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MICROCOMPUTER-BASED BENCHMARK PROBLEM SOLUTIONS

Final Report

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INTRODUCTION

Analytical solutions to 18 repository design, waste package and radiological assessment benchmark problems were performed using FORTRAN, BASIC and LOTUS 1,2,3 spreadsheet programs. These programs are documented and presented in the following sections.

1. BASIC PROGRAM RD2.4

This Basic program performs a transient conduction analysis of an infinite length and width slab with temperature-dependent thermal conductivity exposed to a constant surface temperature at time zero.

Theory

The engineering aspects of this problem are presented in Section 2.4 of Reference 1 (attached for the readers convenience at the end of this section).

Program

Input Data: Input specifications for BETA, X, DX, K, C, RHO, and DT are found in line 70, as well as values for T_0 (=250) and T_i (=30) in line 100, and time (=60000) in line 130. Note that T_0 is input twice in line 100. The specifications may be changed by the user for the solution of other problems. The user is cautioned to select values of Δx and Δt that satisfy the stability condition given on page 24 of the reference.

Line 210: Equation 8 is solved for each time step and distance step defined by parameters DT and DX.

Output: The output from this program is displayed on the screen. Output can be redirected to a printer by capturing it as it appears on the screen or by changing the PRINT statements to LPRINT in line 230 of the program.

The first column of the output is time (hours). The second column gives the temperature of the slab at a distance of DX from the outside boundary (1 meter for this problem). Columns 3 through 10 give the temperature at successive DX steps into the slab, while column 11 is the temperature at the center of the slab.

A listing of the program is contained in Figure 1, and the output for the problem in Reference 1 is shown in Figure 2.

Figure 1

Basic Program RD2.4 Listing

```
70 BETA=.0004:X=10:DX=1!:K=1!:C=725:RHO=2980:DT=100!*3600:TERM=K*DT/(RHO*C*DX*DX
)
80 DIM O(X/DX+2),N(X/DX+2)
100 FOR I=2 TO X/DX+2:O(I)=30:NEXT I:O(1)=250:N(1)=250
110 LPRINT " TIME        TEMPERATURES (C) AT DISTANCES DX FROM THE OUTSIDE BOUNDA
RY"
120 LPRINT "(Hours) DX=1   DX=2   DX=3   DX=4   DX=5   DX=6   DX=7   DX=8   DX=9
  DX=10"
125 LPRINT
130 FOR T = DT TO 60000!*3600 STEP DT
200 FOR I=2 TO X/DX+1
210 N(I)=O(I)*(1-2*TERM*(1+BETA*O(I))) + TERM*(1+BETA*O(I))*(O(I+1)+O(I-1)) +
      TERM*BETA*.25*(O(I+1)*O(I+1)-2*O(I+1)*O(I-1)+O(I-1)*O(I-1))
220 NEXT I
225 PT=T/(1000*3600)
230 IF(INT(PT)=PT) THEN LPRINT USING "#####";T/3600;:FOR I=2 TO X/DX+1:IF(INT(PT
)=PT) THEN LPRINT USING "####.##";N(I);:NEXT I:LPRINT
240 FOR I=2 TO X/DX+1:O(I)=N(I):NEXT I:O(X/DX+2)=O(X/DX)
250 NEXT T
990 END
```

Figure 2

Basic Problem RD2.4 Sample Output

TIME (Hours)	TEMPERATURES (C) AT DISTANCES DX FROM THE OUTSIDE BOUNDARY DX=1	DX=2	DX=3	DX=4	DX=5	DX=6	DX=7	DX=8	DX=9	DX=10
1000	164.01	96.00	55.62	37.72	31.78	30.31	30.04	30.00	30.00	30.00
2000	187.49	131.65	88.47	59.73	43.30	35.22	31.79	30.54	30.15	30.06
3000	198.51	150.59	110.08	79.09	57.67	44.31	36.79	32.98	31.30	30.84
4000	205.21	162.69	125.11	94.28	70.85	54.38	43.69	37.38	34.15	33.18
5000	209.84	171.26	136.25	106.32	82.25	64.10	51.35	43.14	38.63	37.20
6000	213.29	177.74	144.93	116.11	92.09	73.16	59.18	49.73	44.32	42.57
7000	215.99	182.88	151.96	124.31	100.69	81.54	66.95	56.79	50.83	48.87
8000	218.19	187.12	157.86	131.35	108.35	89.33	74.54	64.05	57.80	55.73
9000	220.05	190.72	162.94	137.56	115.27	96.61	81.91	71.35	65.00	62.88
10000	221.66	193.86	167.43	143.13	121.63	103.47	89.03	78.57	72.24	70.13
11000	223.09	196.67	171.47	148.21	127.53	109.94	95.88	85.64	79.43	77.34
12000	224.39	199.22	175.17	152.92	133.05	116.09	102.48	92.53	86.47	84.44
13000	225.58	201.57	178.60	157.31	138.25	121.94	108.81	99.20	93.33	91.36
14000	226.68	203.75	181.81	161.43	143.17	127.52	114.89	105.63	99.97	98.07
15000	227.72	205.81	184.83	165.34	147.85	132.84	120.72	111.82	106.38	104.55
16000	228.70	207.75	187.69	169.04	152.30	137.93	126.31	117.77	112.55	110.80
17000	229.62	209.59	190.41	172.57	156.55	142.79	131.67	123.49	118.48	116.80
18000	230.50	211.34	192.99	175.93	160.61	147.44	136.80	128.97	124.18	122.57
19000	231.34	213.01	195.46	179.14	164.49	151.89	141.71	134.22	129.64	128.10
20000	232.15	214.61	197.82	182.21	168.20	156.15	146.41	139.25	134.87	133.40
21000	232.91	216.13	200.07	185.15	171.74	160.23	150.92	144.07	139.88	138.47
22000	233.65	217.59	202.23	187.95	175.14	164.13	155.23	148.69	144.68	143.34
23000	234.35	218.99	204.29	190.64	178.39	167.87	159.36	153.10	149.28	147.99
24000	235.02	220.32	206.27	193.21	181.50	171.44	163.31	157.33	153.68	152.45
25000	235.67	221.60	208.16	195.67	184.47	174.86	167.09	161.38	157.89	156.71
26000	236.28	222.83	209.97	198.03	187.32	178.13	170.71	165.25	161.91	160.79
27000	236.87	224.00	211.70	200.29	190.05	181.27	174.17	168.96	165.77	164.70
28000	237.44	225.12	213.36	202.45	192.66	184.27	177.48	172.50	169.46	168.43
29000	237.98	226.20	214.95	204.51	195.16	187.13	180.65	175.89	172.98	172.01
30000	238.50	227.23	216.47	206.49	197.55	189.88	183.69	179.14	176.36	175.42
31000	239.00	228.22	217.93	208.39	199.84	192.51	186.59	182.24	179.59	178.69
32000	239.47	229.16	219.32	210.20	202.03	195.02	189.37	185.21	182.68	181.82
33000	239.93	230.07	220.66	211.93	204.12	197.43	192.02	188.05	185.63	184.81
34000	240.37	230.93	221.93	213.59	206.13	199.73	194.56	190.77	188.45	187.67
35000	240.78	231.76	223.16	215.18	208.05	201.93	196.99	193.37	191.16	190.41
36000	241.19	232.56	224.33	216.70	209.88	204.03	199.32	195.86	193.74	193.03
37000	241.57	233.32	225.45	218.16	211.64	206.05	201.54	198.23	196.21	195.53
38000	241.94	234.04	226.52	219.55	213.32	207.98	203.67	200.51	198.58	197.93
39000	242.29	234.74	227.54	220.88	214.92	209.82	205.70	202.68	200.84	200.22
40000	242.62	235.40	228.53	222.16	216.46	211.58	207.65	204.76	203.00	202.40
41000	242.94	236.04	229.46	223.38	217.93	213.27	209.51	206.75	205.06	204.50
42000	243.25	236.65	230.36	224.54	219.34	214.88	211.29	208.65	207.04	206.50
43000	243.55	237.24	231.22	225.66	220.68	216.42	212.99	210.47	208.93	208.41
44000	243.83	237.79	232.04	226.72	221.97	217.90	214.62	212.21	210.74	210.24
45000	244.10	238.33	232.83	227.75	223.20	219.31	216.17	213.87	212.47	211.99
46000	244.36	238.84	233.58	228.72	224.38	220.66	217.66	215.46	214.12	213.67
47000	244.60	239.33	234.30	229.66	225.50	221.95	219.08	216.98	215.70	215.27
48000	244.84	239.79	234.99	230.55	226.58	223.18	220.44	218.44	217.21	216.80
49000	245.07	240.24	235.65	231.40	227.61	224.36	221.74	219.83	218.66	218.26
50000	245.28	240.67	236.28	232.22	228.59	225.49	222.99	221.16	220.04	219.66
51000	245.49	241.08	236.88	233.00	229.53	226.57	224.18	222.43	221.36	221.00
52000	245.69	241.47	237.46	233.75	230.43	227.60	225.32	223.64	222.62	222.28
53000	245.88	241.85	238.01	234.46	231.30	228.59	226.40	224.80	223.83	223.50
54000	246.06	242.20	238.54	235.15	232.12	229.53	227.44	225.91	224.98	224.67
55000	246.23	242.55	239.04	235.80	232.91	230.43	228.44	226.98	226.08	225.78
56000	246.39	242.87	239.52	236.42	233.66	231.29	229.39	227.99	227.14	226.85
57000	246.55	243.19	239.98	237.02	234.38	232.12	230.30	228.96	228.15	227.87
58000	246.70	243.49	240.42	237.59	235.07	232.91	231.16	229.89	229.11	228.85
59000	246.85	243.77	240.84	238.14	235.72	233.66	232.00	230.78	230.03	229.78
60000	246.99	244.05	241.25	238.66	236.35	234.38	232.79	231.62	230.91	230.67

2.4 Transient Conduction Analysis of an Infinite Slab With Temperature-Dependent Thermal Conductivity Exposed to a Constant Surface Temperature at Time Zero (Dowty and Haworth, 1965, and Ozisik, 1968, p. 380)

Problem Statement - This problem deals with the thermal response of a slab of infinite length and width, thickness 2L, and initially at uniform temperature T_i, exposed to a constant surface temperature T_0 on both sides at zero time (Figure 2.4-1). The thermal conductivity of the slab is allowed to vary linearly with temperature. The temperature distribution in the slab at any time is to be calculated. Due to symmetry, only one half of the slab thickness need be modeled.

The governing equation for one-dimensional conduction in a solid may be written in the form:

$$\rho c \frac{\partial T}{\partial t} - \frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right) = 0 \qquad (1)$$

where:

- T = temperature,
- t = time,
- ρ = material density,
- c = specific heat,
- k = thermal conductivity, and
- x = perpendicular distance to a point from the center plane of the slab.

For this problem, the variation in thermal conductivity is expressed as:

$$k = k_0 (1 + \beta T) \qquad (2)$$

where:

- k_0 = thermal conductivity at zero degrees; and
- β = temperature coefficient of thermal conductivity.

The solution to the above equations, subject to the following initial and boundary conditions:

$$T(0 \leq x \leq L) = T_i \quad \text{at} \quad t < 0,$$

$$\frac{\partial T}{\partial x} = 0 \quad \text{at} \quad x = 0, \text{ and}$$

$$T = T_0 \quad \text{at} \quad x = L \quad \text{for} \quad t \geq 0,$$

describes the slab depicted in Figure 2.4-1.

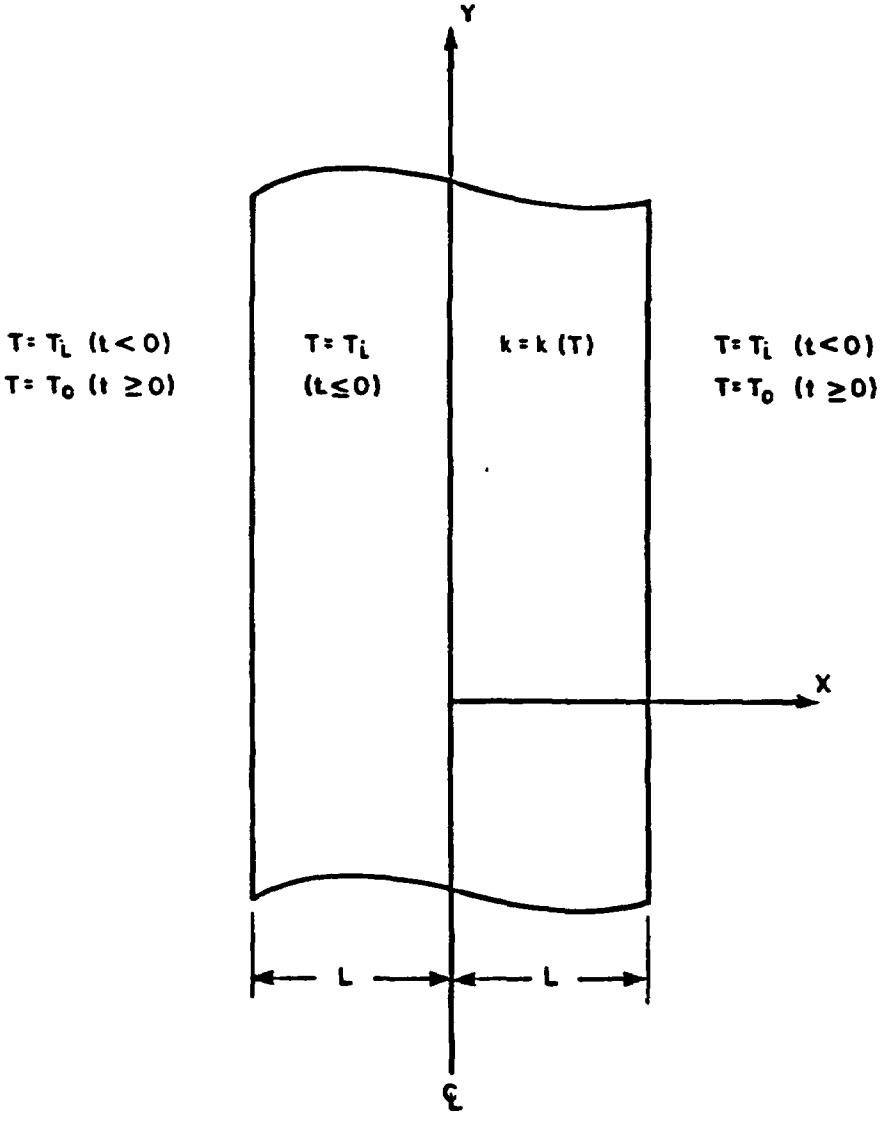


Figure 2.4-1 Infinite Slab with Temperature-Dependent Conductivity

Objectives - The purpose of this problem is to check the numerical techniques in the one-dimensional transient portion of the code with variable conductivity.

Solution - The solution to the above problem is presented by Ozisik (1968) who utilized the numerical results of Dowty and Haworth (1965).

The results were developed from finite-difference formulation and plotted in dimensionless form. Figure 2.4-2a shows the dimensionless center-plane temperature

$$(1 + 0.4\,\beta\,T_i)\left[\frac{T_c - T_o}{T_i - T_o}\right] \tag{3}$$

as a function of the dimensionless time (Fourier modulus)

$$\tau = \frac{\alpha_o t}{L^2} \tag{4}$$

for various values of the parameter

$$\psi = 10\,\beta T_o \tag{5}$$

where:

T_c = center-plane temperature; and
α_o = thermal diffusivity at zero degrees.

Figure 2.4-2b is a position-correction chart which provides a means of evaluating the temperature at other positions in the slab. On this chart, the dimensionless temperature

$$\frac{T - T_o}{T_c - T_o} \tag{6}$$

is plotted as a function of x/L and ψ/τ.

The temperature of a given position can be determined by multiplying the value of

$$(1 + 0.4\,\beta T_i)\left[\frac{T_c - T_o}{T_i - T_o}\right] \tag{7}$$

by the value of

$$\frac{T - T_o}{T_c - T_o}$$

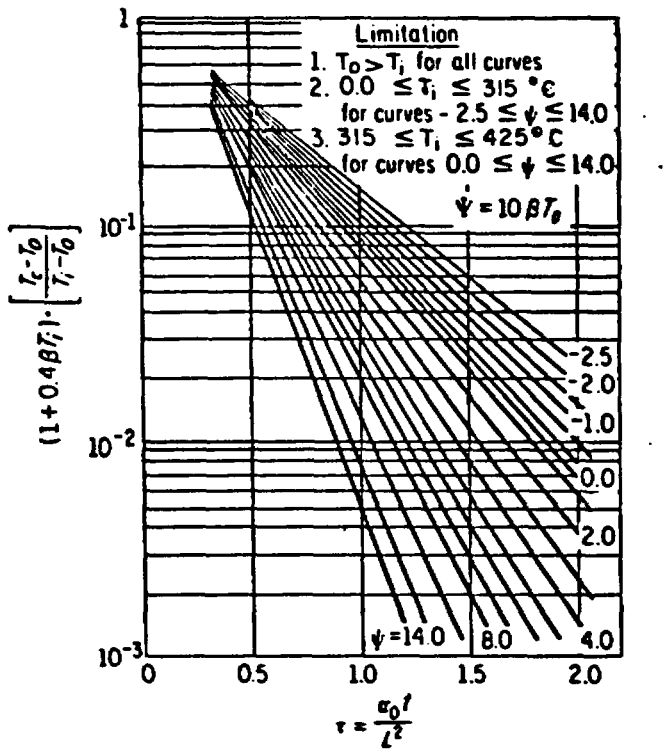


Figure 2.4-2a Dimensionless Center-Plane Temperature of an Infinite Slab (From Dowty and Haworth, 1965)

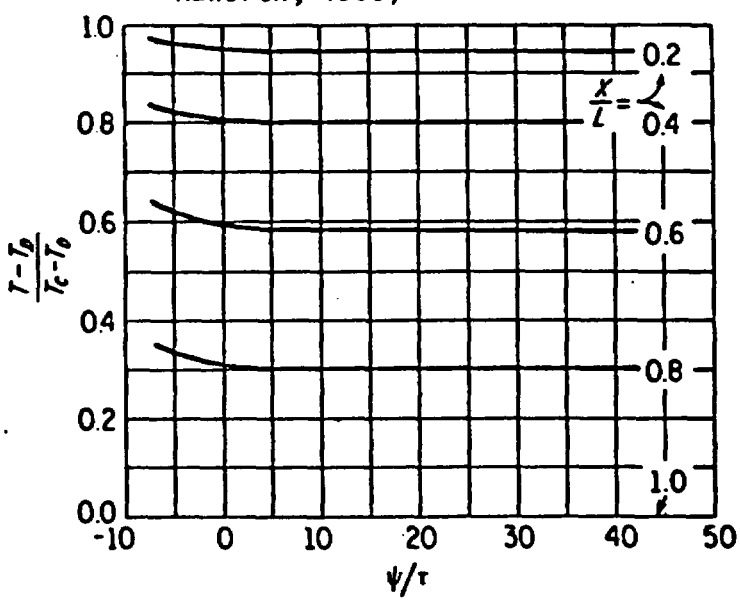


Figure 2.4-2b Position Correction Chart (From Dowty and Haworth, 1965)

The results for comparison have been computed by the following implicit finite-difference formulation:

$$T_{n,t+1} = \left\{1 - 2\left(\frac{\alpha_o \Delta t}{\Delta x^2}\right)(1 + \beta T_{n,t})\right\} T_{n,t}$$

$$+ \frac{\alpha_o \Delta t}{\Delta x^2} (1 + \beta T_{n,t}) (T_{n+1,t} + T_{n-1,t}) \qquad (8)$$

$$+ \frac{\alpha_o \Delta t}{\Delta x^2} \left(\frac{\beta}{4}\right) \left\{T^2_{n+1,t} - (2T_{n+1,t})(T_{n-1,t}) + T^2_{n-1,t}\right\}$$

with the stability condition of:

$$\frac{(\Delta x)^2}{\alpha_o (\Delta t)(1 + \beta T_M)} \geq 2.0$$

where: T_M = 0 if β is negative or the highest temperature encountered if β is positive.

Assumptions - The assumptions made in solving the above equations include:

- Density and specific heat are constant; and
- The slab is uniform section and of infinite length and width.

Input Specifications - An example problem is described by the following data:

- Geometry
  - Slab half-thickness $L = 10.0$ m
- Material Properties
  - Density $\rho = 2980$ kg/m^3
  - Specific heat $c = 725$ J/(kg·°C)
  - Thermal conductivity at zero degrees $k_o = 1.00$ W/(m·°C)
  - Temperature coefficient of thermal conductivity $\beta = 4.00 \times 10^{-4}$/°C
- Initial Conditions/Boundary Conditions
  - Initial slab temperature $T_i = 30$°C
  - Applied surface temperature $T_o = 250$°C

Output Specifications - Temperature profiles of the slab are to be determined after 30,000 and 60,000 hours.

2. BASIC PROGRAM RD2.6

This program calculates the thermal response of an infinite length bar with anisotropic thermal conductivity when exposed to a large mass of fluid.

Theory

The engineering aspects of this problem are discussed in Section 2.6 of Reference 1 (attached for the readers convenience at the end of this section).

Program

Input Data: Time (in seconds) is input by the user via the keyboard when prompted by the program (? prompt immediately after the program starts). Values of k_x, c, ρ, and L_1 are used to calculate the constant in Line 120 $[(k_x/c\rho)/L_1^2 = 9.99E-7/4]$. In a similar manner, values of k_y, c, ρ, and L_2 are used to calculate the constant in Line 130. Lines 140-180 are the first five roots to the characteristic equation and are unique for the Nusselt number $N_u = h \cdot L_1/k_x = h \cdot L_2/k_y = 2$. Values of T_i and T_o are used in Lines 320 and 490 to calculate the constants $(T_i - T_o) = 270$ and $T_o = 30$ where T_i and T_o are in degrees Celsius.

Lines 210-360: The characteristic equation is solved along the y-axis (x = 0) beginning at y = 0 and using step sizes as defined in Line 220.

Lines 380-570: The characteristic equation is solved along the x-axis (y = 0) beginning at x = 0 and using step sizes as defined in Line 390.

Output: The first half of the output gives temperatures (degrees Celsius) along the y-axis at x = 0, while the second half of the output gives temperatures along the x-axis at y = 0.

A listing of the program is contained in Figure 3, and the output for the problem in Reference 1 is shown in Figure 4.

Figure 3

Basic Program RD2.6 Listing

```
5  DEFDBL A-H,K-Z
6  DEFINT I-J
10 INPUT TIME
20 PRINT "    "
30 PRINT "    "
40 PRINT "TIME ";
50 PRINT USING "#######,.";TIME;
60 PRINT " SECONDS"
70 TH=TIME/3600#
80 PRINT "     (";
90 PRINT USING "#######,.";TH;
100 PRINT " HOURS) "
110 PRINT "    "
120 TUX=TIME*.000000999#/4#
130 TUY=TIME*.000000499B#
140 M(1)=1.0769#
150 M(2)=3.6436#
160 M(3)=6.5783#
170 M(4)=9.629599#
180 M(5)=12.7223#
190 PRINT "    X/L1      Y/L2     FSUMX      FSUMY      TEMP (C)"
200 PRINT "    "
210 LX=0#
219 FOR I=0 TO 10 STEP 1
220 LY = I/10#
230 FSUMX=0#
240 FSUMY=0#
250 FOR J=1 TO 5
260 ML=M(J)
263 PX=ML^2*TUX : IF PX>88# THEN PX=88#
266 PY=ML^2*TUY : IF PY>88# THEN PY=88#
270 FX=4#*(((SIN(ML))/(2#*ML+SIN(2#*ML)))/EXP(PX))*COS(ML*LX)
280 FY=4#*(((SIN(ML))/(2#*ML+SIN(2#*ML)))/EXP(PY))*COS(ML*LY)
290 FSUMX=FSUMX+FX
300 FSUMY=FSUMY+FY
310 NEXT J
320 CTEMP=FSUMX*FSUMY*270#+30#
330 PRINT USING "###.####";LX,LY;
340 PRINT USING "####.#####";FSUMX,FSUMY;
350 PRINT USING "######.###";CTEMP
360 NEXT I
370 PRINT "    "
380 LY=0#
389 FOR I=0 TO 10 STEP 1
390 LX = I/10#
400 FSUMX=0#
410 FSUMY=0#
420 FOR J=1 TO 5
430 ML=M(J)
433 PX=ML^2*TUX:IF PX>88# THEN PX=88#
436 PY=ML^2*TUY:IF PY>88# THEN PY=88#
440 FX=4#*(((SIN(ML))/(2#*ML+SIN(2#*ML)))/EXP(PX))*COS(ML*LX)
450 FY=4#*(((SIN(ML))/(2#*ML+SIN(2#*ML)))/EXP(PY))*COS(ML*LY)
460 FSUMX=FSUMX+FX
470 FSUMY=FSUMY+FY
480 NEXT J
490 CTEMP=FSUMX*FSUMY*270#+30#
500 PRINT USING "###.####";LX,LY;
510 PRINT USING "####.#####";FSUMX;FSUMY;
520 PRINT USING "######.###";CTEMP
540 NEXT I
570 END
```

Figure 4

Basic Problem RD2.6 Sample Output

```
RUN
? 1998000

TIME %1,998,000 SECONDS
     (      555 HOURS)
```

X/L1	Y/L2	FSUMX	FSUMY	TEMP (C)
0.0000	0.0000	0.66037	0.37014	95.995
0.0000	0.1000	0.66037	0.36799	95.613
0.0000	0.2000	0.66037	0.36159	94.470
0.0000	0.3000	0.66037	0.35099	92.581
0.0000	0.4000	0.66037	0.33633	89.966
0.0000	0.5000	0.66037	0.31777	86.657
0.0000	0.6000	0.66037	0.29552	82.691
0.0000	0.7000	0.66037	0.26986	78.115
0.0000	0.8000	0.66037	0.24107	72.982
0.0000	0.9000	0.66037	0.20948	67.350
0.0000	1.0000	0.66037	0.17547	61.286
0.0000	0.0000	0.66037	0.37014	95.995
0.1000	0.0000	0.65656	0.37014	95.615
0.2000	0.0000	0.64518	0.37014	94.477
0.3000	0.0000	0.62635	0.37014	92.596
0.4000	0.0000	0.60029	0.37014	89.991
0.5000	0.0000	0.56727	0.37014	86.692
0.6000	0.0000	0.52768	0.37014	82.735
0.7000	0.0000	0.48194	0.37014	78.164
0.8000	0.0000	0.43060	0.37014	73.033
0.9000	0.0000	0.37422	0.37014	67.399
1.0000	0.0000	0.31348	0.37014	61.328

```
RUN
? 3996000

TIME %3,996,000 SECONDS
     (    1,110 HOURS)
```

X/L1	Y/L2	FSUMX	FSUMY	TEMP (C)
0.0000	0.0000	0.37039	0.11625	41.626
0.0000	0.1000	0.37039	0.11558	41.559
0.0000	0.2000	0.37039	0.11357	41.358
0.0000	0.3000	0.37039	0.11024	41.025
0.0000	0.4000	0.37039	0.10563	40.564
0.0000	0.5000	0.37039	0.09981	39.981
0.0000	0.6000	0.37039	0.09282	39.283
0.0000	0.7000	0.37039	0.08476	38.476
0.0000	0.8000	0.37039	0.07572	37.572
0.0000	0.9000	0.37039	0.06579	36.580
0.0000	1.0000	0.37039	0.05511	35.512
0.0000	0.0000	0.37039	0.11625	41.626
0.1000	0.0000	0.36825	0.11625	41.559
0.2000	0.0000	0.36184	0.11625	41.358
0.3000	0.0000	0.35123	0.11625	41.025
0.4000	0.0000	0.33656	0.11625	40.564
0.5000	0.0000	0.31799	0.11625	39.981
0.6000	0.0000	0.29573	0.11625	39.283
0.7000	0.0000	0.27005	0.11625	38.476
0.8000	0.0000	0.24123	0.11625	37.572
0.9000	0.0000	0.20963	0.11625	36.580
1.0000	0.0000	0.17559	0.11625	35.512

Figure 4

Basic Problem RD2.6 Sample Output (continued)

```
RUN
? 7992000

TIME %7,992,000 SECONDS
     (    2,220 HOURS)
```

X/L1	Y/L2	FSUMX	FSUMY	TEMP (C)
0.0000	0.0000	0.11642	0.01147	30.360
0.0000	0.1000	0.11642	0.01140	30.358
0.0000	0.2000	0.11642	0.01120	30.352
0.0000	0.3000	0.11642	0.01088	30.342
0.0000	0.4000	0.11642	0.01042	30.328
0.0000	0.5000	0.11642	0.00985	30.309
0.0000	0.6000	0.11642	0.00916	30.288
0.0000	0.7000	0.11642	0.00836	30.263
0.0000	0.8000	0.11642	0.00747	30.235
0.0000	0.9000	0.11642	0.00649	30.204
0.0000	1.0000	0.11642	0.00544	30.171
0.0000	0.0000	0.11642	0.01147	30.360
0.1000	0.0000	0.11574	0.01147	30.358
0.2000	0.0000	0.11373	0.01147	30.352
0.3000	0.0000	0.11039	0.01147	30.342
0.4000	0.0000	0.10578	0.01147	30.328
0.5000	0.0000	0.09994	0.01147	30.309
0.6000	0.0000	0.09295	0.01147	30.288
0.7000	0.0000	0.08488	0.01147	30.263
0.8000	0.0000	0.07582	0.01147	30.235
0.9000	0.0000	0.06589	0.01147	30.204
1.0000	0.0000	0.05519	0.01147	30.171

2.6 Transient Temperature Analysis of an Infinite Rectangular Bar with Anisotropic Conductivity (Schneider, 1955, p. 261)

Problem Statement - This problem is concerned with the thermal response of an infinite length bar, width $2L_1$ and depth $2L_2$, initially at uniform temperature T_i, exposed to a large mass of fluid of temperature T_0, on all four sides at zero time (Figure 2.6-1). The thermal conductivity of the bar is anisotropic with its principal directions coinciding with the x and y axes. The temperature distribution in the bar is to be calculated along the x and y axes at any time.

The governing equation for transient two-dimensional anisotropic heat conduction in a solid may be written as:

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y}\right) \tag{1}$$

where:

x, y		define a point on a plane in the bar,
T	=	temperature of the solid,
k_x, k_y	=	thermal conductivity in the x and y directions,
ρ	=	material density,
c	=	specific heat, and
t	=	time.

Heat is transferred from the bar's surface to the fluid mass across a thin layer of fluid adjacent to the bar in which a temperature gradient exists. This form of heat transfer is called convection. It acts as a boundary condition for the above conduction equation and may be expressed as:

$$q = A\,h\,(T_s - T_\infty) \tag{2}$$

where:

q	=	rate of heat transfer from surface to fluid,
A	=	surface area,
h	=	convective heat transfer coefficient,
T_s	=	surface temperature, and
T_∞	=	fluid temperature.

The solution to the conduction equation, subject to the convective boundary equation and the following initial and boundary conditions;

$$T = T_i \quad \text{for} \quad t < 0,$$
$$T_\infty = T_i \quad \text{for} \quad t < 0,$$
$$T_\infty = T_0 \quad \text{for} \quad t \geq 0,$$
$$\frac{\partial T}{\partial x} = 0 \quad \text{at} \quad x = 0, \text{ and}$$
$$\frac{\partial T}{\partial y} = 0 \quad \text{at} \quad y = 0,$$

describes the bar depicted in Figure 2.6-1.

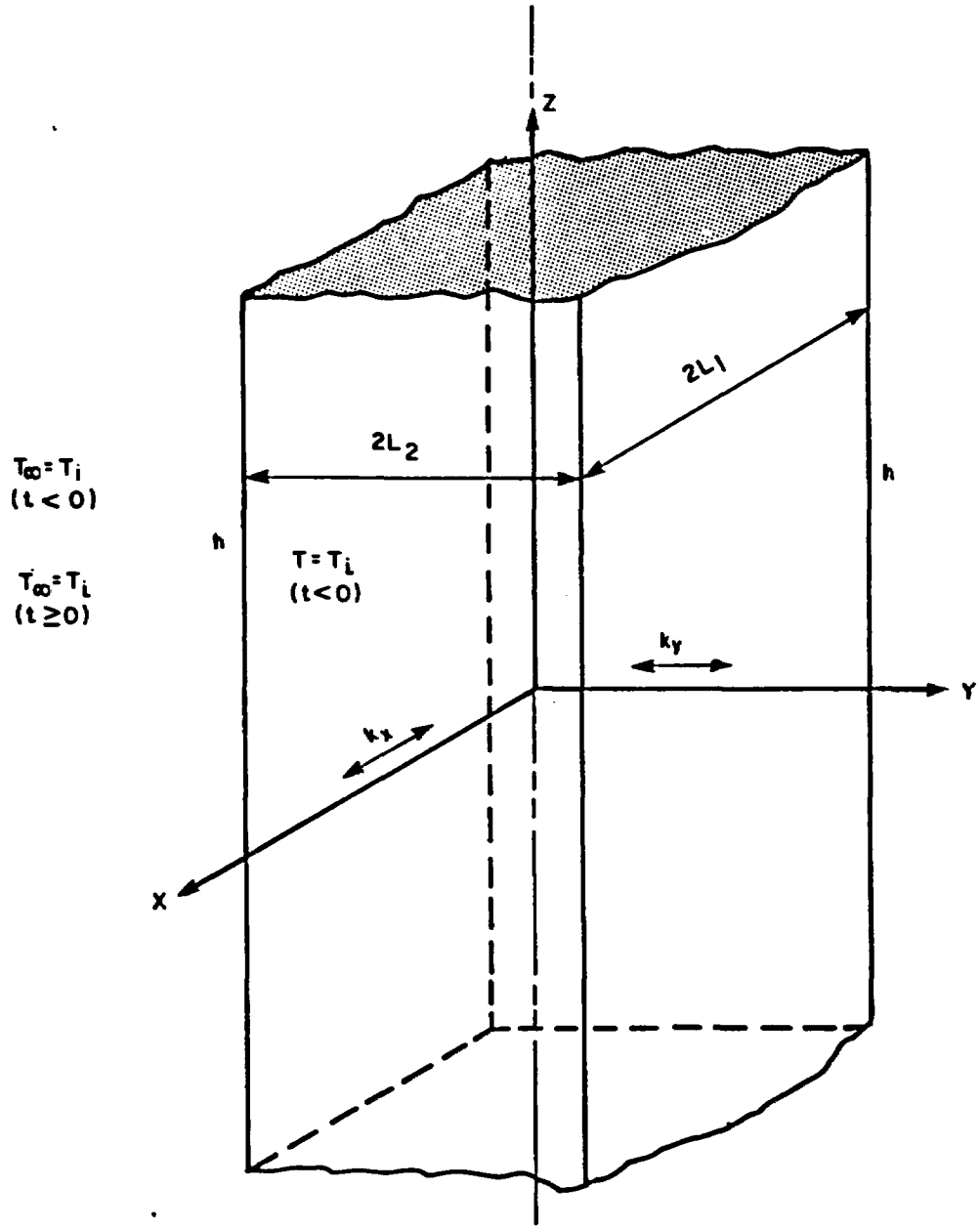


Figure 2.6-1 Rectangular Bar with Anisotropic Conductivity

Objectives - The purpose of this example problem is to check the numerical techniques in the two-dimensional transient anisotropic conduction portion of the code. The problem additionally checks the coding of the convective boundary condition in the computer program.

Solution - The solution to the above problem is presented in Schneider (1955). The analytical solution to a similar problem involving infinite plates was first developed, and then extended to an infinite bar with anisotropic conductivity. Figure 2.6-2a shows the dimensionless center plane temperature history for an infinite plate with surface resistance. In the chart

$$(T_c - T_o) / (T_i - T_o) \tag{3}$$

is a function of the Fourier modulus

$$\tau_x = \frac{\alpha_x t}{L_1^2} \quad \text{or} \quad \tau_y = \frac{\alpha_y t}{L_2^2} \tag{4}$$

for various values of the reciprocal of the Nusselt number

$$(1/N_{Nu})_x = \frac{k_x}{hL_1} \quad \text{or} \quad (1/N_{Nu})_y = \frac{k_y}{hL_2} \tag{5}$$

where:

T_c = center plane or center line temperature,
τ_x and τ_y = Fourier modulus for the x and y axes,
α_x and α_y = thermal diffusivity, $\alpha = k/c\rho$ for the x and y directions, and
N_{Nu} = Nusselt number.

The infinite plate center plane graph is extended to an infinite bar center line solution by finding the product of the term $(T_c-T_o)/(T_i-T_o)$ from both the x and y axes based on an infinite plate and setting this quantity equal to a similar term for the infinite bar. The infinite plate position-correction chart shown in Figure 2.6-2b may then be employed to find the temperature at other locations within the bar. This dimensionless graph shows

$$\frac{T - T_o}{T_c - T_o} \tag{6}$$

as a function of the inverse of the Nusselt number and distance along an axis from the center line divided by the half-bar width. The product of the correction terms from both the x and y axes yields the correction term applicable to the infinite bar case.

Anisotropic conductivity is incorporated into the solution by the Nusselt number, the Fourier modulus, and the thermal diffusivity.

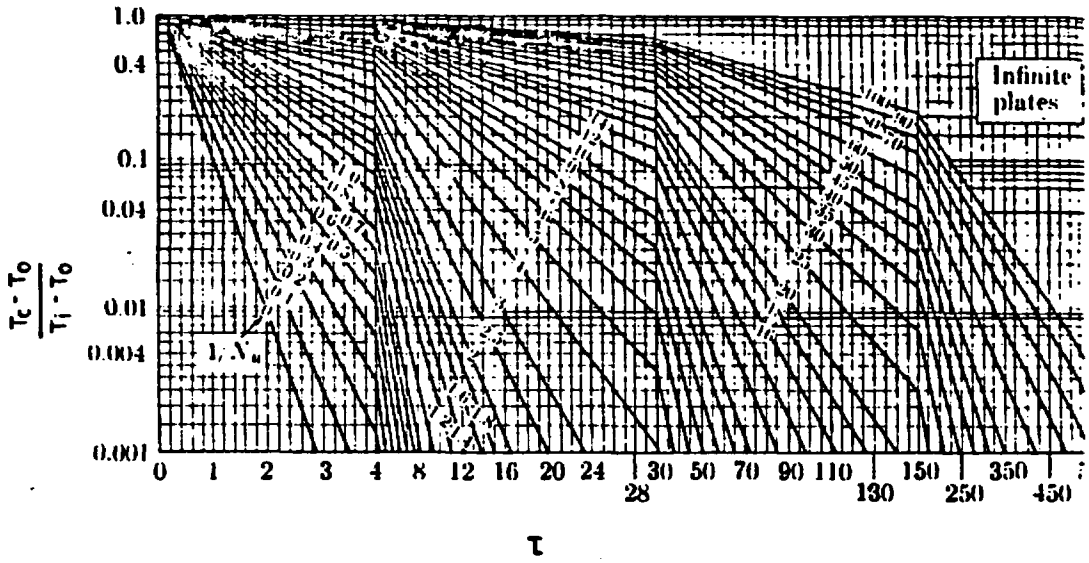


Figure 2.6-2a Dimensionless Centerline Temperature for a Plate with Surface Resistance (From Schneider, 1955)

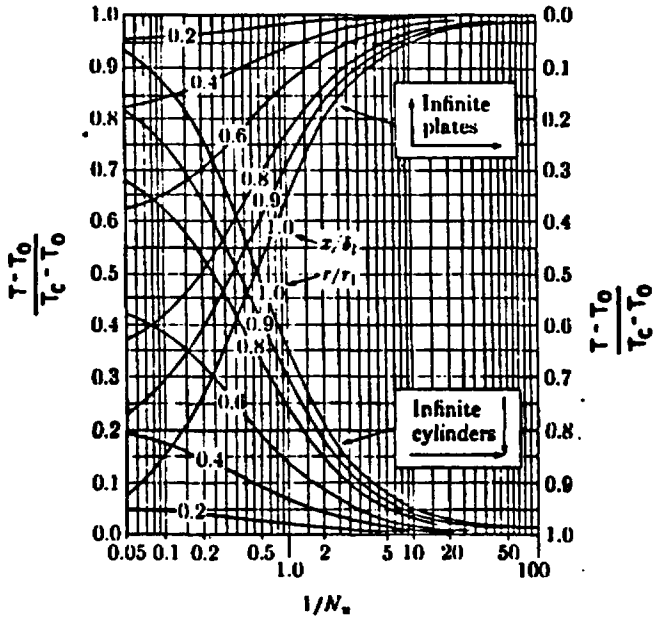


Figure 2.6-2b Dimensionless Position Correction Chart (From Schneider, 1955)

*Reprinted with permission from Schneider, P.D., Conduction Heat Transfer, Addison-Wesley Publishing Company, Inc., Reading, MA, 1955

Assumptions - The assumptions made in solving the above equations include:

- Material parameters such as density, specific heat, and thermal conductivity are constant.
- The convective heat transport coefficient is a constant.

Input Specifications - The example problem is described by the following data:

- Geometry
  - Bar half-width along x axis $L_1 = 2.0$ m
  - Bar half-width along y axis $L_2 = 1.0$ m
- Material Properties
  - Density $\rho = 2760$ kg/m^3
  - Specific heat $c = 725$ J/(kg•°C)
  - Thermal conductivity in the x direction $k_x = 2.00$ W/(m•°C)
  - Thermal conductivity in the y direction $k_y = 1.00$ W/(m•°C)
- Initial Conditions/Boundary Conditions
  - Convective heat transfer coefficient $h = 2.0$ W/(m^2•°C)
  - Initial bar temperature $T_i = 300$°C
  - Fluid temperature $T_o = 30$°C

Output Specifications - Temperature profiles along the x and y axes are to be determined after 555, 1110, and 2220 hours.

3. BASIC PROGRAM RD2.8

This program calculates the transient temperature response to the quench of an infinite length and width slab with a temperature-dependent convection coefficient.

Theory

The engineering aspects of this program are discussed in Section 2.8 of Reference 1 (attached for the readers convenience at the end of this section).

Program

Input Data: The time step, DT, is input in Line 90. Initial temperatures, T_o and T_i are input in line 100 (T_o = 37.8 is input two times in this line). Thermal conductivity, k, and thermal diffusivity, α, are used to calculate the constant in Line 110 (k/α = 44,702,800). Slab thickness, L, is input as $L/10 = \Delta L$ = 0.0203 in Line 110. Variables k and ΔL are input again in Line 120 to calculate $k/\Delta L$. The final time (in seconds) = 25200 is input in Line 130. The variables h_o = 11.36, $\beta \cdot h_o$ = 0.20448 and T_o = 37.8 are input in Lines 140 and 160 (T_o is input two times in each of these lines).

Line 100: The initial temperature distribution in the slab is determined here for the 11 segments (the first segment (I=1) and the last segment (I=11) are one-half the thickness of the other segments).

Lines 140 & 160: Equation 3 of the reference is solved here for the first and last segments.

Lines 150 & 170: The new temperature, N(I), is calculated in these lines for the first and last segments.

Line 210: Here, the new temperature is calculated for the middle segments.

Line 240: The new temperatures, N(I), calculated for the current time increment, T, are set equal to the old temperatures, O(I), for the next time increment.

Output: The surface temperature of the hot-side surface is output to the printer at 0.1 hour increments. The time increments for printing the results may be adjusted by changing the constant in Line 225 (the constant = print time in seconds).

A listing of the program is contained in Figure 5, and the output for the problem in Reference 1 is shown in Figure 6.

Figure 5

Basic Program RD2.8 Listing

```
80 DIM O(11),N(11)
90 DT=10
95 LPRINT "TIME(hr)        TEMP (C)"
100 FOR I=1 TO 11:O(I)=37.8+(260-37.8)*(I-1)*.1:NEXT I
110 C#=44702800#*.0203
115 CI#=1/C#
120 K=3.46/.0203
130 FOR T = DT TO 25200 STEP DT
140 P=-(11.36+.20448*(O(1)-37.8))*(O(1)-37.8)
150 N(1)=O(1)+DT*2*CI#*(P+K*(O(2)-O(1)))
160 P=-(11.36+.20448*(O(11)-37.8))*(O(11)-37.8)
170 N(11)=O(11)+DT*2*CI#*(P+K*(O(10)-O(11)))
200 FOR I=2 TO 10
210 N(I)=O(I)+DT*CI#*(K*(O(I+1)+O(I-1)-2*O(I)))
220 NEXT I
225 X=T/360
230 IF(INT(X)=X) THEN LPRINT T/3600,N(11)
240 FOR I=1 TO 11:O(I)=N(I):NEXT I
250 NEXT T
```

Figure 6

Basic Problem RD2.8 Sample Output

TIME(hr)	TEMP (C)
.1	248.2393
.2	238.6501
.3	230.7266
.4	224.0928
.5	218.4663
.6	213.6336
.7	209.4322
.8	205.7372
.9	202.4522
1	199.5023
1.1	196.8288
1.2	194.3855
1.3	192.1357
1.4	190.0501
1.5	188.105
1.6	186.2815
1.7	184.5637
1.8	182.9389
1.9	181.3964
2	179.9273
2.1	178.5239
2.2	177.1801
2.3	175.8902
2.4	174.6496
2.5	173.4541
2.6	172.3004
2.7	171.185
2.8	170.1054
2.9	169.0591
3	168.0438
3.1	167.0577
3.2	166.0988
3.3	165.1657
3.4	164.2568
3.5	163.3709
3.6	162.5066
3.7	161.663
3.8	160.8389
3.9	160.0333
4	159.2455
4.1	158.4746
4.2	157.7198
4.3	156.9805
4.4	156.2559
4.5	155.5456
4.6	154.8488
4.7	154.1651
4.8	153.4939
4.9	152.8349
5	152.1874
5.1	151.5512
5.2	150.9258
5.3	150.3108
5.4	149.706
5.5	149.1109
5.6	148.5252
5.7	147.9486
5.8	147.3809
5.9	146.8217
6	146.2708
6.1	145.7281
6.2	145.1932
6.3	144.6659
6.4	144.1459
6.5	143.6332
6.6	143.1275
6.7	142.6286
6.8	142.1363
6.9	141.6505
7	141.171

2.8 Transient Temperature Response to the Quench of an Infinite Slab with a Temperature-Dependent Convection Coefficient (Kreith, 1958, p. 161)

Problem Statement - This problem deals with the transient thermal analysis of the quench of one side of an infinite slab with a linearly temperature dependent convection heat transfer coefficient (Figure 2.8-1). The slab, thickness L, is initially in a steady-state condition transferring heat from one side at temperature T_i to its other side at temperature T_0. At time zero, the hot side is exposed to a large fluid mass of temperature T_0. The temperature distribution in the slab at any time is to be calculated.

The governing equation for one-dimensional conduction in a solid may be written in the form of:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} \tag{1}$$

where:

- T = temperature,
- t = time,
- $\alpha = k/\rho c$ = thermal diffusivity,
- k = thermal conductivity,
- ρ = material density,
- c = specific heat, and
- x = distance along the x-axis.

Heat is transferred from the surface of the slab to the fluid mass across a thin layer of fluid adjacent to the slab in which a temperature gradient exists. This convective heat transfer is a boundary condition for the above equation and may be expressed as:

$$q = A\,h\,(T_s - T_\infty) \tag{2}$$

where:

- q = rate of heat transfer from surface to fluid,
- A = surface area,
- h = convection heat transfer coefficient,
- T_s = surface temperature, and
- T_∞ = fluid temperature.

The convection heat transfer coefficient variation may be expressed as:

$$h = h_0\,[1 + \beta\,(T_s - T_\infty)] \tag{3}$$

where:

- h_0 = convection heat transfer coefficient at zero temperature difference, and
- β = temperature coefficient of convection heat transfer coefficient.

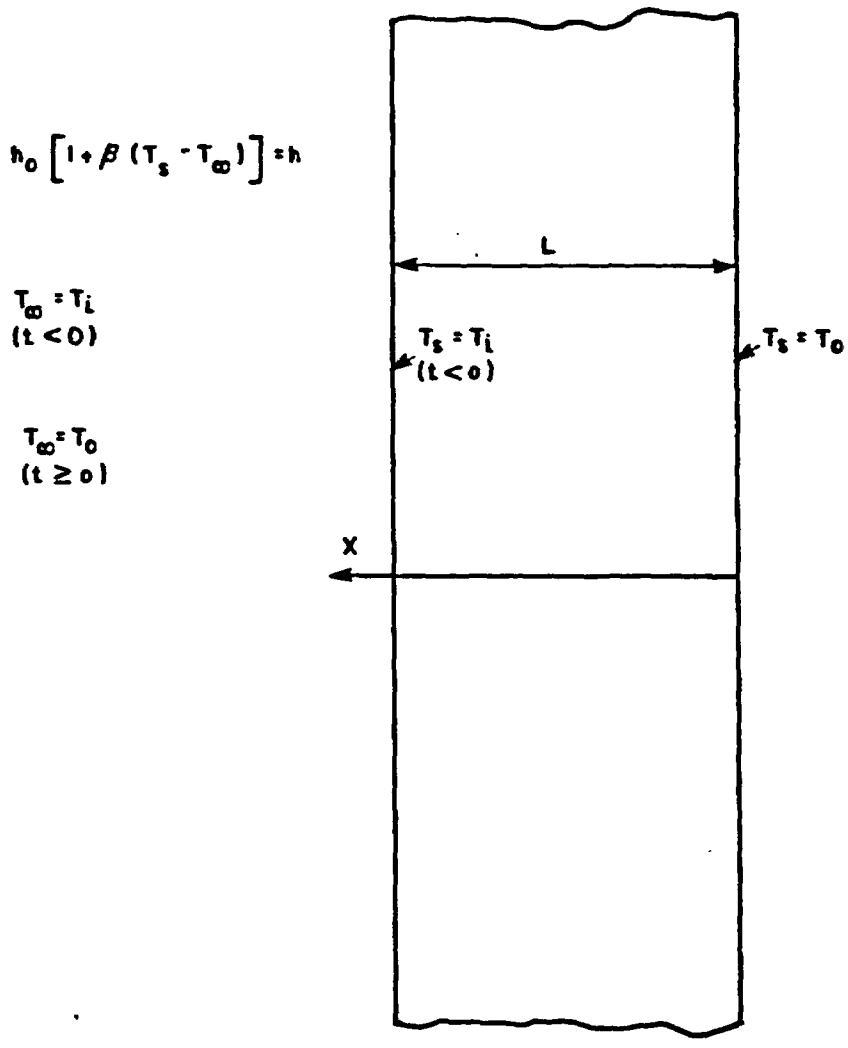


Figure 2.8-1 Transient Response to the Quench of an Infinite Slab with a Temperature-Dependent Convection Coefficient

The solution to the conduction equation subject to the convective boundary equation and the following initial and boundary conditions:

$$T_\infty = T_i \text{ for } t < 0,$$
$$T_\infty = T_o \text{ for } t \geq 0,$$
$$T_s = T_i \text{ at } x = L \text{ for } t < 0, \text{ and}$$
$$T_s = T_o \text{ at } x = 0;$$

describes the slab depicted in Figure 2.8-1.

