeh

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1439

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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-dimenional 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 lengthing 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):

$$\overbrace{\frac{\partial n_e C}{\partial t}}^{a} = \overbrace{\nabla\cdot\left(n_e \bar{\bar{D}}\,\nabla C\right)}^{b} - \overbrace{\nabla\cdot C\vec{q}}^{c} + \overbrace{\dot{M}}^{d} - \overbrace{K\, n_e\, C}^{e} - \overbrace{\lambda n_e C}^{f} - \underbrace{\left\{\frac{\partial(\rho_b C_s)}{\partial t} + \lambda \rho_b C_s\right\}}_{g} \tag{1}$$

where

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

$\bar{\bar{D}}$ = 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°)

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:

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

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:

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

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:

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

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

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

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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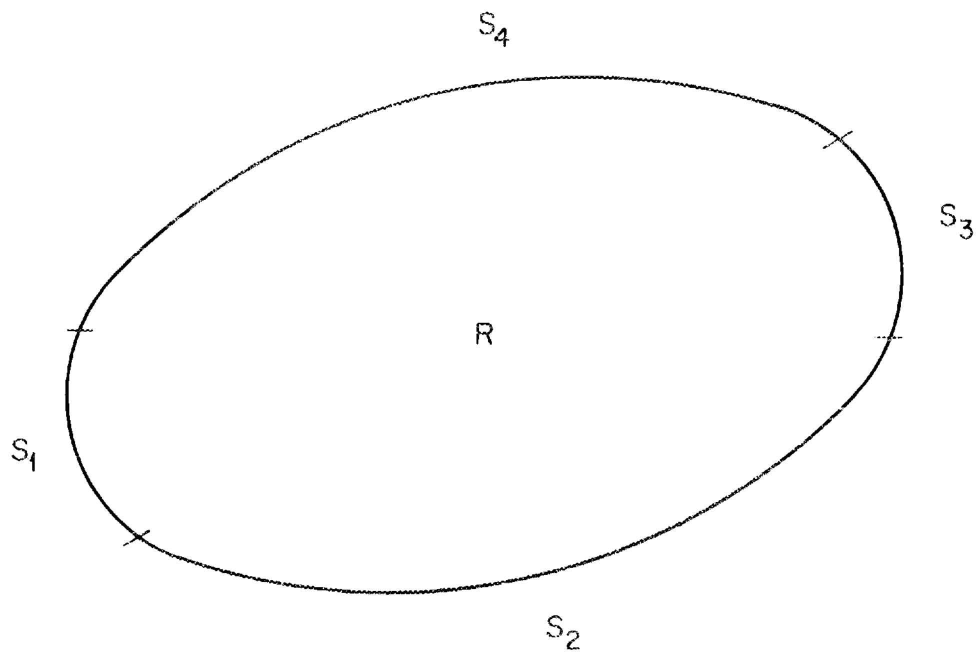

Fig. 1. Spatial boundary of the region of interest.

$$n_e\bar{\bar{D}} \cdot \nabla C \cdot n + n_e K_e^* C = 0 \text{ on } S_4 \quad , \tag{6}$$

where K_e^* is the modified heat exchange coefficient (Yeh 1980), and S_4 is the air-soil interface. The boundaries, S_1, S_2, S_3, and S_4, constitute the whole boundary $S(x,y,z) = 0$ as shown in Fig. 1.

III. ANALYTICAL SIMULATION

The solution of Eq. (1) for a complex groundwater system is extremely difficult. It is the general practice to simplify Eq. (1) before it is adopted. Depending on the physical problems, various simplifications can be made.

Several two-dimensional groundwater mass transport models have been developed (Bredhoft and Pinder 1973, Robertson 1974, Duguid and Reeves 1976, Yeh and Ward 1981, Yeh and Strand 1981) for predicting the movement of containment in a non-homogeneous aquifer system. The groundwater characteristics such as seepage velocity, porosity, permeability, dispersivities, etc., are in general not uniform in space. Numerical simulations of groundwater dynamics and mass transport are therefore necessary. However, for the "first pass" estimates and the design of a monitoring system, transport phenomena on the local scale would be sufficient. Under such circumstances, the assumptions of fairly uniform groundwater characteristics are justifiable. A further assumption is made that the sorption is in a state of instantaneous linear isothermal equilibrium. In other words, it is assumed that the adsorption of the constituent by the solid soil matrix is to occur at a rapid rate such that the dissolved material is in equilibrium with the material absorbed by the solids under isothermal conditions. With these simplifications, Eq. (1) is then reduced to (Robertson 1974):

$$\frac{\partial C}{\partial t} = \nabla \cdot (\bar{\bar{K}} \cdot \nabla C) - \nabla \cdot \vec{U} C - \left(\frac{K}{R_d} + \lambda\right) C + \frac{\dot{M}}{n_e R_d} , \qquad (7)$$

where

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

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

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

K_d = Distribution coefficient

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

$$C(x,y,z,t) = \int_o^t \int_R \frac{\dot{M}}{n_e R_d} G \, dR_o \, d\tau + \int_R (G \, C_i)_{\tau=0} \, dR_o$$
$$- \int_o^t \int_{S_1} \overline{\overline{K}} \cdot \nabla G \cdot \vec{n} \, C_1 \, dS_o \, d\tau - \int_o^t \int_{S_2} \frac{G \, q_2}{n_e R_d} dS_o \, d\tau$$
$$- \int_o^t \int_{S_3} \frac{G \, q_3}{n_e R_d} \, dS_o \, d\tau \qquad (8)$$

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

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

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

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

$$(n_e \overline{\overline{D}} \cdot \nabla_o G + \vec{q}\, G) \cdot \vec{n} = 0 \quad \text{on } S_2 \qquad (11)$$

$$n_e \overline{\overline{D}} \cdot \nabla_o G \cdot \vec{n} = 0 \quad \text{on } S_3 \qquad (12)$$

$$-\overline{\overline{D}} \cdot \nabla G \cdot \vec{n} + K_e^* G = D \quad \text{on } S_4 \qquad (13)$$

and

$$-\frac{\partial G}{\partial \tau} = \nabla_o \cdot (\overline{\overline{K}} \cdot \nabla_o G) + U \cdot \nabla G - (\frac{K}{R_d} + \lambda) G \quad \text{for } t > \tau \quad , \tag{14}$$

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 seperable coordinate system, Green's function, G, can be expressed as:

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

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 $t < T$

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

for finite duration source and $t > T$

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

for instantaneous source

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

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:

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

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:

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

for line source in the x-direction:

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

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

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

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

$$Y_2 = \frac{B_2 - B_1}{B} + \frac{2}{B} \sum_{i=1}^{\infty} \cos\left(\frac{i\pi y}{B}\right) \cdot \frac{B}{i\pi} \left\{ \sin\left(\frac{i\pi B_2}{B}\right) - \sin\left(\frac{i\pi B_1}{B}\right) \right\}$$

$$\exp\left[- \left(\frac{i\pi}{B}\right)^2 K_{yy}(t-\tau)\right] \tag{21}$$

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

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

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

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

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

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

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

$$Z_2 = \sum_{i=1}^{\infty} \Psi_i\ (z)\ \left(\frac{a_i}{\kappa_i}\right)\left\{\sin(\kappa_i H_2) - \sin(\kappa_i H_1) - \right.$$

$$\left.\frac{K_e^*}{K_{zz}\kappa_i}\ [\cos(\kappa_i H_2) - \cos(\kappa_i H_i)]\right\} \cdot \exp\ [-\ \kappa_i^2\ K_{zz}(t-\tau)] \tag{25}$$

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

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

$$-\frac{K_e^*}{K_{zz}}\ \exp\ \left[K_{zz}\ \left(\frac{K_e^*}{K_{zz}}\right)^2\ (t-\tau) + \left(\frac{K_e^*}{K_{zz}}\right)\ (z+z_s)\right]\ \cdot$$

$$\mathrm{erfc}\left[\frac{z+z_s}{\sqrt{4K_{zz}(t-\tau)}} + \frac{K_e^*}{K_{zz}}\ \sqrt{K_{zz}(t-\tau)}\right] \tag{26}$$

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

$$Z_4 = \frac{1}{2} \left\{ \mathrm{erf}\left[\frac{z+H_2}{\sqrt{4K_{zz}(t-\tau)}}\right] - \mathrm{erf}\left[\frac{z+H_1}{\sqrt{4K_{zz}(t-\tau)}}\right] - \mathrm{erf}\left[\frac{z-H_2}{\sqrt{4K_{zz}(t-\tau)}}\right] \right.$$

$$\left. + \mathrm{erf}\left[\frac{z-H_1}{\sqrt{4K_{zz}(t-\tau)}}\right]\right\} - \exp\left[K_{zz}\left(\frac{K_e^*}{K_{zz}}\right)^2 (t-\tau)\right] \cdot$$

$$\left\{ \exp\left[\left(\frac{K_e^*}{K_{zz}}\right)(z+H_2)\right] \cdot \mathrm{erfc}\left[\frac{z+H_2}{\sqrt{4K_{zz}(t-\tau)}} + \left(\frac{K_e^*}{K_{zz}}\right)\sqrt{K_{zz}(t-\tau)}\right]\right. \qquad (27)$$

$$\left. - \exp\left[\left(\frac{K_e^*}{K_{zz}}\right)(z+H_1)\right] \cdot \mathrm{erfc}\left[\frac{z+H_1}{\sqrt{4K_{zz}(t-\tau)}} + \left(\frac{K_e^*}{K_{zz}}\right)\sqrt{K_{zz}(t-\tau)}\right]\right\}$$

$$- \left\{ \mathrm{erf}\left[\frac{z+H_2}{\sqrt{4K_{zz}(t-\tau)}}\right] - \mathrm{erf}\left[\frac{z+H_1}{\sqrt{4K_{zz}(t-\tau)}}\right]\right\}$$

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:

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

where κ_i and a_i are given by the following equations:

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

and

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

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

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

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

(31)

$$Y_2 = \frac{1}{2} \sum_{n=0}^{\infty} \left\{ \text{erf}\left[\frac{(y-B_1)-2nB}{\sqrt{4K_{yy}(t-\tau)}}\right] - \text{erf}\left[\frac{(y-B_2)-2nB}{\sqrt{4K_{yy}(t-\tau)}}\right]\right.$$

$$+ \text{erf}\left[\frac{y-B_1-2(n-1)B}{\sqrt{4K_{yy}(t-\tau)}}\right] - \text{erf}\left[\frac{y-B_2-2(n-1)B}{\sqrt{4K_{yy}(t-\tau)}}\right]$$

$$+ \text{erf}\left[\frac{y+B_2-2(n+1)B}{\sqrt{4K_{yy}(t-\tau)}}\right] - \text{erf}\left[\frac{y+B_1-2(n+1)B}{\sqrt{4K_{yy}(t-\tau)}}\right] \quad (32)$$

$$\left. + \text{erf}\left[\frac{y+B_2-2nB}{\sqrt{4K_{yy}(t-\tau)}}\right] - \text{erf}\left[\frac{y+B_1-2nB}{\sqrt{4K_{yy}(t-\tau)}}\right]\right\}$$

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, $\overset{=}{K}$, 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, $\overset{*}{M}$, 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:

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

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_V 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 ∿ 10^{-2}	10^{-3} ∿ 10^{-4}	10^{-5} ∿ 10^{-6}
Longitudinal dispersivity a_L(m)	10 ∿ 100	1 ∿ 10	0.1 ∿ 1.0
Transverse disversivity a_T(m)	1 ∿ 10	0.1 ∿ 1.0	0.01 ∿ 0.1
Vertical dipersivity a_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 microfishe 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 cm^3/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/cm^3. 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 FW	Aquifer geometry IW	Aquifer geometry FD	Aquifer geometry ID	Source configuration X-direction PS	X-direction LS	Y-direction PS	Y-direction LS	Z-direction PS	Z-direction 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. Similarily, if the model is employed for a two-dimensional problem in the x-z plane (sample cases 41-48), 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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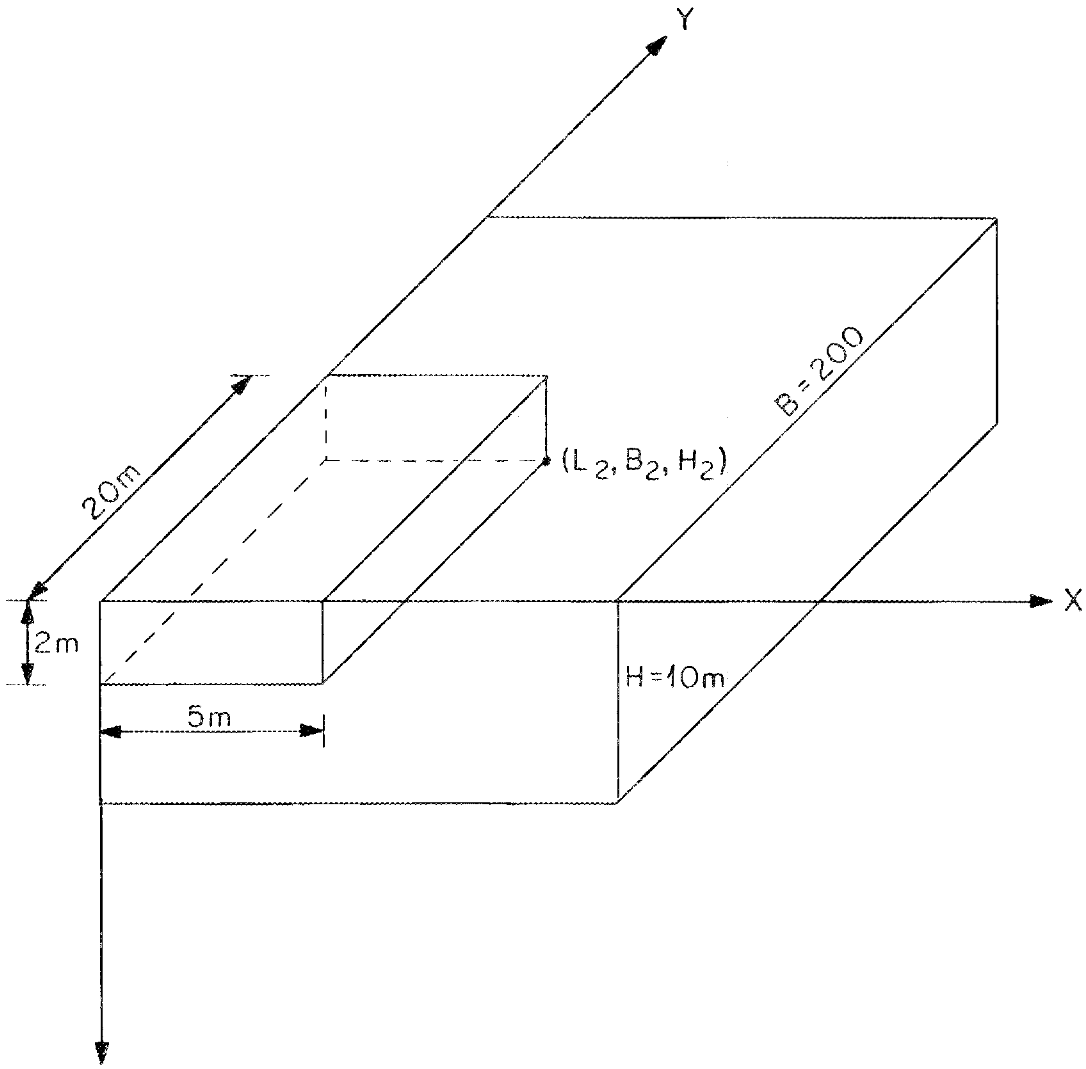

Fig. 2. Schematization of source dimensions and the medium.

the dispersion not been included, the concentration at both points would have been zero since the retarded velocity is 0.176 x 10^{-2} m/hr, thus the mean front of the waste has traveled only to χ = 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 altenuate 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^*	Modified heat exchange coefficient

K_d	Distribution coefficient
$\bar{\bar{K}}$	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
$\dot{M}$	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_o	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
∇_o	Del operator with respect to ξ, ν, 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)

VII. REFERENCES

Bear, J. 1972. Dynamics of fluids in porous media. American Elsevier, New York. 764 pp.

Bredehoeft, J. D., and G. F. Pinder. 1973. Mass transport in flowing groundwater. Water Resour. Res. 9:194-210.

Cleary, R. W., T. J. McAvary, and W. L. Short. 1973. Unsteady state three-dimensional model of thermal pollution in rivers. Water-1972. Amer. Inst. Chem. Eng. Symp. Series 129, Vol. 69:422-431.

Davidson, J. M., C. E. Rick, and P. W. Santelmann. 1968. Influence of water flux and porous material on the movement of selected herbicides. Soil. Sci. Soc. Am. Proc. 32:629-633.

Duguid, J. O., and M. Reeves. 1976. Material transport through porous media: A finite element Galerkin model. ORNL-4928. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Eagleson, P. S. 1970. Dynamic Hydrology. McGraw-Hill Book Company, New York. 462 pp.

Kuo, E. Y. T. 1976. Analytical solution for 3-D diffusion model. J. Environ. Eng. Div. ASCE 102:805-820.

Lai, S. H., and J. J. Jurinak. 1972. The transport of cations in soil columns at different pore velocity's. Soil Sci. Soc. Am. Proc. 36:730-733.

Lapidus, L., and N. R. Amundson. 1952. Mathematics of adsorption in beds, VI. The effect of longitudinal diffusion in ion exchange and chromatographic columns. J. Phys. Chem. 56:984-988.

Lindstrom, F. T., and L. Boersma. 1971. A theory on the mass transport of previously distributed chemicals in a water saturated sorbing-porous medium. Soil Sci. 111:192-199.

Lindstrom, F. T., and W. M. Stone. 1974. On the start up or initial phase of linar mass transport of chemicals in a water saturated sorbing porous medium. I. SIAM J. Appl. Math. 26:578-591.

Marino, A. M. 1974. Distribution of contaminants in porous media flow. Water Resour. Res. 10:1013-1018.