Objective - The purpose of this problem is to check the codes' modeling of a convection boundary condition with a temperature dependent convection heat transfer coefficient. The problem also involves a check of the numerical techniques in the transient one-dimensional conduction portion of the code.

Solution - The numerical solution methodology for the above problem is presented in Kreith (1958). A specific problem is solved by the Schmidt method, a graphical finite-difference solution. The same problem will be used for benchmarking. The solution is given in Table 2.8-1.

Assumptions - The assumptions made in solving the above equations include:

- Material properties are constant; and
- The slab is of infinite width and depth.

Input Specifications.- The example problem is described by the following data:

- Geometry
  - Slab thickness $L = 0.203$ m
- Material Properties
  - Thermal conductivity $k = 3.46$ W/(m·°C)
  - Thermal diffusivity $\alpha = 7.74 \times 10^{-8}$ m^2/s
  - Convection heat transfer coefficient at zero difference $h_o = 11.36$ W/(m^2·°C)
  - Temperature coefficient of convection heat transfer coefficient $\beta = 0.018$ °C^{-1}
- Initial Conditions/Boundary Conditions
  - Low temperature $T_o = 37.8$°C
  - High temperature $T_i = 260.0$°C

Output Specifications - The surface temperature of the hot surface is to be determined at 2.3, 4.6 and 7.0 hours.

Table 2.8-1 Solution to Benchmark Problem 2.8
(From Kreith, 1958)

Time hr	Surface Temperature °C
0	260
2.3	174
4.6	154
7.0	141

4. BASIC PROGRAM RD2.9

This program solves the transient thermal analysis of an infinite width and length slab, with an insulated rear surface, exposed to a uniform radiative environment.

Theory

The engineering aspects of this program are discussed in Section 2.9 of Reference 1 (attached for the readers convenience at the end of this section).

Program

Input Data: T_2 and σ are input in Line 70, while T_0 = 546 is input in Line 100. Variables σ, c, and L/10 (2930, 725, and 0.025 respectively) are used in Line 110 to calculate C. Values for k = 1.15, and L/10 are input in Line 120. The final time step (345600 seconds) is set in Line 130.

Line 100: The initial temperature distribution in the slab is set equal to T_0 for the 11 segments (the first segment (I=1) and the last segment (I=11) are one-half the thickness of the other segments).

Line 150: The new temperature, N(1), is calculated here for the first segment.

Line 160: Equation 3 of the reference is solved in this line.

Line 170: The new temperature, N(11), is calculated for the last segment.

Line 210: In this line, the temperature distribution of the middle segments is calculated.

Line 255: The new temperatures, N(I), calculated for the current time increment, T, are set equal to the old temperatures, O(I), for the next time increment.

Output: The front surface and the rear surface temperatures are output to the printer at times set in Lines 231-245 of the program.

A listing of the program is contained in Figure 7, and the output for this problem is shown in Figure 8.

Figure 7

Basic Program RD2.9 Listing

```
70 T2=273:SIGMA=5.67E-08
80 DIM D(11),N(11)
90 DT=100
100 FOR I=1 TO 11:D(I)=546:NEXT I
110 C#=2930*725*.025
115 CI#=1/C#
120 K=1.15/.025
125 LPRINT "TIME(hrs)     FRONT TEMP(K)  REAR TEMP(K)"
130 FOR T = DT TO 345600! STEP DT
150 N(1)=D(1)+DT*2*CI#*(K*(D(2)-D(1)))
160 P=-SIGMA*(D(11)*D(11)+T2*T2)*(D(11)+T2)*(D(11)-T2)
170 N(11)=D(11)+DT*2*CI#*(P+K*(D(10)-D(11)))
200 FOR I=2 TO 10
210 N(I)=D(I)+DT*CI#*(K*(D(I+1)+D(I-1)-2*D(I)))
220 NEXT I
231 IF T=3600 THEN LPRINT T/3600,N(11),N(1)
235 X=T/7200
240 IF(INT(X)=X) THEN LPRINT T/3600,N(11),N(1)
245 IF T=3600*3 THEN LPRINT T/3600,N(11),N(1)
255 FOR I=1 TO 11:D(I)=N(I):NEXT I
260 NEXT T
```

Figure 8

Basic Problem RD2.9 Sample Output

TIME(hrs)	FRONT TEMP(K)	REAR TEMP(K)
1	446.7353	545.9913
2	428.2263	545.3496
3	417.1388	542.5848
4	409.2268	537.6113
6	397.9985	523.8043
8	389.7539	508.2401
10	382.9131	492.842
12	376.8427	478.2861
14	371.274	464.7595
16	366.0858	452.2672
18	361.2175	440.7494
20	356.6344	430.1283
22	352.3128	420.3241
24	348.234	411.2623
26	344.3825	402.8748
28	340.7441	395.1005
30	337.3056	387.8844
32	334.0553	381.1775
34	330.9817	374.9356
36	328.0745	369.1194
38	325.3236	363.6936
40	322.72	358.6261
42	320.2552	353.8882
44	317.9209	349.4539
46	315.7095	345.2999
48	313.6141	341.4049
50	311.6279	337.7493
52	309.7448	334.3159
54	307.959	331.0882
56	306.2651	328.052
58	304.6577	325.1937
60	303.1322	322.5008
62	301.684	319.9622
64	300.3089	317.5679
66	299.0029	315.3082
68	297.7624	313.1744
70	296.5836	311.1583
72	295.4635	309.2526
74	294.3987	307.4503
76	293.3865	305.7451
78	292.4239	304.1311
80	291.5086	302.6026
82	290.6379	301.1545
84	289.8096	299.7823
86	289.0215	298.4814
88	288.2715	297.2478
90	287.5577	296.0776
92	286.8782	294.9671
94	286.2314	293.913
96	285.6155	292.9123

2.9 Transient Temperature Response of a Slab Exposed to a Uniform Radiative Environment (Rohsenow and Hartnett, 1973, p. 3-49)

Problem Statement - This problem is concerned with the transient thermal analysis of an infinite length and width slab of thickness L, with an insulated rear surface, exposed to a uniform radiative environment on the front (Figure 2.9-1). The surface temperature of both sides of the slab is to be calculated at any time.

The governing equation for one-dimensional conduction in a solid may be written in the form:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} \tag{1}$$

where:

T = temperature;
t = time;
α = $k/\rho c$ = thermal diffusivity;
k = thermal conductivity;
ρ = material density;
c = specific heat; and
x = distance along the x-axis.

Heat is transferred from the surface of the slab to an object of lower temperature by radiation. This radiative heat transfer is a boundary condition for the above conduction equation and may be expressed in terms of absolute temperature as:

$$q = \varepsilon_1 \sigma (T_1^4 - T_2^4) \tag{3}$$

for two black bodies,

where:

q = rate of radiative heat flow per area;
ε_1 = emissivity;
σ = Stefan-Boltzmann constant;
T_1 = higher surface temperature; and
T_2 = lower surface temperature.

For two gray bodies, the radiative heat transfer is given by:

$$q = \sigma F_{1-2} (T_1^4 - T_2^4) \tag{3}$$

where:

F_{1-2} = gray-body shape factor (a modulus which accounts for the emissivities and relative geometries).

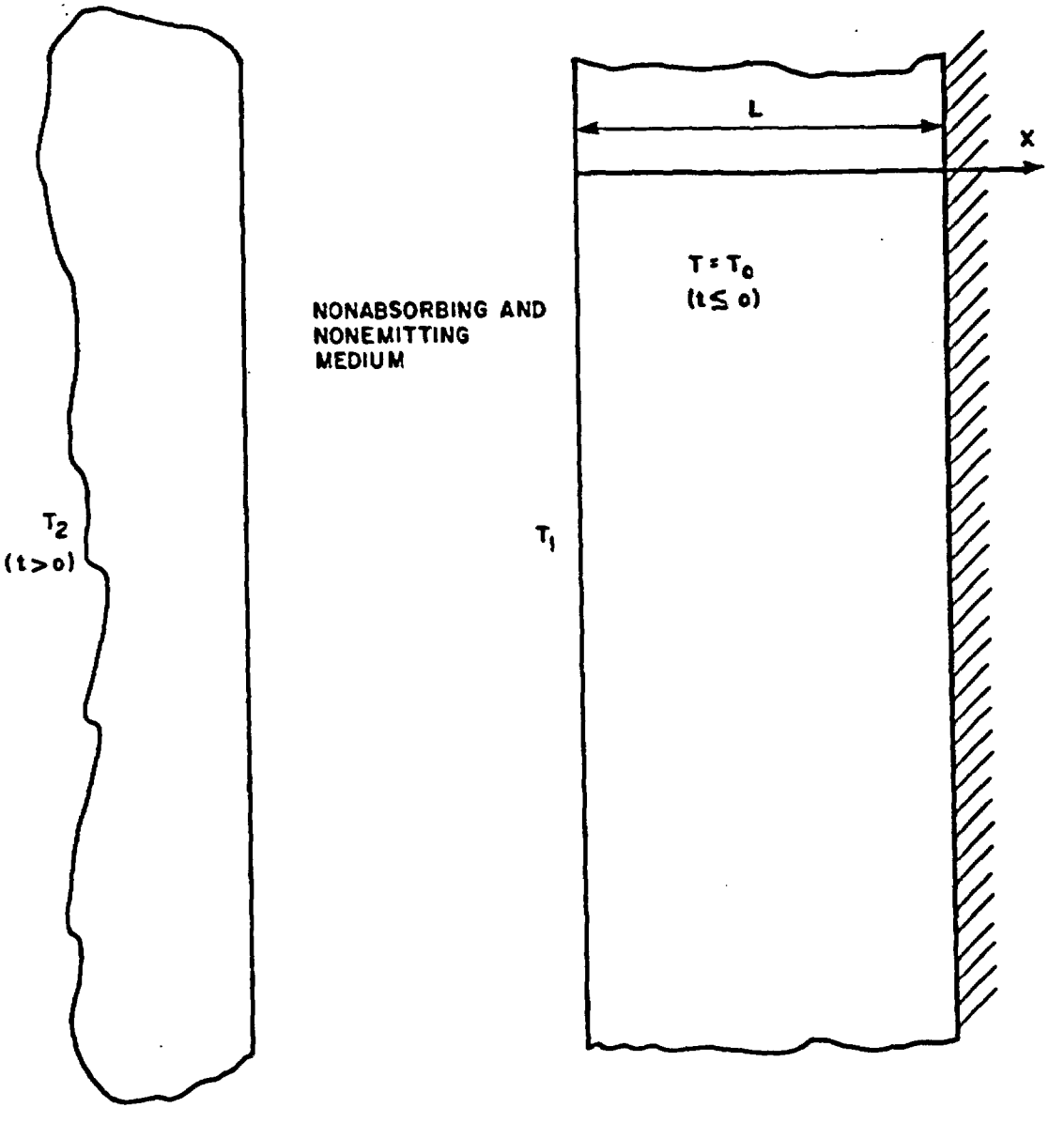


Figure 2.9-1 Radiation from a Slab

The solution to the conduction equation subject to the radiative boundary equation and the following initial and boundary conditions:

$$
\begin{aligned}
T &= T_0 && \text{for } t \leq 0, \\
q &= 0 && \text{for } t \lesssim 0, \\
T_s &= T_2 && \text{for } t \gtrsim 0, \text{ and} \\
\frac{\partial T}{\partial x} &= 0 && \text{at } x > L,
\end{aligned}
$$

describes the slab depicted in Figure 2.9-1.

Objectives - The purpose of this problem is to check the numerical techniques in the one-dimensional transient conduction portion of the code and the radiative boundary condition.

Solution - An approximate solution to the above problem is presented in Rohsenow and Hartnett (1973). Figure 2.9-2 shows the dimensionless absolute surface temperature cooling history for a thick slab with insulated rear surface after sudden exposure to a uniform radiative environment with the initial slab temperature, T_0, two times the radiative environment temperature, T_s. In the charts:

$$(T - T_0) / (T_s - T_0) \tag{4}$$

is given as a function of the cooling radiation number

$$M_0 = \sigma F_{1-2} T_0^3 L/k \tag{5}$$

where:

M_0 = cooling radiation number,

and the Fourier modulus

$$\tau = \frac{\alpha t}{L^2} \tag{6}$$

where:

τ = Fourier modulus, and
α = thermal diffusivity.

Assumptions - The assumptions made in solving the above equations include:

- Material properties are constant;
- The transmitting medium is nonabsorbing and nonemitting;
- Radiation is the only applicable boundary condition on the noninsulated surface; and
- Radiative environment is uniform and of constant temperature.

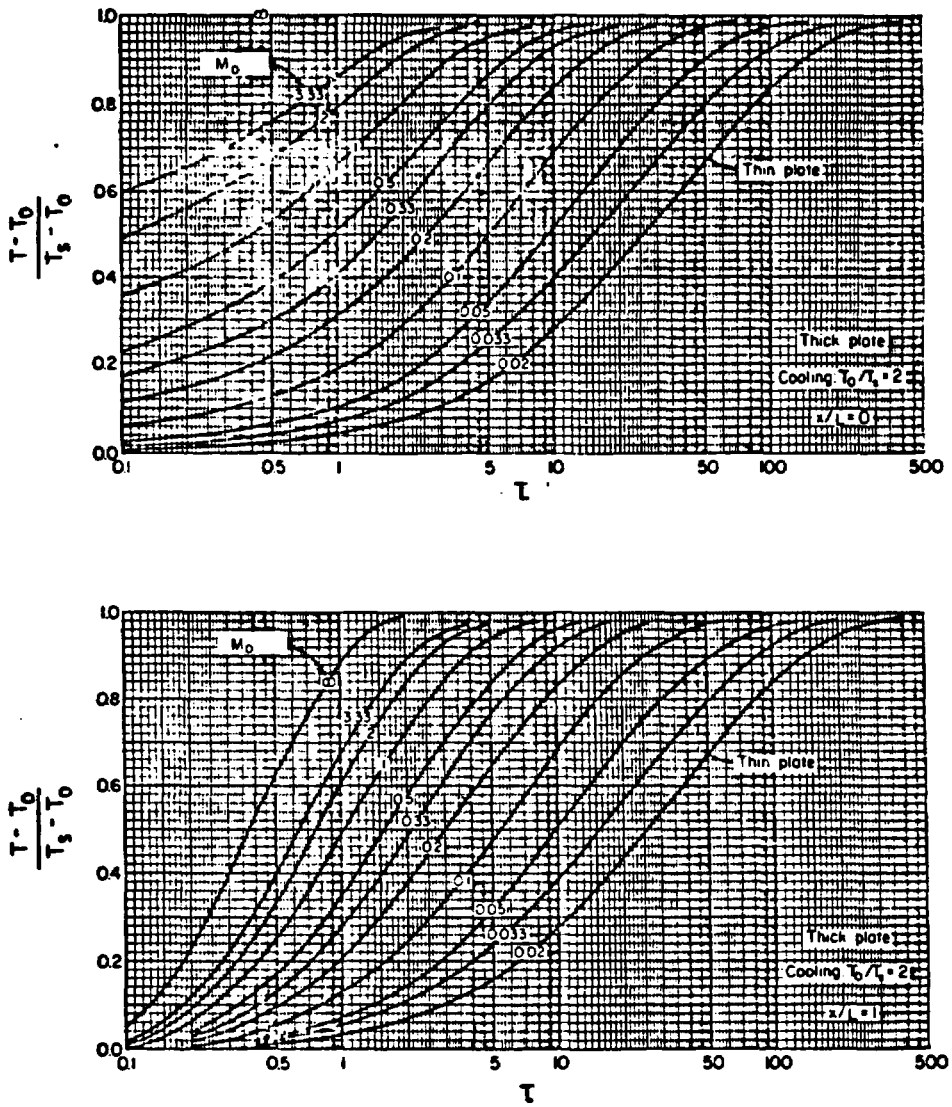


Figure 2.9-2 Temperature Response of Thick Plate With Insulated Rear Face x = L After Sudden Exposure to Uniform Radiative Environment at x = 0 (From Rohsenow and Hartnett, 1973)

*Reprinted with permission from Rohsenow, W.M. and J.P. Hartnett, Handbook of Heat Transfer, McGraw-Hill Book Company, New York, 1973.

Input Specifications - The problem is described by the following data:

- Geometry
  - slab thickness $L = 0.25$ m
  - Gray-body shape factor $F_{1-2} = 1.0$

- Material Properties
  - thermal conductivity $k = 1.15$ W/(m·°C)
  - density $\rho = 2930$ kg/m^3
  - specific heat $c = 725$ J/(kg·°C)
  - thermal diffusivity $\alpha = 5.42 \times 10^{-7}$ m^2/s

- Initial Conditions/Boundary Conditions
  - radiative environment temperature $T_2 = 273$°K
  - initial slab temperature $T_0 = 546$°K
  - Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ W/(m^2·°K^4)

Output Specifications - The surface temperature of both sides of the slab is to be determined at 4, 24, and 96 hours.

5. LOTUS SPREADSHEET RD3.2a

This spreadsheet performs a stress analysis of a circular tunnel in an elastic medium with a biaxial stress field.

Theory

The engineering aspects of this spreadsheet are presented as part a of Problem 3.2 in Reference 1 (Problem 3.2 with corrections is attached for the readers convenience at the end of this section). A discussion of major and minor stresses and the angle to the major stress is not covered in the reference and is given here.

$$\sigma_M = (\sigma_r + \sigma_\theta)/2 + ((\sigma_r - \sigma_\theta)^2/4 + \tau_{r\theta}^2)^{\frac{1}{2}} \qquad \text{(A)}$$

$$\sigma_m = (\sigma_r + \sigma_\theta)/2 - ((\sigma_r - \sigma_\theta)^2/4 + \tau_{r\theta}^2)^{\frac{1}{2}} \qquad \text{(B)}$$

$$\phi = \tfrac{1}{2}\ \text{ARCTAN}\ [(2)\cdot(\tau_{r\theta}/(\sigma_\theta - \sigma_r))] \qquad \text{(C)}$$

where:
- σ_r = radial stress
- σ_θ = circumferential stress
- $\tau_{r\theta}$ = shear stress
- σ_M = major stress
- σ_m = minor stress
- ϕ = angle between the major stress and θ

Spreadsheet

Input Data: Problem specifications are <u>input by the user</u> in cells E7 through E12.

Rows 15-16: Intermediate calculations are performed to find values of variables used repetitively in the displacement and stress calculations.

Rows 20-44:
- **Column A** is for <u>user input</u> of radial distance from the tunnel centerline at which displacements and stresses will be calculated.
- **Column B** is used to calculate radial displacement using Equation 9.
- **Column D** is a copy of column A.
- **Column E** is used to calculate the circumferential displacement using Equation 9.

Rows 52-71: Shear stress, radial stress, and circumferential stress are calculated at the input angular coordinate (θ) in Columns C, E, and G using Equations 3, 1, and 2 respectively.

Rows 80-99: The major stress and minor stress are calculated in Columns C and E using Equations A and B respectively while the angle (ϕ) between the major stress and the angular coordinate (θ) is calculated in Column G using Equation C.

A graph of stresses (shear, radial, circumferential, major, and minor) and the angle to the major stress as a function of radial distance will appear on the screen when the F10 key is pushed.

A sample spreadsheet is shown in Figure 9.

Figure 9

Problem RD3.2a Sample Lotus Spreadsheet

```
        A            B          C          D          E          F          G
 1 PROBLEM RD 3.2a - CIRCULAR TUNNEL IN AN ELASTIC MEDIUM
 2                   WITH A HYDROSTATIC STRESS FIELD
 3
 4 ************************************************
 5 INPUT DATA *                                    *
 6                                                 * NOTE:
 7 TUNNEL RADIUS "a" (m)                     5.00  * BE SURE RANGE PROTECT
 8 HYDROSTATIC STRESS "Sx" (MPa)            30.00  * IS ON (TYPE /WGPE).
 9 HYDROSTATIC STRESS "Sy" (MPa)            15.00  * ALL CELLS EXCEPT
10 POISSON'S RATIO "Nu"                      0.20  * E7..E12 & A25..A44
11 MODULUS OF ELASTICITY "E" (MPa)        6000.00  * ARE PROTECTED.
12 ANGULAR COORDINATE "theta" (degrees)     30.00  *
13 ************************************************
14                    INTERMEDIATE CALCULATIONS
15        a**2=     25.00  Sx-Sy=    15.00      E'=  6250.00
16      Sx+Sy=      45.00    Nu'=     0.25    a**4=   625.00
17
18   ANALYTICAL RESULTS AT  30.00 DEGREES FROM HORIZONTAL
19
20 DISPLACEMENTS (m) ALONG  30.00 DEGREE LINE FROM HORIZONTAL
21
22                  RADIAL                    CIRCUMFERENTIAL
23      RADIUS  DISPLACEMENT        RADIUS  DISPLACEMENT
24        (m)       (m)                (m)       (m)
25        5.00  0.048000              5.00 -0.020785
26        5.50  0.047521              5.50 -0.019110
27        6.00  0.047280              6.00 -0.018048
28        7.00  0.047426              7.00 -0.017028
29        8.50  0.048856              8.50 -0.016949
30       10.00  0.051281             10.00 -0.017699
31       12.00  0.055504             12.00 -0.019306
32       15.00  0.063111             15.00 -0.022324
33       20.00  0.077566             20.00 -0.028031
34       30.00  0.109233             30.00 -0.040300
35       45.00  0.159078             45.00 -0.059332
36       60.00  0.209873             60.00 -0.078596
37       70.00  0.243963             70.00 -0.091492
38       80.00  0.278155             80.00 -0.104412
39       90.00  0.312416             90.00 -0.117348
40      100.00  0.346725            100.00 -0.130294
41      120.00  0.415437            120.00 -0.156210
42      130.00  0.449827            130.00 -0.169175
43      140.00  0.484232            140.00 -0.182144
44      150.00  0.518650            150.00 -0.195116
45
```

Figure 9

Problem RD3.2a Sample Lotus Spreadsheet (continued)

	A	B	C	D	E	F	G
46							
47	ANALYTICAL STRESSES AT 30.00 DEGREES FROM THE HORIZONTAL						
48							
49			SHEAR		RADIAL		CIRCUMFERENTIAL
50	RADIUS		STRESS		STRESS		STRESS
51	(m)		(MPa)		(MPa)		(MPa)
52	5.00		0.0000		0.0000		30.0000
53	5.50		3.9221		2.9422		29.6611
54	6.00		6.1193		5.6337		28.9497
55	7.00		8.0507		10.0458		27.3011
56	8.50		8.6571		14.6212		25.1885
57	10.00		8.5249		17.5781		23.6719
58	12.00		8.1632		20.0787		22.3172
59	15.00		7.6980		22.2222		21.1111
60	20.00		7.2310		23.9502		20.1123
61	30.00		6.8410		25.2170		19.3663
62	45.00		6.6526		25.7888		19.0261
63	60.00		6.5845		25.9901		18.9057
64	70.00		6.5610		26.0590		18.8645
65	80.00		6.5456		26.1037		18.8377
66	90.00		6.5351		26.1344		18.8193
67	100.00		6.5275		26.1563		18.8062
68	120.00		6.5177		26.1849		18.7890
69	130.00		6.5144		26.1946		18.7833
70	140.00		6.5117		26.2022		18.7787
71	150.00		6.5096		26.2083		18.7750
72							
73							
74							
75	**PRINCIPAL STRESSES AT 30.00 DEGREE LINE TO HORIZONTAL**						
76							
77			MAJOR		MINOR		ANGLE TO
78	RADIUS		STRESS		STRESS		MAJOR STRESS*
79	(M)		(MPa)		(MPa)		(degrees)
80	5.00		30.0000		0.0000		0.0000
81	5.50		30.2250		2.3783		8.1807
82	6.00		30.4581		4.1252		13.8476
83	7.00		30.4739		6.8730		21.5093
84	8.50		30.0470		9.7627		29.3016
85	10.00		29.6781		11.5719		35.1664
86	12.00		29.4374		12.9584		41.0964
87	15.00		29.3847		13.9486		-42.9361
88	20.00		29.5125		14.5500		-37.5688
89	30.00		29.7319		14.8514		-33.4237
90	45.00		29.8700		14.9448		-31.5285
91	60.00		29.9247		14.9711		-30.8607
92	70.00		29.9441		14.9793		-30.6325
93	80.00		29.9570		14.9845		-30.4843
94	90.00		29.9658		14.9879		-30.3827
95	100.00		29.9722		14.9903		-30.3100
96	120.00		29.9806		14.9933		-30.2153
97	130.00		29.9835		14.9943		-30.1835
98	140.00		29.9857		14.9951		-30.1582
99	150.00		29.9876		14.9958		-30.1378
100							
101							
102		*	FROM 30.00 DEGREE LINE TO HORIZONTAL				

3.2 Circular Tunnel (Long Cylindrical Hole in an Infinite Medium)

Problem Statement - This problem concerns the stress analysis of a long circular opening in an infinite medium under various boundary conditions and material properties (see Figure 3.2-1). Three variations to this problem will be considered:

(a) Tunnel in an elastic medium with a biaxial stress field;
(b) Tunnel in an elastic-plastic medium with a hydrostatic stress field; and
(c) Lined tunnel in an elastic medium with a biaxial stress field.

Upon excavation of a tunnel, the in situ stresses within the rock or soil mass are redistributed from an uniform orthogonal stress field to a more complex stress distribution. Stress concentrations around a tunnel cause elastic deformations at the periphery and, if the yield strength of the material is exceeded, result in plastic deformations and redistribution of stresses due to yielding of the material. In the case of plastic yielding, a yield zone will develop around the tunnel beyond which the stresses will be elastic. These processes are modeled by parts (a) and (b) of this problem.

Part (c) of this problem involves the interaction of a structural tunnel lining and an elastic media. Although the actual design of a tunnel lining is more complex, this problem checks the basic interaction between the two types of material for non-axisymmetric loadings.

Objectives - This problem has the advantage of being very similar to repository problems as well as having a closed-form analytical solution. Several aspects of the computer model will be tested by this problem:

- The ability of the code to simulate an infinite medium by finite boundaries;
- The solution of equations for displacements in a non-symmetric problem in two dimensions;
- The computation of plastic stresses and deformations; and
- The interaction between two different materials.

Analytical Solution - The analytical solution to part (a) of the problem is given by Obert and Duvall (1967) for the case of plane stress (hole in an infinite plate). The stresses will be the same in the case of plane strain as for plane stress and displacements can be determined by using modified values of E and ν in the displacement equations. The stress distribution around the tunnel is given by:

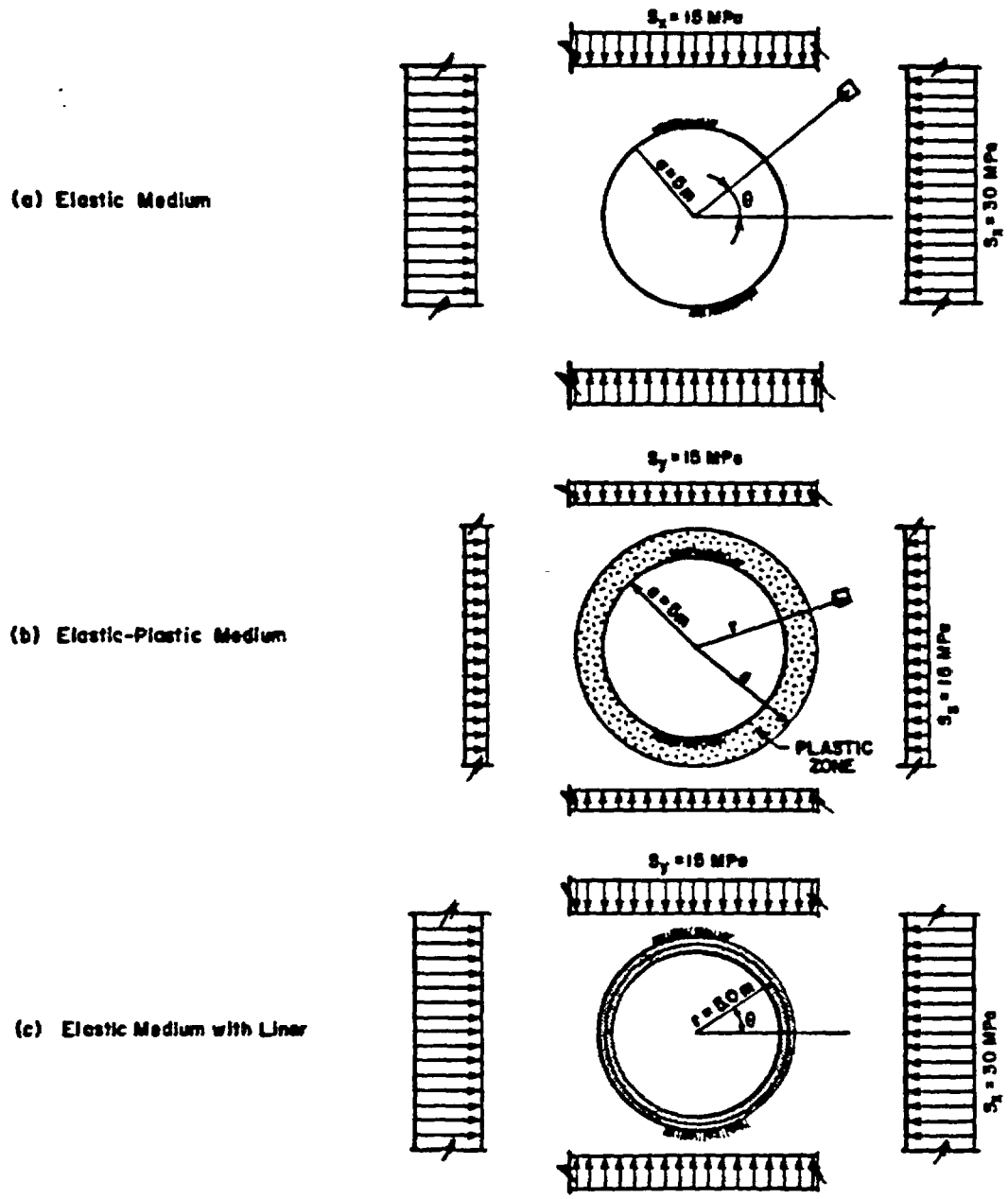


Figure 3.2-1 Circular Tunnel

$$\sigma_r = \frac{1}{2}(S_x + S_y)\left(1 - \frac{a^2}{r^2}\right) + \frac{1}{2}(S_x - S_y)\left(1 + \frac{3a^4}{r^4} - \frac{4a^2}{r^2}\right)\cos 2\theta \quad (1)$$

$$\sigma_\theta = \frac{1}{2}(S_x + S_y)\left(1 + \frac{a^2}{r^2}\right) - \frac{1}{2}(S_x - S_y)\left(1 + \frac{3a^4}{r^4}\right)\cos 2\theta \quad (2)$$

$$\tau_{r\theta} = \frac{1}{2}(S_x - S_y)\left(1 - \frac{3a^4}{r^4} + \frac{2a^2}{r^2}\right)\sin 2\theta \quad (3)$$

where:

r	= radial coordinate,
θ	= angular coordinate measured COUNTER clockwise from the x axis,
σ_r	= radial stress,
σ_θ	= circumferential stress,
$\tau_{r\theta}$	= shear stress,
S_x, S_y	= in situ or initial stresses (tension positive), and
a	= radius of circular hole or tunnel.

Displacements are given by:

$$u = \frac{1}{E'}\left[\left(\frac{S_x + S_y}{2}\right)\left(r + \frac{a^2}{r}\right) + \left(\frac{S_x - S_y}{2}\right)\left(r - \frac{a^4}{r^3} + \frac{4a^2}{r}\right)\cos 2\theta\right]$$
$$- \frac{\nu'}{E'}\left[\left(\frac{S_x + S_y}{2}\right)\left(r - \frac{a^2}{r}\right) - \left(\frac{S_x - S_y}{2}\right)\left(r - \frac{a^4}{r^3}\right)\cos 2\theta\right] \quad (4)$$

and

$$v = \frac{1}{E'}\left[-\left(\frac{S_x - S_y}{2}\right)\left(r + \frac{2a^2}{r} + \frac{a^4}{r^3}\right)\sin 2\theta\right]$$
$$- \frac{\nu'}{E'}\left[\left(\frac{S_x - S_y}{2}\right)\left(r - \frac{2a^2}{r} + \frac{a^4}{r^3}\right)\sin 2\theta\right] \quad (5)$$

where:

$$E' = \frac{E}{(1-\nu^2)} \qquad \nu' = \frac{\nu}{(1-\nu)}$$

where:

u, v	= displacements in radial and circumferential directions, respectively,
E	= modulus of elasticity, and
ν	= Poisson's ratio.

The solution to Part (b) of this problem is also given by Obert and Duvall (1967) after Fara and Wright (1963). Stresses around a circular opening are based on a hydrostatic in situ stress field with yielding defined by the Tresca criterion. In the plastic zone stresses will be given by:

$$\left.\begin{aligned} \sigma''_r &= 2k \ln \frac{r}{a} && (6) \\ \sigma''_\theta &= 2k \left(1 + \ln \frac{r}{a}\right) && (7) \\ \sigma''_z &= k \left(1 + 2 \ln \frac{r}{a}\right) && (8) \end{aligned}\right\} \quad \text{for: } a \leq r \leq c$$

and in the elastic zone:

$$\left.\begin{aligned} \sigma'_r &= S\left[1 - \frac{ka^2}{Sr^2} \exp\left(\frac{S}{k} - 1\right)\right] && (9) \\ \sigma'_\theta &= S\left[1 + \frac{ka^2}{Sr^2} \exp\left(\frac{S}{k} - 1\right)\right] && (10) \\ \sigma'_z &= 2\nu S && (11) \end{aligned}\right\} \quad \text{for: } r \geq c$$

where:

- c = $a \exp[([S/k]-1)/2]$ = radius of elastic-plastic boundary,
- S = in situ hydrostatic stress field,
- k = yielding shear strength of the material (one-half uniaxial compressive strength),
- σ'_r, σ''_r = radial stresses in the elastic and plastic regions, respectively,
- σ'_θ, σ''_θ = circumferential stresses in the elastic and plastic regions, respectively,
- σ'_z, σ''_z = longitudinal stresses in the elastic and plastic regions, respectively, and
- ν = Poisson's ratio.

The solution to Part (c) of this problem is given by Paul et al. (1974) and is based on the work of Burns and Richard (1964). The loads on a tunnel lining have been shown to be a function of two constants given as:

$$C = \frac{\dfrac{E_m}{(1+\nu_m)(1-2\nu_m)}}{\dfrac{E_\ell t}{(1-\nu_\ell^2)}\,\dfrac{1}{R}} \tag{12}$$

$$F = \frac{\dfrac{E_m}{(1+\nu_m)}}{\dfrac{6\,E_\ell I_\ell}{(1-\nu_\ell^2)}\,\dfrac{1}{R^3}} \tag{13}$$

where:

C	=	compressibility ratio,
F	=	flexibility ratio,
E_m, E_ℓ	=	modulus of elasticity for the medium and lining respectively,
ν_m, ν_ℓ	=	Poisson's ratio for the medium and lining, respectively.
R, t	=	radius and effective thickness of the lining, and
I_ℓ	=	effective moment of inertia per unit length of the lining.

For the case of full shear transfer between the liner and the medium, the thrust (T), moment (M), and shear (S) within the liner are given by:

$$\frac{T}{\gamma HR} = \frac{1}{2}\left[(1+K_o)(1-b_1) + (1-K_o)(1+b_2)\cos 2\theta\right] \tag{14}$$

$$\frac{M}{\gamma HR^2} = \frac{1}{4}(1-K_o)(1-b_2-2b_3)\cos 2\theta \tag{15}$$

$$\frac{S}{\gamma HR} = \frac{1}{2}(1-K_o)(1-b_2-2b_3)\sin 2\theta \tag{16}$$

The diameter change is given by:

$$\frac{\Delta D/D}{\gamma H/M_c} = \left[\frac{1}{2}\left[(1-\nu_m)(1+K_o)(1-b_1)\,C - \left(\frac{1-\nu_m}{1-2\nu_m}\right)(1-K_o)(1-b_2-2b_3)\,F\cos 2\theta\right]\right] \tag{17}$$

in which

$$b_1 = \frac{(1 - 2\nu_m)(C - 1)}{(1 - 2\nu_m)(C) + 1} \tag{18}$$

$$b_2 = \frac{(1 - 2\nu_m)(1 - C)\,F - \frac{1}{2}(1 - 2\nu_m)^2\,C + 2}{[(3 - 2\nu_m) + (1 - 2\nu_m)\,C]\,F + (\frac{5}{2} - 8\nu_m + 6\nu_m^2)\,C + 6 - 8\nu_m} \tag{19}$$

$$b_3 = \frac{[1 + (1 - 2\nu_m)\,C]\,F - \frac{1}{2}(1 - 2\nu_m) - 2}{[(3 - 2\nu_m) + (1 - 2\nu_m)\,C]\,F + (\frac{5}{2} - 8\nu_m + 6\nu_m^2)\,C + 6 - 8\nu_m} \tag{20}$$

$$M_c = \frac{E(1 - \nu_m)}{(1 + \nu_m)(1 - 2\nu_m)} \tag{21}$$

where:

- T, M, S = thrust, moment, and transverse shear in the liner, respectively,
- R, D, ΔD = radius, diameter and the change in diameter of the liner, respectively,
- H = distance from the ground surface to the center of the tunnel,
- γ = unit weight,
- K_o = ratio of horizontal to vertical in situ stresses,
- M_c = constrained modulus of the medium surrounding the liner,
- θ = angle defining position on the liner; measured counterclockwise from the right springline (Fig. 3.2-1).

Assumptions - Assumptions which are implicit in the theoretical solutions presented above include the following:

- Plane strain conditions apply, with one of the principal stresses aligned with the tunnel axis; and
- The material is homogeneous and isotropic.

For part (a) the following additional assumption applies:

- The medium is linear-elastic.

For part (b), the following additional assumptions apply:

- The material is elastic-perfectly plastic in its behavior;
- Initial stresses are hydrostatic within the plane of the analysis;
- Yielding occurs when the difference between the maximum and minimum in plane principal stresses reaches twice the shear yield stress (Tresca yield criterion); and
- The out of plane stresses have no effect on the plastic yielding.

For part (c) to this problem the following additional assumptions apply:

- The vertical stress is equal to the weight of the overburden;
- The tunnel liner and the medium are both linear-elastic materials; and
- Because of the elastic assumption and the single-step analysis, the liner is assumed to be in place before excavation of the tunnel.

<u>Input Specifications</u> - The following input specifications apply:

- Geometry
  - Excavated tunnel radius $a = 5.0$ m
- Material properties
  - Modulus of elasticity $E = 6{,}000$ MPa
  - Poisson's Ratio $\nu = 0.20$
- In situ stresses

		(a)	(b)	(c)
- Horizontal stress	S_x	30 MPa	15 MPa	30 MPa
- Vertical stress	S_y	15 MPa	15 MPa	15 MPa

For part (b), the yield strength (Tresca criterion) of the rock will be:

- Shear stress at yield $k = 10$ MPa

Properties for the tunnel lining (part c) are as follows:

- Thickness $t = 0.50$ m
- Modulus of Elasticity $E = 20{,}000$ MPa
- Poisson's Ratio $\nu = 0.20$

Figure 3.2-1 shows the geometry and loading conditions for the three parts to this problem.

Output Specifications - The output for parts (a) and (b) are the stresses and displacements along a line at equals 30 degrees at radii of 5m, 10m, and 20m. (Note: displacements for part (b) are not calculated in the analytical solution). For the lined tunnel, the moment, thrust, shear, and radial displacements in the liner at θ equals 0, 30, 60, and 90 degrees will be computed.

6. LOTUS SPREADSHEET RD3.2b

This spreadsheet performs a stress analysis of a circular tunnel in an elastic-plastic medium with a hydrostatic stress field.

Theory

The engineering aspects of this spreadsheet are presented as part b of problem 3.2 in Reference 1 (Problem 3.2 with corrections is attached for the readers convenience at the end of this section).

Spreadsheet

Input Data: Problem specifications are input by the user in cells C5 through C8.

Row 11: The radius of the elastic-plastic boundary "c" is calculated in cell C12.

Column A: This column is for user input of the radial coordinate "r" for which stresses are to be calculated. The first entry is automatically set equal to the tunnel radius "a", and the tenth entry is automatically set equal to the elastic-plastic boundary "c".

Column B: Radial stress is calculated by Equation 6 for radial distances less than or equal to the elastic-plastic boundary, and by Equation 9 for radial distances greater than the elastic-plastic boundary.

Column C: Circumferential stress is calculated by Equation 7 for radial distances less than or equal to the elastic-plastic boundary, and by Equation 10 for radial distances greater than the elastic-plastic boundary.

Column D: Longitudinal stress is calculated by Equation 8 for radial distances less than or equal to the elastic-plastic boundary, and by Equation 11 for radial distances greater than the elastic-plastic boundary.

A graph of stress as a function of radial distance will appear on the screen when the F10 key is pushed.

A sample spreadsheet is shown in Figure 10.

Figure 10

Problem RD3.2b Sample Lotus Spreadsheet

```
        A                    B                    C                    D
 1 PROBLEM RD 3.2b - CIRCULAR TUNNEL IN AN ELASTIC-PLASTIC MEDIUM
 2                   WITH A HYDROSTATIC STRESS FIELD
 3 ************************************************* NOTE: BE SURE RANGE
 4 * INPUT DATA                                    * PROTECT SWITCH IS
 5 *                                               * ON (TYPE /WGPE).
 6 * TUNNEL RADIUS  "a"  (m)                 5.00 * ALL CELLS EXCEPT
 7 * HYDROSTATIC STRESS "S" (MPa)           15.00 * A20-A27,A29-A47 &
 8 * YIELD STRESS  "k"  (MPa)              10.00 * C6-C9 ARE PROTECTED.
 9 * POISSONS RATIO  "Nu"                  0.20 *
10 *************************************************
11
12   ELASTIC-PLASTIC BOUNDARY "c"          6.4201
13
14
15                          RADIAL    CIRCUMFERENTIAL        LONGITUDINAL
16      RADIUS              STRESS              STRESS              STRESS
17        (m)               (MPa)               (MPa)               (MPa)
18
19      5.0000               0.00               20.00               10.00
20        5.05               0.20               20.20               10.20
21        5.19               0.75               20.75               10.75
22        5.31               1.20               21.20               11.20
23        5.48               1.83               21.83               11.83
24        5.64               2.41               22.41               12.41
25        5.87               3.21               23.21               13.21
26        6.06               3.85               23.85               13.85
27        6.34               4.75               24.75               14.75
28      6.4201               5.00               25.00               15.00
29        6.56               5.42               24.58                6.00
30        6.88               6.29               23.71                6.00
31        7.32               7.31               22.69                6.00
32        8.18               8.84               21.16                6.00
33        8.81               9.69               20.31                6.00
34        9.68              10.60               19.40                6.00
35       10.46              11.23               18.77                6.00
36       11.57              11.92               18.08                6.00
37       12.68              12.44               17.56                6.00
38       14.39              13.01               16.99                6.00
39       16.10              13.41               16.59                6.00
40       18.92              13.85               16.15                6.00
41       22.14              14.16               15.84                6.00
42       27.87              14.47               15.53                6.00
43       33.21              14.63               15.37                6.00
44       41.86              14.76               15.24                6.00
45       48.20              14.82               15.18                6.00
46       56.85              14.87               15.13                6.00
47       60.00              14.89               15.11                6.00
```

3.2 Circular Tunnel (Long Cylindrical Hole in an Infinite Medium)

Problem Statement - This problem concerns the stress analysis of a long circular opening in an infinite medium under various boundary conditions and material properties (see Figure 3.2-1). Three variations to this problem will be considered:

(a) Tunnel in an elastic medium with a biaxial stress field;
(b) Tunnel in an elastic-plastic medium with a hydrostatic stress field; and
(c) Lined tunnel in an elastic medium with a biaxial stress field.

Upon excavation of a tunnel, the in situ stresses within the rock or soil mass are redistributed from an uniform orthogonal stress field to a more complex stress distribution. Stress concentrations around a tunnel cause elastic deformations at the periphery and, if the yield strength of the material is exceeded, result in plastic deformations and redistribution of stresses due to yielding of the material. In the case of plastic yielding, a yield zone will develop around the tunnel beyond which the stresses will be elastic. These processes are modeled by parts (a) and (b) of this problem.

Part (c) of this problem involves the interaction of a structural tunnel lining and an elastic media. Although the actual design of a tunnel lining is more complex, this problem checks the basic interaction between the two types of material for non-axisymmetric loadings.

Objectives - This problem has the advantage of being very similar to repository problems as well as having a closed-form analytical solution. Several aspects of the computer model will be tested by this problem:

- The ability of the code to simulate an infinite medium by finite boundaries;
- The solution of equations for displacements in a non-symmetric problem in two dimensions;
- The computation of plastic stresses and deformations; and
- The interaction between two different materials.

Analytical Solution - The analytical solution to part (a) of the problem is given by Obert and Duvall (1967) for the case of plane stress (hole in an infinite plate). The stresses will be the same in the case of plane strain as for plane stress and displacements can be determined by using modified values of E and ν in the displacement equations. The stress distribution around the tunnel is given by:

(a) Elastic Medium

(b) Elastic-Plastic Medium

(c) Elastic Medium with Liner

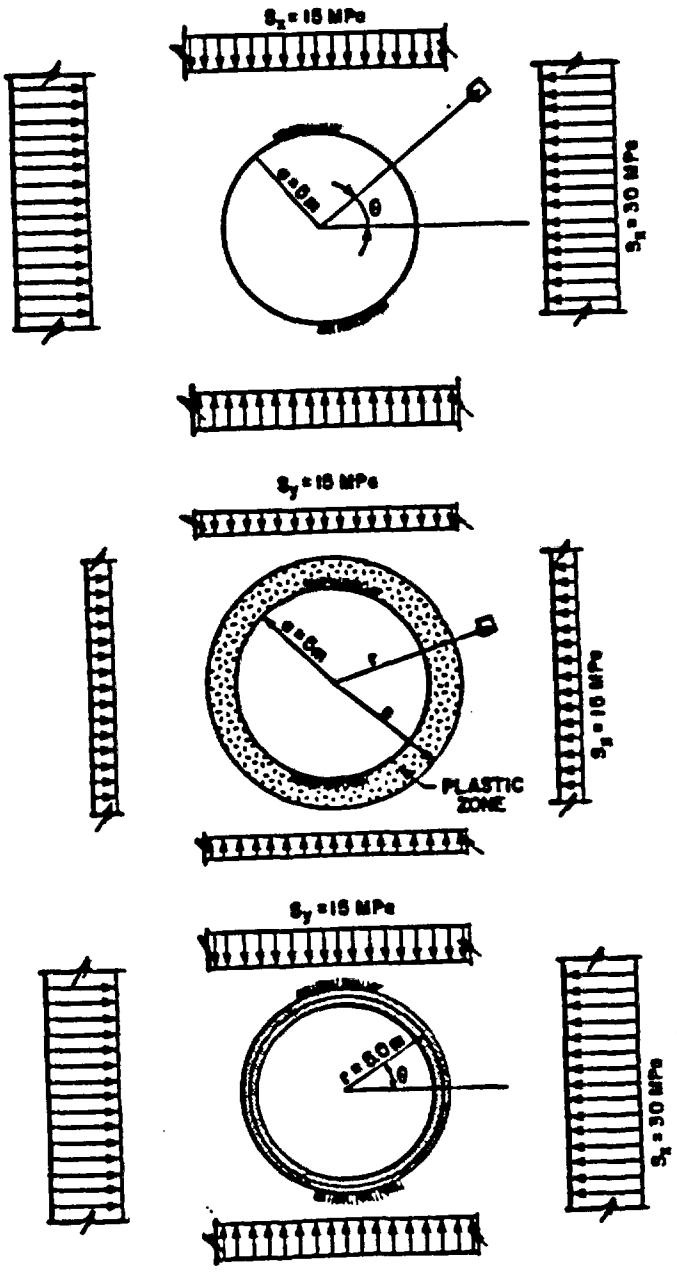


Figure 3.2-1 Circular Tunnel

$$\sigma_r = \frac{1}{2}(S_x + S_y)\left(1 - \frac{a^2}{r^2}\right) + \frac{1}{2}(S_x - S_y)\left(1 + \frac{3a^4}{r^4} - \frac{4a^2}{r^2}\right)\cos 2\theta \quad (1)$$

$$\sigma_\theta = \frac{1}{2}(S_x + S_y)\left(1 + \frac{a^2}{r^2}\right) - \frac{1}{2}(S_x - S_y)\left(1 + \frac{3a^4}{r^4}\right)\cos 2\theta \quad (2)$$

$$\tau_{r\theta} = \frac{1}{2}(S_x - S_y)\left(1 - \frac{3a^4}{r^4} + \frac{2a^2}{r^2}\right)\sin 2\theta \quad (3)$$

where:

r	= radial coordinate,
θ	= angular coordinate measured COUNTER clockwise from the x axis,
σ_r	= radial stress,
σ_θ	= circumferential stress,
$\tau_{r\theta}$	= shear stress,
S_x, S_y	= in situ or initial stresses (tension positive), and
a	= radius of circular hole or tunnel.

Displacements are given by:

$$u = \frac{1}{E'}\left[\left(\frac{S_x + S_y}{2}\right)\left(r + \frac{a^2}{r}\right) + \left(\frac{S_x - S_y}{2}\right)\left(r - \frac{a^4}{r^3} + \frac{4a^2}{r}\right)\cos 2\theta\right]$$
$$- \frac{\nu'}{E'}\left[\left(\frac{S_x + S_y}{2}\right)\left(r - \frac{a^2}{r}\right) - \left(\frac{S_x - S_y}{2}\right)\left(r - \frac{a^4}{r^3}\right)\cos 2\theta\right] \quad (4)$$

and

$$v = \frac{1}{E'}\left[-\left(\frac{S_x - S_y}{2}\right)\left(r + \frac{2a^2}{r} + \frac{a^4}{r^3}\right)\sin 2\theta\right]$$
$$- \frac{\nu'}{E'}\left[\left(\frac{S_x - S_y}{2}\right)\left(r - \frac{2a^2}{r} + \frac{a^4}{r^3}\right)\sin 2\theta\right] \quad (5)$$

where:

$$E' = \frac{E}{(1 - \nu^2)} \qquad \nu' = \frac{\nu}{(1 - \nu)}$$

where:

u, v	= displacements in radial and circumferential directions, respectively,
E	= modulus of elasticity, and
ν	= Poisson's ratio.