Robertson, J. B. 1974. Digital modeling of radioactive and chemical waste transport in the Snake River plain aquifer at the National Reactor Testing Station, Idaho, U.S.G.S. Open-file Report IDO-22054.

Selim, H. M., and R. S. Mansell. 1976. Analytical solution of the equation for transport of reactive solutes through soil. Water Resour. Res. 12:528-532.

Van Genuchten, M. Th., and P. J. Wiesenga. 1976. Mass transfer studies in sorbing porous media. I. Analytical solutions. Soil Sci. Amer. J. 40:473-480.

Wang, S. T., A. F. McMillan, and B. H. Chen. 1977. Analytical model of dispersion in tidal fjords. J. Hydraulic Div., ASCE 103:737-751.

Warrick, A. W., J. W. Biggar, and D. R. Nielsen. 1971. Simultaneous solute and water transfer for an unsaturated soil. Water Resour. Res. 7:1216-1225.

Yeh, G. T., and Y. J. Tsai. 1976. Analytical transient three-dimensional modeling of effluent discharges. Water Resour. Res. 12:533-540.

Yeh, G. T. 1980. Transport and dispersion of pollutants in surface impoundments: A Finite Difference Model. ORNL-5521. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Yeh, G. T. and R. H. Strand. FECWASTE: User's manual of a finite-element computer code for simulating waste transport through saturated-unsaturated porous media. ORNL/TM-7316. Oak Ridge National Laboratory, Oak Ridge, Tennessee (in press).

Yeh, G. T., and D. S. Ward. 1981. FEMWASTE: A finite-element model of waste transport through saturated-unsaturated porous media. ORNL-5601. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

APPENDIX A

DATA INPUT GUIDE

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 intermittant solutions between NBGT1 and NEDT1 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 (8F10.0)

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

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                      CARD 001
   6    6   2 1000  101  103   1    1    0    1    3    1    1                            CARD 002
10.0     200.0     0.0       0.0       10.0      10.0      1.0       1.0                 CARD 003
0.2      0.5       0.05      30.0      5.0       5.0       0.01      0.0                 CARD 004
0.0     0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0                 CARD 005
10.0     20.0      30.0      40.0      50.0      60.0      70.0      80.0                CARD 006
0.0      5.0       10.0      15.0      20.0      25.0                                    CARD 007
2.0      4.0                                                                             CARD 008
        RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 2                      CARD 009
   6    6   2 1000  101  103   1    1    0    1    3    1    1                            CARD 010
10.0     200.0     0.0       5.0       10.0      10.0      1.0       1.0                 CARD 011
0.2      0.5       0.05      30.0      5.0       5.0       0.01      0.0                 CARD 012
0.0     0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0                 CARD 013
10.0     20.0      30.0      40.0      50.0      60.0      70.0      80.0                CARD 014
0.0      5.0       10.0      15.0      20.0      25.0                                    CARD 015
2.0      4.0                                                                             CARD 016
        RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 3                      CARD 017
   6    6   2 1000  101  103   1    1    0    1    3    1    1                            CARD 018
10.0     200.0     0.0       0.0       0.0       20.0      1.0       1.0                 CARD 019
0.2      0.5       0.05      30.0      5.0       5.0       0.01      0.0                 CARD 020
0.0     0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0                 CARD 021
10.0     20.0      30.0      40.0      50.0      60.0      70.0      80.0                CARD 022
0.0      5.0       10.0      15.0      20.0      25.0                                    CARD 023
2.0      4.0                                                                             CARD 024
        RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 4                      CARD 025
   6    6   2 1000  101  103   1    1    0    1    3    1    1                            CARD 026
10.0     200.0     0.0       0.0       10.0      10.0      0.0       2.0                 CARD 027
0.2      0.5       0.05      30.0      5.0       5.0       0.01      0.0                 CARD 028
0.0     0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0                 CARD 029
10.0     20.0      30.0      40.0      50.0      60.0      70.0      80.0                CARD 030
0.0      5.0       10.0      15.0      20.0      25.0                                    CARD 031
2.0      4.0                                                                             CARD 032
        RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 5                      CARD 033
   6    6   2 1000  101  103   1    1    0    1    3    1    1                            CARD 034
10.0     200.0     0.0       0.0       0.0       20.0      0.0       2.0                 CARD 035
0.2      0.5       0.05      30.0      5.0       5.0       0.01      0.0                 CARD 036
0.0     0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0                 CARD 037
10.0     20.0      30.0      40.0      50.0      60.0      70.0      80.0                CARD 038
0.0      5.0       10.0      15.0      20.0      25.0                                    CARD 039
2.0      4.0                                                                             CARD 040
        RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 6                      CARD 041
   6    6   2 1000  101  103   1    1    0    1    3    1    1                            CARD 042
10.0     200.0     0.0       5.0       10.0      10.0      0.0       2.0                 CARD 043
0.2      0.5       0.05      30.0      5.0       5.0       0.01      0.0                 CARD 044
0.0     0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0                 CARD 045
10.0     20.0      30.0      40.0      50.0      60.0      70.0      80.0                CARD 046
0.0      5.0       10.0      15.0      20.0      25.0                                    CARD 047
2.0      4.0                                                                             CARD 048
        RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 7                      CARD 049
   6    6   2 1000  101  103   1    1    0    1    3    1    1                            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                CARD 051
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0                CARD 052
0.0     0.00000283   1400.0     1000.0     0.001      12.0       240.0      1.0                CARD 053
10.0      20.0       30.0       40.0       50.0       60.0       70.0       80.0               CARD 054
0.0       5.0        10.0       15.0       20.0       25.0                                     CARD 055
2.0       4.0                                                                                  CARD 056
        RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 8                          CARD 057
    5   6    2 1000   101   103    1     1    0     1    3     1    1                          CARD 058
10.0      200.0      0.0        5.0        0.0        20.0       0.0        2.0                CARD 059
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0                CARD 060
0.0     0.00000283   1400.0     1000.0     0.001      12.0       240.0      1.0                CARD 061
10.0      20.0       30.0       40.0       50.0       60.0       70.0       80.0               CARD 062
0.0       5.0        10.0       15.0       20.0       25.0                                     CARD 063
2.0       4.0                                                                                  CARD 064
        RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 9                          CARD 065
    6   6    2 1000   101   103    1     1    0     1    3     1    0                          CARD 066
10.0      200.0      0.0        0.0        10.0       10.0       1.0        1.0                CARD 067
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0                CARD 068
0.0     0.00000283   1400.0     1000.0     0.001      12.0       240.0      1.0                CARD 069
10.0      20.0       30.0       40.0       50.0       60.0       70.0       80.0               CARD 070
0.0       5.0        10.0       15.0       20.0       25.0                                     CARD 071
2.0       4.0                                                                                  CARD 072
        RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 10                         CARD 073
    6   6    2 1000   101   103    1     1    0     1    3     1    0                          CARD 074
10.0      200.0      0.0        5.0        10.0       10.0       1.0        1.0                CARD 075
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0                CARD 076
0.0     0.00000283   1400.0     1000.0     0.001      12.0       240.0      1.0                CARD 077
10.0      20.0       30.0       40.0       50.0       60.0       70.0       80.0               CARD 078
0.0       5.0        10.0       15.0       20.0       25.0                                     CARD 079
2.0       4.0                                                                                  CARD 080
        RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 11                         CARD 081
    6   6    2 1000   101   103    1     1    0     1    3     1    0                          CARD 082
10.0      200.0      0.0        0.0        0.0        20.0       1.0        1.0                CARD 083
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0                CARD 084
0.0     0.00000283   1400.0     1000.0     0.001      12.0       240.0      1.0                CARD 085
10.0      20.0       30.0       40.0       50.0       60.0       70.0       80.0               CARD 086
0.0       5.0        10.0       15.0       20.0       25.0                                     CARD 087
2.0       4.0                                                                                  CARD 088
        RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 12                         CARD 089
    6   6    2 1000   101   103    1     1    0     1    3     1    0                          CARD 090
10.0      200.0      0.0        0.0        10.0       10.0       0.0        2.0                CARD 091
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0                CARD 092
0.0     0.00000283   1400.0     1000.0     0.001      12.0       240.0      1.0                CARD 093
10.0      20.0       30.0       40.0       50.0       60.0       70.0       80.0               CARD 094
0.0       5.0        10.0       15.0       20.0       25.0                                     CARD 095
2.0       4.0                                                                                  CARD 096
        RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 13                         CARD 097
    5   6    2 1000   101   103    1     1    0     1    3     1    0                          CARD 098
10.0      200.0      0.0        0.0        0.0        20.0       0.0        2.0                CARD 099
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0                CARD 100
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B.1 INPUT DATA OF ALL FIFTY CASES (continued)