The solution to Part (b) of this problem is also given by Obert and Duvall (1967) after Fara and Wright (1963). Stresses around a circular opening are based on a hydrostatic in situ stress field with yielding defined by the Tresca criterion. In the plastic zone stresses will be given by:

$$\left.\begin{aligned} \sigma''_r &= 2k \ln \frac{r}{a} && (6) \\ \sigma''_\theta &= 2k \left(1 + \ln \frac{r}{a}\right) && (7) \\ \sigma''_z &= k \left(1 + 2 \ln \frac{r}{a}\right) && (8) \end{aligned}\right\} \quad \text{for: } a \leq r \leq c$$

and in the elastic zone:

$$\left.\begin{aligned} \sigma'_r &= S\left[1 - \frac{ka^2}{Sr^2} \exp\left(\frac{S}{k} - 1\right)\right] && (9) \\ \sigma'_\theta &= S\left[1 + \frac{ka^2}{Sr^2} \exp\left(\frac{S}{k} - 1\right)\right] && (10) \\ \sigma'_z &= 2\nu S && (11) \end{aligned}\right\} \quad \text{for: } r \geq c$$

where:

- c = $a \exp[([S/k]-1)/2]$ = radius of elastic-plastic boundary,
- S = in situ hydrostatic stress field,
- k = yielding shear strength of the material (one-half uniaxial compressive strength),
- σ'_r, σ''_r = radial stresses in the elastic and plastic regions, respectively,
- σ'_θ, σ''_θ = circumferential stresses in the elastic and plastic regions, respectively,
- σ'_z, σ''_z = longitudinal stresses in the elastic and plastic regions, respectively, and
- ν = Poisson's ratio.

The solution to Part (c) of this problem is given by Paul et al. (1974) and is based on the work of Burns and Richard (1964). The loads on a tunnel lining have been shown to be a function of two constants given as:

$$C = \frac{\dfrac{E_m}{(1+\nu_m)(1-2\nu_m)}}{\dfrac{E_\ell t}{(1-\nu_\ell^2)}\,\dfrac{1}{R}} \tag{12}$$

$$F = \frac{\dfrac{E_m}{(1+\nu_m)}}{\dfrac{6\,E_\ell I_\ell}{(1-\nu_\ell^2)}\,\dfrac{1}{R^3}} \tag{13}$$

where:

C	=	compressibility ratio,
F	=	flexibility ratio,
E_m, E_ℓ	=	modulus of elasticity for the medium and lining respectively,
ν_m, ν_ℓ	=	Poisson's ratio for the medium and lining, respectively.
R, t	=	radius and effective thickness of the lining, and
I_ℓ	=	effective moment of inertia per unit length of the lining.

For the case of full shear transfer between the liner and the medium, the thrust (T), moment (M), and shear (S) within the liner are given by:

$$\frac{T}{\gamma HR} = \frac{1}{2}\left[(1+K_o)(1-b_1) + (1-K_o)(1+b_2)\cos 2\theta\right] \tag{14}$$

$$\frac{M}{\gamma HR^2} = \frac{1}{4}(1-K_o)(1-b_2-2b_3)\cos 2\theta \tag{15}$$

$$\frac{S}{\gamma HR} = \frac{1}{2}(1-K_o)(1-b_2-2b_3)\sin 2\theta \tag{16}$$

The diameter change is given by:

$$\frac{\Delta D/D}{\gamma H/M_c} = \left[\frac{1}{2}\left[(1-\nu_m)(1+K_o)(1-b_1)\,C - \left(\frac{1-\nu_m}{1-2\nu_m}\right)(1-K_o)(1-b_2-2b_3)\,F\cos 2\theta\right]\right] \tag{17}$$

in which

$$b_1 = \frac{(1 - 2\nu_m)(C - 1)}{(1 - 2\nu_m)(C) + 1} \tag{18}$$

$$b_2 = \frac{(1 - 2\nu_m)(1 - C)\,F - \frac{1}{2}(1 - 2\nu_m)^2\,C + 2}{[(3 - 2\nu_m) + (1 - 2\nu_m)\,C]\,F + (\frac{5}{2} - 8\nu_m + 6\nu_m^2)\,C + 6 - 8\nu_m} \tag{19}$$

$$b_3 = \frac{[1 + (1 - 2\nu_m)\,C]\,F - \frac{1}{2}(1 - 2\nu_m) - 2}{[(3 - 2\nu_m) + (1 - 2\nu_m)\,C]\,F + (\frac{5}{2} - 8\nu_m + 6\nu_m^2)\,C + 6 - 8\nu_m} \tag{20}$$

$$M_c = \frac{E(1 - \nu_m)}{(1 + \nu_m)(1 - 2\nu_m)} \tag{21}$$

where:

- T, M, S = thrust, moment, and transverse shear in the liner, respectively,
- R, D, ΔD = radius, diameter and the change in diameter of the liner, respectively,
- H = distance from the ground surface to the center of the tunnel,
- γ = unit weight,
- K_o = ratio of horizontal to vertical in situ stresses,
- M_c = constrained modulus of the medium surrounding the liner,
- θ = angle defining position on the liner; measured counterclockwise from the right springline (Fig. 3.2-1).

Assumptions - Assumptions which are implicit in the theoretical solutions presented above include the following:

- Plane strain conditions apply, with one of the principal stresses aligned with the tunnel axis; and
- The material is homogeneous and isotropic.

For part (a) the following additional assumption applies:

- The medium is linear-elastic.

For part (b), the following additional assumptions apply:

- The material is elastic-perfectly plastic in its behavior;
- Initial stresses are hydrostatic within the plane of the analysis;
- Yielding occurs when the difference between the maximum and minimum in plane principal stresses reaches twice the shear yield stress (Tresca yield criterion); and
- The out of plane stresses have no effect on the plastic yielding.

For part (c) to this problem the following additional assumptions apply:

- The vertical stress is equal to the weight of the overburden;
- The tunnel liner and the medium are both linear-elastic materials; and
- Because of the elastic assumption and the single-step analysis, the liner is assumed to be in place before excavation of the tunnel.

<u>Input Specifications</u> - The following input specifications apply:

- Geometry
  - Excavated tunnel radius $a = 5.0$ m
- Material properties
  - Modulus of elasticity $E = 6{,}000$ MPa
  - Poisson's Ratio $\nu = 0.20$
- In situ stresses

		(a)	(b)	(c)
- Horizontal stress	S_x	30 MPa	15 MPa	30 MPa
- Vertical stress	S_y	15 MPa	15 MPa	15 MPa

For part (b), the yield strength (Tresca criterion) of the rock will be:

- Shear stress at yield $k = 10$ MPa

Properties for the tunnel lining (part c) are as follows:

- Thickness $t = 0.50$ m
- Modulus of Elasticity $E = 20{,}000$ MPa
- Poisson's Ratio $\nu = 0.20$

Figure 3.2-1 shows the geometry and loading conditions for the three parts to this problem.

Output Specifications - The output for parts (a) and (b) are the stresses and displacements along a line at equals 30 degrees at radii of 5m, 10m, and 20m. (Note: displacements for part (b) are not calculated in the analytical solution). For the lined tunnel, the moment, thrust, shear, and radial displacements in the liner at θ equals 0, 30, 60, and 90 degrees will be computed.

7. BASIC PROGRAM WP2.3

This program calculates the transient temperature response of a solid cylinder with constant thermal conductivity.

Theory

The engineering aspects of this program are discussed in Section 2.3 of Reference 2 (attached for the readers convenience at the end of this section).

Program

Input Data: Values of the input specifications h, α, a, k, T_i, and T_f are contained in Lines 10 - 60. The maximum time for the analysis is set in Line 90 and may be adjusted by changing the constant in the TMAX formula. Time steps as a function of TMAX are also set in Line 90 and may be changed by the user. The radius step size is set in Line 110 (.2 for this problem) along with the number of roots to be calculated for equation 28 of the reference (I=1 to 6). The number of roots (I=1 to 6) is also set in Line 2010. Tolerance for calculating the roots is set in Line 2000 (EPS=.000003).

Lines 110-160: Equation 27 of the reference is solved in these lines.

Lines 1000-2099: These lines are used to find the roots of Equation 28.

A listing of the program is contained in Figure 11, and the output for the problem in Reference 2 is shown in Figure 12.

Figure 11

Basic Program WP2.3 Listing

```
1 CLS
2 PRINT"FIND THE ROOTS OF THE CHARACTERISTIC EQUATION":PRINT
3 PRINT"ROOT NUMBER        VALUE        TOLERANCE"
5 DIM LAMBDA(100)
10 H=2.8
15 RSTEP=.2
20 ALPHA=.014
30 A=1!
40 K=.7
50 TI=300
60 TF=400
90 TMAX=.6*A*A/ALPHA:TSTEP=TMAX/3
100 GOSUB 2000
105 PRINT:PRINT "CALCULATE TEMPERATURES":PRINT
106 PRINT "      RADIUS       TIME       TEMPERATURE"
110 FOR R=0 TO 1 STEP RSTEP:FOR TIME=TSTEP TO TMAX STEP TSTEP:SUM=0:FOR I=1 TO 6

120 ARG=LAMBDA(I)*R:GOSUB 1000:J0R=J0
130 ARG=LAMBDA(I)*A:GOSUB 1000:J0A=J0
140 SUM=SUM+EXP(-ALPHA*LAMBDA(I)*LAMBDA(I)*TIME)*J0R/((LAMBDA(I)*LAMBDA(I)*A*A+(
1*H*A/K)^2)*J0A)
150 NEXT I
160 TEMP=SUM*2*H*A/K*(TI-TF)+TF
170 PRINT USING "########.## ########.## ########.###";R,TIME,TEMP
180 NEXT TIME
190 NEXT R
200 END
1000 IF ABS(ARG) >3 GOTO 1050
1010 X=ARG*ARG/9
1020 J0=1-2.2499997#*X+1.2656208#*X*X-.3163866*X*X*X+.0444479*X*X*X*X-.0039444*X
*X*X*X*X+.00021*X*X*X*X*X*X
1030 GOTO 1099
1050 X=3/ARG
1060 F0=.79788456#-7.7E-07*X-.0055274*X*X-9.512E-05*X*X*X+1.37237E-03*X*X*X*X-7.
2805E-04*X*X*X*X*X+1.4476E-04*X*X*X*X*X*X
1070 THETA0=ARG-.78539816#-.04166397#*X-3.954E-05*X*X+2.62573E-03*X*X*X-5.4125E-
04*X*X*X*X-2.9333E-04*X*X*X*X*X+1.3558E-04*X*X*X*X*X*X
1080 J0=1/SQR(ARG)*F0*COS(THETA0)
1099 RETURN
1100 IF ABS(ARG) >3 GOTO 1150
1110 X=ARG*ARG/9
1120 J1=ARG*(.5-.56249985#*X+.21093573#*X*X-3.954289E-02*X*X*X+4.43319E-03*X*X*X
*X-3.1761E-04*X*X*X*X*X+1.109E-05*X*X*X*X*X*X)
1130 GOTO 1099
1150 X=3/ARG
1160 F1=.79788456#+1.56E-06*X+1.659667E-02*X*X+1.7105E-04*X*X*X-2.49511E-03*X*X*
X*X+1.13653E-03*X*X*X*X*X-2.0033E-04*X*X*X*X*X*X
1170 THETA1=ARG-2.35619449#+.12499612#*X+.0000565*X*X-6.37879E-03*X*X*X+7.434BE-
04*X*X*X*X*X+7.9824E-04*X*X*X*X*X*X+-2.9166E-04*X*X*X*X*X*X
1180 J1=1/SQR(ARG)*F1*COS(THETA1)
1199 RETURN
2000 Z=-1.6:SIGN=1:EPS =.000003
2010 FOR I=1 TO  6
2020 Z=3.14+Z
2030 ARG=Z:GOSUB 1000:GOSUB 1100
2040 V=Z*J1-(H*A/K)*J0:Z=Z-V*RSTEP*SIGN
2050 IF ABS(V)<EPS GOTO 2070
2060 GOTO 2030
2070 PRINT I,Z/A,V
2080 SIGN=-SIGN:LAMBDA(I)=Z/A
2090 NEXT I
2099 RETURN
```

Figure 12

Basic Problem WP2.3 Sample Output

FIND THE ROOTS OF THE CHARACTERISTIC EQUATION

ROOT NUMBER	VALUE	TOLERANCE
1	1.908078	-2.861023E-06
2	4.601846	-2.741814E-06
3	7.520071	2.503395E-06
4	10.54229	-5.364418E-07
5	13.61248	2.801418E-06
6	16.70727	-2.861023E-06

CALCULATE TEMPERATURES

RADIUS	TIME	TEMPERATURE
0.00	14.29	330.091
0.00	28.57	365.755
0.00	42.86	383.459
0.20	14.29	332.440
0.20	28.57	366.988
0.20	42.86	384.056
0.40	14.29	339.336
0.40	28.57	370.555
0.40	42.86	385.782
0.60	14.29	350.276
0.60	28.57	376.076
0.60	42.86	388.451
0.80	14.29	364.311
0.80	28.57	382.966
0.80	42.86	391.779
1.00	14.29	380.023
1.00	28.57	390.501
1.00	42.86	395.416

2.3 Transient Temperature Response of a Solid Cylinder with Constant Thermal Conductivity

Problem Statement. This problem is concerned with the thermal response of an infinite solid cylinder (radial conduction only) of radius a, initially at a uniform temperature T_i which is equal to the atmospheric temperature. The atmospheric temperature is suddenly changed to a constant value of T_f. Subsequent to this change at time zero, the change in the temperature distribution in the cylinder is to be calculated as a function of time. See Figure 2.3-1.

The energy conservation equation for transient radial conduction in the region ($0 \leq r \leq a$) is

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{22}$$

where the thermal conductivity is considered to be invariant and where

T = temperature [θ]

r = radial position [ℓ]

t = time [t]

α = thermal diffusivity [ℓ^2/t]

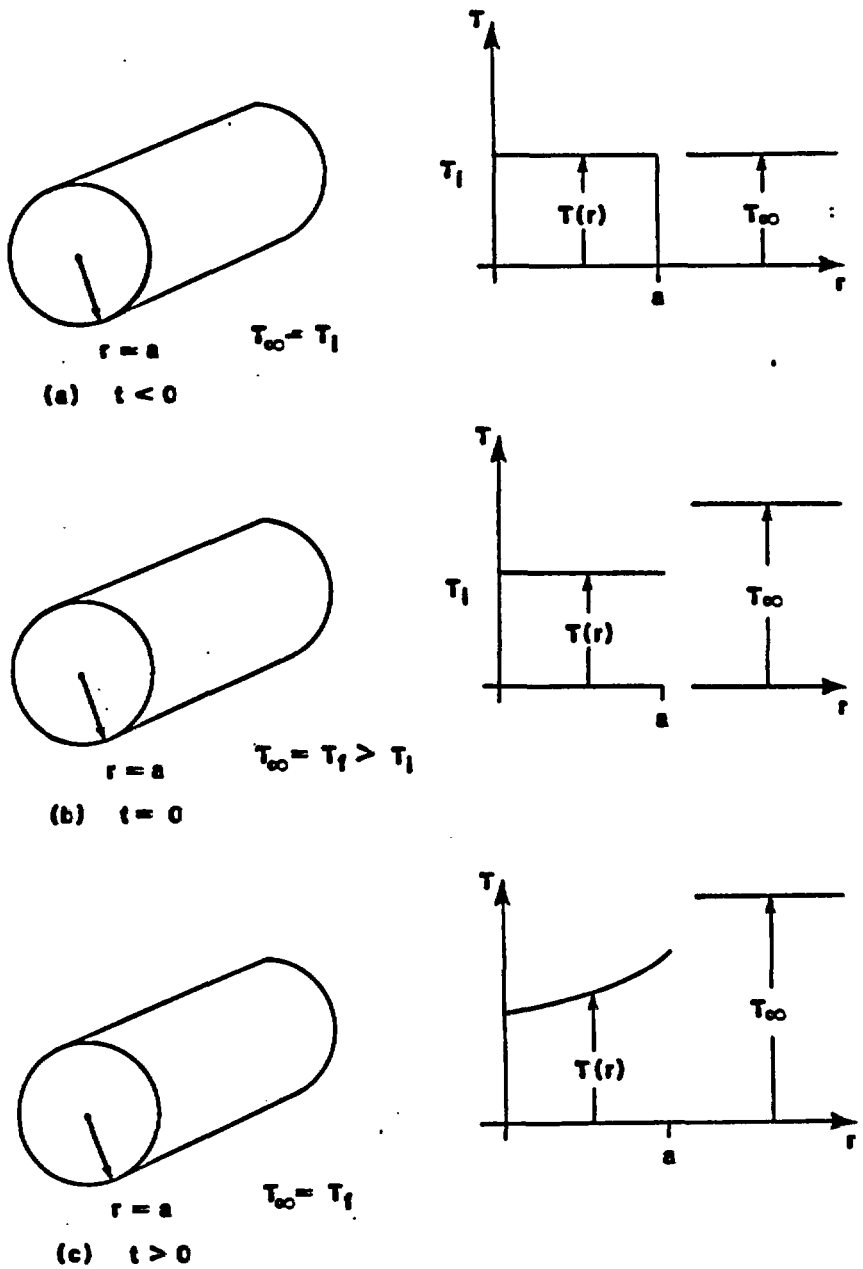


Figure 2.3-1

Cylinder of Radius a Initially in Temperature Equilibrium with Surrounding Atmosphere at Temperature T_i. At Time Zero the Surrounding Atmospheric Temperature Is Increased to a Value $T_\infty = T_f$

At the surface of the cylinder, heat may be transferred by convection between the cylinder and the atmospheric fluid. The characteristic temperature of the atmospheric fluid is T_∞. The initial condition is

$$t < 0 \qquad T(r) = T_i \qquad (0 \leq r \leq a) \tag{23}$$

and the surrounding atmospheric temperature is

$$t < 0 \qquad T_\infty = T_i \tag{24a}$$

$$t \geq 0 \qquad T_\infty = T_f \tag{24b}$$

The boundary conditions are

$$\text{at} \quad r = a, \quad -k \frac{\partial T}{\partial r} = h(T - T_\infty) \tag{25}$$

$$\text{at} \quad r = 0, \quad \frac{\partial T}{\partial r} = 0 \tag{26}$$

where

k = thermal conductivity of cylinder material [$e/t\ell\theta$]

h = convective heat transfer coefficient between the cylinder outer surface and the atmosphere [$e/t\ell^2\theta$]

Objectives. The purpose of this problem is to establish a reference solution for transient radial conduction in a cylinder. It will be representative of waste package transient cooling when there is an abrupt change in atmospheric conditions. The solution can be used to determine thermal conditions where associated thermal stresses may be important.

Analytical Solution. The solution to Equation 22 for the stated initial and boundary conditions (Reference CA-59) is

$$\frac{T(r,t) - T_\infty}{T_i - T_\infty} = \frac{2ha}{k} \sum_{n=1}^{\infty} \frac{e^{-\alpha\lambda_n^2 t} \; J_0(\lambda_n r)}{\left[\lambda_n^2 a^2 + \left(\frac{ha}{k}\right)^2\right] J_0(\lambda_n a)} \tag{27}$$

where λ_n are the characteristic values found from solving

$$(\lambda_n a)\, J_1(\lambda_n a) + \left(\frac{ha}{k}\right) J_0(\lambda_n a) = 0 \tag{28}$$

and where

$J_0(y)$ = Bessel function of first kind and order zero of independent variable y

$J_1(y)$ = Bessel function of first kind and order one of independent variable y

This analytical solution involves evaluation of the terms of an infinite series until the terms of the convergent series become negligible. (For the condition specified with this problem, use of the first two roots, λ_n, is adequate.) A more rapid solution can be obtained by the use of charts developed by Heiser (Reference HE-47), Boelter et al. (Reference BO-42), and Kreith (Reference KR-58). These charts are shown in Figure 2.3-2. They treat r/r_a from 0 to 1.0 in increments of 0.2 (six charts). Each chart presents 11 combinations of values of k/h_a in the range from 0 to 10.

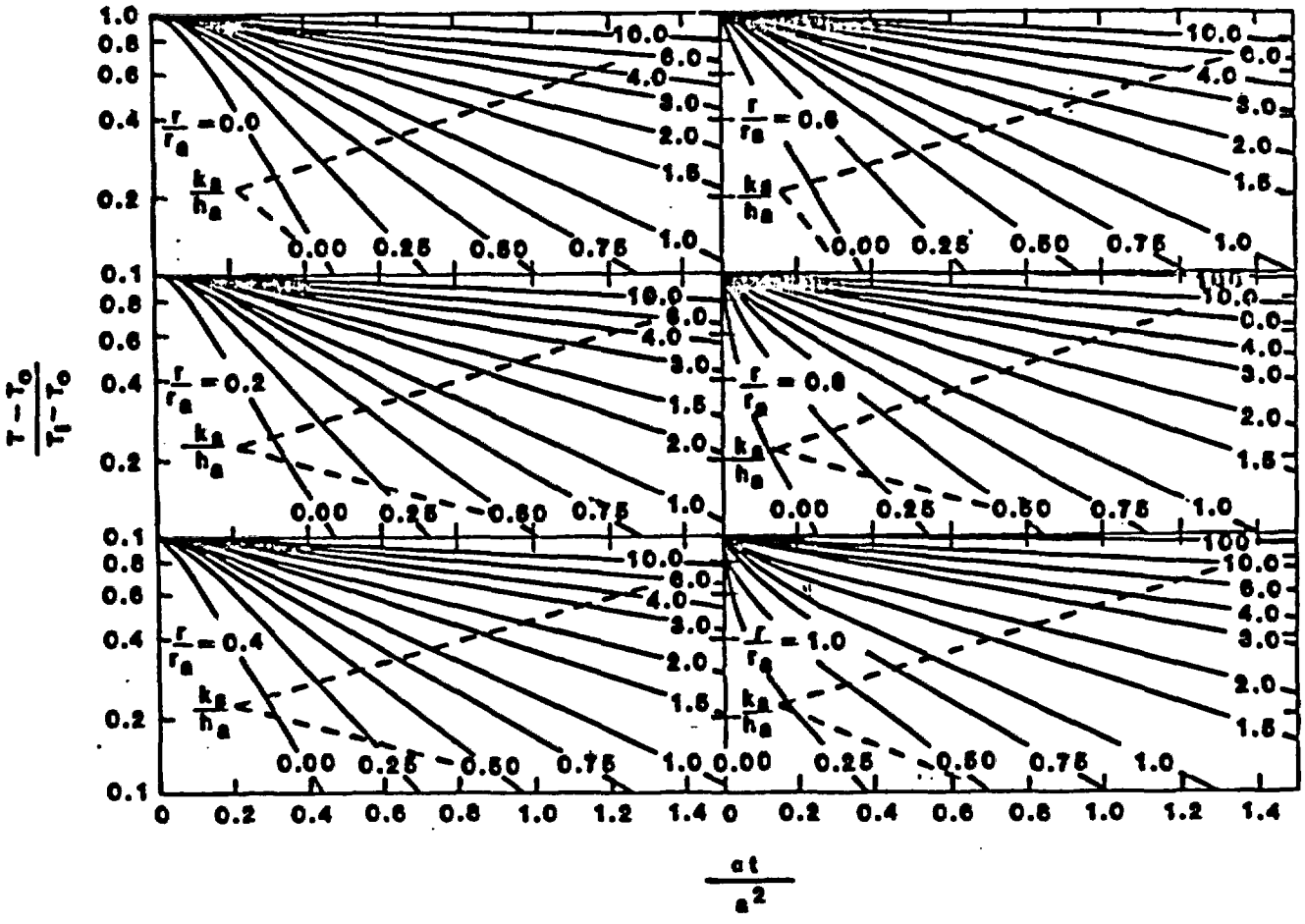


Figure 2.3-2

Dimensionless Temperature Distribution in a Long Cylinder Subjected to a Sudden Change in Environmental Temperature

Assumptions.

- The surface convection heat transfer coefficient is a known constant.
- The atmospheric temperature is constant for $t > 0$ and therefore independent of the thermal energy transferred to the cylinder.
- Thermal conductivity and thermal diffusivity are independent of temperature and thus constant through the transient.

Input Specifications.

- Geometry
  - cylinder radius, $a = 1.0$ (ft)
- Material properties
  - thermal diffusivity of cylinder material, $= 0.014$ (ft^2/hr)
  - thermal conductivity of cylinder material, $k = 0.700$ (Btu/hr-ft-^oF)
- Parameters
  - convective heat transfer coefficient, $h = 2.8$ (Btu/hr-ft^2-^oF)
- Boundary conditions
  - initial temperature of cylinder and pre-step ($t \leq 0$) atmospheric temperature, $T_i = 300$(^oF)
  - post-step ($t > 0$) atmospheric temperature, $t_f = 400$ (^oF)

For this problem, the first six roots of Equation 28, λ_n, are:

n	λ_n
1	1.9081
2	4.6018
3	7.5201
4	10.5423
5	13.6125
6	16.7073

Summations using the first two roots in Equation 27 are adequate to give values of temperature accurate to 0.01°C.

Output Specifications. This problem solves for the temperature response as a function of radius and time. The solution can be compared with the values in the following table, which are given in terms of thermal and geometric parameters:

			T(r)	(°F)
t(hrs)	0.0	14.29	28.57	42.86
$\alpha t/a^2$	0.0	0.2	0.4	0.6
r (ft)				
0	300	330.09	365.76	383.46
0.2	300	332.44	366.99	384.06
0.4	300	339.34	370.56	385.78
0.6	300	350.28	376.08	388.45
0.8	300	364.31	382.97	391.78
1.0	300	380.02	390.50	395.42

8. LOTUS SPREADSHEET WP2.4

This spreadsheet calculates a one-dimensional transient temperature distribution with phase change.

Theory

The engineering aspects of this spreadsheet are discussed in Section 2.4 of Reference 2 (attached for the readers convenience at the end of this section).

Spreadsheet

Input data: Problem specifications are <u>input by the user</u> in rows 6 through 18.

Row 22: λ, which is calculated iteratively in rows 103 through 119, is reported here.

Row 23: Thermal diffusivity is calculated in cell F23.

Row 24: In cell F24, erf(λ) is calculated as follows:

$$\mathrm{erf}(\lambda) = c(T_1-T_0)/[(L\pi^{\frac{1}{2}})\cdot(\lambda e^{\lambda^2})] \qquad \text{(A)}$$

where: variables are as described in the reference

In cell G24, λ convergence is indicated with a value of 1 if the iterative solution converged on the value in Row 22, and by a value $\neq$ 1 if the iterative solution did not converge; in which case the temperatures calculated in Rows 30 through 100 are incorrect.

Rows 30-100: Columns A and B contain the distances and times that were input by the user in Rows 15 through 18.

Column C is used to calculate the temperature at the corresponding time and distance by the equations at the bottom of page 27 of the Reference.

Column D calculates the front location, $2\lambda(at^{\frac{1}{2}})$, at the time (t) shown in Column B.

Columns E through G are used to determine erf(z) where z equals $x/[2(at)^{\frac{1}{2}}]$.

Rows 106-118: The iterative solution for λ begins in cell H106 with an initial guess of $\lambda = [c(T_1-T_0)/2L]^{\frac{1}{2}}$. This iteration may not converge for values of λ greater than 0.75.

A sample spreadsheet is shown in Figure 13.

Figure 13

Problem WP2.4 Sample Lotus Spreadsheet

```
     A          B          C          D          E          F
1  PROBLEM WP 2.4 ONE-DIMENSIONAL TRANSIENT TEMPERATURE DISTRIBUTION
2                 WITH PHASE CHANGE
3
4  ******************************************************* NOTE: BE SURE
5  **INPUT DATA**                                          * RANGE PROTECT
6  * DENSITY "RHO" (g/cm)                            0.92 * SWITCH IS ON
7  * SPECIFIC HEAT "c" (cal/g degree C)              0.48 * (TYPE /WGPE).
8  * THERMAL CONDUCTIVITY "k" (cal/cm sec deg C)     528 * ALL CELLS EXCEPT
9  * INITIAL TEMPERATURE OF LIQUID "T1" (deg C)        0 * F6-F11 & C15-G18
10 * BOUNDARY TEMPERATURE "T0" (deg C)              -45 * ARE PROTECTED.
11 * HEAT OF FUSION "L" (cal/g)                     144 *
12 *******************************************************
13 ***************************************************************
14 *  ==TIMES (sec) AND DISTANCES (cm) FOR USE IN THE PROBLEM==   *
15 *      TIMES 1-5:      0.25     0.50     1.00     2.00     5.00 *
16 *      TIMES 6-9:     10.00    20.00    50.00   100.00          *
17 * DISTANCES 1-5:      1.00     2.00     5.00    10.00    20.00 *
18 * DISTANCES 6-7:     50.00   100.00                             *
19 ***************************************************************
20
21 ============INTERMEDIATE CALCULATIONS================
22  LAMBDA                                      0.267381      LAMBDA
23  THERMAL DIFFUSIVITY "a" (k/RHO c)           1195.652    CONVERGENCE
24  erf(LAMBDA)                                 0.294669        1
25 ==========================================================
26
27                                  FRONT
28 DISTANCE      TIME     TEMP   LOCATION
29    (cm)      (sec)   (deg C)    (cm)      erf(z) 1/(1+P*z)     z
30      1        0.25    -40.02   9.2456    0.0326   0.9906   0.0289
31      2        0.25    -35.04   9.2456    0.0652   0.9814   0.0578
32      5        0.25    -20.26   9.2456    0.1620   0.9548   0.1446
33     10        0.25      0.00   9.2456    0.3175   0.9135   0.2892
34     20        0.25      0.00   9.2456    0.5866   0.8407   0.5784
35     50        0.25      0.00   9.2456    0.9591   0.6786   1.4460
36    100        0.25      0.00   9.2456    1.0000   0.5135   2.8920
37
38      1        0.50    -41.48  13.0752    0.0231   0.9933   0.0204
39      2        0.50    -37.96  13.0752    0.0461   0.9868   0.0409
40      5        0.50    -27.44  13.0752    0.1150   0.9676   0.1022
41     10        0.50    -10.25  13.0752    0.2276   0.9372   0.2045
42     20        0.50      0.00  13.0752    0.4370   0.8818   0.4090
43     50        0.50      0.00  13.0752    0.8518   0.7491   1.0225
44    100        0.50      0.00  13.0752    0.9962   0.5988   2.0449
45
46      1        1.00    -42.51  18.4912    0.0163   0.9953   0.0145
47      2        1.00    -40.02  18.4912    0.0326   0.9906   0.0289
48      5        1.00    -32.56  18.4912    0.0814   0.9769   0.0723
49     10        1.00    -20.26  18.4912    0.1620   0.9548   0.1446
50     20        1.00      0.00  18.4912    0.3175   0.9135   0.2892
51     50        1.00      0.00  18.4912    0.6934   0.8085   0.7230
52    100        1.00      0.00  18.4912    0.9591   0.6786   1.4460
53
54      1        2.00    -43.24  26.1505    0.0115   0.9967   0.0102
55      2        2.00    -41.48  26.1505    0.0231   0.9933   0.0204
56      5        2.00    -36.20  26.1505    0.0576   0.9835   0.0511
57     10        2.00    -27.44  26.1505    0.1150   0.9676   0.1022
58     20        2.00    -10.25  26.1505    0.2276   0.9372   0.2045
59     50        2.00      0.00  26.1505    0.5303   0.8565   0.5112
60    100        2.00      0.00  26.1505    0.8518   0.7491   1.0225
61
62      1        5.00    -43.89  41.3475    0.0073   0.9979   0.0065
63      2        5.00    -42.77  41.3475    0.0146   0.9958   0.0129
64      5        5.00    -39.43  41.3475    0.0365   0.9895   0.0323
65     10        5.00    -33.87  41.3475    0.0729   0.9793   0.0647
66     20        5.00    -22.84  41.3475    0.1451   0.9594   0.1293
67     50        5.00      0.00  41.3475    0.3525   0.9042   0.3233
68    100        5.00      0.00  41.3475    0.6396   0.8252   0.6467
```

Figure 13

Problem WP2.4 Sample Lotus Spreadsheet (continued)

	A	B	C	D	E	F	G	H
69								
70	1	10.00	-44.21	58.4742	0.0052	0.9985	0.0046	
71	2	10.00	-43.42	58.4742	0.0103	0.9970	0.0091	
72	5	10.00	-41.06	58.4742	0.0258	0.9926	0.0229	
73	10	10.00	-37.13	58.4742	0.0516	0.9852	0.0457	
74	20	10.00	-29.28	58.4742	0.1029	0.9709	0.0915	
75	50	10.00	-6.28	58.4742	0.2536	0.9303	0.2286	
76	100	10.00	0.00	58.4742	0.4822	0.8697	0.4573	
77								
78	1	20.00	-44.44	82.6950	0.0036	0.9989	0.0032	
79	2	20.00	-43.89	82.6950	0.0073	0.9979	0.0065	
80	5	20.00	-42.21	82.6950	0.0182	0.9947	0.0162	
81	10	20.00	-39.43	82.6950	0.0365	0.9895	0.0323	
82	20	20.00	-33.87	82.6950	0.0729	0.9793	0.0647	
83	50	20.00	-17.38	82.6950	0.1808	0.9497	0.1617	
84	100	20.00	0.00	82.6950	0.3525	0.9042	0.3233	
85								
86	1	50.00	-44.65	130.7523	0.0023	0.9993	0.0020	
87	2	50.00	-44.30	130.7523	0.0046	0.9987	0.0041	
88	5	50.00	-43.24	130.7523	0.0115	0.9967	0.0102	
89	10	50.00	-41.48	130.7523	0.0231	0.9933	0.0204	
90	20	50.00	-37.96	130.7523	0.0461	0.9868	0.0409	
91	50	50.00	-27.44	130.7523	0.1150	0.9676	0.1022	
92	100	50.00	-10.25	130.7523	0.2276	0.9372	0.2045	
93								
94	1	100.00	-44.75	184.9117	0.0016	0.9995	0.0014	
95	2	100.00	-44.50	184.9117	0.0033	0.9991	0.0029	
96	5	100.00	-43.75	184.9117	0.0082	0.9976	0.0072	
97	10	100.00	-42.51	184.9117	0.0163	0.9953	0.0145	
98	20	100.00	-40.02	184.9117	0.0326	0.9906	0.0289	
99	50	100.00	-32.56	184.9117	0.0814	0.9769	0.0723	
100	100	100.00	-20.26	184.9117	0.1620	0.9548	0.1446	
101								
102								

```
103   ITERATION TO DETERMINE LAMBDA -- MAY NOT CONVERGE IF LAMBDA >.75
104      * ************************************************************
105      * 7thGUESS 6thGUESS 5thGUESS 4thGUESS 3rdGUESS 2ndGUESS 1stGUESS
106      * 0.267381 0.267381 0.267382 0.267369 0.267635 0.260440 0.273861
107      * 0.919462 0.919462 0.919462 0.919459 0.919526 0.917671
108      * 0.267381 0.267381 0.267381 0.267381 0.267393 0.267150
109      * ************************************************************
110      * 14thGUESS13thGUESS12thGUESS11thGUESS10thGUESS9thGUESS 8thGUESS
111      * 0.267381 0.267381 0.267381 0.267381 0.267381 0.267381 0.267381
112      * 0.919462 0.919462 0.919462 0.919462 0.919462 0.919462 0.919462
113      * 0.267381 0.267381 0.267381 0.267381 0.267381 0.267381 0.267381
114      * ************************************************************
115      * 21stGUESS20thGUESS19thGUESS18thGUESS17thGUESS16thGUESS15thGUESS
116      * 0.267381 0.267381 0.267381 0.267381 0.267381 0.267381 0.267381
117      * 0.919462 0.919462 0.919462 0.919462 0.919462 0.919462 0.919462
118      * 0.267381 0.267381 0.267381 0.267381 0.267381 0.267381 0.267381
119      * ************************************************************
```

2.4 One-Dimensional Transient Temperature Distribution with Phase Change

Problem Statement. This problem simulates the transient temperature response of a fluid initially at $0^{o}C$ as one wall is lowered to a temperature of $-45^{o}C$ causing a freezing interface to propagate into the liquid. Temperatures are to be calculated as a function of time and distance from the surface boundary.

Physical Description. A one-dimensional slab is occupied by a liquid at 0°C. At the beginning of the transient (t = 0), the edge is instantaneously lowered to a temperature of -45°C. The freezing temperature of the liquid is -0.01°C. As heat is removed from the liquid, the freezing front propagates away from the cold surface and into the liquid (see Figure 2.4-1.

Problem Solution. Conductive heat transfer with phase change is governed by the following differential equation

$$k \frac{\partial^2 T}{\partial x^2} = \rho c \frac{\partial T}{\partial t} + L \tag{29}$$

where

T = temperature [θ]

x = position measured into the solid/fluid region from the cold edge [ℓ]

ρ = mass density of the fluid and of the solid [m/ℓ^3]

c = specific heat of the fluid and of the solid [e/m]

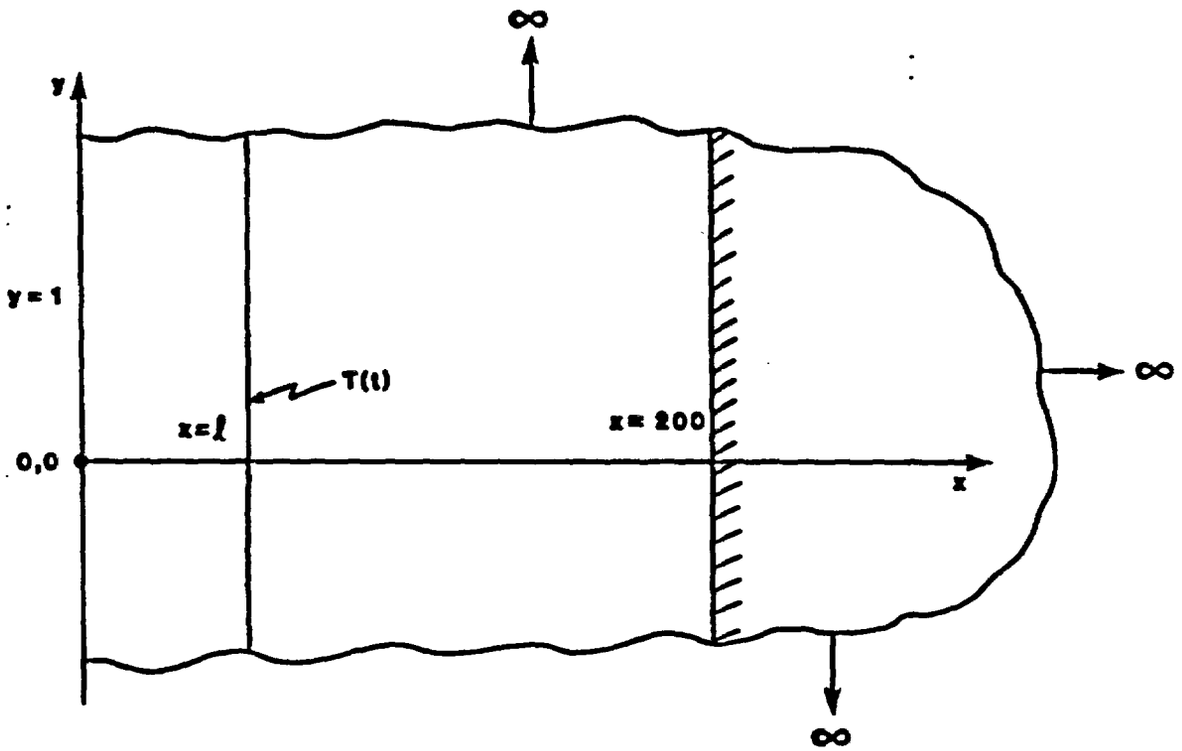
k = thermal conductivity of the fluid and of the solid [$e/t\,\ell\theta$]

L = heat of fusion [e/ℓ^3]

Reference CA-59 provides a solution for this problem of:

$$T(x,t) = T_o\left(1 - \mathrm{erf}\left[\frac{x}{2(at)^{1/2}}\right]/\mathrm{erf}(\lambda)\right) \quad \text{for } x < 2\lambda(at)^{1/2}$$

$$T(x,t) = T_1 \quad \text{for } x \geq 2\lambda(at)^{1/2}$$



$t < 0$	$x \leq 0$	$T = 0°F$
$t < 0$	$0 \leq x \leq \infty$	$T = 0°F$
$t \geq 0$	$x = 0$	$T = -45°F$
$0 \leq t \leq t_{max}$	$x = 200$	$\frac{\partial T}{\partial x} = 0$

where t_{max} is the maximum time to be analyzed

Figure 2.4-1

Slab from Semi-Infinite Freezing Liquid with One Boundary at T = -45°F

where

$T(x,t)$ = temperature

x = distance from the boundary

t = time

T_1 = initial temperature of the liquid

T_0 = boundary temperature

a = thermal diffusivity ($a = k/\rho c$)

λ = an equation parameter that satisfies

$$\lambda e^{\lambda^2} \operatorname{erf}\lambda = \frac{c(T_1 - T_0)}{L\pi^{1/2}}$$

c = specific heat

ρ = density

k = thermal conductivity

L = heat of fusion

Table 2.4-1 provides a list of values of the parameter λ as a function of specific heat, temperature difference, and latent heat. When the value of λ is relatively small ($\lambda \leq 0.2$), it can be approximated by

$$\lambda^2 = C(T_1 - T_0)/2L$$

Objectives. The purpose of this problem is to provide a basis for examining the modeling assumptions and algorithms used by codes for the calculation of temperatures during phase changes for materials with significant latent heats.

Assumptions. In modeling the problem, it can be assumed that at a point 200 centimeters into the fluid undergoing the phase change, the temperature remains constant at the initial fluid temperature. It is also assumed that heat transfer is by conduction only. There is no convective heat transport.

The following input parameter values should be used:

$k = 528$ cal/cm sec ^{o}C

$\rho = 0.92$ g/cm^3

$c = 0.48$ cal/g ^{o}C

$a = 1196$ cm^2/sec

$L = 144$ cal/g

$T_1 = 0^{o}C$

$T_0 = -45^{o}C$

$$\frac{c(T_1-T_0)}{L\pi^{1/2}} = 0.0846$$

$\lambda = 0.267$

Calculated results can be compared with the values in Table 2.4-2.

Output Specifications. The outputs for this problem are the temperature as a function of time and distance. The temperatures are to be calculated at positions 1, 2, 5, 10, 20, 50, and 100 centimeters from the boundary at times of 0.25, 0.5, 1, 2, 5, 10, 20, 50, and 100 seconds.

Table 2.4-1

Values of the Parameter λ

$\frac{c(T_0-T_1)}{L\pi^{1/2}}$	λ
0.01	0.09386
0.02	0.13236
0.03	0.16164
0.04	0.18611
0.05	0.20749
0.06	0.22667
0.07	0.24415
0.08	0.26029
0.09	0.27534
0.10	0.28945
0.20	0.39902
0.30	0.47737
0.40	0.53937
0.50	0.59095
0.60	0.63520
0.70	0.67396
0.80	0.70845
0.90	0.73951
1.0	0.76755
2.0	0.96121
3.0	1.0773
4.0	1.1596
5.0	1.2230
6.0	1.2742
7.0	1.3172
8.0	1.3540
9.0	1.3863
10.	1.4149
20.	1.5974
30.	1.6992
40.	1.7694
50.	1.8226
60.	1.8653
70.	1.9009
80.	1.9314
90.	1.9579

Table 2.4-2

Time-Dependent Temperature Distribution in a One-Dimensional Slab Undergoing Phase Change

Time (seconds)	Distance (cm)	Temperature °C
0.25	1	-40.01
0.25	2	-35.03
0.25	5	-20.23
0.25	9.234*	0.00
0.25	10	0.00
0.25	20	0.00
0.25	50	0.00
0.25	100	0.00
0.50	1	-41.47
0.50	2	-37.95
0.50	5	-27.42
0.50	10	-10.20
0.50	13.058*	0.00
0.50	20	0.00
0.50	50	0.00
0.50	100	0.00
1.0	1	-42.51
1.0	2	-40.01
1.0	5	-32.55
1.0	10	-20.03
1.0	18.467*	0.00
1.0	20	0.00
1.0	50	0.00
1.0	100	0.00
2.0	1	-43.24
2.0	2	-41.47
2.0	5	-36.19
2.0	10	-27.42
2.0	20	-10.02
2.0	26.117*	0.00
2.0	50	0.00
2.0	100	0.00
5.0	1	-43.88
5.0	2	-42.77
5.0	5	-39.42
5.0	10	-33.86
5.0	20	-22.81
5.0	41.294*	0.00
5.0	50	0.00
5.0	100	0.00

Table 2.4.2 (continued)

Time (seconds)	Distance (cm)	Temperature °C
10.0	1	-44.21
10.0	2	-43.42
10.0	5	-41.06
10.0	10	-37.12
10.0	20	-29.27
10.0	50	- 6.23
10.0	58.399*	0.00
10.0	100	0.00
20.0	1	-44.44
20.0	2	-43.88
20.0	5	-42.21
20.0	10	-39.42
20.0	20	-33.86
20.0	50	-17.35
20.0	82.589*	0.00
20.0	100	0.00
50.0	1	-44.61
50.0	2	-44.21
50.0	5	-43.03
50.0	10	-41.06
50.0	20	-37.12
50.0	50	-25.36
50.0	100	- 6.23
50.0	130.585*	0.00
100.0	1	-44.75
100.0	2	-44.50
100.0	5	-43.75
100.0	10	-42.51
100.0	20	-40.01
100.0	50	-32.55
100.0	100	-20.23
100.0	184.674*	0.00

* Location of freezing front

9. LOTUS SPREADSHEET WP3.1

This spreadsheet calculates radial and tangential stresses in a thick-walled cylinder with a radial temperature profile.

Theory

The engineering aspects of this spreadsheet are discussed in Section 3.1 of Reference 2 (attached for the readers convenience at the end of this section).

Spreadsheet

Input Data: Problem specifications are input by the user in cells F6 through F14.

Row 19: Intermediate calculations DT = $T(r_1)-T(r_0)$, A (Equation 49), and B (Equation 50) are calculated here.

Column A: The cylinder radii at which temperatures and stresses will be determined are automatically calculated in Rows 28-37. Values may be input by the user in Rows 46-54.

Column B: Temperature is calculated using equation 42.

Column C: Radial stress is determined by equation 47.

Column D: Tangential stress is calculated using equation 48.

A graph of stresses as a function of radius (automatic radius calculation version) is displayed on the screen when the F10 key is pushed.

A sample spreadsheet is shown in Figure 14.

Figure 14

Problem WP3.1 Sample Lotus Spreadsheet

```
      A          B          C          D          E          F          G
 1 PROBLEM WP 3.1: RADIAL AND TANGENTIAL STRESS COMPONENTS IN A THICK-WALLED
 2                 CYLINDER WITH A RADIAL TEMPERATURE PROFILE
 3
 4 ******************************************************
 5 * INPUT DATA                                          * NOTE: BE SURE
 6 * WASTE REGION RADIUS "rw" (cm)                 30.50 * RANGE PROTECT
 7 * CYLINDER INSIDE RADIUS "ri" (cm)              30.50 * SWITCH IS ON
 8 * CYLINDER OUTSIDE RADIUS "ro" (cm)            67.50 * (TYPE /WGPE)
 9 * THERMAL CONDUCTIVITY "k" (W/cm deg C)         0.50 * ALL CELLS EXCEPT
10 * THERMAL EXPANSION COEFF. "alpha" (1/deg C)  1.1E-05 * A44-A52 & F6-F14
11 * POISSONS RATIO "Nu"                           0.25 * ARE PROTECTED.
12 * ELASTIC MODULUS "E" (MPa)                   1.62E+05 *
13 * CYLINDER OUTSIDE TEMPERATURE "To" (deg C)    200.00 *
14 * VOLUMETRIC HEAT GENERATION "q'''" (W/cc)  1.291E-03 *
15 ******************************************************
16
17 ===============INTERMEDIATE CALCULATIONS===============
18
19       DT=  0.9540        A= 1.426731        B= 0.2038034
20 ========================================================
21
22
23   AUTOMATIC RADIUS CALCULATION VERSION
24
25                          RADIAL TANGENTIAL
26   RADIUS     TEMP.       STRESS   STRESS
27     (cm)   (DEG C)        (MPa)    (MPa)
28     30.5   200.954         .000   -1.422
29     34.6   200.802       -0.138   -0.923
30     38.7   200.667       -0.200   -0.540
31     42.8   200.546       -0.218   -0.235
32     46.9   200.436       -0.208    0.017
33     51.1   200.335       -0.181    0.229
34     55.2   200.242       -0.143    0.413
35     59.3   200.156       -0.099    0.574
36     63.4   200.075       -0.051    0.717
37     67.5   200.000        0.000    0.845
38 ==========================================
39
40
41   USER INPUT RADIUS VERSION
42
43                          RADIAL TANGENTIAL
44   RADIUS     TEMP.       STRESS   STRESS
45     (cm)   (DEG C)        (MPa)    (MPa)
46     30.5   200.954         .000   -1.422
47     35.0   200.789       -0.146   -0.883
48     40.0   200.628       -0.209   -0.439
49     45.0   200.487       -0.215   -0.097
50     50.0   200.360       -0.189    0.178
51     55.0   200.246       -0.145    0.406
52     60.0   200.141       -0.091    0.600
53     65.0   200.045       -0.031    0.769
54     67.5   200.000        0.000    0.845
```

3.1 Radial and Tangential Stress Components in a Thick-Walled Cylinder with a Radial Temperature Profile

Problem Statement. This problem concerns the radial and tangential stress components at the inner and outer surfaces of a hollow cylinder ($r_i \leq r \leq r_o$), which suppports a radial temperature distribution

$$T(r) = T_o + \frac{q'''r_w^2}{2k} \ln (r_o/r) \tag{42}$$

as given in thermal problem 2.1. In this equation

r = radial position $r_i \leq r \leq r_o$ [ℓ]

r_i = inside radius of hollow cylinder [ℓ]

r_o = outside radius of hollow cylinder [ℓ]

r_w = outside radius of solid cylindrical region in which volumetric heat generation q''' applies $r_i \leq r_w$ [ℓ]

k = thermal conductivity of hollow cylinder material (assumed constant) [e/tℓθ]

q''' = uniform volumetric heat generation rate in solid cylindrical region of outer radius r_w [e/tℓ^3]

T_o = temperature of outer surface of hollow cylinder at $r = r_o$ [θ]

Objectives. The solution to this problem can be used to verify the accuracy of the WAPPA and ANSYS structural analysis models. The verification is directed to the treatment of the radial temperature distribution and the structural response, in terms of the radial and circumferential stress components that it causes.