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0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                    CARD 101
10.0        20.0     30.0       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
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 14                           CARD 105
     6   6    2 1000   101   103    1     1     0     1     3     1     0                          CARD 106
10.0        200.0    0.0        5.0        10.0       10.0       0.0        2.0                    CARD 107
0.2         0.5      0.05       30.0       5.0        5.0        0.01       0.0                    CARD 108
0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                    CARD 109
10.0        20.0     30.0       40.0       50.0       60.0       70.0       80.0                   CARD 110
0.0         5.0      10.0       15.0       20.0       25.0                                         CARD 111
2.0         4.0                                                                                    CARD 112
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 15                           CARD 113
     6   6    2 1000   101   103    1     1     0     1     3     1     0                          CARD 114
10.0        200.0    0.0        5.0        0.0        20.0       1.0        1.0                    CARD 115
0.2         0.5      0.05       30.0       5.0        5.0        0.01       0.0                    CARD 116
0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                    CARD 117
10.0        20.0     30.0       40.0       50.0       60.0       70.0       80.0                   CARD 118
0.0         5.0      10.0       15.0       20.0       25.0                                         CARD 119
2.0         4.0                                                                                    CARD 120
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 16                           CARD 121
     6   6    2 1000   101   103    1     1     0     1     3     1     0                          CARD 122
10.0        200.0    0.0        5.0        0.0        20.0       0.0        2.0                    CARD 123
0.2         0.5      0.05       30.0       5.0        5.0        0.01       0.0                    CARD 124
0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                    CARD 125
10.0        20.0     30.0       40.0       50.0       60.0       70.0       80.0                   CARD 126
0.0         5.0      10.0       15.0       20.0       25.0                                         CARD 127
2.0         4.0                                                                                    CARD 128
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 17                           CARD 129
     6   6    2 1000   101   103    1     1     0     1     3     0     1                          CARD 130
10.0        200.0    0.0        0.0        10.0       10.0       1.0        1.0                    CARD 131
0.2         0.5      0.05       30.0       5.0        5.0        0.01       0.0                    CARD 132
0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                    CARD 133
10.0        20.0     30.0       40.0       50.0       60.0       70.0       80.0                   CARD 134
0.0         5.0      10.0       15.0       20.0       25.0                                         CARD 135
2.0         4.0                                                                                    CARD 136
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 18                           CARD 137
     6   6    2 1000   101   103    1     1     0     1     3     0     1                          CARD 138
10.0        200.0    0.0        5.0        10.0       10.0       1.0        1.0                    CARD 139
0.2         0.5      0.05       30.0       5.0        5.0        0.01       0.0                    CARD 140
0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                    CARD 141
10.0        20.0     30.0       40.0       50.0       60.0       70.0       80.0                   CARD 142
0.0         5.0      10.0       15.0       20.0       25.0                                         CARD 143
2.0         4.0                                                                                    CARD 144
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 19                           CARD 145
     6   6    2 1000   101   103    1     1     0     1     3     0     1                          CARD 146
10.0        200.0    0.0        0.0        0.0        20.0       1.0        1.0                    CARD 147
0.2         0.5      0.05       30.0       5.0        5.0        0.01       0.0                    CARD 148
0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                    CARD 149
10.0        20.0     30.0       40.0       50.0       60.0       70.0       80.0                   CARD 150
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B.1 INPUT DATA OF ALL FIFTY CASES (continued)

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0.0        5.0        10.0       15.0       20.0       25.0                                         CARD 151
2.0        4.0                                                                                      CARD 152
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 20                            CARD 153
   6     6    2 1000  101  103    1     1     0     1     3     0     1                             CARD 154
10.0       200.0      0.0        0.0        10.0       10.0       0.0        2.0                    CARD 155
0.2        0.5        0.05       30.0       5.0        5.0        0.01       0.0                    CARD 156
0.0       0.00000283 1400.0      1000.0     0.001      12.0       240.0      1.0                    CARD 157
10.0       20.0       30.0       40.0       50.0       60.0       70.0       80.0                   CARD 158
0.0        5.0        10.0       15.0       20.0       25.0                                         CARD 159
2.0        4.0                                                                                      CARD 160
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 21                            CARD 161
   6     6    2 1000  101  103    1     1     0     1     3     0     1                             CARD 162
10.0       200.0      0.0        0.0        0.0        20.0       0.0        2.0                    CARD 163
0.2        0.5        0.05       30.0       5.0        5.0        0.01       0.0                    CARD 164
0.0       0.00000283 1400.0      1000.0     0.001      12.0       240.0      1.0                    CARD 165
10.0       20.0       30.0       40.0       50.0       60.0       70.0       80.0                   CARD 166
0.0        5.0        10.0       15.0       20.0       25.0                                         CARD 167
2.0        4.0                                                                                      CARD 168
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 22                            CARD 169
   6     6    2 1000  101  103    1     1     0     1     3     0     1                             CARD 170
10.0       200.0      0.0        5.0        10.0       10.0       0.0        2.0                    CARD 171
0.2        0.5        0.05       30.0       5.0        5.0        0.01       0.0                    CARD 172
0.0       0.00000283 1400.0      1000.0     0.001      12.0       240.0      1.0                    CARD 173
10.0       20.0       30.0       40.0       50.0       60.0       70.0       80.0                   CARD 174
0.0        5.0        10.0       15.0       20.0       25.0                                         CARD 175
2.0        4.0                                                                                      CARD 176
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 23                            CARD 177
   6     6    2 1000  101  103    1     1     0     1     3     0     1                             CARD 178
10.0       200.0      0.0        5.0        0.0        20.0       1.0        1.0                    CARD 179
0.2        0.5        0.05       30.0       5.0        5.0        0.01       0.0                    CARD 180
0.0       0.00000283 1400.0      1000.0     0.001      12.0       240.0      1.0                    CARD 181
10.0       20.0       30.0       40.0       50.0       60.0       70.0       80.0                   CARD 182
0.0        5.0        10.0       15.0       20.0       25.0                                         CARD 183
2.0        4.0                                                                                      CARD 184
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 24                            CARD 185
   6     6    2 1000  101  103    1     1     0     1     3     0     1                             CARD 186
10.0       200.0      0.0        5.0        0.0        20.0       0.0        2.0                    CARD 187
0.2        0.5        0.05       30.0       5.0        5.0        0.01       0.0                    CARD 188
0.0       0.00000283 1400.0      1000.0     0.001      12.0       240.0      1.0                    CARD 189
10.0       20.0       30.0       40.0       50.0       60.0       70.0       80.0                   CARD 190
0.0        5.0        10.0       15.0       20.0       25.0                                         CARD 191
2.0        4.0                                                                                      CARD 192
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 25                            CARD 193
   6     6    2 1000  101  103    1     1     0     1     3     0     0                             CARD 194
10.0       200.0      0.0        0.0        10.0       10.0       1.0        1.0                    CARD 195
0.2        0.5        0.05       30.0       5.0        5.0        0.01       0.0                    CARD 196
0.0       0.00000283 1400.0      1000.0     0.001      12.0       240.0      1.0                    CARD 197
10.0       20.0       30.0       40.0       50.0       60.0       70.0       80.0                   CARD 198
0.0        5.0        10.0       15.0       20.0       25.0                                         CARD 199
2.0        4.0                                                                                      CARD 200
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B.1 INPUT DATA OF ALL FIFTY CASES (continued)

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          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 26          CARD 201
   6    6     2 1000  101  103    1    1    0    1    3    0    0                 CARD 202
10.0     200.0       0.0      5.0      10.0     10.0     1.0      1.0             CARD 203
0.2      0.5         0.05     30.0     5.0      5.0      0.01     0.0             CARD 204
0.0     0.00000283  1400.0   1000.0    0.001    12.0     240.0    1.0             CARD 205
10.0     20.0        30.0     40.0     50.0     60.0     70.0     80.0            CARD 206
0.0      5.0         10.0     15.0     20.0     25.0                              CARD 207
2.0      4.0                                                                      CARD 208
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 27          CARD 209
   6    6     2 1000  101  103    1    1    0    1    3    0    0                 CARD 210
10.0     200.0       0.0      0.0      0.0      20.0     1.0      1.0             CARD 211
0.2      0.5         0.05     30.0     5.0      5.0      0.01     0.0             CARD 212
0.0     0.00000283  1400.0   1000.0    0.001    12.0     240.0    1.0             CARD 213
10.0     20.0        30.0     40.0     50.0     60.0     70.0     80.0            CARD 214
0.0      5.0         10.0     15.0     20.0     25.0                              CARD 215
2.0      4.0                                                                      CARD 216
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 28          CARD 217
   6    6     2 1000  101  103    1    1    0    1    3    0    0                 CARD 218
10.0     200.0       0.0      0.0      10.0     10.0     0.0      2.0             CARD 219
0.2      0.5         0.05     30.0     5.0      5.0      0.01     0.0             CARD 220
0.0     0.00000283  1400.0   1000.0    0.001    12.0     240.0    1.0             CARD 221
10.0     20.0        30.0     40.0     50.0     60.0     70.0     80.0            CARD 222
0.0      5.0         10.0     15.0     20.0     25.0                              CARD 223
2.0      4.0                                                                      CARD 224
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 29          CARD 225
   6    6     2 1000  101  103    1    1    0    1    3    0    0                 CARD 226
10.0     200.0       0.0      0.0      0.0      20.0     0.0      2.0             CARD 227
0.2      0.5         0.05     30.0     5.0      5.0      0.01     0.0             CARD 228
0.0     0.00000283  1400.0   1000.0    0.001    12.0     240.0    1.0             CARD 229
10.0     20.0        30.0     40.0     50.0     60.0     70.0     80.0            CARD 230
0.0      5.0         10.0     15.0     20.0     25.0                              CARD 231
2.0      4.0                                                                      CARD 232
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 30          CARD 233
   6    6     2 1000  101  103    1    1    0    1    3    0    0                 CARD 234
10.0     200.0       0.0      5.0      10.0     10.0     0.0      2.0             CARD 235
0.2      0.5         0.05     30.0     5.0      5.0      0.01     0.0             CARD 236
0.0     0.00000283  1400.0   1000.0    0.001    12.0     240.0    1.0             CARD 237
10.0     20.0        30.0     40.0     50.0     60.0     70.0     80.0            CARD 238
0.0      5.0         10.0     15.0     20.0     25.0                              CARD 239
2.0      4.0                                                                      CARD 240
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 31          CARD 241
   6    6     2 1000  101  103    1    1    0    1    3    0    0                 CARD 242
10.0     200.0       0.0      5.0      0.0      20.0     1.0      1.0             CARD 243
0.2      0.5         0.05     30.0     5.0      5.0      0.01     0.0             CARD 244
0.0     0.00000283  1400.0   1000.0    0.001    12.0     240.0    1.0             CARD 245
10.0     20.0        30.0     40.0     50.0     60.0     70.0     80.0            CARD 246
0.0      5.0         10.0     15.0     20.0     25.0                              CARD 247
2.0      4.0                                                                      CARD 248
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 32          CARD 249
   6    6     2 1000  101  103    1    1    0    1    3    0    0                 CARD 250
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B.1 INPUT DATA OF ALL FIFTY CASES (continued)