Analytical Solution. The general solution given by Timoshenko (TI-56) for the radial stress component at any position $r_i \leq r \leq r_o$, where the radial stress is zero on the inside and outside surfaces, is

$$\sigma_r = \frac{E}{1-\nu}\left[-\frac{1}{r^2}\int_{r_i}^{r} \alpha T(r)rdr + \frac{r^2 - r_i^2}{r^2(r_o^2 - r_i^2)}\int_{r_i}^{r_o} \alpha T(r)rdr\right] \tag{43}$$

and the circumferential stress component is given by

$$\sigma_t = \frac{E}{1-\nu}\left[\frac{1}{r^2}\int_{r_i}^{r} \alpha T(r) r dr + \frac{r^2 + r_i^2}{r^2(r_o^2 - r_i^2)}\int_{r_i}^{r_o} \alpha T(r) r dr - \alpha T(r)\right] \tag{44}$$

where

E = material's elastic modulus $[f/\ell^2]$

ν = material's Poisson's ratio [ ]*

α = material's coefficient of thermal expansion $[1/\theta]$

r = general radial position in the range $r_i \leq r \leq r_o$ $[\ell]$

r_i = inside radius of hollow cylinder $[\ell]$

r_o = outside radius of hollow cylinder $[\ell]$

σ_r = radial stress component $[f/\ell^2]$

σ_t = circumferential stress component $[f/\ell^2]$

$T(r)$ = temperature rise at position r $(r_i \leq r \leq r_o)$ in the hollow cylinder $[\theta]$

Figure 3.1-1 shows the solid cylinder configuration in which the heat is generated and the larger concentric hollow cylinder for which the radial and tangential thermal stress components will be analyzed.

Using Equation 42 for the temperature rise

$$T(r) = \frac{q'''r_w^2}{2k} \ln(r_o/r) \tag{42}$$

* Dimensionless

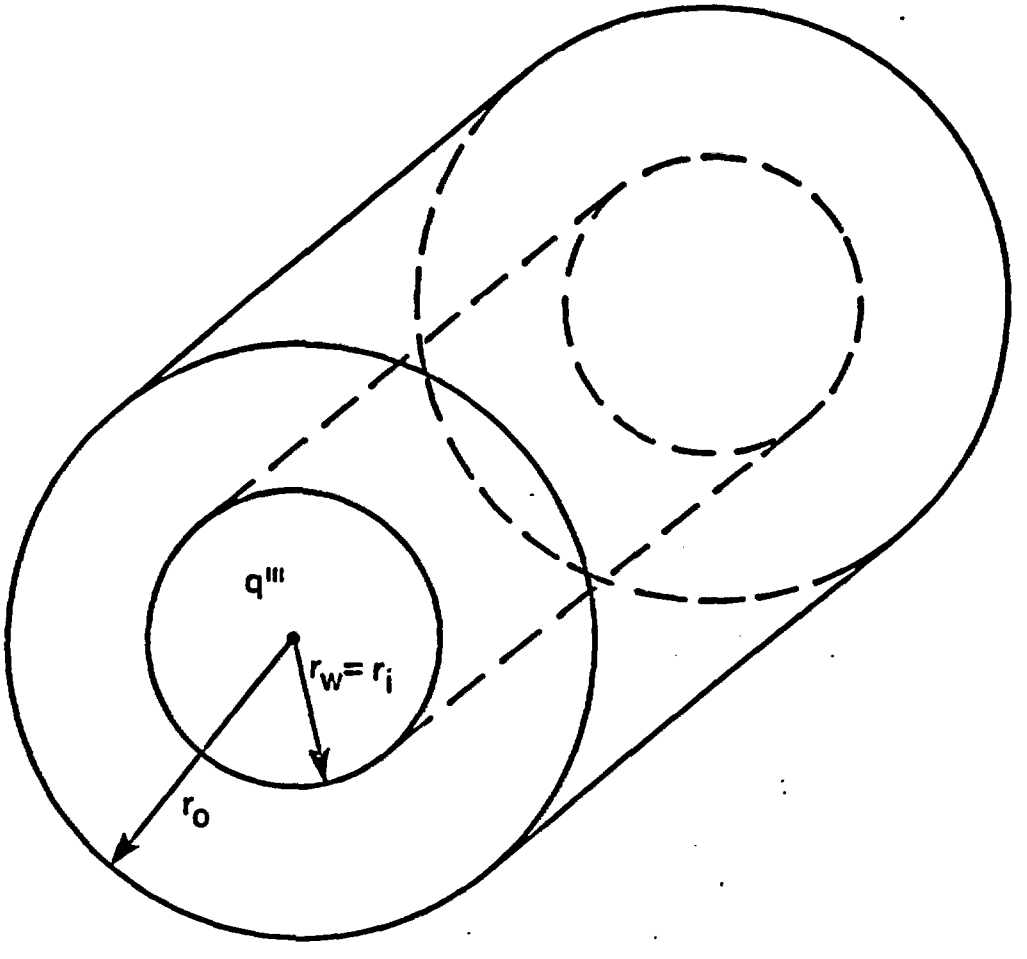


Figure 3.1-1

Hollow Cylinder $r_i \leq r \leq r_o$ with Steady-State Radial Temperature Distribution for Which Radial and Tangential Stress Components Will Be Analyzed

and for k = constant, the integrals are

$$\sigma_r = \frac{E\ \alpha\ T(r_i)-T(r_o)}{2\ (1-\nu)\ln(r_o/r_i)} \left[- \ln\ (r_o/r_i) - \frac{r_i^2}{r_o^2 - r_i^2}\ (1-r_o^2/r^2)\ln\ (r_o/r_i) \right] \tag{45}$$

and

$$\sigma_t = \frac{E\ \alpha\ T(r_i)-T(r_o)}{2\ (1-\nu)\ln(r_o/r_i)} \left[1 - \ln\ (r_o/r_i) - r_i^2/(r_o^2-r_i^2)(1+ r_o^2/r^2)\ \ln\ (r_o/r_i) \right. \tag{46}$$

Thus, Equations 43 and 44 can be evaluated to give the radial and tangential stress components for any radial position r for the temperature distribution given by Equation 42.

Equations 43 and 44 can be written as

$$\sigma_r = A \left[- \ln\ (r_o/r) - B\ (1-r_o^2/r^2) \right] \tag{47}$$

and

$$\sigma_t = A \left[1 - (\ln r_o/r) - B \left(1 + \frac{r_o^2}{r^2} \right) \right] \tag{48}$$

where

$$A = \frac{E \alpha \left[T(r_i) - T(r_o) \right]}{(1-\nu) \ln (r_o/r_i)} \tag{49}$$

and

$$B = \left(\frac{r_i^2}{r_o^2 - r_i^2} \right) \ln (r_o/r_i) \tag{50}$$

Equations 47, 48, 49, and 50 can be evaluated to predict the radial distribution of the radial and tangential stress components.

Assumptions.

- The thermal conductivity of the hollow cylinder material is constant.
- The coefficient of thermal expansion of the hollow cylinder is constant.
- The material is isotropic

Input Specifications.

- Geometry
  - waste region radius r_w = 30.5 (cm)
  - hollow cylinder inside radius r_i = 30.5 (cm)
  - hollow cylinder outside radius r_o = 67.5 (cm)
- Material properties
  - thermal conductivity k = 0.5 (w/cm°C)
  - coefficient of thermal expansion $\alpha = 11 \times 10^{-6}$ (1/°C)
  - Poisson's ratio ν = 0.25 ( )
  - elastic modulus E = 16.2×10^4 (MPa)
- Thermal conditions
  - hollow cylinder outside temperature T_o = 200(°C)
  - volumetric heat generation rate q''' = 0.001291 (w/cm^3)

Equations 47, 48, 49 and 50 have been evaluated at eight radial positions as shown in Table 3.1-1 to determine the radial and tangential stress components at eight values of radius in the range ($r_i \leq r \leq r_o$).

Output Specifications. The solution to this problem will determine the stress components at the radial positions indicated in Table 3.1-1.

Table 3.1-1

Calculated Values of Radial and Tangential Stress Components

r (cm)	T (°C)	σ_r (MPa)	σ_t (MPa)
30.5	200.954	0.00	-1.422
35.0	200.789	-0.146	-0.883
40.0	200.628	-0.209	-0.439
45.0	200.487	-0.215	-0.097
50.0	200.360	-0.189	0.179
55.0	200.246	-0.145	0.406
60.0	200.141	-0.091	0.600
67.5	200.000	0.000	0.845

10. LOTUS SPREADSHEET WP3.3

This spreadsheet calculates the deformation of a thin rod subject to a step load.

Theory

The engineering aspects of this spreadsheet are discussed in Section 3.3 of Reference 2 (attached for the readers convenience at the end of this section).

Spreadsheet

Input Data: Problem specifications are input by the user in cells E5 through E9.

Rows 12-15: Intermediate calculations are performed in cells D12 through D15.

Column B: Time steps are calculated automatically in this column. The user may input specific times by disabling the range protection (type /WGPD) and typing the times in column B.

Column C: For cases in which the applied force (F_1) is greater than the yield force (R_m), displacement is calculated by Equation 73 for times less than or equal to t_e and by Equation 81 for times greater than t_e. In cases where the applied force is less than the yield force, Equation 73 is used for all times.

A graph of displacement as a function of time will appear on the screen when the F10 key is pushed.

A sample spreadsheet is shown in Figure 15.

Figure 15

Problem WP3.3 Sample Lotus Spreadsheet

```
      A          B          C          D          E          F          G
 1   PROBLEM WP 3.3 DEFORMATION OF A THIN ROD SUBJECTED TO A STEP LOAD
 2                  FOR CASES WHERE F1 IS <,=,>, Rm
 3 ***********************************************
 4 INPUT DATA                                      * NOTE: BE SURE RANGE
 5 MASS "m" (lb.)                        3.00E+04 * PROTECT SWITCH IS
 6 APPLIED FORCE "F1" (lb.)              3.00E+06 * ON (TYPE /WGPE).
 7 YIELD FORCE "Rm" (lb.)                5.00E+05 * ALL CELLS EXCEPT
 8 ROD ELONGATION @ START OF                       * E5-E9
 9 PLASTIC DEFORMATION "ye" (in.)        0.166666 * ARE PROTECTED.
10 ***********************************************
11 -------------INTERMEDIATE CALCULATIONS-----------
12                 yst = F1/k =       1.000
13                  k = Rm/ye =    3.00E+06
14         OMEGA = @SQRT(k/m) =       10.00
15 te= @ACOS(1-ye/yst)/OMEGA =    0.058569 OK IF ="ERR" IF "F1"<"Rm"
16 ------------------------------------------------
17
18            TIME              DISPLACEMENT
19          (seconds)             (inches)
20            0.0000                .00000
21            0.0059               0.00171
22            0.0117               0.00685
23            0.0176               0.01540
24            0.0234               0.02732
25            0.0293               0.04257
26            0.0351               0.06111
27            0.0410               0.08287
28            0.0469               0.10778
29            0.0527               0.13574
30          0.058569               0.16667
31            0.0879               0.36427
32            0.1171               0.63334
33            0.1464               0.97388
34            0.1757               1.38588
35            0.2050               1.86934
36            0.2343               2.42427
37            0.2636               3.05066
38            0.2928               3.74852
39            0.3221               4.51784
40            0.3514               5.35862
41            0.4100               7.25458
42            0.4685               9.43639
43            0.5271              11.90407
44            0.5857              14.65760
45            0.6443              17.69698
46            0.7028              21.02222
47            0.7614              24.63332
48            0.8200              28.53027
49            0.8785              32.71308
50            0.9371              37.18175
51            0.9957              41.93627
52            1.0542              46.97665
```

3.3 Deformation of a Thin Rod Subjected to a Step Load

Problem Statement. A mass supported by a thin rod is subjected to a step load which imposes a tensile load in the rod and causes it to experience elastic strain followed by plastic tensile strain. Figure 3.3-1 shows a mechanical model of the structure and the loading history.

Objectives. The objective of this analysis is to determine the displacement transient of the mass and the time when the displacement is at its maximum.

Analytical Solution. The ramp portion of the response when the rod is strained elastically as represented by the spring elongation is regarded as the first stage. In this stage, there is no slipping at the joint p. The differential equation of motion and the boundary conditions are:

$$m\ddot{y} + ky = F_1 \tag{67}$$

$$t = 0,\ y = 0 \tag{68}$$

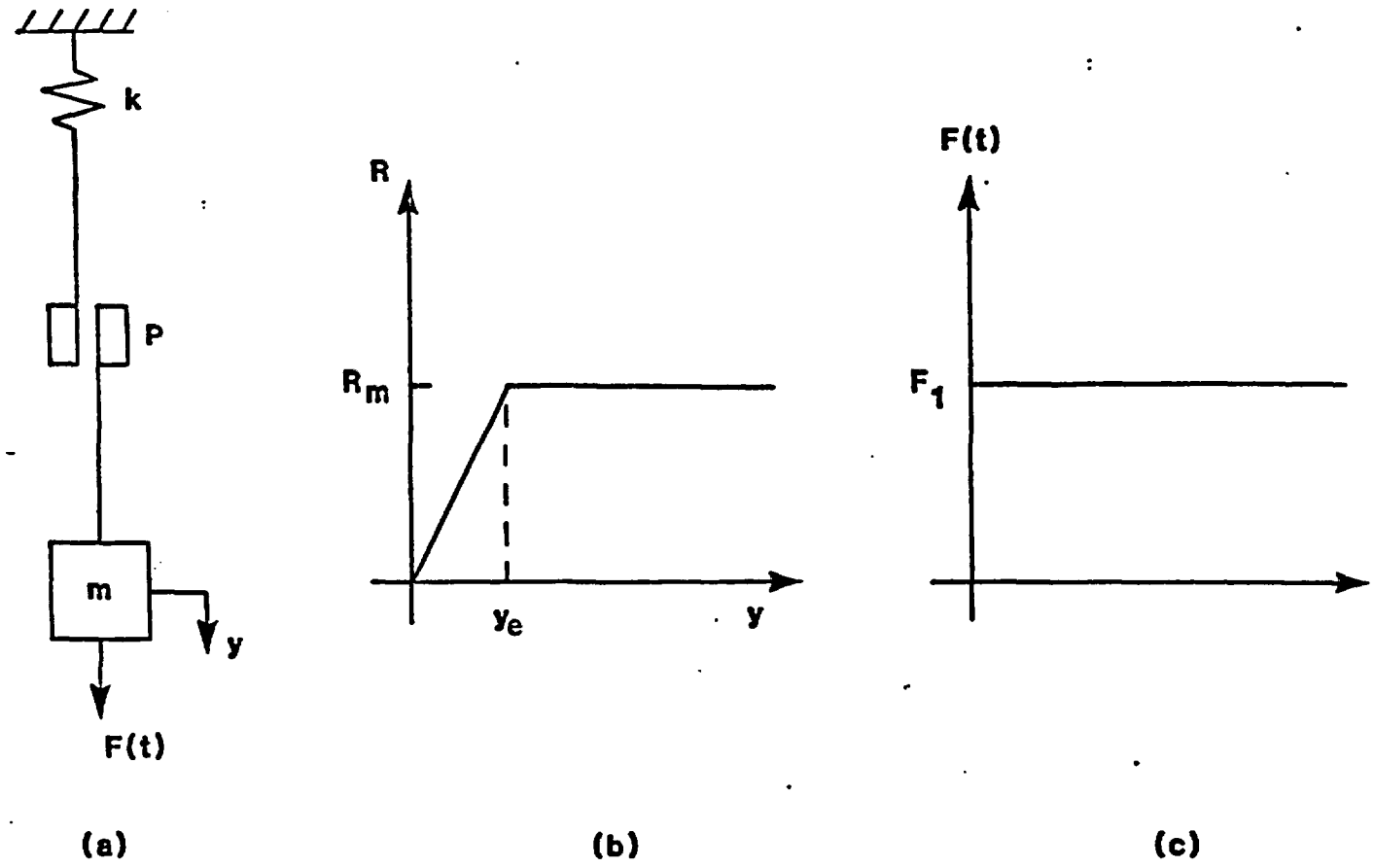


Figure 3.3-1

(a) Mechanical Model and (b) Force Versus Deflection (y) Response Characteristic of the Rod and c) the Load History (f) Versus Time (t). In (a) the Friction Joint p Slips When the Load Reaches R_m Representing Plastic Yielding of the Rod

$$t = 0, \dot{y} = 0 \tag{69}$$

where the differential Equation 67 is based on Newton's second law. The initial conditions state that the initial deflection and initial velocity of the mass are zero. The solution to the differential equation is

$$y = y_{st} + C_1 \text{ Sin } \omega t + C_2 \text{ Cos } \omega t \tag{70}$$

where $y_{st} = F_1/k$. Upon applying the boundary conditions, it is determined that

$$C_1 = 0 \tag{71}$$

$$C_2 = -y_{st} \tag{72}$$

So the solution can be written as

$$y = y_{st} (1\text{-Cos } \omega t) \tag{73}$$

In Equations 70 and 73, ω is the circular frequency defined as

$$\omega = \sqrt{\frac{k}{m}} \tag{74}$$

The second stage begins at time $t = t_e$ when the first stage is completed. Time range for the second stage which begins at zero when $t = t_e$ is

established by defining a time variable t_1 for the second stage according to

$$t_1 = t - t_e \tag{75}$$

The differential equation for the second stage is

$$m\ddot{y} + R_m = F_1 \tag{76}$$

and the boundary conditions are

$$t_1 = 0, \quad y = y_e \tag{77}$$

$$t_1 = 0, \quad \dot{y} = y_{st}\ \omega \operatorname{Sin} \omega t_e \tag{78}$$

The general solution to Equation 76 is

$$y = \left(\frac{F_1 - R_m}{2m}\right) t_1^{\,2} + C_1 t_1 + C_2 \tag{79}$$

Equation 73, which is the dynamic response of the mass during the first stage, can be used to solve for the time t_e at which the transition between the two stages occurs:

$$t_e = \frac{1}{\omega} \operatorname{Cos}^{-1}\left(1 - \frac{y_e}{y_{st}}\right) \tag{80}$$

Applying the boundary conditions of Equations 77 and 78 to the general solution of Equation 79 gives

$$y = \frac{1}{2m} (F_1 - R_m) t_1^2 + (y_{st} \omega \operatorname{Sin} \omega t_e) t_1 + y_e \tag{81}$$

Assumptions. In the analysis, it is assumed that the rod material displays linear elastic response followed by perfectly plastic force versus displacement response.

Input Specifications. The problem is completely specified in terms of four parameters R_m, y_e, m, and F_1 which allow calculation of k and the other parameters such as ω.

R_m = force necessary to cause yielding in the rod (f) = 500,000 (lb_f)

y_e = axial elongation of the rod when plastic deformation begins (ℓ) = 0.1666 (in)

k = spring stiffness effort of the rod when deformation is in the elastic range (f/ℓ) = R_m/y_e = 3.0×10^6 (lb/in)

m = mass attached to the rod = 30,000 (lb_f-sec^2/in)

F_1 = magnitude of uniform tensile force applied to the mass = 3,000,000 (lb_f)

Output Specifications. The output should be the displacements as a function of time. This can be determined by using a structural analysis computer program that will simulate elastic and plastic material behavior for this structure and its loading. Calculated values can be compared with those given in Table 3.3-1.

For these values, Equation 74 gives

ω = 10 (1/sec)

Table 3.3-1

Displacement as a Function of Time

Time (Seconds)	Displacement (Inches)
0.000	.00000
0.010	0.00500
0.020	0.01993
0.030	0.04466
0.040	0.07894
0.050	0.12242
0.059	0.16667
0.060	0.17466
0.070	0.23530
0.080	0.30427
0.090	0.38157
0.100	0.46721
0.110	0.56118
0.120	0.66348
0.130	0.77412
0.140	0.89309
0.150	1.02039
0.160	1.15603
0.170	1.30000
0.180	1.45230
0.190	1.61294
0.200	1.78191
0.300	3.92994
0.400	6.91131
0.500	10.72601
0.600	15.37404
0.700	20.85541
0.800	27.17011
0.900	34.31814
1.000	42.29951

and Equation 80 gives

$$t_e = 0.058568 \text{ (sec)}$$

11. LOTUS SPREADSHEET WP3.4

This spreadsheet calculates the displacement and velocity of a mass when a package is dropped on a rigid floor.

Theory

The engineering aspects of this spreadsheet are discussed in Section 3.4 of Reference 2 (attached for the readers convenience at the end of this section).

Spreadsheet

Input Data: Problem specifications are input by the user in cells C5 through C9.

Rows 11-15: Intermediate calculations are done in these rows.

Rows 18-20: Time intervals for the table are calculated here.

Column A: Time is displayed in this column.

Column B: The distance that the mass has traveled relative to its starting position (positive direction is down) is calculated by Equation 96 for times less than or equal to time to impact with the floor, and by Equation 97 after impact.

Column C: The velocity of the mass is determined by Equation 84 for times less than or equal to time to impact and, after impact, by the first derivative of Equation 97 with respect to time:

$$v = (2 \cdot g \cdot h)^{\frac{1}{2}} \cdot \cos(t_1 \cdot k/m)^{\frac{1}{2}} \qquad \text{(A)}$$

where: t_1 = time after impact $(t-t_0)$ and other variables are as defined on the spreadsheet and in the reference.

A graph of displacement and velocity as a function of time will appear on the screen when the F10 key is pushed.

A sample spreadsheet is shown in Figure 16.

Figure 16

Problem WP3.4 Sample Lotus Spreadsheet

	A	B	C	D
1	PROBLEM WP 3.4 DISPLACEMENT AND VELOCITY OF MASS WHEN A PACKAGE			
2		IS DROPPED ON A RIGID FLOOR		
3	**********			NOTE: BE SURE RANGE
4	INPUT DATA			* PROTECT SWITCH IS
5	CONSTANT "g" (cm/sec*2)		980.621	* ON (TYPE /WGPE).
6	INITIAL HEIGHT "h" (cm)		50.00	* ALL CELLS EXCEPT
7	MASS "m" (kg)		1.00	* C6-C9
8	SPRING CONST."k" (kg/cm)		9.00	* ARE PROTECTED.
9	**********			
10	----------INTERMEDIATE CALCULATIONS----------			
11		MAXIMUM FORCE "Fmax" (kg)	939.4461	[EQUATION 98]
12		TIME TO FLOOR "t0" (sec)	0.3193	[EQUATION 86]
13		TIME TO MAX DEFLECTION (sec)	0.8429	[t0+1/4fn]
14		MAXIMUM DEFLECTION (cm)	154.3829	[@MAX(B25..B55)]
15		RATTLE SPACE (cm)	104.3829	[EQUATION 94]
16				
17	TIME INTERVALS FOR TABLE --------(seconds)			
18		TO IMPACT	0.0319	
19		IMPACT TO MAX DISTANCE	0.0524	
20		MAX DISTANCE TO END	0.1047	
21				
22		TIME	DISTANCE	VELOCITY
23		(sec)	(cm)	(cm/sec)
24		0.0000	0.0000	0.0000
25		0.0319	0.5000	31.3149
26		0.0639	2.0000	62.6297
27		0.0958	4.5000	93.9446
28		0.1277	8.0000	125.2595
29		0.1597	12.5000	156.5743
30		0.1916	18.0000	187.8892
31		0.2235	24.5000	219.2041
32		0.2555	32.0000	250.5189
33		0.2874	40.5000	281.8338
34		0.319337	50.0000	313.1487
35		0.3717	66.3291	309.2933
36		0.4241	82.2561	297.8221
37		0.4764	97.3888	279.0175
38		0.5288	111.3547	253.3426
39		0.5811	123.8099	221.4296
40		0.6335	134.4475	184.0642
41		0.6859	143.0058	142.1665
42		0.7382	149.2740	96.7683
43		0.7906	153.0978	48.9872
44		0.842936	154.3829	.0000
45		0.9477	149.2740	-96.7683
46		1.0524	134.4475	-184.0642
47		1.1571	111.3547	-253.3426
48		1.2618	82.2561	-297.8221
49		1.3665	50.0000	-313.1487
50		1.4713	17.7439	-297.8221
51		1.5760	-11.3547	-253.3426
52		1.6807	-34.4475	-184.0642
53		1.7854	-49.2740	-96.7683
54		1.8901	-54.3829	.0000

3.4 Displacement and Velocity of Mass When a Package Is Dropped on a Rigid Floor

Problem Statement. A mass m represents the contents of a package; the contents are attached to the package with a linear spring of stiffness k. The spring connecting the mass to the package acts in the vertical direction, and all motion of the mass and the package occurs in the vertical direction as shown in Figure 3.4-1.

Objectives. The quantities to be determined are the displacement and velocity of the mass when the container reaches the floor and the subsequent maximum force transmitted to the mass and the required "rattle space" as indicated by the maximum deflection.

Analytical Solution. The dynamics of the package contents following impact are described in Reference TH-65 as

$$m(\ddot{x}_1 + \ddot{x}_2) + kx_1 = 0 \tag{82}$$

where

m = mass of contents [m]

x_1 = position of the mass relative to the container measured vertically [ℓ]

x_2 = position of container measured vertically relative to the floor [ℓ]

k = linear spring force to displacement ratio [f/ℓ]

$\ddot{x}_1, \ddot{x}_2 = \dfrac{d^2x_2}{dt^2}$ [ℓ/t²]

t = time measured through the dynamic transient [θ]

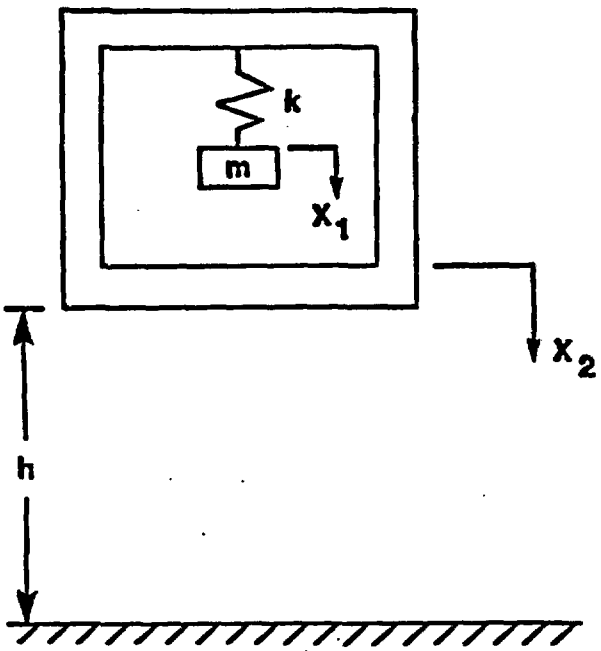


Figure 3.4-1

Package System Used for Drop Dynamics Analytical Solution

All rotation and translation, orthogonal to the vertical, are constrained to zero.

The position of the container before impact is described by

$$x_1 = x_2(t) = \frac{1}{2} gt^2 \tag{83}$$

$$\dot{x}_1 = \dot{x}_2(t) = gt \tag{84}$$

$$\ddot{x}_1 = \ddot{x}_2(t) = g \tag{85}$$

Using Equation 85, the time to fall from the initial height h supporting the container to the floor is

$$t_o = \sqrt{2h/g} \tag{86}$$

Following impact, it is assumed that the box remains in contact with the surface. The mass, M, vibrates on the spring. After impact, Equation 82 becomes:

$$M\ddot{x}_1 + kx_1 = 0 \tag{87}$$

With boundary conditions

$$x_1 (t_o) = 0 \tag{88}$$

$$\dot{x}_1 (t_o) = g \sqrt{2h/g} = \sqrt{2gh} \tag{89}$$

Redefining time such that

$$t' = t - t_o \tag{90}$$

the boundary conditions become

$$x_1 (0) = 0 \tag{91}$$

$$\dot{x}_1 (0) = \sqrt{2gh} \tag{92}$$

In solving Equation 87,

$$x_1 (t) = A \operatorname{Sin} \omega_n t' + B \operatorname{Cos} \omega_n t' \tag{93}$$

for $t' > 0$

where $\omega_n = \sqrt{K/m}$

A, B = constants.

Applying the boundary conditions in Equations 91 and 92 results in

$$A = \frac{\sqrt{2gh}}{\omega_n} = \sqrt{\frac{2mgh}{k}} \tag{94}$$

$$B = 0 \tag{95}$$

The position of the mass as a function of time is:

$$x_1 + x_2 = 1/2\ gt^2 \qquad t \leq \sqrt{2h/g} \tag{96}$$

$$x_1 + x_2 = h + \sqrt{2mgh/k}\ \mathrm{Sin}\ \sqrt{k/m}\ t \qquad t \geq \sqrt{2h/g} \tag{97}$$

The maximum spring force is given by

$$F_{max} = kA = \sqrt{2mgh/k} \tag{98}$$

where

k = spring stiffness [f/ℓ]

A = maximum amplitude of the mass m [ℓ]
(see Equation 94)

<u>Assumptions</u>.

- The mass m is supported within the box by a linear spring of stiffness k.
- The mass of the container is large compared to that of the contents, m, so that the free fall of the container is not influenced by the force associated with the relative motion of the mass, m.
- Upon striking the floor, the container remains in contact with the floor.
- Neither the container nor the floor deforms on impact.

Input Specifications. For an initial height of the box above the plane of

$$h = 50 \text{ cm}$$
$$g = 980.621 \text{ cm/sec}^2$$

the time at which it reaches the plane is given by Equation 86 as

$$t_0 = 0.3193 \text{ (sec)}$$

If the spring stiffness is

$$k = 9 \text{ kg/cm}$$

and the mass of the contents is

$$m = 1 \text{ kg}$$

then the circular natural frequency is

$$\omega_n = \sqrt{\frac{k}{m}} = 3 \frac{1}{\text{sec}}$$

and the vibrational natural frequency is

$$f_n = \omega_n/2\pi = 0.4775 \text{ (1/sec)}$$

Equation 94 can be evaluated to give

$$A = 104.383 \text{ cm}$$

This is the required rattle space in terms of amplitude.

Output Specifications. The output should include the total displacements $x_1 + x_2$ and x_2 as a function of time. Outputs can be compared with values given in Table 3.4-1. The time when the maximum amplitude is reached should also be calculated.

Table 3.4-1

Displacement vs Time

Time (Seconds)	Distance (Centimeters)
0.0000	0.0000
0.0500	1.2258
0.1000	4.9031
0.1500	11.0320
0.2000	19.6124
0.2200	23.7310
0.2400	28.2419
0.2600	33.1450
0.2800	38.4403
0.3000	44.1279
0.3100	47.1188
0.3193	50.0000
0.3200	50.2076
0.3400	56.4664
0.3600	62.7020
0.3800	68.8918
0.4000	75.0137
0.4200	81.0455
0.4400	86.9656
0.4600	92.7527
0.4800	98.3859
0.5000	103.8449
0.5200	109.1102
0.5400	114.1628
0.5600	118.9844
0.5800	123.5578
0.6000	127.8664
0.6500	137.3805
0.7000	144.9323
0.7500	150.3521
0.8000	153.5182
0.8429*	154.3829
0.8500	154.3595
0.9000	152.8571
1.0000	143.0080
1.1000	124.8509
1.2000	100.0075
1.3000	70.6972
1.4000	39.5380
1.5000	9.3133
1.6000	-17.2769
1.7000	-37.8575
1.8000	-50.5900
1.9000	-54.3372
2.0000	-48.7642

* Maximum displacement

12. LOTUS SPREADSHEET WP3.6

This spreadsheet performs a stress analysis of a pretensioned body that experiences stress relaxation due to creep.

Theory

The engineering aspects of this spreadsheet are discussed in Section 3.6 of Reference 2 (attached for the readers convenience at the end of this section).

Spreadsheet

Input Data: Problem specifications are input by the user in cells D6 through D9.

Column B: Time, in years, is input by the user.

Column C: Time, in hours, is calculated using 8760 hours per year.

Column D: Axial stress in the bolt is calculated using equation 119.

A graph of axial stress as a function of time will appear on the screen when the F10 key is pushed.

A sample spreadsheet is shown in Figure 17.

Figure 17

Problem WP3.6 Sample Lotus Spreadsheet

```
      A          B              C                D              E        F
 1 PROBLEM WP 3.6 STRESS IN A PRETENSIONED BODY THAT EXPERIENCES
 2                STRESS RELAXATION DUE TO CREEP
 3
 4 ************************************************  NOTE: BE SURE RANGE
 5 INPUT DATA                                    *  PROTECT SWITCH IS
 6 CREEP CONSTANT  "k"  (1/Hr)            4.78E-37  *  ON (TYPE /WGPE).
 7 CREEP EXPONENT OF STRESS  "n"               6.9  *  ALL CELLS EXCEPT
 8 MODULUS OF ELASTICITY  "E"  (psi)      3.00E+07  *  D6-D9 & B15-B34
 9 INITIAL AXIAL STRESS "sigma"(psi)      1.00E+04  *  ARE PROTECTED.
10 ************************************************
11
12                                     AXIAL STRESS
13              --------TIME--------        IN BOLT
14              YEARS          HOURS          (psi)
15                  0              0          10000
16                  1           8760           9571
17                  2          17520           9244
18                  3          26280           8981
19                  4          35040           8762
20                  5          43800           8576
21                 10          87600           7923
22                 20         175200           7208
23                 50         438000           6267
24                100         876000           5603
25                200        1752000           4996
26                500        4380000           4284
27               1000        8760000           3812
28               2000       17520000           3390
29               5000       43800000           2903
30              10000       87600000           2581
31              20000      175200000           2295
32              50000      438000000           1965
33             100000      876000000           1747
34             200000     1752000000           1554
```

3.6 Stress in a Pretensioned Body That Experiences Stress Relaxation Due to Creep

Problem Statement. The ends of a bolt are held a fixed distance apart for a long period of time. Initially, the bolt is tightened producing an initial stress of σ_0. The bolt material is 0.30% carbon steel, which is assumed to have a creep rate given by

$$\dot{\varepsilon}^c = k\sigma^n \tag{112}$$

where

$\dot{\varepsilon}_c$ = creep rate (1/hr)

k = creep constant (1/hr)

σ = axial stress component in bolt (lb/in^2)

n = creep exponent of stress ( )

The creep causes the elastic strain to decrease while the creep strain increases such that the sum of the two is always equal to a constant. The constant is the amount of elastic strain initially induced in the bolt by the initial stress σ_0 (see Figure 3.6-1 for a schematic of the bolt).

Objectives. The objective is to calculate the bolt stress as a function of time.

Analytical Solution. It is assumed that the initial stress causes only elastic strain on an instantaneous basis and that the total (i.e., instantaneous elastic and creep) strain in the bolt remains constant.

$$\varepsilon_0^e = \varepsilon^e + \varepsilon^c \tag{113}$$

where

ε_0^e = initial elastic strain ( )

ε^e = elastic strain at any time ( )

ε^c = creep strain at any time (initially zero) ( )

The elastic strain is related to the stress by Hook's law

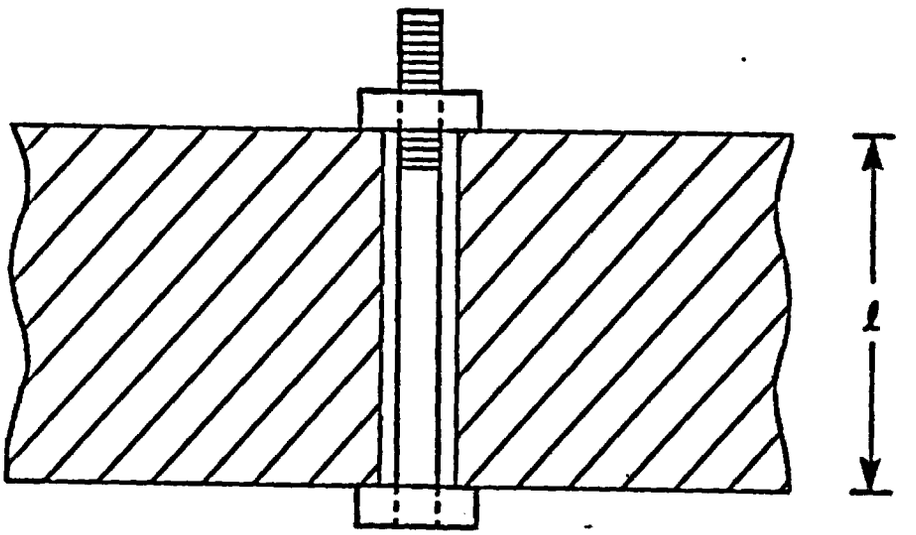


Figure 3.6-1

Bolt of Length l in Unloaded State Which Is Initially Stressed to σ_o = 10,000 psi and Allowed to Stress Relax Due to Creep

$$\varepsilon_0^{e} = \frac{\sigma_0}{E}$$

(114a)

$$\varepsilon^{e} = \frac{\sigma}{E}$$

(114b)

where

E = elastic modulus of bolt material (psi)

σ_0 = initial axial stress component in bolt (psi)

σ = axial stress component in bolt at any time (psi)

Substitution of Equation 114 into Equation 113 gives

$$\frac{\sigma_0}{E} = \frac{\sigma}{E} + \varepsilon^{c}$$

(115)

and differentiating Equation 115 with respect to time gives

$$\frac{d\varepsilon^{c}}{dt} = -\frac{1}{E}\frac{d\sigma}{dt}$$

(116)

where the terms on the left side are the material creep rate. Combining Equations 112 and 115 eliminates the creep rate and gives the first order non-linear differential equation

$$-\frac{1}{kE}\ \sigma^{-n}\ d\sigma = dt$$

(117)

The initial condition is

$$t = 0 \qquad \sigma = \sigma_0 \tag{118}$$

and the solution is of the form

$$\sigma = \sigma_0 \left[kE(n-1)\sigma_0^{\,n-1} \quad t + 1 \right]^{-1(n-1)} \tag{119}$$

Assumptions. It is assumed that initially upon loading, the bolt strain is in the elastic range.

Input Specifications. For the following values of the parameters

$k = 4.78 \times 10^{-37}$ (1/hr)

$n = 6.9$ ( )

$E = 30 \times 10^6$ (psi)

$\sigma_0 = 10{,}000$ (psi)

Equation 119 becomes

$$\sigma = 10{,}000 \left[3.368 \times 10^{-5}\ t + 1 \right]^{-0.1695} \tag{120}$$

Output Specifications. The output is the stress in the bolt as a function of time. The calculated values can be compared with the values given below.

σ (psi)
10,000
9,571
9,244
8,981
8,762
7,922
6,267
5,603
4,996
4,284
3,812

the gamma flux and dose at the outer surface of a niformly dispersed 1 MeV gamma source.

Theory

of this spreadsheet are discussed in Section 4.1 of e readers convenience at the end of this section).

Spreadsheet

cifications are input by the user in cells F6 through

et is contained in these rows to calculate the arce self attenuation distance "z" using data input by from Reference RO-56 (attached for the readers at the end of this section) of Reference 2.

ip factors and attenuation coefficients for various stored in these rows.

tors for iron, concrete, and the system (iron times e calculated using the equation on page 149 of

amber of relaxation lengths "b_2" are determined using on page 148 of Reference 2.

gral, which is determined by numerical integration 3, is reported here.

lux is calculated by Equation 136.

surface dose rate is found by use of the dose age 149 of the reference.

gral is solved numerically in this portion of the

n in Figure 18.

Figure 18

Problem WP4.1 Sample Lotus Spreadsheet

```
  A     B         C         D         E         F         G         H
1      PROBLEM WP 4.1 HYPOTHETICAL RADIATION SHIELDING PROBLEM
2
3  ********************************************** NOTE: BE SURE RANGE
4  * INPUT DATA                                  * PROTECT SWITCH IS
5  * VOLUMETRIC PHOTON SOURCE "Sv"               * ON (TYPE/WGPE).
6  *              (photons/cc/sec)        1.00E+07 * ALL CELLS EXCEPT
7  * RADIUS OF CYLINDER "Ro" (cm)            30.00 * F6-F8,F17,&F19
8  * THICKNESS OF IRON SHIELD "a" (cm)       25.00 * ARE PROTECTED.
9  * ********************************************
10 ==================================================================
11 ==WORKSHEET TO FIND EFFECTIVE SOURCE SELF-ATTENUATION            ==
12 ==DISTANCE (cm) =z USING REFERENCE RO-56, pp362-3 FOR a/Ro < 10.0 ==
13 ==          (FOR a/Ro > 10.0 USE FIGURE ON pg 361.)              ==
14 ==                                                               ==
15 ==                          a/Ro    =     0.833                  ==
16 ==            MUe(CONCRETE)*(a+Ro)  =     3.592                  ==
17 ==              pg. 362 VALUE OF M  =     0.750                  ==
18 ==                 b1=MUe(IRON)*a   =     5.128                  ==
19 ==          pg.363 FACTOR=(1/M)*MUe*z=     1.960                  ==
20 ==          z=FACTOR*M/MUe(CONCRETE) =    22.511                  ==
21 ==================================================================
22
23   DOSE BUILDUP FACTORS AND ATTENUATION COEF. FOR 1MeV GAMMA RAYS
24
25   MATERIAL        A1    ALPHA1    ALPHA2       MUt       MUe       RHO
26   AIR                                      8.220E-05 3.620E-05 1.293E-03
27   WATER      13.5000  -0.1000    0.0100     0.0706    0.0311    1.0000
28   IRON        8.0000  -0.0895    0.0400     0.4677    0.2051    7.8500
29   CONCRETE   10.0000  -0.0880    0.0290     0.1492    0.0653    2.3500
30
31
32   BUILDUP FACTOR (iron)          6.957
33   BUILDUP FACTOR (concrete)      2.757
34   BUILDUP FACTOR (system)       19.177
35
36   RELAXATION LENGTHS (b2)        6.598
37   SIEVERTS INTEGRAL            6.14E-04
38
39   GAMMA FLUX = Phi
40   [photons/cm2/sec]            1.11E+06
41
42   OUTER SURFACE DOSE RATE
43   IN WATER [MeV/cc/sec]        3.47E+04
44                 [Rad/hr]           2.00
45
```

Figure 18

Problem WP4.1 Sample Lotus Spreadsheet (continued)

```
   A      B          C          D          E          F          G          H
46
47 ==========================================================================
48 ==  NUMERICAL INTEGRATION SOLUTION OF SIEVERTS INTEGRAL                  ==
49 ==                                                                       ==
50 ==                 MID                                                   ==
51 ==               POINT     THETA       COS                               ==
52 ==DIVISION [degrees][radians]   THETA [@EXP(-x/COS THETA)]==
53 ==        1        1.5 0.026179 0.999657 1.361E-03                       ==
54 ==        2        4.5 0.078539 0.996917 1.336E-03                       ==
55 ==        3        7.5 0.130899 0.991444 1.288E-03                       ==
56 ==        4       10.5 0.183259 0.983254 1.219E-03                       ==
57 ==        5       13.5 0.235619 0.972369 1.131E-03                       ==
58 ==        6       16.5 0.287979 0.958819 1.027E-03                       ==
59 ==        7       19.5 0.340339 0.942641 9.128E-04                       ==
60 ==        8       22.5 0.392699 0.923879 7.919E-04                       ==
61 ==        9       25.5 0.445058 0.902585 6.691E-04                       ==
62 ==       10       28.5 0.497418 0.878817 5.491E-04                       ==
63 ==       11       31.5 0.549778 0.852640 4.361E-04                       ==
64 ==       12       34.5 0.602138 0.824126 3.336E-04                       ==
65 ==       13       37.5 0.654498 0.793353 2.446E-04                       ==
66 ==       14       40.5 0.706858 0.760405 1.706E-04                       ==
67 ==       15       43.5 0.759218 0.725374 1.122E-04                       ==
68 ==       16       46.5 0.811578 0.688354 6.879E-05                       ==
69 ==       17       49.5 0.863937 0.649448 3.874E-05                       ==
70 ==       18       52.5 0.916297 0.608761 1.965E-05                       ==
71 ==       19       55.5 0.968657 0.566406 8.737E-06                       ==
72 ==       20       58.5 1.021017 0.522498 3.283E-06                       ==
73 ==       21       61.5 1.073377 0.477158 9.889E-07                       ==
74 ==       22       64.5 1.125737 0.430511 2.211E-07                       ==
75 ==       23       67.5 1.178097 0.382683 3.256E-08                       ==
76 ==       24       70.5 1.230457 0.333806 2.609E-09                       ==
77 ==       25       73.5 1.282817 0.284015 8.158E-11                       ==
78 ==       26       76.5 1.335176 0.233445 5.324E-13                       ==
79 ==       27       79.5 1.387536 0.182235 1.893E-16                       ==
80 ==       28       82.5 1.439896 0.130526 1.118E-22                       ==
81 ==       29       85.5 1.492256 0.078459 3.026E-37                       ==
82 ==       30       88.5 1.544616 0.026176 **********                      ==
83 ==                        SIEVERTS X 60/PI=  1.17E-02                    ==
84 ==========================================================================
```

4.1 Hypothetical Radiation Shielding Problem

Problem Statement. The problem requires the estimation of the gamma flux and dose at the outer surface of a solid cylinder containing a uniformly dispersed 1 MeV gamma source. Three subproblems are presented: no external shield, a 5 cm steel shield, and a 25 cm steel shield. This is a relatively simple problem that can be solved analytically by the buildup factor method.

Objectives. The purpose of this problem is to provide a simple analytical solution that can be used to assess the predictive capabilities of shielding codes.

Physical Description. A long concrete cylinder contains a uniformly dispersed 1 MeV gamma emitter with a source strength of 10^7 disintegrations

per cubic centimeter per second and a gamma yield of one gamma per disintegration. The cylinder is 0.60 m in diameter and, for purposes of the analysis, is assumed to be infinitely long. The gamma flux and dose rate are to be calculated for a bare cylinder and for cylinders with 5 cm and 25 cm annular steel shields.

Analytical Solution. This problem can be solved analytically using methods described in Reference RO-56. This method assumes that the shield is a slab. This is a good approximation for the 5 cm thick shield but may be a poor assumption for the 25 cm shield.

For an infinite length cylindrical source, the gamma flux, ϕ, at an exterior point is given by:

$$\phi = \frac{BS_v R_o^2}{2(a+z)} F\left(\frac{\pi}{2}, b_2\right) \tag{136}$$

where:

ϕ = gamma flux, photons/cm^2·sec

B = buildup factor, dimensionless

S_v = volumetric photon source, photons/cm^3·sec

R_o = radius of cylinder, cm

a = distance from cylinder surface to measurement point, cm

z = effective source self-attenuation distance, cm

$(F\frac{\pi}{2}, b_2) = \int_0^{\pi/2} e^{-(b_2 \sec \theta)} d\theta$, Sieverts integral or secant integral, dimensionless

The buildup factor, B, is defined as the rate of the actual gamma flux compared to that calculated using exponential attenuation with the linear attenuation coefficient. Table 4.1-1 gives dose buildup factors and attenuation coefficients for 1 MeV gamma photons in selected materials.

The effective source self-attenuation distance can be calculated using figures in Reference RO-56. The calculated values of z as a function of shield thickness are given below:

Shield Thickness (cm)	Self-Attenuation Factor (cm)
0	18.830
5	21.997
25	22.511

Buildup factors in concrete and iron calculated using values from Table 4.1-1 are given in Table 4.1-2. The total number of relaxation lengths (b_2) can be calculated from the equation:

$$b_2 = \mu_c z + \mu_1 t$$

where:

μ_c = the gamma absorption coefficient for concrete

μ_1 = the gamma absorption coefficient for iron

t = the thickness of the iron shield

Calculated values of b_2 are given below:

t	b_2
0	1.23
5	2.46
25	6.60

The calculated values of b_2 are used to determine $F(\pi/2, b_2)$ from figures in Reference RO-56.

Table 4.1-1

Dose Buildup Factors and Attenuation Coefficients for 1 MeV Gamma Rays

Material	Constant					
	A_1	α_1	α_2	μ_t	μ_e	ρ
Air	--	--	--	.0000822	.0000362	.001293
Water	13.5	-.100	.01	.0706	.0311	1.00
Iron	8.0	-.0895	.04	.4677	.2051	7.85
Concrete	10.0	-.088	.029	.1492	.0653	2.35

$$B(\mu_e x) = A_1 \exp(-\alpha_1 \mu_e x) + (1-A_1) \exp(-\alpha_2 \mu_e x)$$

where:

$B(\mu_e x)$ is the buildup factor [ ]

A_1, α_1, α_2 are the empirically determined coefficients [ ]

μ_t is the total attenuation coefficient [$1/\ell$]

μ_e is the energy attenuation coefficient [$1/\ell$]

ρ is the material density [m/ℓ^3]

$$\text{Dose} = \phi(E)\mu_e/\rho \ \text{MeV/cm}^3\cdot\text{sec}$$

$$= 5.767 \times 10^{-5}\, E\phi(E)\mu_e/\rho \ \text{Rad/hr}^*$$

$$^*5.767 \times 10^{-5} = \frac{1.602 \times 10^{-6}\ \text{erg}}{\text{MeV}} \cdot \frac{1\ \text{Rad}}{100\ \text{erg/g}} \cdot \frac{1}{\rho\ \text{g/cm}^3} \cdot \frac{3600\text{g}}{\text{hr}}$$

Source: AN-63

Table 4.1-2

Calculated Buildup Factors

No Shield

Concrete

$$B_C = 10 \exp(.088 \cdot .0653 \cdot 18.83) - 9 \exp(-.029 \cdot .0653 \cdot 18.83$$
$$= 2.458$$

Iron

$$B_I = 8 \exp(.0895 \cdot .2051 \cdot 0) - 7 \exp(-.04 \cdot .2051 \cdot 0)$$
$$= 1.000$$

$$B_{system} = B_C \cdot B_I$$
$$= 2.458$$

5 cm Shield

Concrete

$$B_C = 10 \exp(.088 \cdot 0653 \cdot 21.997) - 9 \exp(-.029 \cdot .0653 \cdot 21.997)$$
$$= 2.715$$

Iron

$$B_I = 8 \exp(.0895 \cdot .2051 \cdot 5) - 7 \exp(-.04 \cdot .2051 \cdot 5)$$
$$= 2.050$$

$$B_{system} = B_C \cdot B_I$$
$$5.566$$

25 cm Shield

Concrete

$$B_C = 10 \exp(.088 \cdot .0653 \cdot 22.511) - 9 \exp(-.029 \cdot .0653 \cdot 22.511)$$
$$= 2.757$$

Iron

$$B_I = 8 \exp(.0895 \cdot .2051 \cdot 25) - 7 \exp(-.04 \cdot .2051 \cdot 25)$$
$$= 6.957$$

$$B_{system} = B_C \cdot B_I$$
$$= 5.6 \cdot 18$$
$$= 19.177$$

Shield Thickness, t	Sieverts Integral $F(\pi/2, b_2)$
0	0.2456 E-0
5	0.5685 E-1
25	0.6138 E-3

Substituting these values into the equation for the flux and dose at the exterior surface, the following are obtained:

Shield Thickness, t	Gamma Flux, ϕ gammas/cm^2·sec	Outer Surface Dose Rate in Water Rad/hr
0	1.44E+8	258.81
5	5.27E+7	94.60
25	1.11E+6	2.00

The concrete isotopic content in Table 4.1-3 should be used to estimate the gamma flux using a transport theory code.