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10.0      200.0      0.0        5.0        0.0        20.0       0.0        2.0                  CARD 251
0.2        0.5       0.05       30.0       5.0        5.0        0.01       0.0                  CARD 252
0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                  CARD 253
10.0       20.0      30.0       40.0       50.0       60.0       70.0       80.0                 CARD 254
0.0        5.0       10.0       15.0       20.0       25.0                                       CARD 255
2.0        4.0                                                                                   CARD 256
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 33                         CARD 257
    6    6    2 1000  101   103     1       1    0     1    3     1    1                         CARD 258
10.0      200.0      0.0        0.0        10.0       10.0       0.0        10.0                 CARD 259
0.2        0.5       0.05       30.0       5.0        5.0        0.01       0.0                  CARD 260
0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                  CARD 261
10.0       20.0      30.0       40.0       50.0       60.0       70.0       80.0                 CARD 262
0.0        5.0       10.0       15.0       20.0       25.0                                       CARD 263
2.0        4.0                                                                                   CARD 264
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 34                         CARD 265
    6    6    2 1000  101   103     1       1    0     1    3     1    1                         CARD 266
10.0      200.0      0.0        5.0        10.0       10.0       0.0        10.0                 CARD 267
0.2        0.5       0.05       30.0       5.0        5.0        0.01       0.0                  CARD 268
0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                  CARD 269
10.0       20.0      30.0       40.0       50.0       60.0       70.0       80.0                 CARD 270
0.0        5.0       10.0       15.0       20.0       25.0                                       CARD 271
2.0        4.0                                                                                   CARD 272
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 35                         CARD 273
    6    6    2 1000  101   103     1       1    0     1    3     1    1                         CARD 274
10.0      200.0      0.0        0.0        0.0        20.0       0.0        10.0                 CARD 275
0.2        0.5       0.05       30.0       5.0        5.0        0.01       0.0                  CARD 276
0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                  CARD 277
10.0       20.0      30.0       40.0       50.0       60.0       70.0       80.0                 CARD 278
0.0        5.0       10.0       15.0       20.0       25.0                                       CARD 279
2.0        4.0                                                                                   CARD 280
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 36                         CARD 281
    6    6    2 1000  101   103     1       1    0     1    3     1    1                         CARD 282
10.0      200.0      0.0        5.0        0.0        20.0       0.0        10.0                 CARD 283
0.2        0.5       0.05       30.0       5.0        5.0        0.01       0.0                  CARD 284
0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                  CARD 285
10.0       20.0      30.0       40.0       50.0       60.0       70.0       80.0                 CARD 286
0.0        5.0       10.0       15.0       20.0       25.0                                       CARD 287
2.0        4.0                                                                                   CARD 288
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 37                         CARD 289
    6    6    2 1000  101   103     1       1    0     1    3     0    1                         CARD 290
10.0      200.0      0.0        0.0        10.0       10.0       0.0        10.0                 CARD 291
0.2        0.5       0.05       30.0       5.0        5.0        0.01       0.0                  CARD 292
0.0       0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0                  CARD 293
10.0       20.0      30.0       40.0       50.0       60.0       70.0       80.0                 CARD 294
0.0        5.0       10.0       15.0       20.0       25.0                                       CARD 295
2.0        4.0                                                                                   CARD 296
          RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 38                         CARD 297
    6    6    2 1000  101   103     1       1    0     1    3     0    1                         CARD 298
10.0      200.0      0.0        5.0        10.0       10.0       0.0        10.0                 CARD 299
0.2        0.5       0.05       30.0       5.0        5.0        0.01       0.0                  CARD 300
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B.1 INPUT DATA OF ALL FIFTY CASES (continued)

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0.0      0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0                CARD 301
10.0       20.0      30.0      40.0      50.0      60.0      70.0     80.0               CARD 302
0.0        5.0       10.0      15.0      20.0      25.0                                  CARD 303
2.0        4.0                                                                         CARD 304
         RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 39                CARD 305
   6     5    2 1000   101   103     1     1     0     1     3     0     1             CARD 306
10.0       200.0     0.0       0.0       0.0       20.0      0.0       10.0            CARD 307
0.2        0.5       0.05      30.0      5.0       5.0       0.01      0.0             CARD 308
0.0      0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0              CARD 309
10.0       20.0      30.0      40.0      50.0      60.0      70.0     80.0             CARD 310
0.0        5.0       10.0      15.0      20.0      25.0                                CARD 311
2.0        4.0                                                                         CARD 312
         RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 40                CARD 313
   6     6    2 1000   101   103     1     1     0     1     3     0     1             CARD 314
10.0       200.0     0.0       5.0       0.0       20.0      0.0       10.0            CARD 315
0.2        0.5       0.05      30.0      5.0       5.0       0.01      0.0             CARD 316
0.0      0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0              CARD 317
10.0       20.0      30.0      40.0      50.0      60.0      70.0     80.0             CARD 318
0.0        5.0       10.0      15.0      20.0      25.0                                CARD 319
2.0        4.0                                                                         CARD 320
         RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 41                CARD 321
   6     6    2 1000   101   103     1     1     0     1     3     1     1             CARD 322
10.0       200.0     0.0       0.0       0.0       200.0     1.0       1.0             CARD 323
0.2        0.5       0.05      30.0      5.0       5.0       0.01      0.0             CARD 324
0.0      0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0              CARD 325
10.0       20.0      30.0      40.0      50.0      60.0      70.0     80.0             CARD 326
0.0        5.0       10.0      15.0      20.0      25.0                                CARD 327
2.0        4.0                                                                         CARD 328
         RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 42                CARD 329
   6     6    2 1000   101   103     1     1     0     1     3     1     1             CARD 330
10.0       200.0     0.0       5.0       0.0       200.0     1.0       1.0             CARD 331
0.2        0.5       0.05      30.0      5.0       5.0       0.01      0.0             CARD 332
0.0      0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0              CARD 333
10.0       20.0      30.0      40.0      50.0      60.0      70.0     80.0             CARD 334
0.0        5.0       10.0      15.0      20.0      25.0                                CARD 335
2.0        4.0                                                                         CARD 336
         RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 43                CARD 337
   6     6    2 1000   101   103     1     1     0     1     3     1     1             CARD 338
10.0       200.0     0.0       0.0       0.0       200.0     0.0       2.0             CARD 339
0.2        0.5       0.05      30.0      5.0       5.0       0.01      0.0             CARD 340
0.0      0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0              CARD 341
10.0       20.0      30.0      40.0      50.0      60.0      70.0     80.0             CARD 342
0.0        5.0       10.0      15.0      20.0      25.0                                CARD 343
2.0        4.0                                                                         CARD 344
         RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 44                CARD 345
   6     6    2 1000   101   103     1     1     0     1     3     1     1             CARD 346
10.0       200.0     0.0       5.0       0.0       200.0     0.0       2.0             CARD 347
0.2        0.5       0.05      30.0      5.0       5.0       0.01      0.0             CARD 348
0.0      0.00000283 1400.0    1000.0    0.001     12.0      240.0     1.0              CARD 349
10.0       20.0      30.0      40.0      50.0      60.0      70.0     80.0             CARD 350
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B.1 INPUT DATA OF ALL FIFTY CASES (continued)