Assumptions. The analytical solution is based on the following assumptions:

- The gamma source is mono-energetic and evenly dispersed through the cylinder.
- The shield can be approximated as a slab.
- Buildup factors have been appropriately determined.

Output Specifications. The outputs for this problem are the gamma photon flux and the dose rate at the outer shield surface.

Comments. The results given here can be compared with the results from a one-dimensional transport theory calculation. For the 0 cm and 5 cm shields, good agreement (∿20%) between the results given here and code predictions can be expected. For the 25 cm shield, the results predicted in this report may vary from predictions derived from a transport

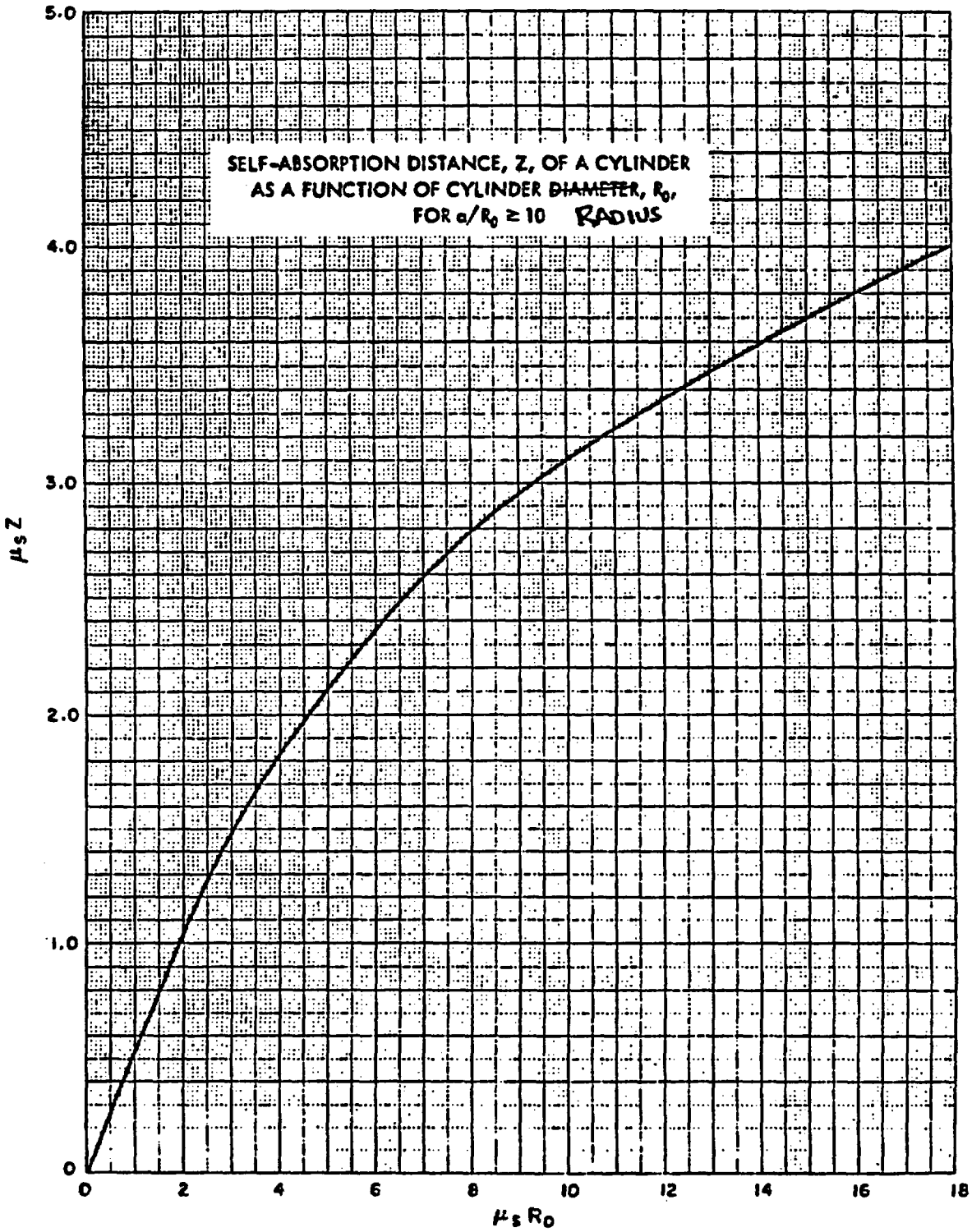
Table 4.1-3

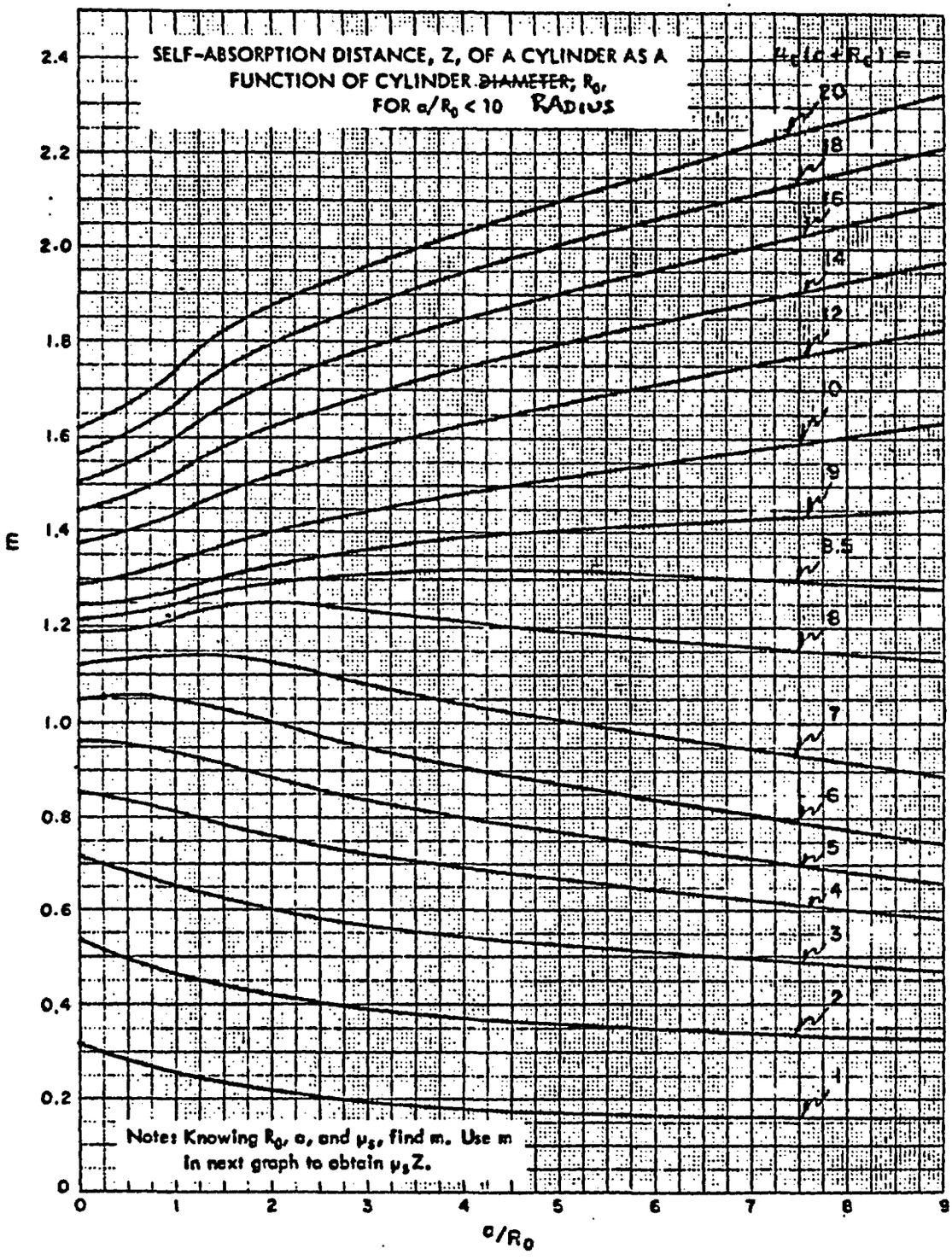
Elemental Content of Type 04 Cement

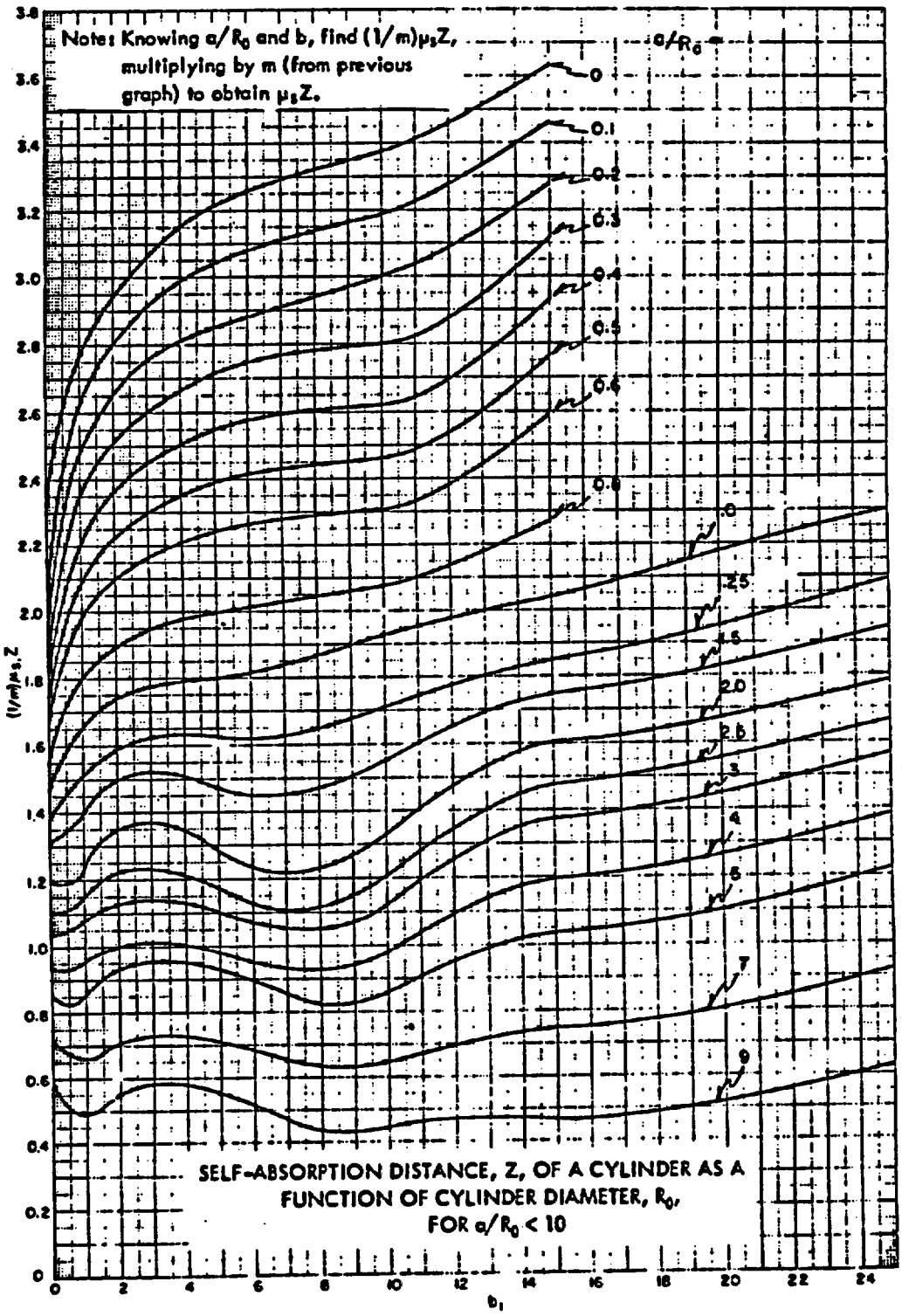
Isotope	Content (g/cm^3)
H	0.014
O (in H_2O)	0.111
O (in dry mix)	1.062
Mg	0.006
Al	0.107
Si	0.737
K	0.045
Ca	0.194
Fe	0.029
Na	0.040
Density - g/cm^3	2.35

Source: AN-63, p. 660. Na content corrected from 0.400 to 0.040. Water content increased slightly (H from 0.013 to 0.014, O from 0.103 to 0.111) to agree with density of 2.35 g/cm^3.

theory code because of the difficulty in calculating attenuation in thick shields using the shielding factor method.


SELF-ABSORPTION DISTANCE, Z, OF A CYLINDER
AS A FUNCTION OF CYLINDER ~~DIAMETER~~, R_0,
FOR $a/R_0 \geq 10$ RADIUS
5.0
4.0
3.0
2.0
1.0
0
$\mu_s Z$
0
2
4
6
8
10
12
14
16
18
$\mu_s R_0$


SELF-ABSORPTION DISTANCE, Z, OF A CYLINDER AS A FUNCTION OF CYLINDER ~~DIAMETER~~, R_0, FOR $a/R_0 < 10$ RADIUS
$\mu_s(a+R_0) =$
20
18
16
14
12
10
9
8.5
8
7
6
5
4
3
2
1
Note: Knowing R_0, a, and μ_s, find m. Use m in next graph to obtain $\mu_s Z$.
m
a/R_0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
0
1
2
3
4
5
6
7
8
9


Note: Knowing a/R0 and b, find (1/m)μsZ, multiplying by m (from previous graph) to obtain μsZ.
a/R0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.8
.0
.25
.5
2.0
2.5
3
4
5
7
9
(1/m)μsZ
b1
SELF-ABSORPTION DISTANCE, Z, OF A CYLINDER AS A FUNCTION OF CYLINDER DIAMETER, R0, FOR a/R0 < 10

14. FORTRAN PROGRAM WP5.2 (RCYLDIF1.EXE)

This Fortran program calculates solute transport by diffusion across an infinitely long cylindrical segment. Solute concentrations are calculated as a function of both distance and time.

Theory

The engineering aspects of this program are discussed in Section 5.2 of Reference 2 (attached for the readers convenience at the end of this section).

Program

Program RCYLDIF1.EXE solves Equation 138 using Function ROOTU1 to solve Equation 139. Functions Y1, XJ1, XJZERO, and YZERO are used to calculate Y_1, J_1, J_0, and Y_0 in Equations 138 and 139. A listing of the source code is shown in Figure 19.

Input Data

Data is input to the program via the input data file CYLDIF.DAT. The first line of the input data contains values for IOUT, NT, NR, and N in I5 FORMAT where IOUT is the output unit number, NT is the number of non-dimensional time values (maximum of 10), NR is the number of evenly spaced non-dimensional radii to be used in the calculation (maximum of 100), and N is the number of terms to be used in the Equation 138 summation (maximum of 100). The second line of input data is the value for RMAX (the maximum value of non-dimensional radius equal to B/A) in F10.2 FORMAT. The remaining lines of input data (in F10.2 FORMAT) contain values of TNDIM (one value per line) where TNDIM is non-dimensional time as defined by:

$$TNDIM = D \cdot T/A^2$$

Where:

D = the diffusion coefficient (Meters squared per second)
T = time (seconds)
A = Radius of the inner cylinder (Meters)

Sample input data files are shown in Figure 20 for B/A = 2, B/A = 4, and B/A = 8.

Output Data

Program output data is contained in file RCYLDIF1.OUT. Sample output data files are shown in Figures 21, 22, and 23 for B/A = 2, B/A = 4, and B/A = 8 respectively.

Figure 19

Program RCYLDIF1.FOR Source Code

```
      PROGRAM RCYLDIF
C     CALCULATION OF A NORMALIZED CONCENTRATION C(R,T)/C(A,INF)
C     AS A FUNCTION OF TIME AND RADIAL DISTANCE FOR THE SPACE
C     BETWEEN TWO INFINITELY LONG CYLINDERS OF RADII A ND B
C     WHERE B IS LARGER THAN A.  THE CONCENTRATION AT THE SURFACE
C     OF THE INNER CYLINDER REACHES A STEADY STATE VALUE C(A,INF)=
C     F*A*LN(B/A)/D WHERE F IS THE CONTAMINANT FLUX(MOLES/(M**2*SEC))
C     AND D IS THE DIFFUSIVITY(M**2/SEC).  AT THE TIME T=0 THE CON-
C     CENTRATION BETWEEN THE TWO CYLINDERS IS ZERO.  TRANSPORT IS
C     ASSUMED TO BE DUE ONLY TO DIFFUSION WITH NO ADVECTION OR REMOVAL
C     BY SORPTION OR DECAY.
C***
C***
C***  GLOSSARY OF TERMS
C     NT=NUMBER OF NON-DIMENSIONAL TIME VALUES  (MAXIMUM OF 10)
C     TNDIM=ARRAY OF NON-DIMENSIONALIZED TIMES.  NON-DIMENSIONALIZED
C           TIME IS EQUAL TO D*T/A**2 WHERE D IS THE DIFFUSION COEFFI-
C           CIENT(M**2/SEC), T IS THE TIME(SEC) AND A IS THE RADIUS OF
C           THE INNER CYLINDER(M)
C     NR=NUMBER OF EVENLY SPACED NON-DIMENSIONAL RADII TO BE USED IN
C        THE CALCULATION(MAXIMUM OF 100)
C     RNDIM=NON-DIMENSIONAL RADIUS EQUAL TO R/A
C     RMAX=MAXIMUM VALUE OF NON-DIMENSIONAL RADIUS EQUAL TO B/A.
C     C=ARRAY OF NORMALIZED CONCENTRATIONS
C     N=NUMBER OF TERMS INCLUDED IN THE SERIES SUMMATION (MAXIMUM OF 100)
C     IOUT=OUTPUT UNIT NUMBER
C*    PROGRAM REVISIONS BY DICK CHAPMAN (RAC) STARTED 4/86 TO ADAPT
C*    THE CODE TO MS-DOS FORTRAN. COMMENTS INDICATED BY C*, CODE ADDITIONS
C*    PRECEEDED BY C*, DATE AND INITIALS, AND FOLLOWED BY C**.
C*    052886RAC
C*    DIMENSION C(8),TERM(40),TNDIM(8),Z(40),CROSS(40),SUM(8),CL(8)
      DIMENSION C(8),TERM(100),TNDIM(8),Z(100),CROSS(100),SUM(8),CL(8)
C**
      IN=5
      NTMAX=10
      NRMAX=100
C*    052886RAC
C*    NMAX=40
      NMAX=100
      PI=3.14159264
C*    042286RAC
C*    CALL OPEN(IN,'CYLDIF  DAT',2)
      OPEN(IN,FILE='CYLDIF.DAT')
      READ(IN,10) IOUT,NT,NR,N
   10 FORMAT(4I5)
C*    042286RAC
      OPEN(IOUT,FILE='RCYLDIF1.OUT')
C**
```

Figure 19

Program RCYLDIF1.FOR Source Code (continued)

```
      WRITE(IOUT,20) NT,NR,N
   20 FORMAT(1X,'NUMBER OF NON-DIMENSIONALIZED TIMES=',I5,/,1X,
     &'NUMBER OF NON-DIMENSIONALIZED RADII=',I5,/,1X,
     &'NUMBER OF TERMS TO BE USED IN THE SERIES SUMMATION=',I5)
      IF(NT.GT.NTMAX) GO TO 1000
      IF(NR.GT.NRMAX) GO TO 1010
      IF(N.GT.NMAX) GO TO 1020
      READ(IN,30) RMAX
   30 FORMAT(F10.2)
      DENOM=(RMAX**2-1.)/2.
      DR=(RMAX-1.)/FLOAT(NR-1)
      READ(IN,30) (TNDIM(IT),IT=1,NT)
      DO 35 IT=1,NT
      SUM(IT)=0.
   35 CONTINUE
      XNU=0.0
      DO 100 I=1,N
      NUM=I
      Z(I)=ROOTU1(XNU,RMAX,NUM)
      TERM(I)=(PI/ALOG(RMAX))*(XJZERO(RMAX*Z(I)))**2/(Z(I)*((XJ1(Z(I)))*
     &*2-(XJZERO(RMAX*Z(I)))**2))
C*    042286RAC
C*    WRITE(IOUT,2010) Z(I),TERM(I)
C**
 2010 FORMAT(8E10.4)
  100 CONTINUE
      WRITE(IOUT,110)
  110 FORMAT(//,49X,'NORMALIZED CONCENTRATIONS',//,44X,
     &'NON-DIMENSIONALIZED TIME(D*T/A**2)')
      WRITE(IOUT,120) (TNDIM(IT),IT=1,NT)
  120 FORMAT(14X,8(E10.4,2X))
      WRITE(IOUT,130)
  130 FORMAT(4X,'NON-',/,1X,'DIMENSIONAL',/,3X,'RADIUS',/)
      DO 500 IR=1,NR
      RNDIM=FLOAT(IR-1)*(RMAX-1.0)/FLOAT(NR-1)+1.0
      TERMO=ALOG(RMAX/RNDIM)/ALOG(RMAX)
      DO 200 I=1,N
      CROSS(I)=XJZERO(Z(I)*RNDIM)*Y1(Z(I))-YZERO(Z(I)*RNDIM)*XJ1(Z(I))
  200 CONTINUE
      DO 400 IT=1,NT
      C(IT)=TERMO
      DO 300 I=1,N
C*    042286RAC
      POWER=TNDIM(IT)*Z(I)*Z(I)
      IF(POWER.GT.80)POWER=80
C**
      C(IT)=C(IT)+TERM(I)*CROSS(I)*EXP(-POWER)
C*    042286RAC
C*    WRITE(IOUT,2020)IR,IT,I
 2020 FORMAT(8I10)
C**
```

Figure 19

Program RCYLDIF1.FOR Source Code (continued)

```
 300 CONTINUE
     IF(IR.EQ.1) GO TO 350
     SUM(IT)=SUM(IT)+(RNDIM-DR/2.)*DR*(C(IT)+CL(IT))/(2.*DENOM)
 350 CL(IT)=C(IT)
 400 CONTINUE
     WRITE(IOUT,410) RNDIM,(C(IT),IT=1,NT)
 410 FORMAT(1X,E10.4,3X,8(E10.4,2X))
 500 CONTINUE
     WRITE(IOUT,550) (SUM(IT),IT=1,NT)
 550 FORMAT(/,1X,'AVERAGE=',5X,8(E10.4,2X))
     GO TO 2000
1000 WRITE(IOUT,1005) NT,NTMAX
1005 FORMAT(/,1X,'NT=',I5,1X,'GT',1X,I5)
     GO TO 2000
1010 WRITE(IOUT,1015) NR,NRMAX
1015 FORMAT(/,1X,'NR=',I5,1X,'GT',1X,I5)
     GO TO 2000
1020 WRITE(IOUT,1025) N,NMAX
1025 FORMAT(/,1X,'N=',I5,1X,'GT',1X,I5)
2000 CONTINUE
     STOP
     END
```

Figure 19

Program RCYLDIF1.FOR Source Code (continued)

```
      FUNCTION ROOTU1(XNU,XLAM,NR)
      DIMENSION XB(1),XH(1),XL(1),D(1)
      PI=3.141592654
      N=1
      IW=0
      IFNS=100
      TOL=1.0E-5
      TOL1=1.0E-4
      A=1.2
      B=0.1
      IF(NR.NE.1) GO TO 100
      XL(1)=0.0
      XB(1)=(NR-0.5)*PI/(XLAM-1.0)
      XH(1)=NR*PI/(XLAM-1.0)
      GO TO 200
  100 XL(1)=(NR-1.0)*PI/(XLAM-1.0)
      XB(1)=(NR-0.5)*PI/(XLAM-1.0)
      XH(1)=NR*PI/(XLAM-1.0)
  200 D(1)=0.24*(XH(1)-XL(1))
      CALL SEARCH(N,XB,FB,XH,XL,A,B,TOL,TOL1,D,IW,IFNS,ICONV,XLAM)
      ROOTU1=XB(1)
      RETURN
      END
      SUBROUTINE EVAL(XB,FB,XLAM)
      DIMENSION XB(1)
      Z=XB(1)
      FB=ABS(XJ1(Z)*YZERO(XLAM*Z)-Y1(Z)*XJZERO(XLAM*Z))
      RETURN
      END
      SUBROUTINE SEARCH(N,XB,FB,XH,XL,A,B,TOL,TOL1,STP,IW,IFNS,
     >CONV,XLAM)
       INTEGER FNS,RVS(20),CONV
      DIMENSION XB(1),XL(1),XH(1),STP(1),BP(20)
      IF (IW.GT.0) WRITE(1,10000) N,IFNS, A,B, TOL,TOL1,(XH(I),XB(I),
     >   XL(I),I=1,N)
      CONV = 0
      IEXP = 0
      DO 10 I =1,N
          IF (XB(I).GT.XH(I))  XB(I)=XH(I)
          IF (XB(I).LT.XL(I))  XB(I) =XL(I)
          IF(XH(I).EQ.XL(I))   STP(I) =0.E0
   10     BP(I)= XB(I)
      FNS = 1
      CALL EVAL(XB,FB,XLAM)
      FP =FB
      FBP =FB
   20 MINFAL = 0
          IF (FNS.GE.IFNS) GO TO 210
          IF (IW.GT.0) WRITE(1,10400) FNS
          IF (IW.GT.0) WRITE(1,10100)FBP,(BP(I),I=1,N)
          IF (IW.GT.0) WRITE(1,11100) (STP(I),I=1,N)
```

Figure 19

Program RCYLDIF1.FOR Source Code (continued)

```
      DO 110 I =1,N
          RVS(I) = 0
          IF (STP(I).EQ.0.0E0)  GO TO 100
          STOR = XB(I)
          XB(I) = XB(I) + STP(I)
          IF (XB(I).GT.XH(I).OR.XB(I).LT.XL(I)) GO TO 40
          FNS =FNS + 1
          CALL EVAL(XB,FB,XLAM)
          IF(IW.GT.1) WRITE(1,10200) I, FB, (XB(J),J=1,N)
          IF (FB.GE.FP-TOL1*ABS(FP)) GO TO 40
          IF (IEXP.EQ.0) STP(I) =STP(I)*A
 30       FP=FB
          GO TO 110
 40       XB(I) = STOR - STP(I)
          IF (XB(I).GT.XH(I).OR.XB(I).LT.XL(I)) GO TO 50
          FNS = FNS + 1
          CALL EVAL(XB,FB,XLAM)
          IF (IW.GT.1) WRITE(1,10300) I,FB,(XB(J),J = 1,N)
          IF (FB.GE.FP-TOL1*ABS(FP)) GO TO 50
          IF (IEXP.EQ.0) STP(I) = STP(I) *A
          RVS(I) = 1
          GO TO 30
 50       XB(I) = STOR
          IF (IEXP.EQ.1) GO TO 110
          STP(I) = STP(I) * B
          TEMP = ABS(XB(I)/STP(I))* TOL
          IF(1.E0-TEMP) 60,70,90
 60       STP(I) = STP(I) * TEMP
 70       TEMP = 1.E - 10/ ABS(STP(I))
          IF(1.E0.GE.TEMP) GO TO 100
 80       STP(I) = STP(I) * TEMP
          GO TO 100
 90       TEMP =1.E-16/ABS(STP(I))
          IF (1.E0 -TEMP) 80,100,110
100       MINFAL =MINFAL +1
110       CONTINUE
      IF ((FBP-FP).LE.TOL*ABS(FBP)) GO TO 140
      IF (IW.GT.2) WRITE(1,10600) FNS
       DO 120 I = 1,N
          IF (RVS(I).EQ.0) GO TO 120
          STP(I) = -STP(I)
120       CONTINUE
          FBP=FP
          DO 130 I =1,N
          PAT= BP(I)
          BP(I) = XB(I)
          XB(I) = 2.E0 * BP(I) -PAT
          XB(I) = AMAX1(XB(I),XL(I))
130       XB(I)=  AMIN1(XB(I),XH(I))
          FNS = FNS +1
          CALL EVAL(XB,FP,XLAM)
```

Figure 19

Program RCYLDIF1.FOR Source Code (continued)

```
      IF(IW.GT.2) WRITE(1,10700) FP,(XB(I),I=1,N)
      IEXP = 1
      GO TO 20
  140 IF (IEXP.EQ.1) GO TO 160
      IF (MINFAL.GE.N) GO TO 180
      IF (IW.GT.2)WRITE(1,10900)
      DO 150 I =1,N
         IF (RVS(I).EQ.0)    GO TO 150
         STP(I) = -STP(I)
  150    CONTINUE
      GO TO 20
  160  IEXP = 0
      FP =  FBP
      DO 170 I = 1,N
  170 XB(I) =BP(I)
      IF (IW.GT.2) WRITE(1,11000)
      GO TO 20
  180 IF (FP.LE.FBP) GO TO 200
      FP = FBP
      DO 190 I=1,N
  190  XB(I) =BP(I)
  200 IF (IW.GT.0)WRITE(1,10500) FP,(XB(I),I=1,N)
      FB = FP
      IF (IW.GT.0) WRITE(1,10400) FNS
      GO TO 230
  210 CONV = 1
      IF (IW.GT.0) WRITE(1,10800) FNS
      IF (IW.GT.0) WRITE(1,10100)FBP,(BP(I),I=I,N)
      FB = FBP
      DO 220 I = 1, N
  220   XB(I) =BP(I)
  230 RETURN
10000 FORMAT(1H1,2X,'N',5X,'FNS',15X, 'A',10X,'B',10X,'TOL',10X,
     > 'TOL1'/1H ,I3,5X,I4, 13X,F7.4,4X,F7.4,4X,D10.3,3X,D10.3/1H0,3X,
     > 'UPPER',13X, 'ST PT',13X,'LOWER'/(1H ,D15.7,3X,D15.7,3X,D15.7))
10100 FORMAT(3H0* ,D15.7,2X,7D15.7/ (3H   ,17X,7D15.7))
10200 FORMAT(2H0F, I2,D15.7,2X,7D15.7/ (3H  ,18X,7D15.7))
10300 FORMAT(2H0R, I2,D15.7,2X,7D15.7/ (3H  ,18X,7D15.7))
10400 FORMAT(1H0,'FNS= ',I5)
10500 FORMAT(1H0,'THE OPTIMUM VALUE HAS BEEN FOUND '/3H0* , D15.7,2X,
     > 7D15.7/(3H    ,17X,7D15.7))
10600 FORMAT(1H0,'AFTER',I5, ' FNS A NEW BASE PT. - START PATTERN MOVE')
10700 FORMAT(1H0,'RESULT OF PATTERN MOVE'/3H P ,D15.7,2X, 7D15.7/(3H
     >  17X,7D15.7))
10800 FORMAT(1H1,'THE NUMBER OF FUNCTION EVALUATIONS  EXCEEDED ',I5)
10900 FORMAT(1H0,'BASE PT. EXPLORATORY MODE FAILURE')
11000 FORMAT(1H0,'PATTERN MODE EXPLORATORY FAILURE RESTORE BASE PT.')
11100 FORMAT(1H ,'DEL-S',14X,7D15.7/(1H ,19X,7D15.7))
      END
```

Figure 19

Program RCYLDIF1.FOR Source Code (continued)

```
      FUNCTION Y1(X)
C     CALCULATE THE FIRST ORDER Y FUNCTION FOR POSITIVE ARGUMENTS
      PI=3.141592654
      IF(X.LE.0.0) GO TO 100
      IF(X.GE.3.0) GO TO 50
      XD3=X/3.0
      Y1=(2.0*X*ALOG(0.5*X)*XJ1(X)/PI-0.6366198
     &+0.2212091*XD3**2+2.1682709*XD3**4-
     &1.3164827*XD3**6+0.3123951*XD3**8-
     &0.400976E-1*XD3**10+0.27873E-2*XD3**12)/
     &X
      GO TO 200
   50 XI3=3.0/X
      THETA=X-2.35619449+0.12499612*XI3
     &+0.5650E-4*XI3**2-0.637879E-2*XI3**3
     &+0.74348E-3*XI3**4+0.79824E-3*XI3**5
     &-0.29166E-3*XI3**6
      Y1=(SIN(THETA)/SQRT(X))*(0.79788456+
     &0.156E-5*XI3+0.1659667E-1*XI3**2+
     &0.17105E-3*XI3**3-0.249511E-2*XI3**4+
     &0.113653E-2*XI3**5-0.20033E-3*XI3**6)
      GO TO 200
  100 WRITE(2,110) X
  110 FORMAT(1X,'ARGUMENT=',E12.3,1X,'LE',1X,'ZERO')
      STOP
  200 CONTINUE
      RETURN
      END
```

Figure 19

Program RCYLDIF1.FOR Source Code (continued)

```
      FUNCTION XJ1(X)
C     CALCULATE THE FIRST ORDER J FUNCTION FOR POSITIVE ARGUMENTS
      IF(X.LE.0.0) GO TO 100
      IF(X.GE.3.0) GO TO 50
      XD3=X/3.0
      XJ1=(0.5-0.56249985*XD3**2+0.21093573*XD3**4
     &-0.3954289E-1*XD3**6+0.443319E-2*XD3**8
     &-0.31761E-3*XD3**10+0.1109E-4*XD3**12)*X
      GO TO 200
   50 XI3=3.0/X
      THETA=X-2.35619449+0.12499612*XI3
     &+0.5650E-4*XI3**2-0.637879E-2*XI3**3
     &+0.74348E-3*XI3**4+0.79824E-3*XI3**5
     &-0.29166E-3*XI3**6
      XJ1=(COS(THETA)/SQRT(X))*(0.79788456+
     &0.156E-5*XI3+0.1659667E-1*XI3**2+
     &0.17105E-3*XI3**3-0.249511E-2*XI3**4+
     &0.113653E-2*XI3**5-0.20033E-3*XI3**6)
      GO TO 200
  100 WRITE(2,110) X
  110 FORMAT(1X,'ARGUMENT=',E12.3,1X,'LE',1X,'ZERO')
      STOP
  200 CONTINUE
      RETURN
      END
```

Figure 19

Program RCYLDIF1.FOR Source Code (continued)

```
      FUNCTION XJZERO(X)
C     CALCULATE THE ZEROTH ORDER J FUNCTION FOR POSITIVE ARGUMENTS
      IF(X.LE.0.0) GO TO 100
      IF(X.GE.3.0) GO TO 50
      XD3=X/3.0
      XJZERO=1.0-2.2499997*XD3**2+1.2656208*XD3**4
     &-0.3163866*XD3**6+0.0444479*XD3**8
     &-0.39444E-2*XD3**10+0.21E-3*XD3**12
      GO TO 200
   50 XI3=3.0/X
      THETA=X-0.78539816-0.04166397*XI3
     &-0.3954E-4*XI3**2+0.262573E-2*XI3**3
     &-.54125E-3*XI3**4-0.29333E-3*XI3**5
     &+0.13558E-3*XI3**6
      XJZERO=(COS(THETA)/SQRT(X))*(0.79788456-
     &0.77E-6*XI3-0.552740E-2*XI3**2
     &-0.9512E-4*XI3**3+0.137237E-2*XI3**4
     &-0.72805E-3*XI3**5+0.14476E-3*XI3**6)
      GO TO 200
  100 WRITE(2,110) X
  110 FORMAT(1X,'ARGUMENT=',E12.3,1X,'LT',1X,'ZERO')
      STOP
  200 CONTINUE
      RETURN
      END
```

Figure 19

Program RCYLDIF1.FOR Source Code (continued)

```
      FUNCTION YZERO(X)
C     CALCULATE THE ZEROTH ORDER Y FUNCTION FOR POSITIVE ARGUMENTS
      PI=3.141592654
      IF(X.LE.0.0) GO TO 100
      IF(X.GE.3.0) GO TO 50
      XD3=X/3.0
      YZERO=(2.0/PI)*ALOG(X*0.5)*XJZERO(X)+
     &0.36746691+0.60559366*XD3**2-0.74350384*XD3**4+
     &0.25300117*XD3**6-0.04261214*XD3**8+
     &0.427916E-2*XD3**10-0.24846E-3*XD3**12
      GO TO 200
   50 XI3=3.0/X
      THETA=X-0.78539816-0.4166397E-1*XI3-
     &0.3954E-4*XI3**2+0.262573E-2*XI3**3-
     &0.54125E-3*XI3**4-0.29333E-3*XI3**5+
     &0.13558E-3*XI3**6
      YZERO=(SIN(THETA)/SQRT(X))*(0.79788456-
     &0.77E-6*XI3-0.55274E-2*XI3**2-
     &0.9512E-4*XI3**3+0.137237E-2*XI3**4-
     &0.72805E-3*XI3**5+0.14476E-3*XI3**6)
      GO TO 200
  100 WRITE(2,110) X
  110 FORMAT(1X,'ARGUMENT=',E12.3,1X,'LT',1X,'ZERO')
      STOP
  200 CONTINUE
      RETURN
      END
```

Figure 20

Program RCYLDIF1 Input Data File CYLDIF.DAT for B/A=2, B/A=4 andB/A=8

B/A = 2

```
    2     5    40    40
2.0
0.01
0.1
1.0
10.0
100.0
```

B/A = 4

```
    2     5    40    40
4.0
0.01
0.1
1.0
10.0
100.0
```

B/A = 8

```
    2     5    40    40
8.0
0.01
0.1
1.0
10.0
100.0
```

Figure 21

Program RCYLDIF1 Output Data File RCYLDIF1.OUT for B/A=2

```
NUMBER OF NON-DIMENSIONALIZED TIMES=    5
NUMBER OF NON-DIMENSIONALIZED RADII=   40
NUMBER OF TERMS TO BE USED IN THE SERIES SUMMATION=   40
```

NORMALIZED CONCENTRATIONS

NON-DIMENSIONALIZED TIME(D*T/A**2)

NON-DIMENSIONAL RADIUS	.1000E-01	.1000E+00	.1000E+01	.1000E+02	.1000E+03
.1000E+01	.1560E+00	.4533E+00	.9705E+00	.1000E+01	.1000E+01
.1026E+01	.1219E+00	.4175E+00	.9340E+00	.9635E+00	.9635E+00
.1051E+01	.9337E-01	.3838E+00	.8985E+00	.9279E+00	.9279E+00
.1077E+01	.7007E-01	.3522E+00	.8638E+00	.8931E+00	.8931E+00
.1103E+01	.5147E-01	.3226E+00	.8301E+00	.8591E+00	.8591E+00
.1128E+01	.3696E-01	.2950E+00	.7972E+00	.8260E+00	.8260E+00
.1154E+01	.2594E-01	.2693E+00	.7651E+00	.7935E+00	.7935E+00
.1179E+01	.1777E-01	.2453E+00	.7338E+00	.7618E+00	.7618E+00
.1205E+01	.1188E-01	.2230E+00	.7032E+00	.7308E+00	.7308E+00
.1231E+01	.7751E-02	.2023E+00	.6733E+00	.7004E+00	.7004E+00
.1256E+01	.4928E-02	.1832E+00	.6440E+00	.6707E+00	.6707E+00
.1282E+01	.3054E-02	.1656E+00	.6154E+00	.6415E+00	.6415E+00
.1308E+01	.1844E-02	.1493E+00	.5875E+00	.6130E+00	.6130E+00
.1333E+01	.1085E-02	.1344E+00	.5601E+00	.5850E+00	.5850E+00
.1359E+01	.6221E-03	.1206E+00	.5333E+00	.5575E+00	.5575E+00
.1385E+01	.3475E-03	.1081E+00	.5071E+00	.5305E+00	.5305E+00
.1410E+01	.1888E-03	.9663E-01	.4814E+00	.5040E+00	.5040E+00
.1436E+01	.9914E-04	.8618E-01	.4562E+00	.4780E+00	.4780E+00
.1462E+01	.4985E-04	.7669E-01	.4315E+00	.4525E+00	.4525E+00
.1487E+01	.2304E-04	.6808E-01	.4072E+00	.4274E+00	.4274E+00
.1513E+01	.8610E-05	.6028E-01	.3835E+00	.4028E+00	.4028E+00
.1538E+01	.1004E-05	.5324E-01	.3601E+00	.3785E+00	.3785E+00
.1564E+01	-.2879E-05	.4690E-01	.3372E+00	.3547E+00	.3547E+00
.1590E+01	-.4884E-05	.4120E-01	.3147E+00	.3312E+00	.3312E+00
.1615E+01	-.5819E-05	.3608E-01	.2926E+00	.3081E+00	.3081E+00
.1641E+01	-.6127E-05	.3150E-01	.2709E+00	.2854E+00	.2854E+00
.1667E+01	-.6060E-05	.2740E-01	.2495E+00	.2630E+00	.2630E+00
.1692E+01	-.6231E-05	.2374E-01	.2285E+00	.2410E+00	.2410E+00
.1718E+01	-.6239E-05	.2047E-01	.2078E+00	.2193E+00	.2193E+00
.1744E+01	-.6372E-05	.1755E-01	.1875E+00	.1979E+00	.1979E+00
.1769E+01	-.6697E-05	.1494E-01	.1675E+00	.1769E+00	.1769E+00
.1795E+01	-.7495E-05	.1261E-01	.1478E+00	.1561E+00	.1561E+00
.1821E+01	-.8779E-05	.1051E-01	.1284E+00	.1357E+00	.1357E+00
.1846E+01	-.1016E-04	.8625E-02	.1092E+00	.1155E+00	.1155E+00
.1872E+01	-.1196E-04	.6912E-02	.9040E-01	.9558E-01	.9558E-01
.1897E+01	-.1393E-04	.5345E-02	.7182E-01	.7595E-01	.7595E-01
.1923E+01	-.1589E-04	.3895E-02	.5350E-01	.5658E-01	.5658E-01
.1949E+01	-.1827E-04	.2535E-02	.3543E-01	.3747E-01	.3747E-01
.1974E+01	-.2060E-04	.1239E-02	.1760E-01	.1862E-01	.1862E-01
.2000E+01	-.2267E-04	-.1567E-04	-.8616E-06	-.2270E-18	-.4803E-39
AVERAGE=	.9681E-02	.9481E-01	.3718E+00	.3881E+00	.3881E+00

Figure 22

Program RCYLDIF1 Output Data File RCYLDIF1.OUT for B/A=4

NUMBER OF NON-DIMENSIONALIZED TIMES= 5
NUMBER OF NON-DIMENSIONALIZED RADII= 40
NUMBER OF TERMS TO BE USED IN THE SERIES SUMMATION= 40

NORMALIZED CONCENTRATIONS

NON-DIMENSIONALIZED TIME(D*T/A**2)

NON-DIMENSIONAL RADIUS	.1000E-01	.1000E+00	.1000E+01	.1000E+02	.1000E+03
.1000E+01	.7775E-01	.2264E+00	.5784E+00	.9925E+00	.1000E+01
.1077E+01	.3480E-01	.1758E+00	.5256E+00	.9390E+00	.9465E+00
.1154E+01	.1271E-01	.1344E+00	.4776E+00	.8893E+00	.8968E+00
.1231E+01	.3597E-02	.1009E+00	.4339E+00	.8428E+00	.8502E+00
.1308E+01	.6256E-03	.7440E-01	.3940E+00	.7991E+00	.8065E+00
.1385E+01	-.1334E-03	.5380E-01	.3576E+00	.7580E+00	.7653E+00
.1462E+01	-.2840E-03	.3812E-01	.3243E+00	.7191E+00	.7263E+00
.1538E+01	-.3019E-03	.2643E-01	.2939E+00	.6822E+00	.6893E+00
.1615E+01	-.2926E-03	.1792E-01	.2660E+00	.6471E+00	.6541E+00
.1692E+01	-.2761E-03	.1185E-01	.2406E+00	.6137E+00	.6205E+00
.1769E+01	-.2583E-03	.7637E-02	.2173E+00	.5817E+00	.5884E+00
.1846E+01	-.2429E-03	.4777E-02	.1960E+00	.5512E+00	.5577E+00
.1923E+01	-.2319E-03	.2885E-02	.1765E+00	.5219E+00	.5283E+00
.2000E+01	-.2262E-03	.1666E-02	.1588E+00	.4938E+00	.5000E+00
.2077E+01	-.2248E-03	.9017E-03	.1426E+00	.4668E+00	.4728E+00
.2154E+01	-.2257E-03	.4363E-03	.1278E+00	.4407E+00	.4465E+00
.2231E+01	-.2261E-03	.1621E-03	.1144E+00	.4156E+00	.4212E+00
.2308E+01	-.2235E-03	.6719E-05	.1022E+00	.3914E+00	.3968E+00
.2385E+01	-.2160E-03	-.7688E-04	.9119E-01	.3679E+00	.3731E+00
.2462E+01	-.2022E-03	-.1183E-03	.8117E-01	.3452E+00	.3502E+00
.2538E+01	-.1825E-03	-.1355E-03	.7211E-01	.3233E+00	.3280E+00
.2615E+01	-.1592E-03	-.1396E-03	.6392E-01	.3020E+00	.3065E+00
.2692E+01	-.1353E-03	-.1365E-03	.5653E-01	.2813E+00	.2856E+00
.2769E+01	-.1143E-03	-.1300E-03	.4987E-01	.2612E+00	.2653E+00
.2846E+01	-.9877E-04	-.1218E-03	.4388E-01	.2417E+00	.2455E+00
.2923E+01	-.9026E-04	-.1128E-03	.3849E-01	.2227E+00	.2263E+00
.3000E+01	-.8841E-04	-.1036E-03	.3364E-01	.2042E+00	.2075E+00
.3077E+01	-.9107E-04	-.9461E-04	.2929E-01	.1862E+00	.1893E+00
.3154E+01	-.9436E-04	-.8542E-04	.2538E-01	.1687E+00	.1714E+00
.3231E+01	-.9527E-04	-.7636E-04	.2187E-01	.1515E+00	.1541E+00
.3308E+01	-.9131E-04	-.6722E-04	.1871E-01	.1348E+00	.1371E+00
.3385E+01	-.8171E-04	-.5791E-04	.1586E-01	.1185E+00	.1205E+00
.3462E+01	-.6712E-04	-.4838E-04	.1328E-01	.1026E+00	.1043E+00
.3538E+01	-.4953E-04	-.3862E-04	.1094E-01	.8695E-01	.8844E-01
.3615E+01	-.3156E-04	-.2878E-04	.8792E-02	.7169E-01	.7293E-01
.3692E+01	-.1527E-04	-.1881E-04	.6817E-02	.5676E-01	.5774E-01
.3769E+01	-.1814E-05	-.8734E-05	.4979E-02	.4214E-01	.4286E-01
.3846E+01	.8374E-05	.1214E-05	.3251E-02	.2781E-01	.2829E-01
.3923E+01	.1605E-04	.1126E-04	.1605E-02	.1377E-01	.1401E-01
.4000E+01	.2175E-04	.2093E-04	.1393E-04	.2550E-06	.1042E-23
AVERAGE=	.8890E-03	.9570E-02	.9357E-01	.2904E+00	.2941E+00

Figure 23

Program RCYLDIF1 Output Data File RCYLDIF1.OUT for B/A=8

```
NUMBER OF NON-DIMENSIONALIZED TIMES=    5
NUMBER OF NON-DIMENSIONALIZED RADII=   40
NUMBER OF TERMS TO BE USED IN THE SERIES SUMMATION=   40
```

NORMALIZED CONCENTRATIONS

NON-DIMENSIONALIZED TIME(D*T/A**2)

NON-DIMENSIONAL RADIUS	.1000E-01	.1000E+00	.1000E+01	.1000E+02	.1000E+03
.1000E+01	.5426E-01	.1517E+00	.3857E+00	.7928E+00	.1000E+01
.1179E+01	.7581E-02	.8219E-01	.3085E+00	.7137E+00	.9206E+00
.1359E+01	.8231E-03	.4035E-01	.2463E+00	.6465E+00	.8525E+00
.1538E+01	-.7197E-03	.1758E-01	.1960E+00	.5882E+00	.7928E+00
.1718E+01	-.1545E-02	.6570E-02	.1551E+00	.5369E+00	.7397E+00
.1897E+01	-.1658E-02	.1968E-02	.1220E+00	.4914E+00	.6919E+00
.2077E+01	-.1062E-02	.4306E-03	.9515E-01	.4506E+00	.6485E+00
.2256E+01	-.6969E-04	.1451E-03	.7361E-01	.4137E+00	.6086E+00
.2436E+01	.8539E-03	.2364E-03	.5643E-01	.3803E+00	.5718E+00
.2615E+01	.1321E-02	.3210E-03	.4283E-01	.3498E+00	.5376E+00
.2795E+01	.1128E-02	.2670E-03	.3218E-01	.3219E+00	.5057E+00
.2974E+01	.4581E-03	.8215E-04	.2392E-01	.2963E+00	.4758E+00
.3154E+01	-.4170E-03	-.1503E-03	.1758E-01	.2727E+00	.4476E+00
.3333E+01	-.1068E-02	-.3264E-03	.1277E-01	.2510E+00	.4210E+00
.3513E+01	-.1268E-02	-.3712E-03	.9166E-02	.2309E+00	.3958E+00
.3692E+01	-.8833E-03	-.2707E-03	.6497E-02	.2123E+00	.3718E+00
.3872E+01	-.1669E-03	-.7525E-04	.4545E-02	.1951E+00	.3490E+00
.4051E+01	.5865E-03	.1257E-03	.3137E-02	.1791E+00	.3272E+00
.4231E+01	.1012E-02	.2438E-03	.2135E-02	.1643E+00	.3063E+00
.4410E+01	.9755E-03	.2315E-03	.1430E-02	.1504E+00	.2864E+00
.4590E+01	.4619E-03	.1002E-03	.9426E-03	.1376E+00	.2672E+00
.4769E+01	-.2285E-03	-.8616E-04	.6095E-03	.1256E+00	.2487E+00
.4949E+01	-.8201E-03	-.2421E-03	.3854E-03	.1145E+00	.2310E+00
.5128E+01	-.1027E-02	-.2984E-03	.2370E-03	.1041E+00	.2138E+00
.5308E+01	-.8034E-03	-.2330E-03	.1402E-03	.9433E-01	.1973E+00
.5487E+01	-.2223E-03	-.7820E-04	.7832E-04	.8524E-01	.1813E+00
.5667E+01	.4235E-03	.9443E-04	.3951E-04	.7671E-01	.1658E+00
.5846E+01	.8548E-03	.2076E-03	.1589E-04	.6872E-01	.1508E+00
.6026E+01	.8648E-03	.2126E-03	.2004E-05	.6122E-01	.1363E+00
.6205E+01	.4927E-03	.1105E-03	-.5702E-05	.5415E-01	.1222E+00
.6385E+01	-.1179E-03	-.4975E-04	-.9479E-05	.4749E-01	.1085E+00
.6564E+01	-.6639E-03	-.1943E-03	-.1088E-04	.4119E-01	.9512E-01
.6744E+01	-.9095E-03	-.2580E-03	-.1083E-04	.3522E-01	.8215E-01
.6923E+01	-.7478E-03	-.2132E-03	-.9798E-05	.2955E-01	.6952E-01
.7103E+01	-.2700E-03	-.8148E-04	-.8255E-05	.2413E-01	.5721E-01
.7282E+01	.3147E-03	.7770E-04	-.6391E-05	.1895E-01	.4521E-01
.7462E+01	.7410E-03	.1940E-03	-.4392E-05	.1398E-01	.3351E-01
.7641E+01	.8244E-03	.2179E-03	-.2382E-05	.9178E-02	.2208E-01
.7821E+01	.5260E-03	.1425E-03	-.4448E-06	.4527E-02	.1091E-01
.8000E+01	.6669E-05	.5761E-05	.1649E-05	.4044E-06	.7444E-10
AVERAGE=	.2275E-03	.1580E-02	.1535E-01	.1305E+00	.2247E+00

5.2 Solute Transport by Diffusion Across an Infinitely Long Cylindrical Segment

Problem Statement. A constant flux of F and a constant concentration of zero are specified for the inner and outer surface, respectively, of an infinitely long cylindrical segment (see Figure 5.2-1) with inner radius a and outer radius b. The solute diffusion coefficient, D, is assumed to be constant throughout the segment. No solute is assumed to be present in the segment initially. The values to be calculated as a function of time are (1) the concentration profile across the segment, (2) the average concentration within the segment, and (3) the concentration gradient at the radius b. As a second part of the problem, these values are to be calculated at equilibrium.

Objectives. This problem is designed to test the assumption commonly used in backfill leaching calculation that the backfill can be treated as a single, uniformly mixed cell.

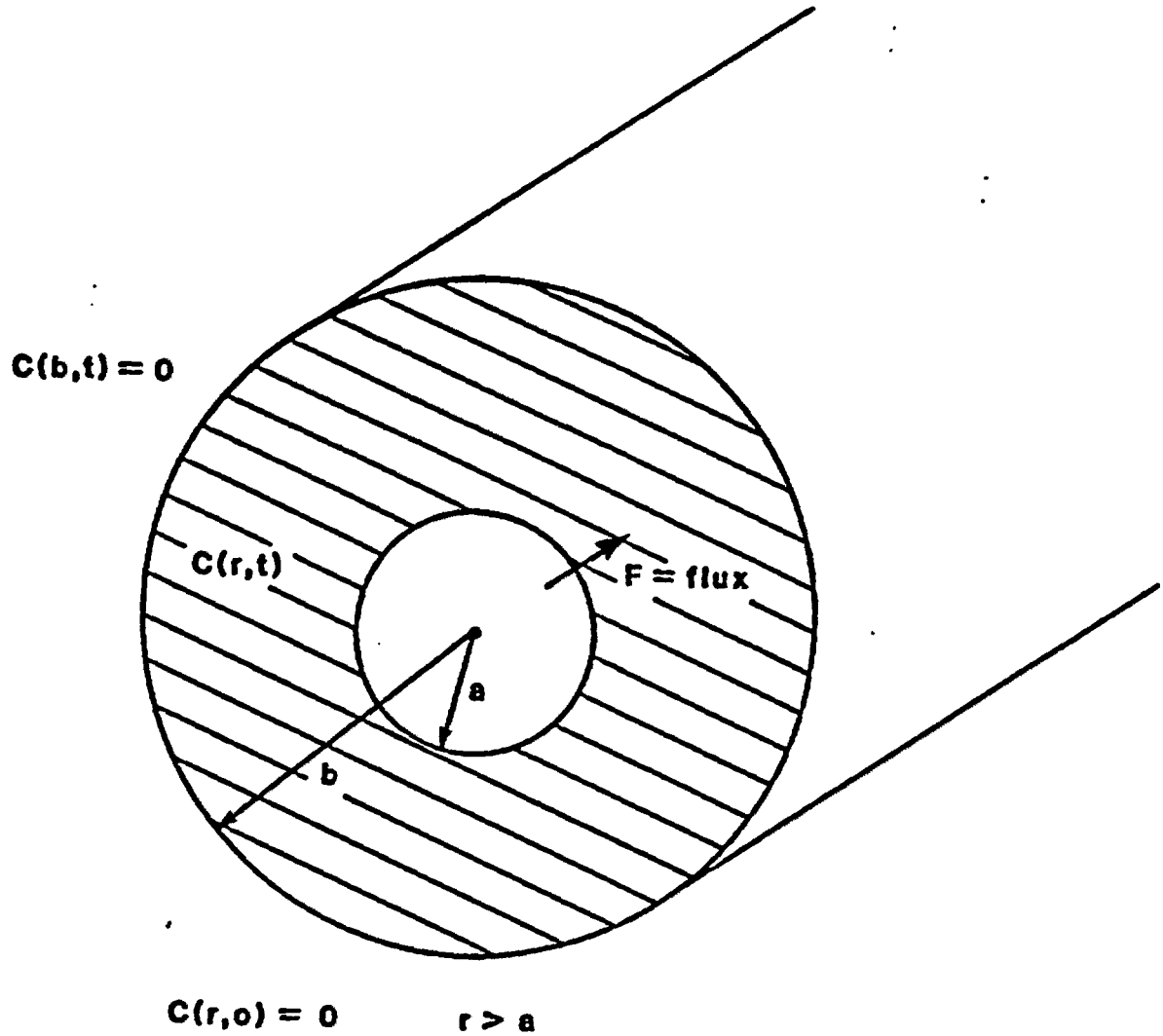


Figure 5.2-1

Cross Section of Infinitely Long Cylinder

Analytical Solution. The concentration of solute as a function of time can be described by the diffusion equation in cylindrical coordinates:

$$\frac{\partial^2 C}{\partial r^2} + \frac{1}{r}\frac{\partial C}{\partial r} = \frac{1}{D}\frac{\partial C}{\partial t} \tag{137}$$

with the following boundary conditions:

$$-D\left(\frac{\partial C}{\partial r}\right)_{r=a} = F \text{ (a constant)}$$

$$C(b,t) = 0$$

$$C(r,o) = 0 \text{ for } r \geq a$$

The analytical solution to this equation is given as follows:

$$C(r,t) = \frac{aF}{D}\ln\left(\frac{b}{r}\right) + \frac{\pi F}{D}\sum_{n=1}^{\infty}\exp(-D\alpha_n^2 t) \times \frac{J_o^2(b\alpha_n)\left[J_o(r\alpha_n)Y_1(a\alpha_n)-Y_o(r\alpha_n)J_1(a\alpha_n)\right]}{\alpha_n\left[J_1^2(a\alpha_n) - J_o^2(b\alpha_n)\right]} \tag{138}$$

where α_n are the positive roots of

$$J_1(a\alpha)Y_o(b\alpha) - Y_1(a\alpha)J_o(b\alpha) = 0 \tag{139}$$

At equilibrium, Equation 137 becomes:

$$\frac{\partial^2 C}{\partial r^2} + \frac{1}{r}\frac{\partial C}{\partial r} = 0 \tag{140}$$

with the boundary conditions

$$-D\left(\frac{\partial C}{\partial r}\right)_{r=a} = F \text{ (a constant)}$$

$$C(b) = 0$$

The analytical solution is

$$C(r) = \frac{aF}{D}\,\ell n\left(\frac{b}{r}\right) \tag{141}$$

Assumptions. There is no variation of solute concentration with the angle or along the axis of the cylindrical segment. Also, solute advection, adsorption, and decay within the segment are neglected.

Input Specification. Calculations are to be performed for a range of values of inner radius a, outer radius b, diffusion coefficient D, and flux F at radius a given in Table 5.2-1.

Output Specifications. The solute concentration as a function of time is calculated for a range of distances between a and b. Also, the average concentration within the cylindrical segment is calculated as a function of time. Finally, the concentration gradient at r = b is calculated as a function of time. Concentration profiles for different

Table 5.2-1

Average Normalized Concentrations and Boundary Derivatives for Different Values of b/a*

Non-dimensionalized Time $t_{ND} = Dt/a^2$	Average Non-dimensionalized Concentration $C_{ND} = \frac{CD}{F_a \ln (b/a)}$			Negative Derivative of Non-dimensionalized Concentration** $-\left(\frac{\partial C_{ND}}{\partial (r/a)}\right)_{(r/a) = b/a}$		
	b/a			b/a		
	2.0	4.0	8.0	2.0	4.0	8.0
0.01	0.99×10^{-2}	0.93×10^{-3}	0.24×10^{-3}	-	-	-
0.1	0.0950	0.96×10^{-2}	0.16×10^{-2}	0.05	-	-
1.0	0.372	0.936×10^{-1}	0.154×10^{-1}	0.69	0.021	-
10	0.388	0.290	0.131	0.73	0.18	0.025
100	0.388	0.294	0.225	0.73	0.18	0.061

* Results based on the evaluation of 40 terms in the Equation 138 summation.

** Slope based on the last two points plotted in each of the Figures 5.2-2 through 5.2-4.

values of b/a were calculated by use of Equation 138 and are displayed in Figures 5.2-2 through 5.2-4. The associated average concentrations and concentration derivatives at r = b are given in Table 5.2-1. In reporting these results, all concentrations, distances, and times have been normalized as indicated in Figures 5.2-2 through 5.2-4.

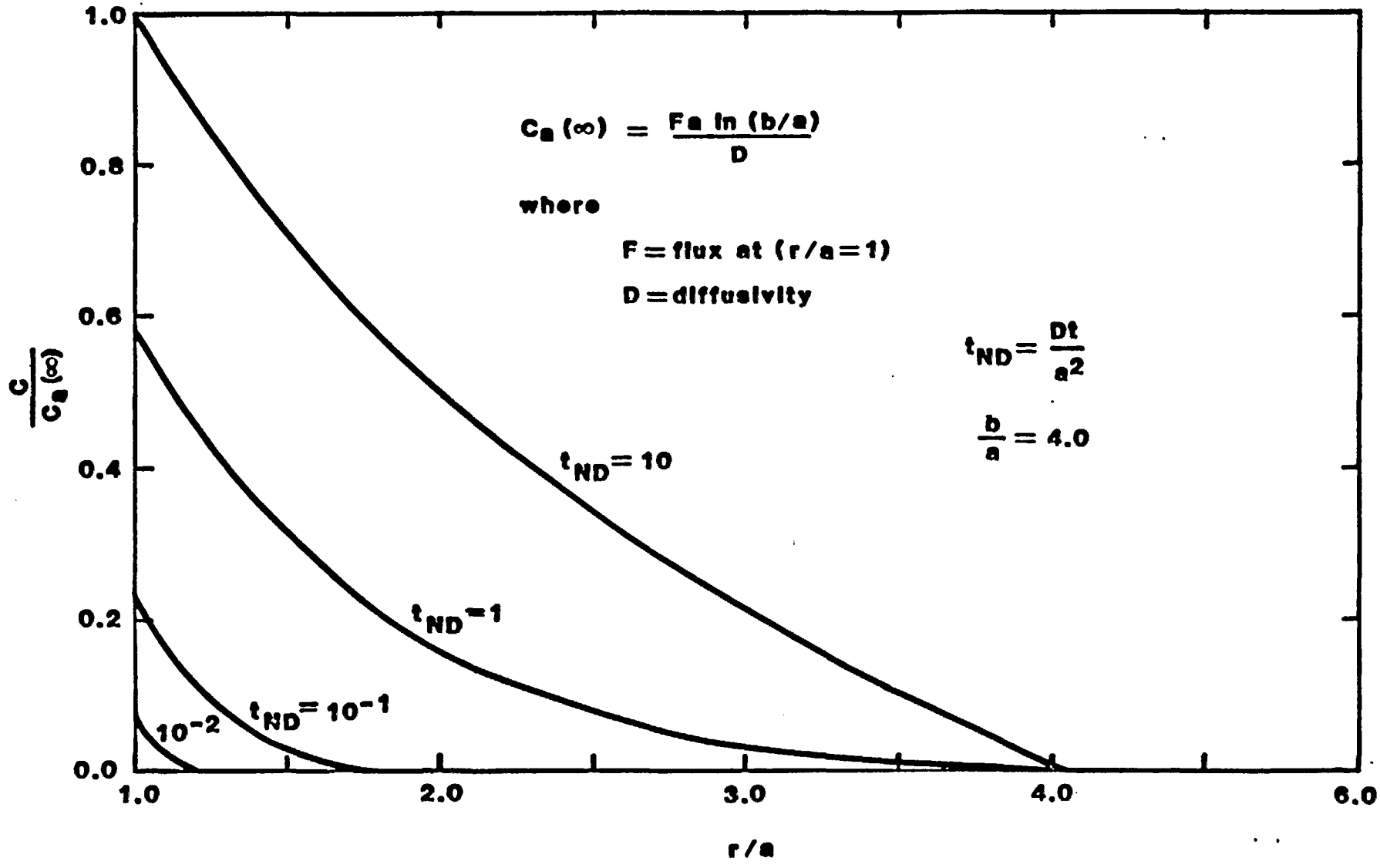


Figure 5.2-2

Normalized Concentration Curve for b/a = 2

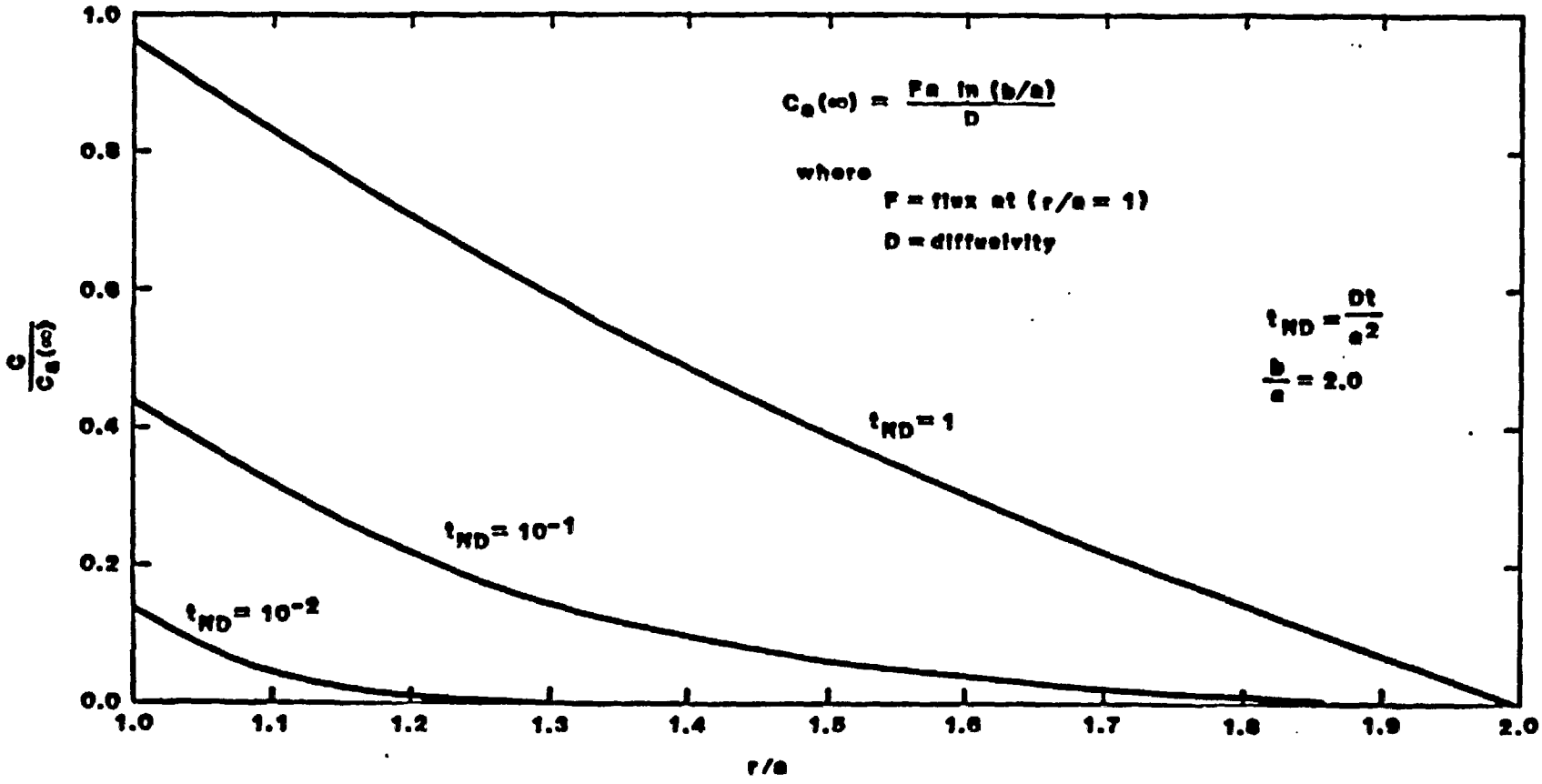


Figure 5.2-3

Normalized Concentration Curve for b/a = 4

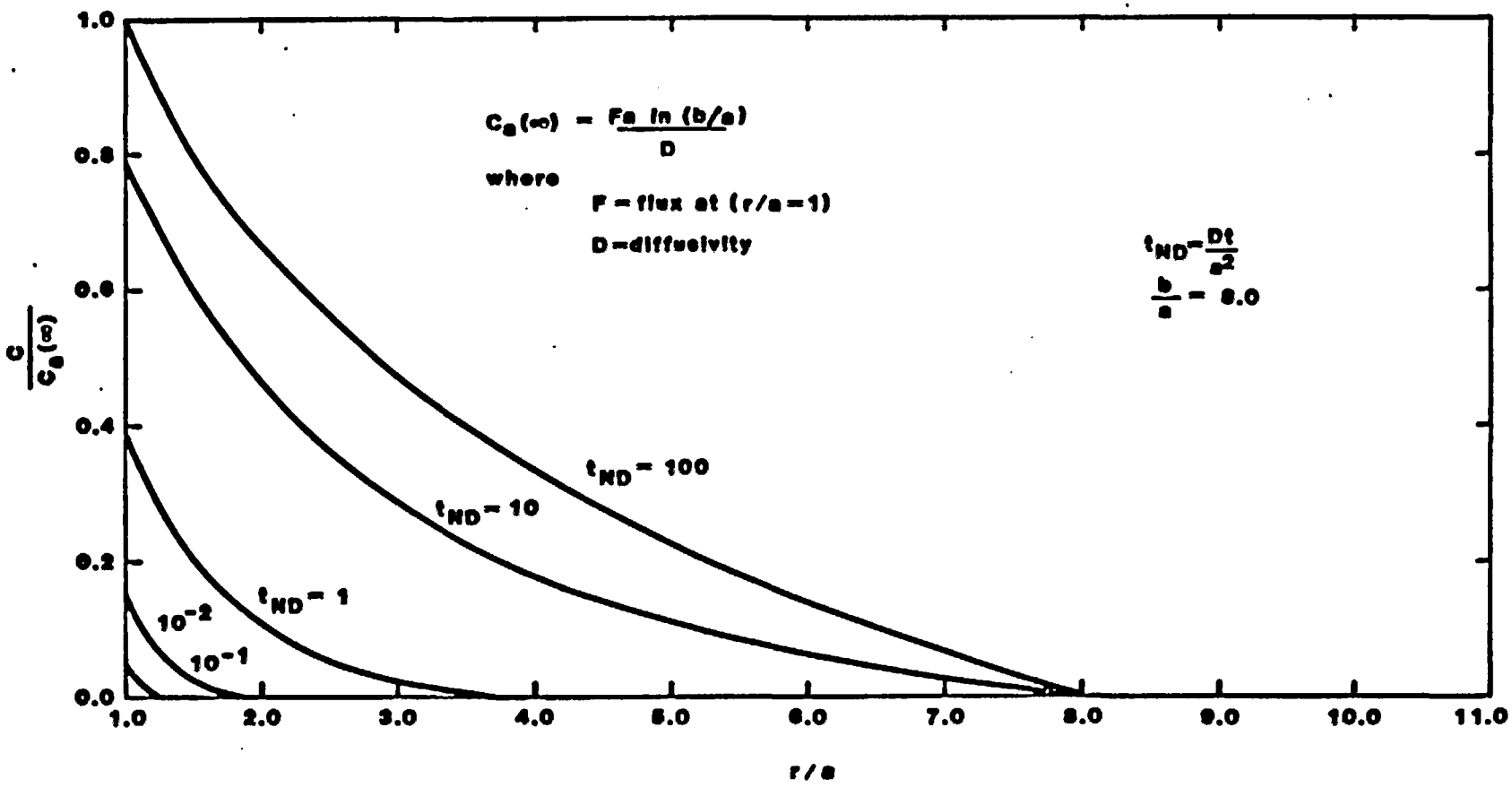


Figure 5.2-4

Normalized Concentration Curve for b/a = 8

15. LOTUS SPREADSHEET RAU234

This spreadsheet calculates the number of enriching stages and the U^{234} enrichment based on feed assay and U^{235} enrichment values input by the user. It was used to estimate the U^{234} content of fresh fuel for radiological assessment benchmark problems 2.4 and 2.5.

Theory

The theoretical aspects of this spreadsheet are discussed in Appendix A of Reference 3 (attached for the readers convenience at the end of this section).

Spreadsheet

Column A is for user input of U^{235} enrichment values (in percent)

Column B calculates the number of enriching stages (n_p)

Column C calculates the U^{234} enrichment values (x_p^{234}) in percent

A sample spreadsheet is shown in Figure 24.

Figure 24

RAU234 Sample Lotus Spreadsheet

	A	B	C	D
1	WORKSHEET FOR U-234 IN ENRICHED URANIUM			
2				NOTE: BE SURE RANGE
3	***********FEED ASSAY**********			PROTECT SWITCH IS
4	XF-235	0.00711	[U-235 FRACTION]	ON (TYPE /WGPE).
5	XF-234	0.00005477	[U-234 FRACTION]	ALL CELLS EXCEPT
6				A15-A55
7	******CALCULATED SEPARATION FACTORS*******			ARE PROTECTED.
8	ALPHA-235	1.0042887974	[@SQRT(352/349)]	
9	ALPHA-234	1.0057307059	[@SQRT(352/348)]	
10				
11		NUMBER OF		
12	U-235	ENRICHING	U-234	
13	ENRICHMENT	STAGES	ENRICHMENT	
14	(percent)		(percent)	
15	1.0	161	0.008670	
16	1.1	206	0.009860	
17	1.2	247	0.011089	
18	1.3	285	0.012357	
19	1.4	320	0.013660	
20	1.5	353	0.014998	
21	1.6	383	0.016370	
22	1.7	412	0.017774	
23	1.8	439	0.019210	
24	1.9	465	0.020676	
25	2.0	489	0.022171	
26	2.1	513	0.023695	
27	2.2	535	0.025248	
28	2.3	556	0.026828	
29	2.4	577	0.028435	
30	2.5	596	0.030069	
31	2.6	615	0.031728	
32	2.7	633	0.033414	
33	2.8	651	0.035124	
34	2.9	667	0.036859	
35	3.0	684	0.038618	
36	3.1	700	0.040401	
37	3.2	715	0.042208	
38	3.3	730	0.044038	
39	3.4	744	0.045892	
40	3.5	758	0.047768	
41	3.6	772	0.049667	
42	3.7	785	0.051588	
43	3.8	798	0.053531	
44	3.9	811	0.055496	
45	4.0	823	0.057483	
46	4.1	835	0.059491	
47	4.2	847	0.061521	
48	4.3	858	0.063572	
49	4.4	869	0.065644	
50	4.5	880	0.067737	
51	4.6	891	0.069850	
52	4.7	902	0.071984	
53	4.8	912	0.074139	
54	4.9	922	0.076314	
55	5.0	932	0.078509	

APPENDIX A

Method for Estimating U-234 Content of Enriched Uranium

CorSTAR

ORIGEN results for benchmark problems 2.4 and 2.5 were in poor agreement with measured U-234 data. Since U-234 is a precursor of Ra-226, a potentially important radionuclide in estimating dose-to-man, better agreement was desired. In reviewing the benchmark problem inputs, the most likely source of error was the fuel initial U-234 content. To improve our estimate of U-234 content the following method was used.

Step 1: Estimate the number of enriching stages required to produce U-235 of the desired product enrichment. From Reference Benedict and Pigford (1957),

$$n_p = \frac{\mathrm{Ln}\left(\dfrac{x_p^{235}(1 - x_f^{235})}{(1-x_p^{235})\, x_f^{235}}\right)}{\mathrm{Ln}\ \beta^{235}}$$

where:

n_p = number of stages in the enriching section of an ideal cascade

x_f^{235} = enrichment plant U-235 feed assay

x_p^{235} = enrichment plant U-235 product assay

$\beta^{235} = \sqrt{\alpha^{235}}$

α^{235} = separation factor for U-235

$$= \sqrt{\frac{\text{mass of } U^{235} F_6}{\text{mass of } U^{238} F_6}}$$

Knowing the number of product stages, the U-234 content can be estimated by:

$$x_p^{234} = \frac{1}{1 - (\beta^{234})^{-n_p}(1 - 1/x_f^{234})}$$

where:

x_p^{234} = enrichment plant U-234 product assay

x_f^{234} = enrichment plant U-234 feed assay

$$\beta^{234} = \sqrt{\alpha^{234}}$$

$$\alpha^{234} = \sqrt{\frac{\text{mass of } U^{234} F_6}{\text{mass of } U^{238} F_6}}$$

The U-234 product assay from a diffusion enrichment plant for typical U-235 enrichments are given in the attached worksheet.

Reference

Benedict, M. and T. H. Pigford, Nuclear Chemical Engineering, McGraw Hill, New York, 1957, p. 388.

Table 1

U-234 in Enriched Uranium

U-235 Enrichment	No. of Enriching Stages	U-234 Enrichment
1.0	161	0.008670
1.1	206	0.009860
1.2	247	0.011089
1.3	285	0.012357
1.4	320	0.013660
1.5	353	0.014998
1.6	383	0.016370
1.7	412	0.017774
1.8	439	0.019210
1.9	465	0.020676
2.0	489	0.022171
2.1	513	0.023695
2.2	535	0.025248
2.3	556	0.026828
2.4	577	0.028435
2.5	596	0.030069
2.6	615	0.031728
2.7	633	0.033414
2.8	651	0.035124
2.9	667	0.036859
3.0	684	0.038618
3.1	700	0.040401
3.2	715	0.042208
3.3	730	0.044038
3.4	744	0.045892
3.5	758	0.047768
3.6	772	0.049667
3.7	785	0.051588
3.8	798	0.053531
3.9	811	0.055496
4.0	823	0.057483
4.1	835	0.059491
4.2	847	0.061521
4.3	858	0.063572
4.4	869	0.065644
4.5	880	0.067737
4.6	891	0.069850
4.7	902	0.071984
4.8	912	0.074139
4.9	922	0.076314
5.0	932	0.078509

16. FORTRAN PROGRAM ANSIDECH

The Fortran program ANSIDECH uses two ANS methods for computing fission-product afterheat power from light water reactor fuel. This program was used in the solution of the Radiological Assessment Benchmark Problems 2.1, 2.2 and 2.3.

Theory

The engineering aspects of this program are discussed in Section 3.2 of Reference 3 (attached for the readers convenience at the end of this section).

Program

Program ANSIDECH.EXE solves Equations 3.2.1 through 3.2.7 for the detailed method of computing fission-product afterheat power and Equation 3.2.8 for the simplified method. A listing of the Fortran source code is shown in Figure 25.

Input Data

Data is input to the program via the input data file ANSI.DAT. Input data names, formats and descriptions are shown in Table 1. Input data files for Benchmark Problems 2.1, 2.2, and 2.3 are given in Figure 26.

Output Data

The output data from this program is sent to a parallel interface printer. The user can redirect the output by changing the OPEN(2,FILE=/PRN/) statement in the code. The output data for Benchmark Problems 2.1, 2.2 and 2.3 is shown in Figure 27.

Figure 25

Fortran Program ANSIDECH Source Code

```
      PROGRAM ANSIDECH
C**** PURPOSE:  CALCULATION OF AFTERHEAT POWER BY THE METHODS OF
C****           AMERICAN NATIONAL STANDARD ANSI/ANS-5.1-1979,
C****           'DECAY HEAT POWER IN LIGHT WATER REACTORS',
C****           AMERICAN NUCLEAR SOCIETY, 555 N. KENSINGTON AVE.,
C****           LAGRANGE PARK, ILLINOIS  60525
C****
C**** METHODS:  FOR FISSION PRODUCTS, THE LONG (STANDARD) AND/OR
C****           SHORT (SIMPLIFIED) METHODS AS DESCRIBED IN
C****           SECTIONS 3.4, 3.5, AND 3.6 OF THE STANDARD.
C****
C****           FOR U239 AND NP239, THE METHOD DESCRIBED IN
C****           SECTION 4 OF THE STANDARD.
C****
C**** REMARKS:  A DESCRIPTION OF ALL INPUT DATA IS GIVEN IN
C****           COMMENT CARDS WITHIN THE PROGRAM.
C****
C**** AUTHORS:  C. C. WEBSTER, WITH MODIFICATION BY J. C. RYMAN
C****
      REAL LAM1,LAM2
      CHARACTER*8 NAME
      CHARACTER*4 QUIT
      DIMENSION TITLE(20), Q(6), TCDOL(51), TA(40), PDW(3,40), G(51),
     * ALF(23,3), XLAM(23,3), TC(40), PDEC(51), TCDA(51), PDECIS(3,51),
     * DECHPR(3,51),DHPIS(3,51),F239U(51),F239NP(51), PDHE(51),NAME(3)
     *,TGMAX(55),GMAX(55)
      DATA ALF/6.5057E-01,5.1264E-01,2.4384E-01,1.3850E-01,5.5440E-02,
     1         2.2225E-02,3.3088E-03,9.3015E-04,8.0943E-04,1.9567E-04,
     2         3.2535E-05,7.5595E-06,2.5232E-06,4.9948E-07,1.8531E-07,
     3         2.6608E-08,2.2398E-09,8.1641E-12,8.7797E-11,2.5131E-14,
     4         3.2176E-16,4.5038E-17,7.4791E-17,2.0830E-01,3.8530E-01,
     5         2.2130E-01,9.4600E-02,3.5310E-02,2.2920E-02,3.9460E-03,
     6         1.3170E-03,7.0520E-04,1.4320E-04,1.7650E-05,7.3470E-06,
     7         1.7470E-06,5.4810E-07,1.6710E-07,2.1120E-08,2.9960E-09,
     8         5.1070E-11,5.7300E-11,4.1380E-14,1.0880E-15,2.4540E-17,
     9         7.5570E-17,1.2311E+00,1.1486E+00,7.0701E-01,2.5209E-01,
     A         7.1870E-02,2.8291E-02,6.8382E-03,1.2322E-03,6.8409E-04,
     B         1.6975E-04,2.4182E-05,6.6356E-06,1.0075E-06,4.9894E-07,
     C         1.6352E-07,2.3355E-08,2.8094E-09,3.6236E-11,6.4577E-11,
     D         4.4963E-14,3.6654E-16,5.6293E-17,7.1602E-17/
      DATA XLAM /2.2138E+01,5.1587E-01,1.9594E-01,1.0314E-01,3.3656E-02,
     1           1.1681E-02,3.5870E-03,1.3930E-03,6.2630E-04,1.8906E-04,
     2           5.4988E-05,2.0958E-05,1.0010E-05,2.5438E-06,6.6361E-07,
     3           1.2290E-07,2.7213E-08,4.3714E-09,7.5780E-10,2.4786E-10,
     4           2.2384E-13,2.4600E-14,1.5699E-14,1.0020E+01,6.4330E-01,
     5           2.1860E-01,1.0040E-01,3.7280E-02,1.4350E-02,4.5490E-03,
     6           1.3280E-03,5.3560E-04,1.7300E-04,4.8810E-05,2.0060E-05,
     7           8.3190E-06,2.3580E-06,6.4500E-07,1.2780E-07,2.4660E-08,
     8           9.3780E-09,7.4500E-10,2.4260E-10,2.2100E-13,2.6400E-14,
     9           1.3800E-14,3.2881E+00,9.3805E-01,3.7073E-01,1.1118E-01,
     A           3.6143E-02,1.3272E-02,5.0133E-03,1.3655E-03,5.5158E-04,
     B           1.7873E-04,4.9032E-05,1.7058E-05,7.0465E-06,2.3190E-06,
     C           6.4480E-07,1.2649E-07,2.5548E-08,8.4782E-09,7.5130E-10,
     D           2.4188E-10,2.2739E-13,9.0536E-14,5.6098E-15/
      DATA TGMAX/1.0,1.5,2.0,4.0,6.0,8.0,1.0E+1,1.5E+1,2.0E+1,4.0E+1,
     1          6.0E+1,8.0E+1,1.0E+2,1.5E+2,2.0E+2,4.0E+2,6.0E+2,8.0E+2,
     2          1.0E+3,1.5E+3,2.0E+3,4.0E+3,6.0E+3,8.0E+3,1.0E+4,1.5E+4,
     3          2.0E+4,4.0E+4,6.0E+4,8.0E+4,1.0E+5,1.5E+5,2.0E+5,4.0E+5,
     4          6.0E+5,8.0E+5,1.0E+6,1.5E+6,2.0E+6,4.0E+6,6.0E+6,8.0E+6,
     5          1.0E+7,1.5E+7,2.0E+7,4.0E+7,6.0E+7,8.0E+7,1.0E+8,1.5E+8,
     6          2.0E+8,4.0E+8,6.0E+8,8.0E+8,1.0E+9/
      DATA GMAX /1.02,1.02,1.02,1.021,1.022,1.022,1.022,1.022,1.022,
     1           1.022,1.022,1.022,1.023,1.024,1.025,1.028,1.030,1.032,
     2           1.033,1.037,1.039,1.048,1.054,1.060,1.064,1.074,1.081,
     3           1.098,1.111,1.119,1.124,1.130,1.131,1.126,1.124,1.123,
     4           1.124,1.125,1.127,1.134,1.146,1.162,1.181,1.233,1.284,
     5           1.444,1.535,1.586,1.598,1.498,1.343,1.065,1.021,1.012,
     6           1.007/
```

Figure 25

Fortran Program ANSIDECH Source Code (continued)

```
      DATA LAM1,LAM2,E239U,E239NP/4.91E-04,3.41E-06,0.474,0.419/
      DATA NAME/' U-235  ','PU-239  ',' U-238  '/
      DATA NRD,NPRT/5,2/
      DATA QUIT/'END '/
      OPEN(5,FILE='ANSI.DAT')
      OPEN(2,FILE='PRN')
   90 CONTINUE
C**** READ AND PRINT ONE TITLE CARD
      READ(NRD,10000) TITLE
      IF(TITLE(1).EQ.QUIT) GO TO 350
      WRITE(NPRT,10100) TITLE
      READ(NRD,10200) ILONG, ISHORT, IG, I39DEC
C**** ILONG = 0/1 : NO/YES : USE LONG METHOD
C**** ISHORT= 0/1 : NO/YES : USE SHORT METHOD
C**** IG    = 0   : USE G=1.0 FOR NEUTRON CAPTURE CORRECTION
C****               AT ALL COOLING TIMES
C**** IG    = 1   : USE MAXIMUM NEUTRON CAPTURE CORRECTION FACTORS
C****               INTERPOLATED FROM TABLE 10(ANSI/ANS-5.1-1979)
C**** I39DEC= 0/1 : NO/YES : CALCULATE AFTERHEAT POWER FROM
C****               U239 AND NP239
      READ(NRD,10200) NCOOLT,NOPP,NFISIS
C**** NCOOLT = NUMBER OF COOLING TIMES
C**** NOPP   = NUMBER OF IRRADIATION PERIODS
C**** NFISIS = NUMBER OF FISSIONABLE ISOTOPES
C****        = 1 FOR U235 ONLY
C****        = 2 FOR U235 AND PU239
C****        = 3 FOR U235, PU239, AND U238
      READ(NRD,10300) TIME, POWER
C**** TIME   = TOTAL OPERATING PERIOD(DAYS)
      READ(NRD,10300) (Q(I),I=1,NFISIS)
C**** Q      = TOTAL RECOVERABLE ENERGY ASSOCIATED WITH ONE FISSION
C****          (MEV/FISSION) IN ORDER OF U235, PU239, AND U238
      READ(NRD,10300) (TCOOL(K),K=1,NCOOLT)
C**** TCOOL  = ARRAY OF COOLING TIMES(DAYS)
      IF(ILONG.EQ.0) GO TO 110
      DO 100 ID=1,NOPP
         READ(NRD,10400) IPR,TA(IPR),(POW(I,IPR),I=1,NFISIS)
C**** IPR    = SUBSCRIPT IDENTIFYING IRRADIATION PERIOD
C**** TA(IPR)= LENGTH OF IRRADIATION PERIOD(DAYS)
C**** POW(I,IPR)= POWER(MW) GENERATED FROM FISSIONABLE ISOTOPE
C****             I DURING IRRADIATION PERIOD IPR
  100 CONTINUE
C**** SET DEFAULT VALUES OF NEUTRON CAPTURE CORRECTION FACTOR TO 1.0
  110 DO 120 K=1,NCOOLT
  120    G(K)=1.0
      IF(IG.EQ.0) GO TO 130
      DO 122 IT=1,NCOOLT
      TG=TCOOL(IT)*86400.
      IF(TG.GT.1.0E9) GO TO 121
      IND=0
      IORDER=3
      IMAX=55
      CALL LINT(GINT,TG,TGMAX,GMAX,IND,IORDER,IMAX,IEX)
      IF(GINT.LT.1.0) GINT=1.0
      G(IT)=GINT
      GO TO 122
  121 G(IT)=1.0
  122 CONTINUE
  130 IF (I39DEC.NE.0) READ(NRD,10300) QS,R
C**** QS     = EFFECTIVE ENERGY RELEASE PER FISSION (MEV/FISSION)
C****          EVALUATED FOR THE REACTOR COMPOSITION AT THE TIME
C****          OF SHUTDOWN
C**** R      = ATOMS OF U239 PRODUCED PER SECOND PER FISSION PER
C****          SECOND EVALUATIED FOR THE REACTOR COMPOSITION AT THE
C****          TIME OF SHUTDOWN
```

Figure 25

Fortran Program ANSIDECH Source Code (continued)

```
      WRITE(NPRT,10500) ILONG,ISHORT,IG,I39DEC
      WRITE(NPRT,10500) NCOOLT,NOPP,NFISIS
      WRITE(NPRT,10600) TIME,POWER
      WRITE(NPRT,10600) (Q(I),I=1,NFISIS)
      WRITE(NPRT,10600) (TCOOL(K),K=1,NCOOLT)
      WRITE(NPRT,10610) (G(K),K=1,NCOOLT)
      DO 140 K=1,NCOOLT
      TCDA(K)=TCOOL(K)
      TCOOL(K)=TCOOL(K)*(8.64E+04)
  140 CONTINUE
      TIME = TIME*(8.64E+04)
      IF(ILONG.EQ.0) GO TO 160
      DO 150 IPR=1,NOPP
         WRITE(NPRT,10700) IPR,TA(IPR),(POW(I,IPR),I=1,NFISIS)
  150 CONTINUE
  160 IF (I39DEC.NE.0) WRITE(NPRT,10600) QS,R
      IF (ILONG.EQ.0) GO TO 280
C**** LONG METHOD
      WRITE(NPRT,10800)
      WRITE(NPRT,10900)
      DO 170 J=1,NOPP
         TA(J) = TA(J) * (8.64E+04)
  170 CONTINUE
      DO 270 K=1,NCOOLT
         PDEC(K) = 0.0
         DO 230 N=1,NFISIS
            TALF = TCOOL(K)
            DO 210 J=1,NOPP
               IF (POW(N,J).EQ.0.0) TALF = TALF +TA(J)
               IF (POW(N,J).EQ.0.0) GO TO 210
               TC(J)=TA(J)
               DO 200 M=1,2
                  DECHP = 0.0
                  IF (M.EQ.2) TALF = TALF + TA(J)
                  DO 180 I=1,23
                     B = 0.0
                     C = XLAM(I,N) * TALF
                     IF (C.LT.50) B = EXP(-C)
                     D = 0.0
                     E = XLAM(I,N) * 1.0E+13
                     IF(E.LT.50.0) D=EXP(-E)
  180                DECHP = ALF(I,N) * B* (1-D) / XLAM(I,N) + DECHP
C                 IF(IG.EQ.1) GO TO 190
C                 WRITE(NPRT,11000) N,TCDA(K),DECHP
  190             CONTINUE
                  IF (M.EQ.1) DECHPT = DECHP
                  IF (M.EQ.2) DECHPT = DECHPT-DECHP
  200             CONTINUE
               PDEC(K) = PDEC(K) + POW(N,J) * DECHPT / Q(N)
               PDECIS(N,K) = PDEC(K)
  210          CONTINUE
C           IF (IG.EQ.1) GO TO 220
C           WRITE(NPRT,11100) K, PDEC(K)
C           GO TO 230
  220       PDECIS(N,K) = PDECIS(N,K) * (1.0E+06)
  230       CONTINUE
         DO 250 IS=1,NFISIS
            IF (IS.EQ.1) DHPIS(IS,K) = PDECIS(IS,K)
            IF (IS.EQ.1) GO TO 240
            DHPIS(IS,K) = PDECIS(IS,K) - PDECIS(IS-1,K)
  240       DECHPR(IS,K) = DHPIS(IS,K)/PDECIS(NFISIS,K)
  250       CONTINUE
         DO 260 N=1,NFISIS
            TDECHP = PDECIS(N,K) * G(K)
            WRITE(NPRT,11200) NAME(N),TCDA(K),DHPIS(N,K),PDECIS(N,K),
     *       DECHPR(N,K),G(K),TDECHP
            IF(N.EQ.NFISIS) WRITE(NPRT,11300)
  260       CONTINUE
  270    CONTINUE
  280 IF (ISHORT.EQ.0) GO TO 320
```

Figure 25

Fortran Program ANSIDECH Source Code (continued)

```
C**** SHORT METHOD
      WRITE(NPRT,11400)
      DO 310 K=1,NCOOLT
         T=TCOOL(K)
         DO 300 M=1,2
            DECHP=0.0
            IF (M.EQ.2) T=T+TIME
            DO 290 I=1,23
               B=0.0
               C=XLAM(I,1)*T
               IF (C.LT. 85.) B=EXP(-C)
               D=0.0
               E=XLAM(I,1)*1.0E+13
               IF (E.LT. 85.) D=EXP(-E)
  290          DECHP=ALF(I,1)*B*(1.0-D)/XLAM(I,1) + DECHP
            IF (M.EQ.1) DECHPT=DECHP
  300       IF (M.EQ.2) DECHPT=DECHPT-DECHP
         PDEC(K)=1.02E+06*POWER*DECHPT/Q(1)
         TDECHP=G(K)*PDEC(K)
  310    WRITE(NPRT,11500) TCDA(K),PDEC(K),G(K),TDECHP
  320 IF (I39DEC.EQ.0) GO TO 340
C**** U239 AND NP239 DECAY HEAT POWER.
      WRITE(NPRT,11600)
      DO 330 K=1,NCOOLT
         T=TCOOL(K)
         B=0.0
         C=LAM1*T
         IF (C.LT. 85.) B=EXP(-C)
         D=0.0
         E=LAM1*TIME
         IF (E.LT. 85.) D=EXP(-E)
         F239U(K)=E239U*R*(1.0-D)*B
         TERM2=(LAM2/(LAM1-LAM2))*(1.0-D)*B
         B=0.0
         C=LAM2*T
         IF (C.LT. 85.) B=EXP(-C)
         D=0.0
         E=LAM2*TIME
         IF (E.LT. 85.) D=EXP(-E)
         TERM1=(LAM1/(LAM1-LAM2))*(1.0-D)*B
         F239NP(K)=E239NP*R*(TERM1-TERM2)
         PDHE(K)=1.0E+06*POWER*(F239U(K)+F239NP(K))/QS
  330    WRITE(NPRT,11700) TCDA(K),F239U(K),F239NP(K),PDHE(K)
  340 CONTINUE
      GO TO 90
  350 CONTINUE
      STOP
10000 FORMAT(1X,20A4)
10100 FORMAT(/////,1X,20A4//)
10200 FORMAT(10I5)
10300 FORMAT(6E10.4)
10400 FORMAT( I3, 7X, 4F10.5, 30X)
10500 FORMAT (1X,10I5)
10600 FORMAT(6(2X,F10.1,2X))
10610 FORMAT(6(2X,F10.4,2X))
10700 FORMAT(1X,I3,7X,F10.3,1P3E11.4)
10800 FORMAT(///,1X,'****  LONG METHOD FOR FISSION PRODUCT DECAY HEAT PO
     *WER  ****')
10900 FORMAT(///,12X,12HCOOLING TIME,8X,7HISOTOPE,12X,5HTOTAL, 47X,8HADJ
     *USTED,/ 2X,7HISOTOPE,3X,14HAFTER SHUTDOWN,2X,16HDECAY HEAT POWER,
     * 2X,16HDECAY HEAT POWER,8X,5HRATIO,25X,16HDECAY HEAT POWER,/ 15X,
     * 6H(DAYS),12X,7H(WATTS),11X,7H(WATTS),8X, 13HISOTOPE/TOTAL,8X,7HG-
     *VALUE,11X,7H(WATTS)/)
11000 FORMAT( 5X,I5,12X,1E10.5,12X,1E10.5)
11100 FORMAT(1X,I5,5X,E10.4)
11200 FORMAT(2H  ,A6,1PE16.5,5E18.5)
11300 FORMAT(///)
```

Figure 25

Fortran Program ANSIDECH Source Code (continued)

```
11400 FORMAT(62H0****  SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER
     *  ****/14H0 COOLING TIME,25X,7HCAPTURE,9X,8HADJUSTED/67H AFTER SHU
     *TDOWN  DECAY HEAT POWER     CORRECTION   DECAY HEAT POWER/1H ,4X,6
     *H(DAYS),11X,7H(WATTS),10X,7HG-VALUE,10X,7H(WATTS)/)
11500 FORMAT(1H ,4(1PE13.5,4X))
11600 FORMAT(44H1****  U239 AND NP239 DECAY HEAT POWER  ****/14H0 COOLIN
     *G TIME/15H AFTER SHUTDOWN,10X,5HF239U,16X,6HF239NP,9X,16HDECAY HEA
     *T POWER/1H ,4X,6H(DAYS),4X,2(2X,20H(MEV/SEC)/(FISS/SEC)),7X,7H(WAT
     *TS)/)
11700 FORMAT(1H ,1PE13.5,7X,E12.5,2X,2(8X,E12.5))
      END
      SUBROUTINE LINT(YLAG,XI,X,Y,IND1,N1,IMAX,IEX)
C
C***  LAGRANGIAN INTERPOLATION
C***  XI IS THE INTERPOLATED ENTRY INTO THE X-ARRAY
C***  N IS THE ORDER OF LAGRANGIAN INTERPOLATION
C***  Y IS THE ARRAY FROM WHICH YLAG IS OBTAINED BY INTERPOLATION
C***  IND IS THE MIN-I FOR X(I).GT.XI
C***  IF IND=0, X-ARRAY WILL BE SEARCHED
C***  IMAX IS THE MAX INDEX OF X- AND Y-ARRAYS
C***  EXTRAPOLATION CAN OCCUR, IEX=-1 OR +1
C
      DIMENSION X(1),Y(1)
      IND=IND1
      N=N1
      IEX=0
      IF(N.LE.IMAX) GO TO 10
      N=IMAX
      IEX=N
   10 IF(IND.GT.0) GO TO 40
      DO 20 J=1,IMAX
         IF(XI-X(J)) 30,130,20
   20    CONTINUE
      IEX=1
      GO TO 70
   30 IND=J
   40 IF(IND.GT.1) GO TO 50
      IEX=-1
   50 INL=IND-(N+1)/2
      IF(INL.GT.0) GO TO 60
      INL=1
   60 INU=INL+N-1
      IF(INU.LE.IMAX) GO TO 80
   70 INL=IMAX-N+1
      INU=IMAX
   80 S=0.
      P=1.
      DO 110 J=INL,INU
         P=P*(XI-X(J))
      D=1.
      DO 100 I=INL,INU
         IF(I.NE.J) GO TO 90
         XD=XI
         GO TO 100
   90    XD=X(J)
  100    D=D*(XD-X(I))
  110 S=S+Y(J)/D
      YLAG=S*P
  120 RETURN
  130 YLAG=Y(J)
      GO TO 120
      END
```

TABLE 1

PROGRAM ANSIDECH INPUT DATA (ANSI.DAT) DESCRIPTION

CARD	VARIABLE	FORMAT	DESCRIPTION
1	TITLE	1X,20A4	PROBLEM TITLE
2	ILONG	10I5	0 = NO, DON'T USE LONG METHOD, 1 = YES, USE LONG METHOD
2	ISHORT	10I5	0 = NO, DON'T USE SHORT METHOD, 1 = YES, USE SHORT METHOD
2	IG	10I5	0 = USE G = 1.0 FOR NEUTRON CAPTURE CORRECTION AT ALL COOLING TIMES 1 = USE MAXIMUM NEUTRON CAPTURE CORRECTION FACTORS INTREPOLATED FROM TABLE 10 (ANSI/ANS-5.1-1979)
2	I39DEC	10I5	0 = DON'T CALCULATE AFTERHEAT POWER FROM U239 AND NP239 1 = CALCULATE AFTERHEAT POWER FROM U239 AND NP239
3	NCOOLT	10I5	NUMBER OF COOLING TIMES
3	NOPP	10I5	NUMBER OF IRRADIATION PERIODS
3	NFISIS	10I5	NUMBER OF FISSIONABLE ISOTOPES 1 = U235 ONLY 2 = U235 AND PU239 3 = U235, PU239, AND U238
4	TIME	6E10.4	TOTAL OPERATING PERIOD (DAYS)
4	POWER	6E10.4	MAXIMUM POWER LEVEL AT WHICH FUEL OPERATES WHILE IN THE CORE (MW/KG)
5	Q(I)	6E10.4	I = 1,NFISIS. TOTAL RECOVERABLE ENERGY ASSOCIATED WITH ONE FISSION (MEV/FISSION) FOR U235, PU239, AND U238
6	TCOOL(K)	6E10.4	K = 1,NCOOLT. ARRAY OF COOLING TIMES (DAYS)