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0.0       5.0        10.0       15.0       20.0       25.0                                  CARD 351
2.0       4.0                                                                               CARD 352
         RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 45                     CARD 353
    6    6    2 1000  101   103     1     1    0     1    3     1    0                      CARD 354
10.0      200.0      0.0        0.0        0.0        200.0      1.0        1.0             CARD 355
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0             CARD 356
0.0      0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0             CARD 357
10.0      20.0       30.0       40.0       50.0       60.0       70.0       80.0            CARD 358
0.0       5.0        10.0       15.0       20.0       25.0                                  CARD 359
2.0       4.0                                                                               CARD 360
         RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 46                     CARD 361
    6    5    2 1000  101   103     1     1    0     1    3     1    0                      CARD 362
10.0      200.0      0.0        5.0        0.0        200.0      1.0        1.0             CARD 363
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0             CARD 364
0.0      0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0             CARD 365
10.0      20.0       30.0       40.0       50.0       60.0       70.0       80.0            CARD 366
0.0       5.0        10.0       15.0       20.0       25.0                                  CARD 367
2.0       4.0                                                                               CARD 368
         RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 47                     CARD 369
    6    5    2 1000  101   103     1     1    0     1    3     1    0                      CARD 370
10.0      200.0      0.0        0.0        0.0        200.0      0.0        2.0             CARD 371
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0             CARD 372
0.0      0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0             CARD 373
10.0      20.0       30.0       40.0       50.0       60.0       70.0       80.0            CARD 374
0.0       5.0        10.0       15.0       20.0       25.0                                  CARD 375
2.0       4.0                                                                               CARD 376
         RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 48                     CARD 377
    6    5    2 1000  101   103     1     1    0     1    3     1    0                      CARD 378
10.0      200.0      0.0        5.0        0.0        200.0      0.0        2.0             CARD 379
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0             CARD 380
0.0      0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0             CARD 381
10.0      20.0       30.0       40.0       50.0       60.0       70.0       80.0            CARD 382
0.0       5.0        10.0       15.0       20.0       25.0                                  CARD 383
2.0       4.0                                                                               CARD 384
         RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 49                     CARD 385
    6    6    2 1000  101   103     1     1    0     1    3     1    1                      CARD 386
10.0      200.0      0.0        0.0        0.0        200.0      0.0        10.0            CARD 387
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0             CARD 388
0.0      0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0             CARD 389
10.0      20.0       30.0       40.0       50.0       60.0       70.0       80.0            CARD 390
0.0       5.0        10.0       15.0       20.0       25.0                                  CARD 391
2.0       4.0                                                                               CARD 392
         RAD WASTE DISTRIBUTION IN GROUND WATER: SAMPLE PROBLEM CASE 50                     CARD 393
    6    6    2 1000  101   103     1     1    0     1    3     1    1                      CARD 394
10.0      200.0      0.0        5.0        0.0        200.0      0.0        10.0            CARD 395
0.2       0.5        0.05       30.0       5.0        5.0        0.01       0.0             CARD 396
0.0      0.00000283 1400.0     1000.0     0.001      12.0       240.0      1.0             CARD 397
10.0      20.0       30.0       40.0       50.0       60.0       70.0       80.0            CARD 398
0.0       5.0        10.0       15.0       20.0       25.0                                  CARD 399
2.0       4.0                                                                               CARD 400

IHC002I STOP      0
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B.2 OUTPUT OF SAMPLE CASE NO. 1

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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 = 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) ...........   0.0
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 DESPERSIVITY (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 TOROSITY (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 DIEPSERSION 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	X = 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

Y	X = 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

Y	X = 10.	20.	30.	40.	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	X = 10.	20.	30.	40.	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	0.181E 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 \ X	10.	20.	30.	40.	50.	60.
0.	0.167E 00	0.529E-01	0.712E-02	0.415E-03	0.108E-04	0.130E-06
5.	0.274E 03	0.960E 02	0.150E 02	0.105E 01	0.332E-01	0.473E-03
10.	0.333E 05	0.105E 05	0.140E 04	0.797E 02	0.201E 01	0.231E-01
15.	0.274E 03	0.960E 02	0.150E 02	0.105E 01	0.332E-01	0.473E-03
20.	0.234E 00	0.744E-01	0.100E-01	0.582E-03	0.152E-04	0.184E-06
25.	0.504E-01	0.158E-01	0.208E-02	0.116E-03	0.280E-05	0.301E-07

Z = 4.00

Y \ X	10.	20.	30.	40.	50.	60.
0.	0.199E-01	0.681E-02	0.103E-02	0.693E-04	0.211E-05	0.294E-07
5.	0.718E 02	0.253E 02	0.401E 01	0.285E 00	0.910E-02	0.132E-03
10.	0.372E 04	0.126E 04	0.187E 03	0.123E 02	0.359E 00	0.474E-02
15.	0.718E 02	0.253E 02	0.401E 01	0.285E 00	0.910E-02	0.132E-03
20.	0.267E-01	0.918E-02	0.140E-02	0.953E-04	0.295E-05	0.419E-07
25.	0.535E-02	0.178E-02	0.255E-03	0.159E-04	0.436E-06	0.529E-08

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 \ X	10.	20.	30.	40.	50.	60.
0.	0.166E 00	0.537E-01	0.739E-02	0.444E-03	0.120E-04	0.152E-06
5.	0.273E 03	0.971E 02	0.155E 02	0.112E 01	0.366E-01	0.544E-03
10.	0.333E 05	0.107E 05	0.145E 04	0.854E 02	0.224E 01	0.269E-01
15.	0.273E 03	0.971E 02	0.155E 02	0.112E 01	0.366E-01	0.544E-03
20.	0.234E 00	0.754E-01	0.104E-01	0.623E-03	0.169E-04	0.214E-06
25.	0.504E-01	0.160E-01	0.216E-02	0.124E-03	0.313E-05	0.352E-07

Z = 4.00

Y \ X	10.	20.	30.	40.	50.	60.
0.	0.199E-01	0.689E-02	0.106E-02	0.737E-04	0.233E-05	0.339E-07
5.	0.717E 02	0.256E 02	0.413E 01	0.302E 00	0.100E-01	0.151E-03
10.	0.372E 04	0.128E 04	0.194E 03	0.131E 02	0.397E 00	0.548E-02
15.	0.717E 02	0.256E 02	0.413E 01	0.302E 00	0.100E-01	0.151E-03
20.	0.267E-01	0.929E-02	0.144E-02	0.101E-03	0.325E-05	0.482E-07
25.	0.535E-02	0.180E-02	0.264E-03	0.170E-04	0.483E-06	0.615E-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 ......................    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 = 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
LONGITIDUNAL DESPERSIVITY (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 TOROSITY (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 DIEPSERSION 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 HRS

Z = 2.00

Y	X = 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

Y	X = 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

Y	X = 10.	20.	30.	40.	50.	60.
0.	0.116E 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	0.736E 03	0.987E 02	0.571E 01	0.146E 00	0.170E-02
15.	0.232E 04	0.735E 03	0.985E 02	0.570E 01	0.146E 00	0.169E-02
20.	0.116E 04	0.368E 03	0.493E 02	0.286E 01	0.732E-01	0.850E-03
25.	0.352E 01	0.122E 01	0.189E 00	0.130E-01	0.402E-03	0.555E-05

Z = 4.00

Y	X = 10.	20.	30.	40.	50.	60.
0.	0.116E 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	0.736E 03	0.987E 02	0.571E 01	0.146E 00	0.170E-02
15.	0.232E 04	0.735E 03	0.985E 02	0.570E 01	0.146E 00	0.169E-02
20.	0.116E 04	0.368E 03	0.493E 02	0.286E 01	0.732E-01	0.850E-03
25.	0.352E 01	0.122E 01	0.189E 00	0.130E-01	0.402E-03	0.555E-05

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

DISTRIBUTION OF RAD WASTE IN PCI AT 0.1212E 04 HRS

Z = 2.00

Y \ X	10.	20.	30.	40.	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 \ X	10.	20.	30.	40.	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 \ X	10.	20.	30.	40.	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 \ X	10.	20.	30.	40.	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 .......................      5
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 = 0 NO SUCH OUTPUT ....      1
CASE CONTROL =1 THERMAL, = 2 FOR CHEMICAL, = 3 RAD       3

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 02
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 TOROSITY (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 DIEPSERSION 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

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.	0.661E 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

Y	10.	20.	30.	40.	X 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

Z = 2.00

X

Y	10.	20.	30.	40.	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 = 4.00

X

Y	10.	20.	30.	40.	50.	60.
0.	0.107E 03	0.453E 02	0.852E 01	0.715E 00	0.271E-01	0.471E-03
5.	0.107E 03	0.453E 02	0.852E 01	0.715E 00	0.271E-01	0.471E-03
10.	0.107E 03	0.453E 02	0.852E 01	0.715E 00	0.271E-01	0.471E-03
15.	0.107E 03	0.453E 02	0.852E 01	0.715E 00	0.271E-01	0.471E-03
20.	0.107E 03	0.453E 02	0.852E 01	0.715E 00	0.271E-01	0.471E-03
25.	0.107E 03	0.453E 02	0.852E 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