TABLE 1

PROGRAM ANSIDECH INPUT DATA (ANSI.DAT) DESCRIPTION (continued)

CARD	VARIABLE	FORMAT	DESCRIPTION
7	IPR	I3,7X,4F10.5	SUBSCRIPT IDENTIFYING IRRADIATION PERIOD
7	TA(IPR)	I3,7X,4F10.5	LENGTH OF IRRADIATION PERIOD (DAYS)
7	POW(I,IPR)	I3,7X,4F10.5	I = 1,NFISIS. POWER (MW) GENERATED FROM FISSIONABLE ISOTOPE I DURING IRRADIATION PERIOD IPR

Figure 26

Program ANSIDECH Input File (ANSI.DAT)

```
DECAY HEAT PROBLEM 2.1.1 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9    1    3
  370.E+0    41.E+0
207.92E+0 207.92E+0 207.92E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1             370.    22.322    15.742     2.936
DECAY HEAT PROBLEM 2.1.2 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9    3    3
  690.E+0    43.E+0
206.56E+0 206.56E+0 206.56E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1             370.    29.670    10.546     2.784
 2              60.       0.        0.        0.
 3             260.    17.171    18.124     2.705
DECAY HEAT PROBLEM 2.1.3 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9    5    3
 1050.E+0    45.E+0
205.77E+0 205.77E+0 205.77E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1             370.    22.850     3.967     1.683
 2              60.       0.        0.        0.
 3             260.    28.723    13.356     2.920
 4              60.       0.        0.        0.
 5             300.    21.290    17.848     2.861
DECAY HEAT PROBLEM 2.1.4 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9    1    3
 1080.E+0  31.25E+0
206.19E+0 206.19E+0 206.19E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1            1080.    19.420     9.790     2.040
DECAY HEAT PROBLEM 2.1.4A W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9   10    3
 1080.E+0  31.25E+0
206.19E+0 206.19E+0 206.19E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1             108.    27.163     2.338     1.749
 2             108.    24.515     4.835     1.900
 3             108.    22.620     6.663     1.967
 4             108.    21.001     8.233     2.016
 5             108.    19.543     9.652     2.055
 6             108.    18.193    10.969     2.089
 7             108.    16.920    12.211     2.119
 8             108.    15.707    13.396     2.147
 9             108.    14.541    14.536     2.173
10             108.    13.411    15.640     2.199
```

Figure 26

Program ANSIDECH Input File (ANSI.DAT) (continued)

```
DECAY HEAT PROBLEM 2.1.5 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9   10    3
 1035.E+0    41.E+0
206.19E+0 206.19E+0 206.19E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1              150.    28.770     3.280     1.951
 2              150.    25.076     6.799     2.125
 3               60.       0.        0.        0.
 4              150.    26.722    11.611     2.667
 5               15.       0.        0.        0.
 6              150.    23.444    14.805     2.751
 7               45.       0.        0.        0.
 8              150.    18.854    16.070     2.576
 9               15.       0.        0.        0.
10              150.    16.545    18.327     2.628
DECAY HEAT PROBLEM 2.2.1 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9    1    3
  370.E+0    30.E+0
212.88E+0 212.88E+0 212.88E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1              370.    15.787    12.034     2.178
DECAY HEAT PROBLEM 2.2.2 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9    3    3
  690.E+0    30.E+0
211.36E+0 211.36E+0 211.36E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1              370.    23.360     4.905     1.734
 2               60.       0.        0.        0.
 3              260.    15.558     9.652     1.790
DECAY HEAT PROBLEM 2.2.3 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9    5    3
 1050.E+0    30.E+0
211.36E+0 211.36E+0 211.36E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1              370.    16.391     2.453     1.157
 2               60.       0.        0.        0.
 3              260.    19.315     8.781     1.904
 4               60.       0.        0.        0.
 5              300.    14.666    13.350     1.985
DECAY HEAT PROBLEM 2.2.3A W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9    6    3
 1080.E+0    30.E+0
211.36E+0 211.36E+0 211.36E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1              370.    16.391     2.453     1.157
 2               60.       0.        0.        0.
 3              260.    19.315     8.781     1.904
 4               60.       0.        0.        0.
 5              300.    14.666    13.350     1.985
 6               30.       0.        0.        0.
```

Figure 26

Program ANSIDECH Input File (ANSI.DAT) (continued)

```
DECAY HEAT PROBLEM 2.2.3B W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9    6    3
 1050.E+0    30.E+0
211.36E+0 211.36E+0 211.36E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1            185.    17.426     1.468     1.106
 2            185.    15.346     3.446     1.208
 3             60.        0.        0.        0.
 4            130.    20.478     7.642     1.880
 5            130.    18.147     9.925     1.928
 6             60.        0.        0.        0.
 7            150.    15.830    12.202     1.967
 8            150.    13.497    14.501     2.002
DECAY HEAT PROBLEM 2.2.4 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9    1    3
 1080.E+0    25.E+0
211.35E+0 211.35E+0 211.35E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1           1080.    16.056     7.396     1.547
DECAY HEAT PROBLEM 2.2.5 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9   10    3
 1035.E+0    33.E+0
211.36E+0 211.36E+0 211.36E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1            150.    23.344     2.065     1.591
 2            150.    23.979     5.311     1.710
 3             60.        0.        0.        0.
 4            150.    19.251     7.811     1.938
 5             15.        0.        0.        0.
 6            150.    19.986    11.075     1.939
 7             45.        0.        0.        0.
 8            150.    14.160    11.883     1.957
 9             15.        0.        0.        0.
10            150.    14.817    15.237     1.947
DECAY HEAT PROBLEM 2.2.5A W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9   12    3
 1080.E+0    33.E+0
211.36E+0 211.36E+0 211.36E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1            150.    23.344     2.065     1.591
 2             15.        0.        0.        0.
 3            150.    23.979     5.311     1.710
 4             45.        0.        0.        0.
 5            150.    19.251     7.811     1.938
 6             15.        0.        0.        0.
 7            150.    19.986    11.075     1.939
 8             45.        0.        0.        0.
 9            150.    14.160    11.883     1.957
10             15.        0.        0.        0.
11            150.    14.817    15.237     1.947
12             45.        0.        0.        0.
```

Figure 26

Program ANSIDECH Input File (ANSI.DAT) (continued)

```
DECAY HEAT PROBLEM 2.2.6 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9   10    3
 1035.E+0    33.E+0
211.36E+0 211.36E+0 211.36E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1              150.    27.096     2.341     1.564
 2              150.    20.228     5.032     1.740
 3               60.        0.        0.        0.
 4              150.    22.513     8.597     1.889
 5               15.        0.        0.        0.
 6              150.    16.724    10.286     1.989
 7               45.        0.        0.        0.
 8              150.    16.888    13.195     1.917
 9               15.        0.        0.        0.
10              150.    12.089    13.923     1.988
DECAY HEAT PROBLEM 2.2.6A W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   9   12    3
 1080.E+0    33.E+0
211.36E+0 211.36E+0 211.36E+0
365.25E+01095.75E+0 3652.5E+010957.5E+0 36525.E+0109575.E+0
36525.E+1109575.E+1 36525.E+2
 1              150.    27.096     2.341     1.564
 2               15.        0.        0.        0.
 3              150.    20.228     5.032     1.740
 4               45.        0.        0.        0.
 5              150.    22.513     8.597     1.889
 6               15.        0.        0.        0.
 7              150.    16.724    10.286     1.989
 8               45.        0.        0.        0.
 9              150.    16.888    13.195     1.917
10               15.        0.        0.        0.
11              150.    12.089    13.923     1.988
12               45.        0.        0.        0.
DECAY HEAT PROBLEM 2.3.1 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   1    5    3
 1069.E+0 31.827E+0
206.79E+0 206.79E+0 206.79E+0
  864.E+0
 1              310.    21.964     4.735     1.762
 2               64.        0.        0.        0.
 3              321.    18.224    11.429     2.174
 4               69.        0.        0.        0.
 5              305.    12.256    14.600     2.073
DECAY HEAT PROBLEM 2.3.2A W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   1    5    3
 1069.E+0 32.475E+0
206.90E+0 206.90E+0 206.90E+0
  962.E+0
 1              310.    22.348     4.892     1.801
 2               64.        0.        0.        0.
 3              321.    18.441    11.812     2.222
 4               69.        0.        0.        0.
 5              305.    12.303    15.095     2.120
```

Figure 26

Program ANSIDECH Input File (ANSI.DAT) (continued)

```
DECAY HEAT PROBLEM 2.3.2B W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   1    5    3
 1069.E+0 32.475E+0
206.90E+0 206.90E+0 206.90E+0
  1143.E+0
 1              310.    22.348     4.892     1.801
 2               64.        0.        0.        0.
 3              321.    18.441    11.812     2.222
 4               69.        0.        0.        0.
 5              305.    12.303    15.095     2.120
DECAY HEAT PROBLEM 2.3.3 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS
   1    1    1    0
   1    5    3
 1069.E+0 30.253E+0
206.54E+0 206.54E+0 206.54E+0
  963.E+0
 1              310.    21.023     4.361     1.670
 2               64.        0.        0.        0.
 3              321.    17.677    10.518     2.058
 4               69.        0.        0.        0.
 5              305.    12.113    13.424     1.961
END
```

Figure 27

Program ANSIDECH Output

```
DECAY HEAT PROBLEM 2.1.1 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9    1    3
     370.0        41.0
     207.9       207.9       207.9
     365.3      1095.8      3652.5      10957.5      36525.0     109575.0
  365250.0   1095750.0   3652500.0
    1.3850      1.5986      1.1156       1.0079       1.0000       1.0000
    1.0000      1.0000      1.0000
 1          370.000 2.2322E+01 1.5742E+01 2.9360E+00
```

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	2.96004E+03	2.96004E+03	4.79850E-01	1.38505E+00	4.09980E+03
PU-239	3.65250E+02	2.73523E+03	5.69527E+03	4.43406E-01	1.38505E+00	7.88822E+03
U-238	3.65250E+02	4.73412E+02	6.16869E+03	7.67444E-02	1.38505E+00	8.54392E+03
U-235	1.09575E+03	6.85128E+02	6.85128E+02	4.71440E-01	1.59861E+00	1.09526E+03
PU-239	1.09575E+03	6.57692E+02	1.34282E+03	4.52561E-01	1.59861E+00	2.14665E+03
U-238	1.09575E+03	1.10448E+02	1.45327E+03	7.59994E-02	1.59861E+00	2.32321E+03
U-235	3.65250E+03	2.42002E+02	2.42002E+02	6.33407E-01	1.11561E+00	2.69979E+02
PU-239	3.65250E+03	1.16059E+02	3.58061E+02	3.03769E-01	1.11561E+00	3.99456E+02
U-238	3.65250E+03	2.40029E+01	3.82064E+02	6.28243E-02	1.11561E+00	4.26233E+02
U-235	1.09575E+04	1.45766E+02	1.45766E+02	6.40105E-01	1.00794E+00	1.46924E+02
PU-239	1.09575E+04	6.77921E+01	2.13559E+02	2.97696E-01	1.00794E+00	2.15254E+02
U-238	1.09575E+04	1.41641E+01	2.27723E+02	6.21988E-02	1.00794E+00	2.29531E+02

Figure 27

Program ANSIDECH Output (continued)

U-235	3.65250E+04	2.72796E+01	2.72796E+01	6.33165E-01	1.00000E+00	2.72796E+01
PU-239	3.65250E+04	1.31052E+01	4.03849E+01	3.04175E-01	1.00000E+00	4.03849E+01
U-238	3.65250E+04	2.69968E+00	4.30846E+01	6.26600E-02	1.00000E+00	4.30846E+01
U-235	1.09575E+05	2.37316E-01	2.37316E-01	6.02425E-01	1.00000E+00	2.37316E-01
PU-239	1.09575E+05	1.30941E-01	3.68257E-01	3.32393E-01	1.00000E+00	3.68257E-01
U-238	1.09575E+05	2.56774E-02	3.93934E-01	6.51819E-02	1.00000E+00	3.93934E-01
U-235	3.65250E+05	1.07484E-03	1.07484E-03	2.89168E-01	1.00000E+00	1.07484E-03
PU-239	3.65250E+05	2.46792E-03	3.54277E-03	6.63952E-01	1.00000E+00	3.54277E-03
U-238	3.65250E+05	1.74251E-04	3.71702E-03	4.68793E-02	1.00000E+00	3.71702E-03
U-235	1.09575E+06	1.04985E-03	1.04985E-03	2.99735E-01	1.00000E+00	1.04985E-03
PU-239	1.09575E+06	2.29164E-03	3.34149E-03	6.54271E-01	1.00000E+00	3.34149E-03
U-238	1.09575E+06	1.61100E-04	3.50259E-03	4.59946E-02	1.00000E+00	3.50259E-03
U-235	3.65250E+06	9.74859E-04	9.74859E-04	2.90958E-01	1.00000E+00	9.74859E-04
PU-239	3.65250E+06	2.22113E-03	3.19599E-03	6.62923E-01	1.00000E+00	3.19599E-03
U-238	3.65250E+06	1.54525E-04	3.35051E-03	4.61196E-02	1.00000E+00	3.35051E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	5.54560E+03	1.38505E+00	7.68092E+03
1.09575E+03	1.28358E+03	1.59861E+00	2.05195E+03
3.65250E+03	4.53387E+02	1.11561E+00	5.05803E+02
1.09575E+04	2.73092E+02	1.00794E+00	2.75260E+02
3.65250E+04	5.11081E+01	1.00000E+00	5.11081E+01
1.09575E+05	4.44608E-01	1.00000E+00	4.44608E-01
3.65250E+05	2.01371E-03	1.00000E+00	2.01371E-03
1.09575E+06	1.96688E-03	1.00000E+00	1.96688E-03
3.65250E+06	1.82639E-03	1.00000E+00	1.82639E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.1.2 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

  1    1    1    0
  9    3    3
    690.0        43.0
    206.6       206.6       206.6
    365.3      1095.8      3652.5      10957.5      36525.0     109575.0
 365250.0   1095750.0   3652500.0
   1.3850      1.5986      1.1156       1.0079       1.0000       1.0000
   1.0000      1.0000      1.0000
1          370.000 2.9670E+01 1.0546E+01 2.7840E+00
2           60.000  .0000E+00  .0000E+00  .0000E+00
3          260.000 1.7171E+01 1.8124E+01 2.7050E+00

****  LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER  ****
```

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	4.61148E+03	4.61148E+03	5.74323E-01	1.38505E+00	6.38711E+03
PU-239	3.65250E+02	2.83368E+03	7.44515E+03	3.52913E-01	1.38505E+00	1.03119E+04
U-238	3.65250E+02	5.84253E+02	8.02941E+03	7.27641E-02	1.38505E+00	1.11211E+04
U-235	1.09575E+03	1.15856E+03	1.15856E+03	5.64315E-01	1.59861E+00	1.85210E+03
PU-239	1.09575E+03	7.47140E+02	1.90570E+03	3.63918E-01	1.59861E+00	3.04649E+03
U-238	1.09575E+03	1.47340E+02	2.05304E+03	7.17666E-02	1.59861E+00	3.28203E+03
U-235	3.65250E+03	4.51579E+02	4.51579E+02	6.86234E-01	1.11561E+00	5.03785E+02
PU-239	3.65250E+03	1.68536E+02	6.20114E+02	2.56113E-01	1.11561E+00	6.91805E+02
U-238	3.65250E+03	3.79391E+01	6.58054E+02	5.76536E-02	1.11561E+00	7.34130E+02
U-235	1.09575E+04	2.72389E+02	2.72389E+02	6.90434E-01	1.00794E+00	2.74552E+02
PU-239	1.09575E+04	9.96027E+01	3.71992E+02	2.52466E-01	1.00794E+00	3.74946E+02
U-238	1.09575E+04	2.25271E+01	3.94519E+02	5.71001E-02	1.00794E+00	3.97652E+02
U-235	3.65250E+04	5.09814E+01	5.09814E+01	6.84030E-01	1.00000E+00	5.09814E+01
PU-239	3.65250E+04	1.92557E+01	7.02371E+01	2.58358E-01	1.00000E+00	7.02371E+01
U-238	3.65250E+04	4.29386E+00	7.45310E+01	5.76118E-02	1.00000E+00	7.45310E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	4.43590E-01	4.43590E-01	6.55211E-01	1.00000E+00	4.43590E-01
PU-239	1.09575E+05	1.92568E-01	6.36158E-01	2.84436E-01	1.00000E+00	6.36158E-01
U-238	1.09575E+05	4.08603E-02	6.77018E-01	6.03533E-02	1.00000E+00	6.77018E-01
U-235	3.65250E+05	1.99936E-03	1.99936E-03	3.38476E-01	1.00000E+00	1.99936E-03
PU-239	3.65250E+05	3.62540E-03	5.62476E-03	6.13753E-01	1.00000E+00	5.62476E-03
U-238	3.65250E+05	2.82181E-04	5.90695E-03	4.77710E-02	1.00000E+00	5.90695E-03
U-235	1.09575E+06	1.96592E-03	1.96592E-03	3.45193E-01	1.00000E+00	1.96592E-03
PU-239	1.09575E+06	3.46567E-03	5.43159E-03	6.08534E-01	1.00000E+00	5.43159E-03
U-238	1.09575E+06	2.63531E-04	5.69512E-03	4.62731E-02	1.00000E+00	5.69512E-03
U-235	3.65250E+06	1.84623E-03	1.84623E-03	3.39959E-01	1.00000E+00	1.84623E-03
PU-239	3.65250E+06	3.33641E-03	5.18264E-03	6.14355E-01	1.00000E+00	5.18264E-03
U-238	3.65250E+06	2.48107E-04	5.43075E-03	4.56856E-02	1.00000E+00	5.43075E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	8.03328E+03	1.38505E+00	1.11265E+04
1.09575E+03	2.13900E+03	1.59861E+00	3.41944E+03
3.65250E+03	8.81337E+02	1.11561E+00	9.83227E+02
1.09575E+04	5.31997E+02	1.00794E+00	5.36221E+02
3.65250E+04	9.95750E+01	1.00000E+00	9.95750E+01
1.09575E+05	8.66454E-01	1.00000E+00	8.66454E-01
3.65250E+05	3.95506E-03	1.00000E+00	3.95506E-03
1.09575E+06	3.85618E-03	1.00000E+00	3.85618E-03
3.65250E+06	3.65843E-03	1.00000E+00	3.65843E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.1.3 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9    5    3
   1050.0        45.0
    205.8       205.8       205.8
    365.3      1095.8      3652.5      10957.5      36525.0     109575.0
 365250.0   1095750.0   3652500.0
   1.3850      1.5986      1.1156       1.0079       1.0000       1.0000
   1.0000      1.0000      1.0000
 1          370.000 2.2850E+01 3.9670E+00 1.6830E+00
 2           60.000  .0000E+00  .0000E+00  .0000E+00
 3          260.000 2.8723E+01 1.3356E+01 2.9200E+00
 4           60.000  .0000E+00  .0000E+00  .0000E+00
 5          300.000 2.1290E+01 1.7848E+01 2.8610E+00
```

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	4.69871E+03	4.69871E+03	6.47472E-01	1.38505E+00	6.50793E+03
PU-239	3.65250E+02	2.05082E+03	6.74953E+03	2.82599E-01	1.38505E+00	9.34842E+03
U-238	3.65250E+02	5.07472E+02	7.25700E+03	6.99286E-02	1.38505E+00	1.00513E+04
U-235	1.09575E+03	1.38806E+03	1.38806E+03	6.42807E-01	1.59861E+00	2.21897E+03
PU-239	1.09575E+03	6.25826E+02	2.01369E+03	2.89818E-01	1.59861E+00	3.21943E+03
U-238	1.09575E+03	1.45486E+02	2.15937E+03	6.73741E-02	1.59861E+00	3.45200E+03
U-235	3.65250E+03	6.43802E+02	6.43802E+02	7.25283E-01	1.11561E+00	7.18231E+02
PU-239	3.65250E+03	1.95821E+02	8.39623E+02	2.20605E-01	1.11561E+00	9.36691E+02
U-238	3.65250E+03	4.80331E+01	8.87656E+02	5.41123E-02	1.11561E+00	9.90277E+02
U-235	1.09575E+04	3.89313E+02	3.89313E+02	7.27235E-01	1.00794E+00	3.92405E+02
PU-239	1.09575E+04	1.17261E+02	5.06574E+02	2.19043E-01	1.00794E+00	5.10597E+02
U-238	1.09575E+04	2.87592E+01	5.35333E+02	5.37221E-02	1.00794E+00	5.39584E+02
U-235	3.65250E+04	7.28788E+01	7.28788E+01	7.21342E-01	1.00000E+00	7.28788E+01
PU-239	3.65250E+04	2.26713E+01	9.55501E+01	2.24396E-01	1.00000E+00	9.55501E+01
U-238	3.65250E+04	5.48217E+00	1.01032E+02	5.42616E-02	1.00000E+00	1.01032E+02

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	6.34355E-01	6.34355E-01	6.94395E-01	1.00000E+00	6.34355E-01
PU-239	1.09575E+05	2.26962E-01	8.61317E-01	2.48443E-01	1.00000E+00	8.61317E-01
U-238	1.09575E+05	5.22196E-02	9.13536E-01	5.71620E-02	1.00000E+00	9.13536E-01
U-235	3.65250E+05	2.89742E-03	2.89742E-03	3.85121E-01	1.00000E+00	2.89742E-03
PU-239	3.65250E+05	4.26029E-03	7.15771E-03	5.66272E-01	1.00000E+00	7.15771E-03
U-238	3.65250E+05	3.65684E-04	7.52339E-03	4.86062E-02	1.00000E+00	7.52339E-03
U-235	1.09575E+06	2.82338E-03	2.82338E-03	3.86240E-01	1.00000E+00	2.82338E-03
PU-239	1.09575E+06	4.14479E-03	6.96817E-03	5.67009E-01	1.00000E+00	6.96817E-03
U-238	1.09575E+06	3.41746E-04	7.30992E-03	4.67510E-02	1.00000E+00	7.30992E-03
U-235	3.65250E+06	2.68923E-03	2.68923E-03	3.86606E-01	1.00000E+00	2.68923E-03
PU-239	3.65250E+06	3.94521E-03	6.63444E-03	5.67168E-01	1.00000E+00	6.63444E-03
U-238	3.65250E+06	3.21551E-04	6.95599E-03	4.62265E-02	1.00000E+00	6.95599E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	9.91443E+03	1.38505E+00	1.37320E+04
1.09575E+03	2.96727E+03	1.59861E+00	4.74351E+03
3.65250E+03	1.38973E+03	1.11561E+00	1.55040E+03
1.09575E+04	8.40483E+02	1.00794E+00	8.47158E+02
3.65250E+04	1.57339E+02	1.00000E+00	1.57339E+02
1.09575E+05	1.36956E+00	1.00000E+00	1.36956E+00
3.65250E+05	6.38816E-03	1.00000E+00	6.38816E-03
1.09575E+06	6.12848E-03	1.00000E+00	6.12848E-03
3.65250E+06	5.81686E-03	1.00000E+00	5.81686E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.1.4 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9    1    3
    1080.0          31.3
     206.2         206.2          206.2
     365.3        1095.8         3652.5       10957.5       36525.0      109575.0
  365250.0     1095750.0      3652500.0
    1.3850        1.5986         1.1156        1.0079        1.0000        1.0000
    1.0000        1.0000         1.0000
 1          1080.000 1.9420E+01 9.7900E+00 2.0400E+00
```

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	4.22582E+03	4.22582E+03	5.52450E-01	1.38505E+00	5.85296E+03
PU-239	3.65250E+02	2.87468E+03	7.10050E+03	3.75813E-01	1.38505E+00	9.83453E+03
U-238	3.65250E+02	5.48729E+02	7.64923E+03	7.17366E-02	1.38505E+00	1.05945E+04
U-235	1.09575E+03	1.27577E+03	1.27577E+03	5.74340E-01	1.59861E+00	2.03946E+03
PU-239	1.09575E+03	7.93532E+02	2.06930E+03	3.57242E-01	1.59861E+00	3.30801E+03
U-238	1.09575E+03	1.51975E+02	2.22128E+03	6.84178E-02	1.59861E+00	3.55096E+03
U-235	3.65250E+03	6.02876E+02	6.02876E+02	7.05730E-01	1.11561E+00	6.72574E+02
PU-239	3.65250E+03	2.04018E+02	8.06894E+02	2.38825E-01	1.11561E+00	9.00178E+02
U-238	3.65250E+03	4.73648E+01	8.54259E+02	5.54455E-02	1.11561E+00	9.53019E+02
U-235	1.09575E+04	3.64661E+02	3.64661E+02	7.09069E-01	1.00794E+00	3.67556E+02
PU-239	1.09575E+04	1.21309E+02	4.85970E+02	2.35981E-01	1.00794E+00	4.89229E+02
U-238	1.09575E+04	2.83115E+01	5.14281E+02	5.50506E-02	1.00794E+00	5.18365E+02
U-235	3.65250E+04	6.82654E+01	6.82654E+01	7.02932E-01	1.00000E+00	6.82654E+01
PU-239	3.65250E+04	2.34530E+01	9.17185E+01	2.41497E-01	1.00000E+00	9.17185E+01
U-238	3.65250E+04	5.39677E+00	9.71152E+01	5.55708E-02	1.00000E+00	9.71152E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	5.94236E-01	5.94236E-01	6.75050E-01	1.00000E+00	5.94236E-01
PU-239	1.09575E+05	2.34652E-01	8.28888E-01	2.66563E-01	1.00000E+00	8.28888E-01
U-238	1.09575E+05	5.13974E-02	8.80285E-01	5.83873E-02	1.00000E+00	8.80285E-01
U-235	3.65250E+05	2.78500E-03	2.78500E-03	3.68303E-01	1.00000E+00	2.78500E-03
PU-239	3.65250E+05	4.42196E-03	7.20697E-03	5.84783E-01	1.00000E+00	7.20697E-03
U-238	3.65250E+05	3.54751E-04	7.56172E-03	4.69140E-02	1.00000E+00	7.56172E-03
U-235	1.09575E+06	2.67536E-03	2.67536E-03	3.67900E-01	1.00000E+00	2.67536E-03
PU-239	1.09575E+06	4.26720E-03	6.94255E-03	5.86801E-01	1.00000E+00	6.94255E-03
U-238	1.09575E+06	3.29412E-04	7.27196E-03	4.52989E-02	1.00000E+00	7.27196E-03
U-235	3.65250E+06	2.52185E-03	2.52185E-03	3.65187E-01	1.00000E+00	2.52185E-03
PU-239	3.65250E+06	4.06821E-03	6.59006E-03	5.89113E-01	1.00000E+00	6.59006E-03
U-238	3.65250E+06	3.15590E-04	6.90565E-03	4.57003E-02	1.00000E+00	6.90565E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	6.93604E+03	1.38505E+00	9.60675E+03
1.09575E+03	2.09398E+03	1.59861E+00	3.34747E+03
3.65250E+03	9.89530E+02	1.11561E+00	1.10393E+03
1.09575E+04	5.98535E+02	1.00794E+00	6.03288E+02
3.65250E+04	1.12047E+02	1.00000E+00	1.12047E+02
1.09575E+05	9.75349E-01	1.00000E+00	9.75349E-01
3.65250E+05	4.57116E-03	1.00000E+00	4.57116E-03
1.09575E+06	4.39119E-03	1.00000E+00	4.39119E-03
3.65250E+06	4.13924E-03	1.00000E+00	4.13924E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.1.4A W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9   10    3
    1080.0          31.3
     206.2         206.2          206.2
     365.3        1095.8         3652.5        10957.5        36525.0       109575.0
  365250.0     1095750.0      3652500.0
    1.3850        1.5986         1.1156         1.0079         1.0000         1.0000
    1.0000        1.0000         1.0000
 1          108.000 2.7163E+01 2.3380E+00 1.7490E+00
 2          108.000 2.4515E+01 4.8350E+00 1.9000E+00
 3          108.000 2.2620E+01 6.6630E+00 1.9670E+00
 4          108.000 2.1001E+01 8.2330E+00 2.0160E+00
 5          108.000 1.9543E+01 9.6520E+00 2.0550E+00
 6          108.000 1.8193E+01 1.0969E+01 2.0890E+00
 7          108.000 1.6920E+01 1.2211E+01 2.1190E+00
 8          108.000 1.5707E+01 1.3396E+01 2.1470E+00
 9          108.000 1.4541E+01 1.4536E+01 2.1730E+00
10          108.000 1.3411E+01 1.5640E+01 2.1990E+00


**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****
```

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	4.81342E+03	4.81342E+03	6.41890E-01	1.38505E+00	6.66682E+03
PU-239	3.65250E+02	2.15906E+03	6.97248E+03	2.87919E-01	1.38505E+00	9.65721E+03
U-238	3.65250E+02	5.26351E+02	7.49883E+03	7.01911E-02	1.38505E+00	1.03862E+04
U-235	1.09575E+03	1.35688E+03	1.35688E+03	6.27383E-01	1.59861E+00	2.16913E+03
PU-239	1.09575E+03	6.57707E+02	2.01459E+03	3.04105E-01	1.59861E+00	3.22055E+03
U-238	1.09575E+03	1.48175E+02	2.16276E+03	6.85120E-02	1.59861E+00	3.45742E+03
U-235	3.65250E+03	6.04217E+02	6.04217E+02	7.07738E-01	1.11561E+00	6.74070E+02
PU-239	3.65250E+03	2.02207E+02	8.06425E+02	2.36852E-01	1.11561E+00	8.99655E+02
U-238	3.65250E+03	4.73052E+01	8.53730E+02	5.54100E-02	1.11561E+00	9.52429E+02
U-235	1.09575E+04	3.65186E+02	3.65186E+02	7.09804E-01	1.00794E+00	3.68086E+02
PU-239	1.09575E+04	1.21007E+02	4.86193E+02	2.35198E-01	1.00794E+00	4.90054E+02
U-238	1.09575E+04	2.82957E+01	5.14489E+02	5.49976E-02	1.00794E+00	5.18574E+02
U-235	3.65250E+04	6.83599E+01	6.83599E+01	7.03660E-01	1.00000E+00	6.83599E+01
PU-239	3.65250E+04	2.33953E+01	9.17553E+01	2.40819E-01	1.00000E+00	9.17553E+01
U-238	3.65250E+04	5.39379E+00	9.71491E+01	5.55208E-02	1.00000E+00	9.71491E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	5.94962E-01	5.94962E-01	6.75717E-01	1.00000E+00	5.94962E-01
PU-239	1.09575E+05	2.34157E-01	8.29119E-01	2.65940E-01	1.00000E+00	8.29119E-01
U-238	1.09575E+05	5.13704E-02	8.80490E-01	5.83430E-02	1.00000E+00	8.80490E-01
U-235	3.65250E+05	2.77602E-03	2.77602E-03	3.67822E-01	1.00000E+00	2.77602E-03
PU-239	3.65250E+05	4.41617E-03	7.19219E-03	5.85143E-01	1.00000E+00	7.19219E-03
U-238	3.65250E+05	3.54979E-04	7.54716E-03	4.70348E-02	1.00000E+00	7.54716E-03
U-235	1.09575E+06	2.67081E-03	2.67081E-03	3.65646E-01	1.00000E+00	2.67081E-03
PU-239	1.09575E+06	4.30353E-03	6.97434E-03	5.89172E-01	1.00000E+00	6.97434E-03
U-238	1.09575E+06	3.30030E-04	7.30437E-03	4.51825E-02	1.00000E+00	7.30437E-03
U-235	3.65250E+06	2.51422E-03	2.51422E-03	3.63299E-01	1.00000E+00	2.51422E-03
PU-239	3.65250E+06	4.09028E-03	6.60450E-03	5.91035E-01	1.00000E+00	6.60450E-03
U-238	3.65250E+06	3.16028E-04	6.92053E-03	4.56653E-02	1.00000E+00	6.92053E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	6.93604E+03	1.38505E+00	9.60675E+03
1.09575E+03	2.09398E+03	1.59861E+00	3.34747E+03
3.65250E+03	9.89530E+02	1.11561E+00	1.10393E+03
1.09575E+04	5.98535E+02	1.00794E+00	6.03289E+02
3.65250E+04	1.12047E+02	1.00000E+00	1.12047E+02
1.09575E+05	9.75349E-01	1.00000E+00	9.75349E-01
3.65250E+05	4.57116E-03	1.00000E+00	4.57116E-03
1.09575E+06	4.39119E-03	1.00000E+00	4.39119E-03
3.65250E+06	4.13924E-03	1.00000E+00	4.13924E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.1.5 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9   10    3
  1035.0        41.0
   206.2       206.2        206.2
   365.3      1095.8       3652.5       10957.5       36525.0       109575.0
365250.0    1095750.0    3652500.0
  1.3850       1.5986       1.1156        1.0079        1.0000        1.0000
  1.0000       1.0000       1.0000
 1          150.000 2.8770E+01 3.2800E+00 1.9510E+00
 2          150.000 2.5076E+01 6.7990E+00 2.1250E+00
 3           60.000  .0000E+00  .0000E+00  .0000E+00
 4          150.000 2.6722E+01 1.1611E+01 2.6670E+00
 5           15.000  .0000E+00  .0000E+00  .0000E+00
 6          150.000 2.3444E+01 1.4805E+01 2.7510E+00
 7           45.000  .0000E+00  .0000E+00  .0000E+00
 8          150.000 1.8854E+01 1.6070E+01 2.5760E+00
 9           15.000  .0000E+00  .0000E+00  .0000E+00
10          150.000 1.6545E+01 1.8327E+01 2.6280E+00
```

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	4.90874E+03	4.90874E+03	6.39742E-01	1.38505E+00	6.79883E+03
PU-239	3.65250E+02	2.22550E+03	7.13423E+03	2.90043E-01	1.38505E+00	9.88125E+03
U-238	3.65250E+02	5.38757E+02	7.67299E+03	7.02148E-02	1.38505E+00	1.06275E+04
U-235	1.09575E+03	1.36883E+03	1.36883E+03	6.25128E-01	1.59861E+00	2.18823E+03
PU-239	1.09575E+03	6.70595E+02	2.03942E+03	3.06253E-01	1.59861E+00	3.26025E+03
U-238	1.09575E+03	1.50252E+02	2.18968E+03	6.86185E-02	1.59861E+00	3.50045E+03
U-235	3.65250E+03	6.04755E+02	6.04755E+02	7.07576E-01	1.11561E+00	6.74670E+02
PU-239	3.65250E+03	2.02562E+02	8.07317E+02	2.37002E-01	1.11561E+00	9.00650E+02
U-238	3.65250E+03	4.73685E+01	8.54686E+02	5.54221E-02	1.11561E+00	9.53495E+02
U-235	1.09575E+04	3.65468E+02	3.65468E+02	7.09748E-01	1.00794E+00	3.68371E+02
PU-239	1.09575E+04	1.21137E+02	4.86605E+02	2.35251E-01	1.00794E+00	4.90469E+02
U-238	1.09575E+04	2.83216E+01	5.14927E+02	5.50012E-02	1.00794E+00	5.19016E+02
U-235	3.65250E+04	6.84124E+01	6.84124E+01	7.03603E-01	1.00000E+00	6.84124E+01
PU-239	3.65250E+04	2.34203E+01	9.18327E+01	2.40872E-01	1.00000E+00	9.18327E+01
U-238	3.65250E+04	5.39873E+00	9.72315E+01	5.55245E-02	1.00000E+00	9.72315E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	5.95387E-01	5.95387E-01	6.75651E-01	1.00000E+00	5.95387E-01
PU-239	1.09575E+05	2.34394E-01	8.29781E-01	2.65993E-01	1.00000E+00	8.29781E-01
U-238	1.09575E+05	5.14240E-02	8.81205E-01	5.83564E-02	1.00000E+00	8.81205E-01
U-235	3.65250E+05	2.79365E-03	2.79365E-03	3.68887E-01	1.00000E+00	2.79365E-03
PU-239	3.65250E+05	4.42268E-03	7.21633E-03	5.83992E-01	1.00000E+00	7.21633E-03
U-238	3.65250E+05	3.56858E-04	7.57319E-03	4.71212E-02	1.00000E+00	7.57319E-03
U-235	1.09575E+06	2.66841E-03	2.66841E-03	3.64855E-01	1.00000E+00	2.66841E-03
PU-239	1.09575E+06	4.30954E-03	6.97795E-03	5.89250E-01	1.00000E+00	6.97795E-03
U-238	1.09575E+06	3.35658E-04	7.31361E-03	4.58950E-02	1.00000E+00	7.31361E-03
U-235	3.65250E+06	2.50009E-03	2.50009E-03	3.63271E-01	1.00000E+00	2.50009E-03
PU-239	3.65250E+06	4.06964E-03	6.56974E-03	5.91331E-01	1.00000E+00	6.56974E-03
U-238	3.65250E+06	3.12435E-04	6.88217E-03	4.53977E-02	1.00000E+00	6.88217E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	8.97093E+03	1.38505E+00	1.24252E+04
1.09575E+03	2.67312E+03	1.59861E+00	4.27328E+03
3.65250E+03	1.24627E+03	1.11561E+00	1.39035E+03
1.09575E+04	7.53666E+02	1.00794E+00	7.59651E+02
3.65250E+04	1.41086E+02	1.00000E+00	1.41086E+02
1.09575E+05	1.22804E+00	1.00000E+00	1.22804E+00
3.65250E+05	5.71402E-03	1.00000E+00	5.71402E-03
1.09575E+06	5.52513E-03	1.00000E+00	5.52513E-03
3.65250E+06	5.19457E-03	1.00000E+00	5.19457E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.2.1 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9    1    3
     370.0        30.0
     212.9       212.9       212.9
     365.3      1095.8      3652.5      10957.5      36525.0     109575.0
  365250.0   1095750.0   3652500.0
    1.3850      1.5986      1.1156       1.0079       1.0000       1.0000
    1.0000      1.0000      1.0000
 1          370.000 1.5787E+01 1.2034E+01 2.1780E+00
```

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	2.04468E+03	2.04468E+03	4.61562E-01	1.38505E+00	2.83198E+03
PU-239	3.65250E+02	2.04223E+03	4.08692E+03	4.61009E-01	1.38505E+00	5.66057E+03
U-238	3.65250E+02	3.43007E+02	4.42992E+03	7.74295E-02	1.38505E+00	6.13565E+03
U-235	1.09575E+03	4.73260E+02	4.73260E+02	4.53165E-01	1.59861E+00	7.56560E+02
PU-239	1.09575E+03	4.91060E+02	9.64319E+02	4.70209E-01	1.59861E+00	1.54157E+03
U-238	1.09575E+03	8.00238E+01	1.04434E+03	7.66260E-02	1.59861E+00	1.66950E+03
U-235	3.65250E+03	1.67165E+02	1.67165E+02	6.16367E-01	1.11561E+00	1.86491E+02
PU-239	3.65250E+03	8.66543E+01	2.53820E+02	3.19509E-01	1.11561E+00	2.83164E+02
U-238	3.65250E+03	1.73910E+01	2.71211E+02	6.41237E-02	1.11561E+00	3.02565E+02
U-235	1.09575E+04	1.00690E+02	1.00690E+02	6.23202E-01	1.00794E+00	1.01489E+02
PU-239	1.09575E+04	5.06163E+01	1.51306E+02	3.13281E-01	1.00794E+00	1.52508E+02
U-238	1.09575E+04	1.02625E+01	1.61569E+02	6.35176E-02	1.00794E+00	1.62852E+02
U-235	3.65250E+04	1.88437E+01	1.88437E+01	6.16117E-01	1.00000E+00	1.88437E+01
PU-239	3.65250E+04	9.78490E+00	2.86286E+01	3.19929E-01	1.00000E+00	2.86286E+01
U-238	3.65250E+04	1.95603E+00	3.05847E+01	6.39547E-02	1.00000E+00	3.05847E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	1.63928E-01	1.63928E-01	5.84835E-01	1.00000E+00	1.63928E-01
PU-239	1.09575E+05	9.77659E-02	2.61694E-01	3.48792E-01	1.00000E+00	2.61694E-01
U-238	1.09575E+05	1.86043E-02	2.80299E-01	6.63733E-02	1.00000E+00	2.80299E-01
U-235	3.65250E+05	7.42460E-04	7.42460E-04	2.73833E-01	1.00000E+00	7.42460E-04
PU-239	3.65250E+05	1.84265E-03	2.58511E-03	6.79603E-01	1.00000E+00	2.58511E-03
U-238	3.65250E+05	1.26252E-04	2.71136E-03	4.65641E-02	1.00000E+00	2.71136E-03
U-235	1.09575E+06	7.25194E-04	7.25194E-04	2.84061E-01	1.00000E+00	7.25194E-04
PU-239	1.09575E+06	1.71103E-03	2.43623E-03	6.70218E-01	1.00000E+00	2.43623E-03
U-238	1.09575E+06	1.16724E-04	2.55295E-03	4.57211E-02	1.00000E+00	2.55295E-03
U-235	3.65250E+06	6.73394E-04	6.73394E-04	2.75559E-01	1.00000E+00	6.73394E-04
PU-239	3.65250E+06	1.65839E-03	2.33178E-03	6.78626E-01	1.00000E+00	2.33178E-03
U-238	3.65250E+06	1.11960E-04	2.44374E-03	4.58149E-02	1.00000E+00	2.44374E-03

SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	3.96322E+03	1.38505E+00	5.48924E+03
1.09575E+03	9.17321E+02	1.59861E+00	1.46644E+03
3.65250E+03	3.24017E+02	1.11561E+00	3.61477E+02
1.09575E+04	1.95167E+02	1.00794E+00	1.96717E+02
3.65250E+04	3.65248E+01	1.00000E+00	3.65248E+01
1.09575E+05	3.17743E-01	1.00000E+00	3.17743E-01
3.65250E+05	1.43911E-03	1.00000E+00	1.43911E-03
1.09575E+06	1.40565E-03	1.00000E+00	1.40565E-03
3.65250E+06	1.30524E-03	1.00000E+00	1.30524E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.2.2 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9    3    3
     690.0        30.0
     211.4       211.4       211.4
     365.3      1095.8      3652.5      10957.5      36525.0     109575.0
  365250.0    1095750.0   3652500.0
    1.3850      1.5986      1.1156       1.0079       1.0000       1.0000
    1.0000      1.0000      1.0000
 1          370.000 2.3360E+01 4.9050E+00 1.7340E+00
 2           60.000  .0000E+00  .0000E+00  .0000E+00
 3          260.000 1.5558E+01 9.6520E+00 1.7900E+00

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****
```

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	3.62384E+03	3.62384E+03	6.78909E-01	1.38505E+00	5.01919E+03
PU-239	3.65250E+02	1.35323E+03	4.97708E+03	2.53522E-01	1.38505E+00	6.89349E+03
U-238	3.65250E+02	3.60667E+02	5.33774E+03	6.75693E-02	1.38505E+00	7.39303E+03
U-235	1.09575E+03	9.19525E+02	9.19525E+02	6.70977E-01	1.59861E+00	1.46996E+03
PU-239	1.09575E+03	3.59622E+02	1.27915E+03	2.62416E-01	1.59861E+00	2.04486E+03
U-238	1.09575E+03	9.12792E+01	1.37043E+03	6.66065E-02	1.59861E+00	2.19078E+03
U-235	3.65250E+03	3.62295E+02	3.62295E+02	7.73281E-01	1.11561E+00	4.04180E+02
PU-239	3.65250E+03	8.25572E+01	4.44852E+02	1.76210E-01	1.11561E+00	4.96281E+02
U-238	3.65250E+03	2.36647E+01	4.68517E+02	5.05099E-02	1.11561E+00	5.22682E+02
U-235	1.09575E+04	2.18566E+02	2.18566E+02	7.76582E-01	1.00794E+00	2.20302E+02
PU-239	1.09575E+04	4.88258E+01	2.67392E+02	1.73481E-01	1.00794E+00	2.69516E+02
U-238	1.09575E+04	1.40546E+01	2.81447E+02	4.99369E-02	1.00794E+00	2.83682E+02
U-235	3.65250E+04	4.09081E+01	4.09081E+01	7.71468E-01	1.00000E+00	4.09081E+01
PU-239	3.65250E+04	9.43927E+00	5.03474E+01	1.78011E-01	1.00000E+00	5.03474E+01
U-238	3.65250E+04	2.67894E+00	5.30263E+01	5.05210E-02	1.00000E+00	5.30263E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	3.55949E-01	3.55949E-01	7.48034E-01	1.00000E+00	3.55949E-01
PU-239	1.09575E+05	9.44037E-02	4.50352E-01	1.98391E-01	1.00000E+00	4.50352E-01
U-238	1.09575E+05	2.54932E-02	4.75846E-01	5.35745E-02	1.00000E+00	4.75846E-01
U-235	3.65250E+05	1.60353E-03	1.60353E-03	4.50826E-01	1.00000E+00	1.60353E-03
PU-239	3.65250E+05	1.77718E-03	3.38071E-03	4.99645E-01	1.00000E+00	3.38071E-03
U-238	3.65250E+05	1.76167E-04	3.55688E-03	4.95287E-02	1.00000E+00	3.55685E-03
U-235	1.09575E+06	1.57780E-03	1.57780E-03	4.58095E-01	1.00000E+00	1.57780E-03
PU-239	1.09575E+06	1.70188E-03	3.27968E-03	4.94120E-01	1.00000E+00	3.27968E-03
U-238	1.09575E+06	1.64583E-04	3.44426E-03	4.77848E-02	1.00000E+00	3.44426E-03
U-235	3.65250E+06	1.48346E-03	1.48346E-03	4.52821E-01	1.00000E+00	1.48346E-03
PU-239	3.65250E+06	1.63773E-03	3.12120E-03	4.99912E-01	1.00000E+00	3.12120E-03
U-238	3.65250E+06	1.54848E-04	3.27604E-03	4.72666E-02	1.00000E+00	3.27604E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	5.47733E+03	1.38505E+00	7.58637E+03
1.09575E+03	1.45844E+03	1.59861E+00	2.33148E+03
3.65250E+03	6.00922E+02	1.11561E+00	6.70394E+02
1.09575E+04	3.62731E+02	1.00794E+00	3.65612E+02
3.65250E+04	6.78933E+01	1.00000E+00	6.78933E+01
1.09575E+05	5.90774E-01	1.00000E+00	5.90774E-01
3.65250E+05	2.69668E-03	1.00000E+00	2.69668E-03
1.09575E+06	2.62926E-03	1.00000E+00	2.62926E-03
3.65250E+06	2.49443E-03	1.00000E+00	2.49443E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.2.3 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9    5    3
    1050.0          30.0
     211.4         211.4         211.4
     365.3        1095.8        3652.5       10957.5       36525.0      109575.0
  365250.0     1095750.0     3652500.0
    1.3850        1.5986        1.1156        1.0079        1.0000        1.0000
    1.0000        1.0000        1.0000
 1          370.000 1.6391E+01 2.4530E+00 1.1570E+00
 2           60.000  .0000E+00  .0000E+00  .0000E+00
 3          260.000 1.9315E+01 6.7810E+00 1.9040E+00
 4           60.000  .0000E+00  .0000E+00  .0000E+00
 5          300.000 1.4666E+01 1.3350E+01 1.9850E+00
```

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	3.21855E+03	3.21855E+03	6.57542E-01	1.38505E+00	4.45785E+03
PU-239	3.65250E+02	1.34102E+03	4.55957E+03	2.73967E-01	1.38505E+00	6.31522E+03
U-238	3.65250E+02	3.35250E+02	4.894B2E+03	6.84908E-02	1.38505E+00	6.77956E+03
U-235	1.09575E+03	9.44048E+02	9.44048E+02	6.48887E-01	1.59861E+00	1.50917E+03
PU-239	1.09575E+03	4.14796E+02	1.35884E+03	2.85108E-01	1.59861E+00	2.17227E+03
U-238	1.09575E+03	9.60280E+01	1.45487E+03	6.60044E-02	1.59861E+00	2.32578E+03
U-235	3.65250E+03	4.35273E+02	4.35273E+02	7.25514E-01	1.11561E+00	4.85594E+02
PU-239	3.65250E+03	1.32982E+02	5.68255E+02	2.21655E-01	1.11561E+00	6.33950E+02
U-238	3.65250E+03	3.16965E+01	5.99951E+02	5.28319E-02	1.11561E+00	6.69311E+02
U-235	1.09575E+04	2.63195E+02	2.63195E+02	7.27317E-01	1.00794E+00	2.65285E+02
PU-239	1.09575E+04	7.96978E+01	3.42893E+02	2.20238E-01	1.00794E+00	3.45616E+02
U-238	1.09575E+04	1.89782E+01	3.61871E+02	5.24448E-02	1.00794E+00	3.64745E+02
U-235	3.65250E+04	4.92695E+01	4.92695E+01	7.21411E-01	1.00000E+00	4.92695E+01
PU-239	3.65250E+04	1.54089E+01	6.46783E+01	2.25619E-01	1.00000E+00	6.46783E+01
U-238	3.65250E+04	3.61769E+00	6.82960E+01	5.29708E-02	1.00000E+00	6.82960E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	4.28849E-01	4.28849E-01	6.94406E-01	1.00000E+00	4.28849E-01
PU-239	1.09575E+05	1.54268E-01	5.83117E-01	2.49795E-01	1.00000E+00	5.83117E-01
U-238	1.09575E+05	3.44601E-02	6.17577E-01	5.57989E-02	1.00000E+00	6.17577E-01
U-235	3.65250E+05	1.95890E-03	1.95890E-03	3.84448E-01	1.00000E+00	1.95890E-03
PU-239	3.65250E+05	2.89518E-03	4.85408E-03	5.68199E-01	1.00000E+00	4.85408E-03
U-238	3.65250E+05	2.41277E-04	5.09535E-03	4.73524E-02	1.00000E+00	5.09535E-03
U-235	1.09575E+06	1.90853E-03	1.90853E-03	3.85301E-01	1.00000E+00	1.90853E-03
PU-239	1.09575E+06	2.81940E-03	4.72793E-03	5.69190E-01	1.00000E+00	4.72793E-03
U-238	1.09575E+06	2.25424E-04	4.95335E-03	4.55094E-02	1.00000E+00	4.95335E-03
U-235	3.65250E+06	1.81693E-03	1.81693E-03	3.85695E-01	1.00000E+00	1.81693E-03
PU-239	3.65250E+06	2.68166E-03	4.49859E-03	5.69258E-01	1.00000E+00	4.49859E-03
U-238	3.65250E+06	2.12211E-04	4.71080E-03	4.50477E-02	1.00000E+00	4.71080E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	6.43481E+03	1.38505E+00	8.91252E+03
1.09575E+03	1.92586E+03	1.59861E+00	3.07871E+03
3.65250E+03	9.01984E+02	1.11561E+00	1.00626E+03
1.09575E+04	5.45503E+02	1.00794E+00	5.49835E+02
3.65250E+04	1.02119E+02	1.00000E+00	1.02119E+02
1.09575E+05	8.88892E-01	1.00000E+00	8.88892E-01
3.65250E+05	4.14614E-03	1.00000E+00	4.14614E-03
1.09575E+06	3.97760E-03	1.00000E+00	3.97760E-03
3.65250E+06	3.77535E-03	1.00000E+00	3.77535E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.2.3A W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9    6    3
   1080.0          30.0
    211.4         211.4         211.4
    365.3        1095.8        3652.5       10957.5       36525.0      109575.0
  365250.0     1095750.0     3652500.0
   1.3850        1.5986        1.1156        1.0079        1.0000        1.0000
   1.0000        1.0000        1.0000
 1          370.000 1.6391E+01 2.4530E+00 1.1570E+00
 2           60.000  .0000E+00  .0000E+00  .0000E+00
 3          260.000 1.9315E+01 8.7810E+00 1.9040E+00
 4           60.000  .0000E+00  .0000E+00  .0000E+00
 5          300.000 1.4666E+01 1.3350E+01 1.9850E+00
 6           30.000  .0000E+00  .0000E+00  .0000E+00