Z = 2.00

X

Y	10.	20.	30.	40.	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 = 4.00

X

Y	10.	20.	30.	40.	50.	60.
0.	0.107E 03	0.457E 02	0.875E 01	0.754E 00	0.296E-01	0.532E-03
5.	0.107E 03	0.457E 02	0.875E 01	0.754E 00	0.296E-01	0.532E-03
10.	0.107E 03	0.457E 02	0.875E 01	0.754E 00	0.296E-01	0.532E-03
15.	0.107E 03	0.457E 02	0.875E 01	0.754E 00	0.296E-01	0.532E-03
20.	0.107E 03	0.457E 02	0.875E 01	0.754E 00	0.296E-01	0.532E-03
25.	0.107E 03	0.457E 02	0.875E 01	0.754E 00	0.296E-01	0.532E-03

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 ..................   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 = 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
LONGITIDUNAL DESPERSIVITY (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 TOROSITY (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 DIEPSERSION 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.	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.	0.268E 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	X = 10.	20.	30.	40.	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	X = 10.	20.	30.	40.	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	X = 10.	20.	30.	40.	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	X = 10.	20.	30.	40.	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

APPENDIX C

LISTING OF FORTRAN SOURCE PROGRAM

APPENDIX C
LISTING OF FORTRAN SOURCE PROGRAM

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C
C          *****************************************************************
C          *                                                               *
C          *  YEH G. T. 1979. ANALYTICAL SIMULATION OF WASTE TRANSPORT    *
C          *                                                               *
C          *     IN THE AQUIFER SYSTEM.   ORNL-5602, OAK RIDGE NATIONAL    *
C          *                                                               *
C          *     LABORATORY, OAK RIDGE, TENNESSEE 37830                    *
C          *                                                               *
C          *****************************************************************
C
C
C   TO SIMULATE THE WASTE (INCLUDING THERMAL, CHEMICAL, OR RADIOACTIVE)
C   TRANSPORT IN SATURATED AQUIFER BY ANALYTICAL METHOD
C   FOR ANY QUESTION ON THE PROGRAM CONTACT DR. G. T. YEH OF ORNL
C   AT (615) 574-7285
C
      DIMENSION TITLE(20), XDIM(15),YDIM(10),ZDIM(10)
      DIMENSION TEMP(15,10,10),TEMPO(15,10,10)
      DIMENSION RTY(1000),AIY(1000),PSIS(1000),FCTY(10,1201)
      DIMENSION RTZ(1000),AIZ(1000),PHIS(1000),FCTZ(10,1201)
      DIMENSION QS(1201)
C
      DATA MAXNX,MAXNY,MAXNZ,MAXNTI,MAXRUT /15,10,10,1201,1000/
C
C
C ------- ALL UNITS IN THIS PROGRAM ARE THE SI SYSTEM
C
C
C
      DO 100 I=1,MAXNX
         DO 100 J=1,MAXNY
            DO 100 K=1,MAXNZ
               TEMPO(I,J,K)=0.0
  100          TEMP(I,J,K)=0.0
C
      DO 210 I=1,MAXNX
  210    XDIM(I)=0.0
C
      DO 220 I=1,MAXNY
         YDIM(I)=0.0
         DO 220 J=1,MAXNTI
  220       FCTY(I,J)=0.0
C
      DO 230 I=1,MAXNZ
         ZDIM(I)=0.0
         DO 230 J=1,MAXNTI
  230       FCTZ(I,J)=0.0
C
      DO 300 I=1,MAXNTI
```

APPENDIX C (continued)

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

APPENDIX C (continued)

```
      SUBROUTINE AT123D(TEMP,TEMPO,XDIM,YDIM,ZDIM,RTY,AIY,PSIS,FCTY,
     > RTZ,AIZ,PHIS,FCTZ,QS,TITLE,MAXNX,MAXNY,MAXNZ,MAXNTI,MAXRUT)
C
      DIMENSION TITLE(20),XDIM(MAXNX),YDIM(MAXNY),ZDIM(MAXNZ)
      DIMENSION TEMP(MAXNX,MAXNY,MAXNZ),TEMPO(MAXNX,MAXNY,MAXNZ)
      DIMENSION RTY(MAXRUT),AIY(MAXRUT),PSIS(MAXRUT),FCTY(MAXNY,MAXNTI)
      DIMENSION RTZ(MAXRUT),AIZ(MAXRUT),PHIS(MAXRUT),FCTZ(MAXNZ,MAXNTI)
      DIMENSION QS(MAXNTI)
C
      DATA CP,PAI/1.0,3.141593/
C
C ------- READ IN TITLE, SYSTEM PARAMETERS, AND CONTROL INPUTS
C
C
  999 READ(5,10,END=9999) TITLE
      READ(5,20) NX,NY,NZ,NROOT,NBGTI,NEDTI,NPRINT,INSTAN,NSOURS,INTER,
     1 ICASE,IWID,IDEP,IBUG
      READ(5,30) DEPTH,WIDTH,RL1,RL2,RB1,RB2,RH1,RH2
      READ(5,30) POR,HCOND,HGRAD,AELONG,ATRANV,AVERTI,AKD,AKE
      READ(5,30) AMTAU,RAMADA,RHOB,RHOW,ACCU,DT,TDISP,Q
      READ(5,30) (XDIM(I),I=1,NX)
      READ(5,30) (YDIM(I),I=1,NY)
      READ(5,30) (ZDIM(I),I=1,NZ)
      IF(NSOURS.NE.0) READ(5,30) (QS(I),I=1,NSOURS)
      IF(IWID.EQ.0) WIDTH=0.0
      IF(IDEP.EQ.0) DEPTH=0.0
C
C
C ------- PRINT TITLE, SYSTEM PARAMETERS AND CONTROL INPUTS
C
      WRITE(6,1000) (TITLE(I),I=1,20)
      WRITE(6,1100) NX,NY,NZ,NROOT,NBGTI,NEDTI,NPRINT,INSTAN,NSOURS,
     > INTER,ICASE
      WRITE(6,1200) DEPTH,WIDTH,RL1,RL2,RB1,RB2,RH1,RH2
      WRITE(6,1300) POR,HCOND,HGRAD,AELONG,ATRANV,AVERTI,AKD,AKE
      WRITE(6,1400) AMTAU,RAMADA,RHOB,ACCU,RHOW,DT,TDISP,Q
      IF(NSOURS.NE.0) WRITE(6,2000) (QS(I),I=1,NSOURS)
C
C
C ------- MAKE SOME PRELIMINARY COMPUTATIONS
C
      NTDISP=TDISP/DT + 1.0001
      XS=0.0
      YS=0.0
      ZS=0.0
      IF(RL1.EQ.RL2) XS=RL1
      IF(RB1.EQ.RB2) YS=RB1
      IF(RH1.EQ.RH2) ZS=RH1
      QTOTAL=Q
      IF(NSOURS.NE.0) Q=1.0
```

```
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-RL1)
      IF(RB1.NE.RB2) RATIO=RATIO/(RB2-RB1)
      IF(RH1.NE.RH2) RATIO=RATIO/(RH2-RH1)
C
C
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=ATRANV*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
C
C ------- COMPUTE RTY(I) AND AIY(I) FOR FINITE WIDTH CASE
C
      IF(IWID.EQ.0) GO TO 180
      DO 130 I=1,NROOT
      RTY(I)=I*PAI/WIDTH
  130 AIY(I)=2.0/WIDTH
C
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
C
C ------- COMPUTE RTZ(I) AND AIZ(I) FOR FINITE DEPTH CASE
C
  180 IF(IDEP.EQ.0) GO TO 290
C
C ------- FOR THE THERMAL CASE, I.E. AKE NOT EQUAL TO 0.0
C
      IF(ICASE.NE.1) GO TO 250
      DO 200 I=1,NROOT
  200 CALL ROOT(RTZ,I,ROTPAR,MAXRUT)
      DO 210 I=1,NROOT
      RTZ(I) = RTZ(I)/DEPTH
```

```
      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(IBUG.EQ.0) GO TO 290
      WRITE(6,3300) (RTZ(I),I=1,NROOT)
      WRITE(6,3400) (AIZ(I),I=1,NROOT)
C
C
C ------- COMPUTE SOURCE PART OF EACH OF THE SERIES TERMS
C
C
C ------- 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(IBUG.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
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
```

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

APPENDIX C (continued)

```
C
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 SERIFZ(SERZ,Z,TIMED,AKZ,RKE,RTZ,AIZ,PHIS,MAXRUT,NROOT)
          FCTZ(IZ,IT)=SERZ
          IF(AKE.EQ.0. .AND. RH1.EQ.RH2) FCTZ(IZ,IT)=1.0/DEPTH+SERZ
          IF(AKE.EQ.0. .AND. RH1.NE.RH2) FCTZ(IZ,IT)=(RH2-RH1)/DEPTH+
     >     SERZ
          IF(RH1.EQ.0.0 .AND. RH2.EQ.DEPTH) FCTZ(IZ,IT)=1.0
          GO TO 480
C
C ------- TO EVALUATE THE FUNCTION Z3(Z,T;TAU) OR Z4(Z,T;TAU)
C
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
          AKZTPI=AKZT*PAI
          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)/SQRT(AKZT) + RKE*SQRT(AKZT4S)
          TERM1=0.0
          IF(EARG1.LT.100.0) TERM1=EXP(-EARG1)/SQRT(AKZTPI)
          TERM2=0.0
          IF(EARG2.LE.100.0) TERM2=EXP(-EARG2)/SQRT(AKZTPI)
          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
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
```

APPENDIX C (continued)

```
            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))
            TERM5=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(IZ,IT)=TERMS4+TERM5+TERM6+TERM78
C
  480     CONTINUE
  490 CONTINUE
C
C
C ------- START TRANSIENT LOOP COMPUTATION
C
      TIME=0.0
      DO 800 ITT=NBGTI,NEDTI,NPRINT
C
         DO 710 IX=1,NX
            DO 710 IY=1,NY
               DO 710 IZ=1,NZ
  710          TEMPO(IX,IY,IZ)=TEMP(IX,IY,IZ)
C
         IF(INTER.EQ.0) GO TO 725
C
         IF(ICASE.EQ.1) WRITE(6,5100) TIME
         IF(ICASE.EQ.2) WRITE(6,5200) TIME
         IF(ICASE.EQ.3) WRITE(6,5300) TIME
C
         DO 720 IZOUT=1,NZ
            WRITE(6,6000) ZDIM(IZOUT)
  720       CALL ALLOUT(TEMP,XDIM,YDIM,ZDIM,IZOUT,NX,NY,NZ,
     >       MAXNX,MAXNY,MAXNZ)
C
  725    TIME=(ITT-1)*DT
C
         DO 760 IXX=1,NX
            X=XDIM(IXX)
            DO 750 IYY=1,NY
               Y=YDIM(IYY)
               DO 740 IZZ=1,NZ
```

```
                  Z=ZDIM(IZZ)
C
C ------- BRANCH TO INSTANTANEOUS SOURCE OR CONTINUOUS SOURCE
C
                  IF(INSTAN) 731,732,731
C
C ------- 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,QS,
     >             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,QS,
     >             MAXNY,MAXNZ,MAXNTI,INSTAN)
                  GO TO 733
C
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,QS,MAXNY,MAXNZ,MAXNTI,INSTAN)
                  S=S*2.0/DT
  733             TEMP(IXX,IYY,IZZ)=S*Q*RATIO*FACTOR/(POR*RETARD)
  740          CONTINUE
  750       CONTINUE
  760    CONTINUE
C
         IF(ITT.EQ.NBGTI) GO TO 800
         IF(NSOURS.NE.0) GO TO 800
C
C ------- CHECK IF STEADY STATE SOLUTION HAS BEEN OBTAINED
C ------- BEFORE THE FINIAL SIMULATING TIME
C
         DIFMAX=0.0
         DO 770 IX=1,NX
            DO 770 IY=1,NY
               DO 770 IZ=1,NZ
                  IF(TEMPO(IX,IY,IZ).EQ.0.0) GO TO 770
                  DIF=ABS(TEMP(IX,IY,IZ)/TEMPO(IX,IY,IZ)-1.0)
                  IF(DIF.LE.DIFMAX) GO TO 770
                  DIFMAX=DIF
  770          CONTINUE
C
         IF(DIFMAX.LE.ACCU) GO TO 910
C
  800 CONTINUE
C
      WRITE(6,7000)
      GO TO 920
  910 WRITE(6,8000)
  920 CONTINUE
```

APPENDIX C (continued)

```
      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
  950          TEMP(IX,IY,IZ)=0.0
      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 ......................',I5/5X,
     > 'NO. OF POINTS IN Y-DIRECTION ......................',I5/5X,
     > 'NO. OF POINTS IN Z-DIRECTION ......................',I5/5X,
     > 'NO. OF ROOTS: NO. OF SERIES TERMS .................',I5/5X,
     > 'NO. OF BEGINNING TIME STEPS .......................',I5/5X,
     > 'NO. OF ENDING TIME STEP ...........................',I5/5X,
     > 'NO. OF TIME INTERVALS FOR PRINTED OUT SOLUTION ....',I5/5X,
     > 'INSTANTANEOUS SOURCE CONTROL = 0 FOR INSTANT SOURCE',I5/5X,
     > 'SOURCE CONDITION CONTROL = 0 FOR STEADY SOURCE ....',I5/5X,
     > 'INTERMITTENT OUTPUT CONTROL = 0 NO SUCH OUTPUT ....',I5/5X,
     > 'CASE CONTROL =1 THERMAL, = 2 FOR CHEMICAL, = 3 RAD ',I5/)
 1200 FORMAT(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,
     > 'LONGITIDUNAL DESPERSIVITY (METER) .................',E12.4/5X,
     > 'LATERAL DISPERSIVITY (METFR) ......................',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/)
```

```
1400 FORMAT(1H ,/5X,
    > 'MOLECULAR DIFFUSION MULTIPLY BY POROSITY (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 DIEPSERSION 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
```

APPENDIX C (continued)

```
      SUBROUTINE ROOT(RTZ,I,ROTPAR,MAXRUT)
C
      DIMENSION RTZ(MAXRUT)
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*COS(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
```

APPENDIX C (continued)

```
      SUBROUTINE SERIFY(SER,Y,YS,RB1,RB2,B,TIMED,AKY,RTY,AIY,
     > PSIS,MAXRUT,NROOT)
C
      DIMENSION RTY(MAXRUT),AIY(MAXRUT),PSIS(MAXRUT)
      DIMENSION YTEUL(15)
C
      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
    3 J=0
    4 I=I+1
      IF(I-NROOT) 5,5,12
    5 N=I
      ASSIGN 200 TO IFC
      GO TO 500
  200 AMN=FCT
      DO 6 K=1,M
      AMP=(AMN+YTEUL(K))*0.5
      YTEUL(K)=AMN
    6 AMN=AMP
      IF(ABS(AMN)-ABS(YTEUL(M))) 7,9,9
    7 IF(M-15) 8,9,9
    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
      AKYTPI=4.0*3.141593*AKY*TIMED
```

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(AKYTPI)
      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: SERIESY AT Y =',F8.2,'  TIMED=',F8.2,'
     1NEEDS MORE TERMS')
      END
```

```
      SUBROUTINE SERIEZ(SER,Z,TIMED,AKZ,RKE,RTZ,AIZ,PHIS,MAXRUT,NROOT)
C
      DIMENSION RTZ(MAXRUT),AIZ(MAXRUT),PHIS(MAXRUT)
      DIMENSION YTEUL(15)
C
      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
    3 J=0
    4 I=I+1
      IF(I-NROOT) 5,5,12
    5 N=I
      ASSIGN 200 TO IFC
      GO TO 500
  200 AMN=FCT
      DO 6 K=1,M
      AMP=(AMN+YTEUL(K))*0.5
      YTEUL(K)=AMN
    6 AMN=AMP
      IF(ABS(AMN)-ABS(YTEUL(M))) 7,9,9
    7 IF(M-15) 8,9,9
    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) Z,TIMED
      RETURN
C
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
      IF(EARG.GT.100.0) FCT=0.0
      IF(EARG.LE.100) FCT=AIZ(N)*(COS(RTZ(N)*Z)+RKE/RTZ(N)*
     1 SIN(RTZ(N)*Z))*PHIS(N)*EXP(-EARG)
      GO TO IFC, (100,200)
C
 1000 FORMAT(1H0,10X,'WARNING: SERIESZ AT Z =',F8.2,'  TIMED=',F8.2,'
     1NEEDS MORE TERMS')
      END
```

```
      SUBROUTINE TINTEG(S,X,XS,RL1,RL2,FCTY,FCTZ,TIME,IYY,IZZ,ITT,
     > UF,DT,AKX,RAMADA,QS, MAXNY,MAXNZ,MAXNTI,INSTAN)
C
      DIMENSION FCTY(MAXNY,MAXNTI),FCTZ(MAXNZ,MAXNTI),QS(MAXNTI)
C
      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
C ------- COMPUTE FUNCTION VALUE OF THE INTEGRAND
C ------- FUNCTION F(ITAU)
C
C
C ------- TO EVALUATE THE FUNCTION X1(X,T;TAU) OR X2(X,T;TAU)
C
```

```
  800 XPART=0.0
      TIMD=TIME-(ITAU-1)*DT
      IF(ITAU.EQ.ITT) TIMD=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*TIMD)**2/(4.0*AKX*TIMD)
      IF(ABS(EARG).GT.150.) GO TO 850
      XPART=(1.0/(SQRT(4.0*PAI*AKX*TIMD)))*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*TIMD)
      EAR=-UF*TIMD
      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. 16
C
  850 IT=ITT-ITAU + 1
      FIT=XPART*FCTZ(IZZ,IT)*FCTY(IYY,IT)*QS(ITAU)*EXP(-RAMADA*TIMD)
      GO TO M,(100,200,300,600)
  900 RETURN
      END
```

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(4X,'        '))
      DO 97 NN=1,NY
      Y=YDIM(NN)
      WRITE(6,224) Y, (FTV(J,NN,IZ),J=JAA,JZZ)
  224 FORMAT(1H,F5.0,10E12.3)
   97 CONTINUE
   96 CONTINUE
      RETURN
      END

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```

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