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****
```

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	3.21855E+03	3.21855E+03	6.57542E-01	1.38505E+00	4.45785E+03
PU-239	3.65250E+02	1.34102E+03	4.55957E+03	2.73967E-01	1.38505E+00	6.31522E+03
U-238	3.65250E+02	3.35250E+02	4.89482E+03	6.84908E-02	1.38505E+00	6.77956E+03
U-235	1.09575E+03	9.44048E+02	9.44048E+02	6.48887E-01	1.59861E+00	1.50917E+03
PU-239	1.09575E+03	4.14796E+02	1.35884E+03	2.85108E-01	1.59861E+00	2.17227E+03
U-238	1.09575E+03	9.60280E+01	1.45487E+03	6.60044E-02	1.59861E+00	2.32578E+03
U-235	3.65250E+03	4.35273E+02	4.35273E+02	7.25514E-01	1.11561E+00	4.85594E+02
PU-239	3.65250E+03	1.32982E+02	5.68255E+02	2.21655E-01	1.11561E+00	6.33950E+02
U-238	3.65250E+03	3.16965E+01	5.99951E+02	5.28319E-02	1.11561E+00	6.69311E+02
U-235	1.09575E+04	2.63195E+02	2.63195E+02	7.27317E-01	1.00794E+00	2.65285E+02
PU-239	1.09575E+04	7.96978E+01	3.42893E+02	2.20238E-01	1.00794E+00	3.45616E+02
U-238	1.09575E+04	1.89762E+01	3.61871E+02	5.24448E-02	1.00794E+00	3.64745E+02
U-235	3.65250E+04	4.92695E+01	4.92695E+01	7.21411E-01	1.00000E+00	4.92695E+01
PU-239	3.65250E+04	1.54089E+01	6.46783E+01	2.25619E-01	1.00000E+00	6.46783E+01
U-238	3.65250E+04	3.61769E+00	6.82960E+01	5.29708E-02	1.00000E+00	6.82960E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	4.28849E-01	4.28849E-01	6.94406E-01	1.00000E+00	4.28849E-01
PU-239	1.09575E+05	1.54268E-01	5.83117E-01	2.49795E-01	1.00000E+00	5.83117E-01
U-238	1.09575E+05	3.44601E-02	6.17577E-01	5.57989E-02	1.00000E+00	6.17577E-01
U-235	3.65250E+05	1.95890E-03	1.95890E-03	3.84448E-01	1.00000E+00	1.95890E-03
PU-239	3.65250E+05	2.89518E-03	4.85408E-03	5.68199E-01	1.00000E+00	4.85408E-03
U-238	3.65250E+05	2.41277E-04	5.09535E-03	4.73524E-02	1.00000E+00	5.09535E-03
U-235	1.09575E+06	1.90853E-03	1.90853E-03	3.85301E-01	1.00000E+00	1.90853E-03
PU-239	1.09575E+06	2.81940E-03	4.72793E-03	5.69190E-01	1.00000E+00	4.72793E-03
U-238	1.09575E+06	2.25424E-04	4.95335E-03	4.55094E-02	1.00000E+00	4.95335E-03
U-235	3.65250E+06	1.81693E-03	1.81693E-03	3.85695E-01	1.00000E+00	1.81693E-03
PU-239	3.65250E+06	2.68166E-03	4.49859E-03	5.69258E-01	1.00000E+00	4.49859E-03
U-238	3.65250E+06	2.12211E-04	4.71080E-03	4.50477E-02	1.00000E+00	4.71080E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	6.49573E+03	1.38505E+00	8.99689E+03
1.09575E+03	1.96105E+03	1.59861E+00	3.13496E+03
3.65250E+03	9.26713E+02	1.11561E+00	1.03385E+03
1.09575E+04	5.60539E+02	1.00794E+00	5.64990E+02
3.65250E+04	1.04934E+02	1.00000E+00	1.04934E+02
1.09575E+05	9.13432E-01	1.00000E+00	9.13432E-01
3.65250E+05	4.28097E-03	1.00000E+00	4.28097E-03
1.09575E+06	4.11243E-03	1.00000E+00	4.11243E-03
3.65250E+06	3.87647E-03	1.00000E+00	3.87647E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.2.3B W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9    8    3
    1050.0        30.0
     211.4       211.4        211.4
     365.3      1095.8       3652.5       10957.5       36525.0      109575.0
  365250.0    1095750.0    3652500.0
    1.3850       1.5986       1.1156        1.0079        1.0000        1.0000
    1.0000       1.0000       1.0000
 1          185.000 1.7426E+01 1.4680E+00 1.1060E+00
 2          185.000 1.5346E+01 3.4460E+00 1.2080E+00
 3           60.000  .0000E+00  .0000E+00  .0000E+00
 4          130.000 2.0478E+01 7.6420E+00 1.8800E+00
 5          130.000 1.8147E+01 9.9250E+00 1.9280E+00
 6           60.000  .0000E+00  .0000E+00  .0000E+00
 7          150.000 1.5830E+01 1.2202E+01 1.9670E+00
 8          150.000 1.3497E+01 1.4501E+01 2.0020E+00
```

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	3.26355E+03	3.26355E+03	6.67680E-01	1.38505E+00	4.52018E+03
PU-239	3.65250E+02	1.29128E+03	4.55483E+03	2.64179E-01	1.38505E+00	6.30866E+03
U-238	3.65250E+02	3.33066E+02	4.88790E+03	6.81410E-02	1.38505E+00	6.76997E+03
U-235	1.09575E+03	9.49294E+02	9.49294E+02	6.54130E-01	1.59861E+00	1.51756E+03
PU-239	1.09575E+03	4.06235E+02	1.35553E+03	2.79924E-01	1.59861E+00	2.16697E+03
U-238	1.09575E+03	9.57031E+01	1.45123E+03	6.59461E-02	1.59861E+00	2.31996E+03
U-235	3.65250E+03	4.35361E+02	4.35361E+02	7.25716E-01	1.11561E+00	4.85693E+02
PU-239	3.65250E+03	1.32857E+02	5.68218E+02	2.21463E-01	1.11561E+00	6.33909E+02
U-238	3.65250E+03	3.16876E+01	5.99906E+02	5.28210E-02	1.11561E+00	6.69260E+02
U-235	1.09575E+04	2.63231E+02	2.63231E+02	7.27409E-01	1.00794E+00	2.65322E+02
PU-239	1.09575E+04	7.96698E+01	3.42901E+02	2.20158E-01	1.00794E+00	3.45624E+02
U-238	1.09575E+04	1.89743E+01	3.61875E+02	5.24332E-02	1.00794E+00	3.64749E+02
U-235	3.65250E+04	4.92763E+01	4.92763E+01	7.21503E-01	1.00000E+00	4.92763E+01
PU-239	3.65250E+04	1.54035E+01	6.46797E+01	2.25537E-01	1.00000E+00	6.46797E+01
U-238	3.65250E+04	3.61694E+00	6.82967E+01	5.29593E-02	1.00000E+00	6.82967E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	4.28882E-01	4.28882E-01	6.94484E-01	1.00000E+00	4.28882E-01
PU-239	1.09575E+05	1.54221E-01	5.83103E-01	2.49728E-01	1.00000E+00	5.83103E-01
U-238	1.09575E+05	3.44518E-02	6.17554E-01	5.57874E-02	1.00000E+00	6.17554E-01
U-235	3.65250E+05	1.95706E-03	1.95706E-03	3.83766E-01	1.00000E+00	1.95706E-03
PU-239	3.65250E+05	2.90127E-03	4.85833E-03	5.68918E-01	1.00000E+00	4.85833E-03
U-238	3.65250E+05	2.41290E-04	5.09962E-03	4.73154E-02	1.00000E+00	5.09962E-03
U-235	1.09575E+06	1.90556E-03	1.90556E-03	3.85414E-01	1.00000E+00	1.90556E-03
PU-239	1.09575E+06	2.81318E-03	4.71874E-03	5.68986E-01	1.00000E+00	4.71874E-03
U-238	1.09575E+06	2.25459E-04	4.94420E-03	4.56008E-02	1.00000E+00	4.94420E-03
U-235	3.65250E+06	1.81770E-03	1.81770E-03	3.85742E-01	1.00000E+00	1.81770E-03
PU-239	3.65250E+06	2.68229E-03	4.49999E-03	5.69222E-01	1.00000E+00	4.49999E-03
U-238	3.65250E+06	2.12219E-04	4.71221E-03	4.50359E-02	1.00000E+00	4.71221E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	6.43481E+03	1.38505E+00	8.91252E+03
1.09575E+03	1.92586E+03	1.59861E+00	3.07871E+03
3.65250E+03	9.01984E+02	1.11561E+00	1.00626E+03
1.09575E+04	5.45503E+02	1.00794E+00	5.49835E+02
3.65250E+04	1.02119E+02	1.00000E+00	1.02119E+02
1.09575E+05	8.88892E-01	1.00000E+00	8.88892E-01
3.65250E+05	4.14614E-03	1.00000E+00	4.14614E-03
1.09575E+06	3.97760E-03	1.00000E+00	3.97760E-03
3.65250E+06	3.77535E-03	1.00000E+00	3.77535E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.2.4 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9    1    3
    1080.0          25.0
     211.4         211.4         211.4
     365.3        1095.8        3652.5       10957.5       36525.0      109575.0
  365250.0     1095750.0     3652500.0
    1.3850        1.5986        1.1156        1.0079        1.0000        1.0000
    1.0000        1.0000        1.0000
 1          1080.000 1.6056E+01 7.3960E+00 1.5470E+00

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****
```

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	3.40851E+03	3.40851E+03	5.74484E-01	1.38505E+00	4.72095E+03
PU-239	3.65250E+02	2.11870E+03	5.52721E+03	3.57094E-01	1.38505E+00	7.65544E+03
U-238	3.65250E+02	4.05960E+02	5.93317E+03	6.84222E-02	1.38505E+00	8.21772E+03
U-235	1.09575E+03	1.02902E+03	1.02902E+03	5.96084E-01	1.59861E+00	1.64501E+03
PU-239	1.09575E+03	5.84850E+02	1.61387E+03	3.38787E-01	1.59861E+00	2.57996E+03
U-238	1.09575E+03	1.12434E+02	1.72631E+03	6.51297E-02	1.59861E+00	2.75970E+03
U-235	3.65250E+03	4.86275E+02	4.86275E+02	7.23966E-01	1.11561E+00	5.42492E+02
PU-239	3.65250E+03	1.50365E+02	6.36640E+02	2.23864E-01	1.11561E+00	7.10241E+02
U-238	3.65250E+03	3.50414E+01	6.71681E+02	5.21697E-02	1.11561E+00	7.49334E+02
U-235	1.09575E+04	2.94132E+02	2.94132E+02	7.27177E-01	1.00794E+00	2.96468E+02
PU-239	1.09575E+04	8.94072E+01	3.83539E+02	2.21040E-01	1.00794E+00	3.86585E+02
U-238	1.09575E+04	2.09453E+01	4.04485E+02	5.17828E-02	1.00794E+00	4.07697E+02
U-235	3.65250E+04	5.50623E+01	5.50623E+01	7.21274E-01	1.00000E+00	5.50623E+01
PU-239	3.65250E+04	1.72854E+01	7.23477E+01	2.26425E-01	1.00000E+00	7.23477E+01
U-238	3.65250E+04	3.99264E+00	7.63403E+01	5.23005E-02	1.00000E+00	7.63403E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	4.79306E-01	4.79306E-01	6.94371E-01	1.00000E+00	4.79306E-01
PU-239	1.09575E+05	1.72943E-01	6.52249E-01	2.50543E-01	1.00000E+00	6.52249E-01
U-238	1.09575E+05	3.80248E-02	6.90273E-01	5.50866E-02	1.00000E+00	6.90273E-01
U-235	3.65250E+05	2.24636E-03	2.24636E-03	3.89459E-01	1.00000E+00	2.24636E-03
PU-239	3.65250E+05	3.25908E-03	5.50544E-03	5.65038E-01	1.00000E+00	5.50544E-03
U-238	3.65250E+05	2.62451E-04	5.76789E-03	4.55022E-02	1.00000E+00	5.76789E-03
U-235	1.09575E+06	2.15792E-03	2.15792E-03	3.89050E-01	1.00000E+00	2.15792E-03
PU-239	1.09575E+06	3.14501E-03	5.30293E-03	5.67012E-01	1.00000E+00	5.30293E-03
U-238	1.09575E+06	2.43705E-04	5.54663E-03	4.39374E-02	1.00000E+00	5.54663E-03
U-235	3.65250E+06	2.03410E-03	2.03410E-03	3.86276E-01	1.00000E+00	2.03410E-03
PU-239	3.65250E+06	2.99835E-03	5.03246E-03	5.69386E-01	1.00000E+00	5.03246E-03
U-238	3.65250E+06	2.33479E-04	5.26593E-03	4.43377E-02	1.00000E+00	5.26593E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	5.41336E+03	1.38505E+00	7.49777E+03
1.09575E+03	1.63429E+03	1.59861E+00	2.61259E+03
3.65250E+03	7.72297E+02	1.11561E+00	8.61581E+02
1.09575E+04	4.67138E+02	1.00794E+00	4.70848E+02
3.65250E+04	8.74495E+01	1.00000E+00	8.74495E+01
1.09575E+05	7.61229E-01	1.00000E+00	7.61229E-01
3.65250E+05	3.56765E-03	1.00000E+00	3.56765E-03
1.09575E+06	3.42719E-03	1.00000E+00	3.42719E-03
3.65250E+06	3.23055E-03	1.00000E+00	3.23055E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.2.5 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1   1   1   0
   9  10   3
   1035.0      33.0
    211.4     211.4       211.4
    365.3    1095.8      3652.5      10957.5      36525.0     109575.0
 365250.0 1095750.0    3652500.0
   1.3850     1.5986      1.1156       1.0079       1.0000       1.0000
   1.0000     1.0000      1.0000
 1        150.000 2.3344E+01 2.0650E+00 1.5910E+00
 2        150.000 2.3979E+01 5.3110E+00 1.7100E+00
 3         60.000  .0000E+00  .0000E+00  .0000E+00
 4        150.000 1.9251E+01 7.8110E+00 1.9380E+00
 5         15.000  .0000E+00  .0000E+00  .0000E+00
 6        150.000 1.9986E+01 1.1075E+01 1.9390E+00
 7         45.000  .0000E+00  .0000E+00  .0000E+00
 8        150.000 1.4160E+01 1.1883E+01 1.9570E+00
 9         15.000  .0000E+00  .0000E+00  .0000E+00
10        150.000 1.4817E+01 1.5237E+01 1.9470E+00


**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****
```

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	3.99660E+03	3.99660E+03	6.66957E-01	1.38505E+00	5.53547E+03
PU-239	3.65250E+02	1.58961E+03	5.58621E+03	2.65277E-01	1.38505E+00	7.73717E+03
U-238	3.65250E+02	4.06073E+02	5.99228E+03	6.77660E-02	1.38505E+00	8.29960E+03
U-235	1.09575E+03	1.11155E+03	1.11155E+03	6.51063E-01	1.59861E+00	1.77693E+03
PU-239	1.09575E+03	4.83567E+02	1.59511E+03	2.83238E-01	1.59861E+00	2.54997E+03
U-238	1.09575E+03	1.12165E+02	1.70728E+03	6.56984E-02	1.59861E+00	2.72928E+03
U-235	3.65250E+03	4.89054E+02	4.89054E+02	7.27219E-01	1.11561E+00	5.45594E+02
PU-239	3.65250E+03	1.48570E+02	6.37624E+02	2.20922E-01	1.11561E+00	7.11340E+02
U-238	3.65250E+03	3.48754E+01	6.72500E+02	5.18594E-02	1.11561E+00	7.50247E+02
U-235	1.09575E+04	2.95534E+02	2.95534E+02	7.29208E-01	1.00794E+00	2.97880E+02
PU-239	1.09575E+04	8.89028E+01	3.84436E+02	2.19361E-01	1.00794E+00	3.87489E+02
U-238	1.09575E+04	2.08441E+01	4.05280E+02	5.14313E-02	1.00794E+00	4.08499E+02
U-235	3.65250E+04	5.53211E+01	5.53211E+01	7.23315E-01	1.00000E+00	5.53211E+01
PU-239	3.65250E+04	1.71883E+01	7.25095E+01	2.24735E-01	1.00000E+00	7.25095E+01
U-238	3.65250E+04	3.97333E+00	7.64828E+01	5.19506E-02	1.00000E+00	7.64828E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	4.81450E-01	4.81450E-01	6.96416E-01	1.00000E+00	4.81450E-01
PU-239	1.09575E+05	1.72030E-01	6.53480E-01	2.48841E-01	1.00000E+00	6.53480E-01
U-238	1.09575E+05	3.78454E-02	6.91326E-01	5.47433E-02	1.00000E+00	6.91326E-01
U-235	3.65250E+05	2.25900E-03	2.25900E-03	3.91619E-01	1.00000E+00	2.25900E-03
PU-239	3.65250E+05	3.24684E-03	5.50584E-03	5.62868E-01	1.00000E+00	5.50584E-03
U-238	3.65250E+05	2.62537E-04	5.76838E-03	4.55131E-02	1.00000E+00	5.76838E-03
U-235	1.09575E+06	2.15796E-03	2.15796E-03	3.87550E-01	1.00000E+00	2.15796E-03
PU-239	1.09575E+06	3.16356E-03	5.32151E-03	5.68146E-01	1.00000E+00	5.32151E-03
U-238	1.09575E+06	2.46693E-04	5.56821E-03	4.43038E-02	1.00000E+00	5.56821E-03
U-235	3.65250E+06	2.02006E-03	2.02006E-03	3.85784E-01	1.00000E+00	2.02006E-03
PU-239	3.65250E+06	2.98639E-03	5.00645E-03	5.70332E-01	1.00000E+00	5.00645E-03
U-238	3.65250E+06	2.29792E-04	5.23624E-03	4.38849E-02	1.00000E+00	5.23624E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	7.04389E+03	1.38505E+00	9.75612E+03
1.09575E+03	2.09890E+03	1.59861E+00	3.35534E+03
3.65250E+03	9.78559E+02	1.11561E+00	1.09169E+03
1.09575E+04	5.91771E+02	1.00794E+00	5.96471E+02
3.65250E+04	1.10779E+02	1.00000E+00	1.10779E+02
1.09575E+05	9.64247E-01	1.00000E+00	9.64247E-01
3.65250E+05	4.48659E-03	1.00000E+00	4.48659E-03
1.09575E+06	4.33828E-03	1.00000E+00	4.33828E-03
3.65250E+06	4.07872E-03	1.00000E+00	4.07872E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.2.5A W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9   12    3
  1080.0          33.0
   211.4         211.4         211.4
   365.3        1095.8        3652.5       10957.5       36525.0      109575.0
365250.0     1095750.0     3652500.0
  1.3850        1.5986        1.1156        1.0079        1.0000        1.0000
  1.0000        1.0000        1.0000
 1          150.000 2.3344E+01 2.0650E+00 1.5910E+00
 2           15.000  .0000E+00  .0000E+00  .0000E+00
 3          150.000 2.3979E+01 5.3110E+00 1.7100E+00
 4           45.000  .0000E+00  .0000E+00  .0000E+00
 5          150.000 1.9251E+01 7.8110E+00 1.9380E+00
 6           15.000  .0000E+00  .0000E+00  .0000E+00
 7          150.000 1.9986E+01 1.1075E+01 1.9390E+00
 8           45.000  .0000E+00  .0000E+00  .0000E+00
 9          150.000 1.4160E+01 1.1883E+01 1.9570E+00
10           15.000  .0000E+00  .0000E+00  .0000E+00
11          150.000 1.4817E+01 1.5237E+01 1.9470E+00
12           45.000  .0000E+00  .0000E+00  .0000E+00
```

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	3.95566E+03	3.95566E+03	6.6622BE-01	1.38505E+00	5.47878E+03
PU-239	3.65250E+02	1.57898E+03	5.53464E+03	2.65937E-01	1.38505E+00	7.66574E+03
U-238	3.65250E+02	4.02768E+02	5.93741E+03	6.78357E-02	1.38505E+00	8.22359E+03
U-235	1.09575E+03	1.10624E+03	1.10624E+03	6.50924E-01	1.59861E+00	1.76845E+03
PU-239	1.09575E+03	4.81632E+02	1.58787E+03	2.83397E-01	1.59861E+00	2.53840E+03
U-238	1.09575E+03	1.11621E+02	1.69950E+03	6.56789E-02	1.59861E+00	2.71664E+03
U-235	3.65250E+03	4.88928E+02	4.88928E+02	7.27211E-01	1.11561E+00	5.45452E+02
PU-239	3.65250E+03	1.48539E+02	6.37467E+02	2.20931E-01	1.11561E+00	7.11164E+02
U-238	3.65250E+03	3.48660E+01	6.72333E+02	5.18583E-02	1.11561E+00	7.50061E+02
U-235	1.09575E+04	2.95472E+02	2.95472E+02	7.29188E-01	1.00794E+00	2.97818E+02
PU-239	1.09575E+04	8.88939E+01	3.84366E+02	2.19379E-01	1.00794E+00	3.87418E+02
U-238	1.09575E+04	2.08409E+01	4.05207E+02	5.14328E-02	1.00794E+00	4.08424E+02
U-235	3.65250E+04	5.53094E+01	5.53094E+01	7.23294E-01	1.00000E+00	5.53094E+01
PU-239	3.65250E+04	1.71866E+01	7.24960E+01	2.24754E-01	1.00000E+00	7.24960E+01
U-238	3.65250E+04	3.97271E+00	7.64687E+01	5.19521E-02	1.00000E+00	7.64687E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	4.81371E-01	4.81371E-01	6.96410E-01	1.00000E+00	4.81371E-01
PU-239	1.09575E+05	1.72007E-01	6.53378E-01	2.48846E-01	1.00000E+00	6.53378E-01
U-238	1.09575E+05	3.78398E-02	6.91217E-01	5.47437E-02	1.00000E+00	6.91217E-01
U-235	3.65250E+05	2.23259E-03	2.23259E-03	3.88820E-01	1.00000E+00	2.23259E-03
PU-239	3.65250E+05	3.24684E-03	5.47943E-03	5.65458E-01	1.00000E+00	5.47943E-03
U-238	3.65250E+05	2.62537E-04	5.74196E-03	4.57224E-02	1.00000E+00	5.74196E-03
U-235	1.09575E+06	2.15796E-03	2.15796E-03	3.87550E-01	1.00000E+00	2.15796E-03
PU-239	1.09575E+06	3.16356E-03	5.32151E-03	5.68146E-01	1.00000E+00	5.32151E-03
U-238	1.09575E+06	2.46693E-04	5.56821E-03	4.43038E-02	1.00000E+00	5.56821E-03
U-235	3.65250E+06	2.04647E-03	2.04647E-03	3.87846E-01	1.00000E+00	2.04647E-03
PU-239	3.65250E+06	2.99810E-03	5.04457E-03	5.68197E-01	1.00000E+00	5.04457E-03
U-238	3.65250E+06	2.31937E-04	5.27650E-03	4.39565E-02	1.00000E+00	5.27650E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	7.14530E+03	1.38505E+00	9.89658E+03
1.09575E+03	2.15716E+03	1.59861E+00	3.44846E+03
3.65250E+03	1.01938E+03	1.11561E+00	1.13723E+03
1.09575E+04	6.16593E+02	1.00794E+00	6.21489E+02
3.65250E+04	1.15428E+02	1.00000E+00	1.15428E+02
1.09575E+05	1.00477E+00	1.00000E+00	1.00477E+00
3.65250E+05	4.70907E-03	1.00000E+00	4.70907E-03
1.09575E+06	4.52367E-03	1.00000E+00	4.52367E-03
3.65250E+06	4.26412E-03	1.00000E+00	4.26412E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.2.6 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9   10    3
  1035.0        33.0
   211.4       211.4       211.4
   365.3      1095.8      3652.5      10957.5      36525.0     109575.0
365250.0    1095750.0   3652500.0
  1.3850       1.5986      1.1156       1.0079       1.0000       1.0000
  1.0000       1.0000      1.0000
 1          150.000 2.7096E+01 2.3410E+00 1.5640E+00
 2          150.000 2.0228E+01 5.0320E+00 1.7400E+00
 3           60.000  .0000E+00  .0000E+00  .0000E+00
 4          150.000 2.2513E+01 8.5970E+00 1.8890E+00
 5           15.000  .0000E+00  .0000E+00  .0000E+00
 6          150.000 1.6724E+01 1.0286E+01 1.9890E+00
 7           45.000  .0000E+00  .0000E+00  .0000E+00
 8          150.000 1.6838E+01 1.3195E+01 1.9170E+00
 9           15.000  .0000E+00  .0000E+00  .0000E+00
10          150.000 1.2089E+01 1.3923E+01 1.9880E+00


**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****
```

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	4.13348E+03	4.13348E+03	6.72096E-01	1.38505E+00	5.72507E+03
PU-239	3.65250E+02	1.61180E+03	5.74528E+03	2.62075E-01	1.38505E+00	7.95749E+03
U-238	3.65250E+02	4.04859E+02	6.15014E+03	6.58292E-02	1.38505E+00	8.51824E+03
U-235	1.09575E+03	1.12743E+03	1.12743E+03	6.52716E-01	1.59861E+00	1.80233E+03
PU-239	1.09575E+03	4.87874E+02	1.61530E+03	2.82450E-01	1.59861E+00	2.58225E+03
U-238	1.09575E+03	1.11987E+02	1.72729E+03	6.48341E-02	1.59861E+00	2.76127E+03
U-235	3.65250E+03	4.89575E+02	4.89575E+02	7.27320E-01	1.11561E+00	5.46174E+02
PU-239	3.65250E+03	1.48661E+02	6.38236E+02	2.20853E-01	1.11561E+00	7.12022E+02
U-238	3.65250E+03	3.48854E+01	6.73122E+02	5.18263E-02	1.11561E+00	7.50941E+02
U-235	1.09575E+04	2.95799E+02	2.95799E+02	7.29321E-01	1.00794E+00	2.98148E+02
PU-239	1.09575E+04	8.89309E+01	3.84730E+02	2.19268E-01	1.00794E+00	3.87785E+02
U-238	1.09575E+04	2.08513E+01	4.05581E+02	5.14108E-02	1.00794E+00	4.08802E+02
U-235	3.65250E+04	5.53700E+01	5.53700E+01	7.23428E-01	1.00000E+00	5.53700E+01
PU-239	3.65250E+04	1.71937E+01	7.25638E+01	2.24642E-01	1.00000E+00	7.25638E+01
U-238	3.65250E+04	3.97469E+00	7.65385E+01	5.19307E-02	1.00000E+00	7.65385E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	4.81867E-01	4.81867E-01	6.96535E-01	1.00000E+00	4.81867E-01
PU-239	1.09575E+05	1.72080E-01	6.53947E-01	2.48741E-01	1.00000E+00	6.53947E-01
U-238	1.09575E+05	3.78587E-02	6.91806E-01	5.47245E-02	1.00000E+00	6.91806E-01

U-235	3.65250E+05	2.25902E-03	2.25902E-03	3.91531E-01	1.00000E+00	2.25902E-03
PU-239	3.65250E+05	3.24811E-03	5.50714E-03	5.62958E-01	1.00000E+00	5.50714E-03
U-238	3.65250E+05	2.62588E-04	5.76973E-03	4.55113E-02	1.00000E+00	5.76973E-03

U-235	1.09575E+06	2.15856E-03	2.15856E-03	3.87443E-01	1.00000E+00	2.15856E-03
PU-239	1.09575E+06	3.16601E-03	5.32457E-03	5.68270E-01	1.00000E+00	5.32457E-03
U-238	1.09575E+06	2.46734E-04	5.57131E-03	4.42866E-02	1.00000E+00	5.57131E-03

U-235	3.65250E+06	2.02308E-03	2.02308E-03	3.86115E-01	1.00000E+00	2.02308E-03
PU-239	3.65250E+06	2.98656E-03	5.00963E-03	5.70000E-01	1.00000E+00	5.00963E-03
U-238	3.65250E+06	2.29940E-04	5.23957E-03	4.38853E-02	1.00000E+00	5.23957E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	7.04389E+03	1.38505E+00	9.75612E+03
1.09575E+03	2.09890E+03	1.59861E+00	3.35534E+03
3.65250E+03	9.78559E+02	1.11561E+00	1.09169E+03
1.09575E+04	5.91771E+02	1.00794E+00	5.96471E+02
3.65250E+04	1.10779E+02	1.00000E+00	1.10779E+02
1.09575E+05	9.64247E-01	1.00000E+00	9.64247E-01
3.65250E+05	4.48659E-03	1.00000E+00	4.48659E-03
1.09575E+06	4.33828E-03	1.00000E+00	4.33828E-03
3.65250E+06	4.07872E-03	1.00000E+00	4.07872E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.2.6A W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   9   12    3
    1080.0        33.0
     211.4       211.4       211.4
     365.3      1095.8      3652.5      10957.5      36525.0     109575.0
  365250.0   1095750.0   3652500.0
    1.3850      1.5986      1.1156       1.0079       1.0000       1.0000
    1.0000      1.0000      1.0000
 1          150.000 2.7096E+01 2.3410E+00 1.5640E+00
 2           15.000  .0000E+00  .0000E+00  .0000E+00
 3          150.000 2.0228E+01 5.0320E+00 1.7400E+00
 4           45.000  .0000E+00  .0000E+00  .0000E+00
 5          150.000 2.2513E+01 8.5970E+00 1.8890E+00
 6           15.000  .0000E+00  .0000E+00  .0000E+00
 7          150.000 1.6724E+01 1.0286E+01 1.9890E+00
 8           45.000  .0000E+00  .0000E+00  .0000E+00
 9          150.000 1.6888E+01 1.3195E+01 1.9170E+00
10           15.000  .0000E+00  .0000E+00  .0000E+00
11          150.000 1.2089E+01 1.3923E+01 1.9880E+00
12           45.000  .0000E+00  .0000E+00  .0000E+00


**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****
```

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	3.65250E+02	4.09896E+03	4.09896E+03	6.71721E-01	1.38505E+00	5.67725E+03
PU-239	3.65250E+02	1.60172E+03	5.70067E+03	2.62484E-01	1.38505E+00	7.89570E+03
U-238	3.65250E+02	4.01496E+02	6.10217E+03	6.57956E-02	1.38505E+00	8.45180E+03
U-235	1.09575E+03	1.12296E+03	1.12296E+03	6.52718E-01	1.59861E+00	1.79517E+03
PU-239	1.09575E+03	4.86041E+02	1.60900E+03	2.82511E-01	1.59861E+00	2.57217E+03
U-238	1.09575E+03	1.11433E+02	1.72043E+03	6.47707E-02	1.59861E+00	2.75031E+03
U-235	3.65250E+03	4.89468E+02	4.89468E+02	7.27319E-01	1.11561E+00	5.46055E+02
PU-239	3.65250E+03	1.48632E+02	6.38100E+02	2.20858E-01	1.11561E+00	7.11870E+02
U-238	3.65250E+03	3.48758E+01	6.72976E+02	5.18232E-02	1.11561E+00	7.50778E+02
U-235	1.09575E+04	2.95747E+02	2.95747E+02	7.29307E-01	1.00794E+00	2.98095E+02
PU-239	1.09575E+04	8.89225E+01	3.84669E+02	2.19282E-01	1.00794E+00	3.87724E+02
U-238	1.09575E+04	2.08480E+01	4.05517E+02	5.14109E-02	1.00794E+00	4.09738E+02
U-235	3.65250E+04	5.53602E+01	5.53602E+01	7.23413E-01	1.00000E+00	5.53602E+01
PU-239	3.65250E+04	1.71921E+01	7.25523E+01	2.24656E-01	1.00000E+00	7.25523E+01
U-238	3.65250E+04	3.97407E+00	7.65263E+01	5.19307E-02	1.00000E+00	7.65263E+01

Figure 27

Program ANSIDECH Output (continued)

U-235	1.09575E+05	4.81800E-01	4.81800E-01	6.96534E-01	1.00000E+00	4.81800E-01
PU-239	1.09575E+05	1.72058E-01	6.53858E-01	2.48743E-01	1.00000E+00	6.53858E-01
U-238	1.09575E+05	3.78530E-02	6.91711E-01	5.47237E-02	1.00000E+00	6.91711E-01
U-235	3.65250E+05	2.23674E-03	2.23674E-03	3.89172E-01	1.00000E+00	2.23674E-03
PU-239	3.65250E+05	3.24811E-03	5.48485E-03	5.65141E-01	1.00000E+00	5.48485E-03
U-238	3.65250E+05	2.62588E-04	5.74744E-03	4.56878E-02	1.00000E+00	5.74744E-03
U-235	1.09575E+06	2.15856E-03	2.15856E-03	3.87443E-01	1.00000E+00	2.15856E-03
PU-239	1.09575E+06	3.16601E-03	5.32457E-03	5.68270E-01	1.00000E+00	5.32457E-03
U-238	1.09575E+06	2.46734E-04	5.57131E-03	4.42866E-02	1.00000E+00	5.57131E-03
U-235	3.65250E+06	2.04536E-03	2.04536E-03	3.87736E-01	1.00000E+00	2.04536E-03
PU-239	3.65250E+06	2.99764E-03	5.04300E-03	5.68259E-01	1.00000E+00	5.04300E-03
U-238	3.65250E+06	2.32130E-04	5.27513E-03	4.40045E-02	1.00000E+00	5.27513E-03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
3.65250E+02	7.14530E+03	1.38505E+00	9.89658E+03
1.09575E+03	2.15716E+03	1.59861E+00	3.44846E+03
3.65250E+03	1.01938E+03	1.11561E+00	1.13723E+03
1.09575E+04	6.16593E+02	1.00794E+00	6.21489E+02
3.65250E+04	1.15428E+02	1.00000E+00	1.15428E+02
1.09575E+05	1.00477E+00	1.00000E+00	1.00477E+00
3.65250E+05	4.70907E-03	1.00000E+00	4.70907E-03
1.09575E+06	4.52367E-03	1.00000E+00	4.52367E-03
3.65250E+06	4.26412E-03	1.00000E+00	4.26412E-03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.3.1 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   1    5    3
  1069.0          31.8
   206.8         206.8         206.8
   864.0
  1.5763
1          310.000 2.1964E+01 4.7350E+00 1.7620E+00
2           64.000  .0000E+00  .0000E+00  .0000E+00
3          321.000 1.8224E+01 1.1429E+01 2.1740E+00
4           69.000  .0000E+00  .0000E+00  .0000E+00
5          305.000 1.2256E+01 1.4600E+01 2.0730E+00
```

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	8.64000E+02	1.44501E+03	1.44501E+03	5.84333E-01	1.57628E+00	2.27773E+03
PU-239	8.64000E+02	8.49252E+02	2.29426E+03	3.43421E-01	1.57628E+00	3.61638E+03
U-238	8.64000E+02	1.78657E+02	2.47292E+03	7.22456E-02	1.57628E+00	3.89800E+03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
8.64000E+02	2.79335E+03	1.57628E+00	4.40309E+03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.3.2A W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   1    5    3
    1069.0          32.5
     206.9         206.9          206.9
     962.0
    1.5904
 1          310.000 2.2348E+01 4.8920E+00 1.8010E+00
 2           64.000  .0000E+00  .0000E+00  .0000E+00
 3          321.000 1.8441E+01 1.1812E+01 2.2220E+00
 4           69.000  .0000E+00  .0000E+00  .0000E+00
 5          305.000 1.2303E+01 1.5095E+01 2.1200E+00
```

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	9.62000E+02	1.27937E+03	1.27937E+03	5.82937E-01	1.59044E+00	2.03475E+03
PU-239	9.62000E+02	7.58151E+02	2.03752E+03	3.45447E-01	1.59044E+00	3.24054E+03
U-238	9.62000E+02	1.57175E+02	2.19470E+03	7.16157E-02	1.59044E+00	3.49052E+03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
9.62000E+02	2.50936E+03	1.59044E+00	3.99097E+03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.3.2B W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

    1    1    1    0
    1    5    3
    1069.0          32.5
     206.9         206.9          206.9
    1143.0
    1.5984
  1          310.000 2.2348E+01 4.8920E+00 1.8010E+00
  2           64.000  .0000E+00  .0000E+00  .0000E+00
  3          321.000 1.8441E+01 1.1812E+01 2.2220E+00
  4           69.000  .0000E+00  .0000E+00  .0000E+00
  5          305.000 1.2303E+01 1.5095E+01 2.1200E+00
```

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	1.14300E+03	1.03057E+03	1.03057E+03	5.90536E-01	1.59839E+00	1.64726E+03
PU-239	1.14300E+03	5.92266E+02	1.62284E+03	3.39379E-01	1.59839E+00	2.59353E+03
U-238	1.14300E+03	1.22309E+02	1.74515E+03	7.00850E-02	1.59839E+00	2.78943E+03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
1.14300E+03	2.05266E+03	1.59839E+00	3.28095E+03

Figure 27

Program ANSIDECH Output (continued)

```
DECAY HEAT PROBLEM 2.3.3 W/O G-FACTOR CORRECTION--LONG AND SHORT METHODS

   1    1    1    0
   1    5    3
    1069.0          30.3
     206.5         206.5          206.5
     963.0
    1.5905
 1          310.000 2.1023E+01 4.3610E+00 1.6700E+00
 2           64.000  .0000E+00  .0000E+00  .0000E+00
 3          321.000 1.7677E+01 1.0518E+01 2.0580E+00
 4           69.000  .0000E+00  .0000E+00  .0000E+00
 5          305.000 1.2113E+01 1.3424E+01 1.9610E+00
```

**** LONG METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

ISOTOPE	COOLING TIME AFTER SHUTDOWN (DAYS)	ISOTOPE DECAY HEAT POWER (WATTS)	TOTAL DECAY HEAT POWER (WATTS)	RATIO ISOTOPE/TOTAL	G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
U-235	9.63000E+02	1.21827E+03	1.21827E+03	5.97430E-01	1.59054E+00	1.93772E+03
PU-239	9.63000E+02	6.75262E+02	1.89354E+03	3.31142E-01	1.59054E+00	3.01176E+03
U-238	9.63000E+02	1.45656E+02	2.03919E+03	7.14284E-02	1.59054E+00	3.24343E+03

**** SHORT METHOD FOR FISSION PRODUCT DECAY HEAT POWER ****

COOLING TIME AFTER SHUTDOWN (DAYS)	DECAY HEAT POWER (WATTS)	CAPTURE CORRECTION G-VALUE	ADJUSTED DECAY HEAT POWER (WATTS)
9.63000E+02	2.33887E+03	1.59054E+00	3.72007E+03

3.2 ANSIDECH/BURNUP

3.2.1 Code Description

The computer programs ANSIDECH and BURNUP were developed to estimate the fission-product thermal energy release from light water reactor fuel. The program ANSIDECH implements American National Standard ANSI/ANS-5.1-1979. The program BURNUP can be used to estimate the fraction of fission events occurring in ^{235}U, ^{238}U, and ^{239}Pu, one of the required inputs to ANSIDECH.

ANSIDECH uses two ANS methods (Reference 6) for computing fission-product afterheat power. One is a simplified and conservative method in which all fissions are assumed to occur in ^{235}U. The other method, a detailed one, accounts for fission in ^{235}U, ^{238}U, and ^{239}Pu. A short review of these two methods follows.

We begin with the detailed method. When the operating history of a reactor can be represented by a histogram of N time intervals with constant power $P_{i\alpha}$ from fissionable nuclide i during irradiation period α, then the fission-product afterheat power (uncorrected for neutron capture) from fissionable nuclide i is given by the following equations:

$$P'_{di}(t,T) = \sum_{\alpha=1}^{N} \frac{P_{i\alpha} F_i(t_\alpha, T_\alpha)}{Q_i} \tag{3.2.1}$$

$$t_1 = t,\ t_2 = t + T_1,\ \ldots,\ t_N = t + \sum_{\alpha=1}^{N-1} T_\alpha \tag{3.2.2}$$

$$T = \sum_{\alpha=1}^{N} T_\alpha\ , \tag{3.2.3}$$

where

T_α = the duration of irradiation period α (s)

t_α = the elapsed time after irradiation period α (s)

$P'_{di}(t,T)$ = Fission product decay heat power contribution to $P_d(t,T)$ by ith fissionable nuclide, uncorrected for neutron capture in fission products, MeV/sec.

$P_{i\alpha}$ = Average power from fissioning of nuclide i during operation period T_α, MeV/sec.

Q_i = total recoverable energy per fission for nuclide i (MeV per fission)

The value of Q_i includes fission fragment and neutron kinetic energy, prompt gamma energy, the energy of gamma and beta radiation from complete decay of fission products, and the energy of gamma and beta radiation from capture reactions in all fuel, coolant, and structural materials. The units of $P_{i\alpha}$ and P'_{di} must be the same. In Equation 3.2.1, F_i, the decay heat power t seconds after an irradiation period of T seconds, is found from

$$F_i(t_\alpha,T_\alpha) = F_i(t_\alpha,\infty) - F_i(t_\alpha + T_\alpha,\infty) \tag{3.2.4}$$

The values of $F_i(t_\alpha,T_\alpha)$ for ^{235}U, ^{238}U, and ^{239}Pu can be calculated from formulas given in Tables 3-20, 3-21, and 3-22.

The total fission-product afterheat power is given by

$$P_d(t,T) = P'_d(t,T) \cdot G(t) \tag{3.2.5}$$

$$P'_d(t,T) = \sum_{i=1}^{3} P'_{di}(t,T), \tag{3.2.6}$$

Table 3-20

Parameters for ^{235}U Thermal Fission Function F(t,T)*

α	λ
6.5057E-01**	2.2138E+01
5.1264E-01	5.1587E-01
2.4384E-01	1.9594E-01
1.3850E-01	1.0314E-01
5.5440E-02	3.3656E-02
2.2225E-02	1.1681E-02
3.3088E-03	3.5870E-03
9.3015E-04	1.3930E-03
8.0943E-04	6.2630E-04
1.9567E-04	1.8906E-04
3.2535E-05	5.4988E-05
7.5595E-06	2.0958E-05
2.5232E-06	1.0010E-05
4.9948E-07	2.5438E-06
1.8531E-07	6.6361E-07
2.6608E-08	1.2290E-07
2.2398E-09	2.7213E-08
8.1641E-12	4.3714E-09
8.7797E-11	7.5780E-10
2.5131E-14	2.4786E-10
3.2176E-16	2.2384E-13
4.5038E-17	2.4600E-14
7.4791E-17	1.5699E-14

Source: Reference 6. (Table extracted from American National Standard ANSI/ANS-5.1-1979 with permission of the publishers, the American Nuclear Society.)

* $F(t,T) = \sum_{i=1}^{23} \frac{\alpha_i}{\lambda_i} e^{-\lambda_i t} (1-e^{-\lambda_i T})$ MeV/Fission

$F(T,\infty) = F(t,10^{13})$

t and T in seconds

** Read as 6.5057×10^{-1}.

Table 3-21

Parameters for ^{238}U Fast Fission Function F(t,T)*

α	λ
1.2311E+0**	3.2881E+0
1.1486E+0	9.3805E-1
7.0701E-1	3.7073E-1
2.5209E-1	1.1118E-1
7.1870E-2	3.6143E-2
2.8291E-2	1.3272E-2
6.8382E-3	5.0133E-3
1.2322E-3	1.3655E-3
6.8409E-4	5.5158E-4
1.6975E-4	1.7873E-4
2.4182E-5	4.9032E-5
6.6356E-6	1.7058E-5
1.0075E-6	7.0465E-6
4.9894E-7	2.3190E-6
1.6352E-7	6.4480E-7
2.3355E-8	1.2649E-7
2.8094E-9	2.5548E-8
3.6236E-11	8.4782E-9
6.4577E-11	7.5130E-10
4.4963E-14	2.4188E-10
3.6654E-16	2.2739E-13
5.6293E-17	9.0536E-14
7.1602E-17	5.6098E-15

Source: Reference 6. (Table extracted from American National Standard ANSI/ANS-5.1-1979 with permission of the publishers, the American Nuclear Society.)

* $F(t,T) = \sum_{i=1}^{23} \frac{\alpha_i}{\lambda_i} e^{-\lambda_i t} (1-e^{-\lambda_i T})$ MeV/Fission

$F(T,\infty) = F(t,10^{13})$

t and T in seconds

** Read as 1.2311×10^0.

Table 3-22

Parameters for ^{239}Pu Thermal Fission Function F(t,T)*

α	λ
2.083E-01**	1.002E+01
3.853E-01	6.433E-01
2.213E-01	2.186E-01
9.460E-02	1.004E-01
3.531E-02	3.728E-02
2.292E-02	1.435E-02
3.946E-03	4.549E-03
1.317E-03	1.328E-03
7.052E-04	5.356E-04
1.432E-04	1.730E-04
1.765E-05	4.881E-05
7.347E-06	2.006E-05
1.747E-06	8.319E-06
5.481E-07	2.358E-06
1.671E-07	6.450E-07
2.112E-08	1.278E-07
2.996E-09	2.466E-08
5.107E-11	9.378E-09
5.730E-11	7.450E-10
4.138E-14	2.426E-10
1.088E-15	2.210E-13
2.454E-17	2.640E-14
7.557E-17	1.380E-14

Source: Reference 6. (Table extracted from American National Standard ANSI/ANS-5.1-1979 with permission of the publishers, the American Nuclear Society.)

* $F(t,T) = \sum_{i=1}^{23} \frac{\alpha_i}{\lambda_i} e^{-\lambda_i t} (1-e^{-\lambda_i T})$ MeV/Fission

$F(T,\infty) = F(t,10^{13})$

t and T in seconds

** Read as 2.083×10^{-1}.

with i = 1,2,3 representing ^{235}U (thermal fission), ^{238}U (fast fission), and ^{239}Pu (thermal fission). Here, ^{235}U includes all other fissionable nuclides not explicitly mentioned (i.e., all others are assumed to behave as does ^{235}U). G(t) is a correction factor used to account for neutron capture in fission products. For shutdown times of t 10^4 s, operating times of T 1.2614×10^8 s (four years), and 3.0, G(t) is found from

$$G(t) = 1.0 + (3.24 \times 10^{-6} + 5.23 \times 10^{-10} t) T^{0.4} \psi, \qquad (3.2.7)$$

where ψ is the number of fissions per initial fissile atom. For shutdown times in the range of $10^4 < t < 10^9$ s, Table 3-23 provides a tabulation of the maximum correction factors, $G_{max}(t)$, to apply.

The decay heat power should also be obtained by using the following simplified method. It is assumed that the decay heat power from fissile isotopes other than ^{235}U is identical to that of ^{235}U and that the fission rate is constant over the operating history of the level corresponding to the maximum power P_{max}. Only the infinite operating period data for ^{235}U are used. This simplified method overestimates decay heat power, especially with respect to LWR cores containing an appreciable amount of plutonium.

For finite reactor operating time, T, the decay heat power without neutron absorption in fission products is

$$P'_d(t,T) = 1.02 \frac{P_{max}}{Q} \left[F(t,\infty) - F(t + T,\infty) \right], \qquad (3.2.8)$$

where F and Q are for ^{235}U.

Table 3-23

Ratio of Decay Heat with Absorption to Values without Absorption*

Time after Shutdown (sec)	$G_{max}(t)$	Time after Shutdown (sec)	$G_{max}(t)$
1.0	1.020	1.5E+5	1.130
1.5	1.020	2.0E+5	1.131
2.0	1.020	4.0E+5	1.126
4.0	1.021	6.0E+5	1.124
6.0	1.022	8.0E+5	1.123
8.0	1.022	1.0E+6	1.124
1.0E+1	1.022	1.5E+6	1.125
1.5E+1	1.022	2.0E+6	1.127
2.0E+1	1.022	4.0E+6	1.134
4.0E+1	1.022	6.0E+6	1.146
6.0E+1	1.022	8.0E+6	1.162
8.0E+1	1.022	1.0E+7	1.181
1.0E+2	1.023	1.5E+7	1.233
1.5E+2	1.024	2.0E+7	1.284
2.0E+2	1.025	4.0E+7	1.444
4.0E+2	1.028	6.0E+7	1.535
6.0E+2	1.030	8.0E+7	1.586
8.0E+2	1.032	1.0E+8	1.598
1.0E+3	1.033	1.5E+8	1.498
1.5E+3	1.037	2.0E+8	1.343
2.0E+3	1.039	4.0E+8	1.065
4.0E+3	1.048	6.0E+8	1.021
6.0E+3	1.054	8.0E+8	1.012
8.0E+3	1.060	1.0E+9	1.007
1.0E+4	1.064		
1.5E+4	1.074		
2.0E+4	1.081		
4.0E+4	1.098		
6.0E+4	1.111		
8.0E+4	1.119		
1.0E+5	1.124		

Source: Reference 6. (Table extracted from American National Standard ANSI/ANS-5.1-1979 with permission of the publishers, the American Nuclear Society.)

* Ratio based on following assumptions: ^{235}U thermal fission for four years; no depletion; typical LWR spectrum.

17. FORTRAN PROGRAM BURNUP

The Fortran program BURNUP estimates the fraction of fission events occurring in ^{235}U, ^{238}U, and ^{239}Pu, one of the required inputs to ANSIDECH. This program was used in the solution of the Radiological Assessment Benchmark Problems 2.1, 2.2 and 2.3.

Theory

The engineering aspects of this program are discussed in Section 3.2 of Reference 3 (attached for the readers convenience at the end of this section).

Program

Program BURNUP.EXE solves Equations 3.2.9 through 3.2.11. A listing of the Fortran source code is shown in Figure 28.

Input Data

Data is input to the program via the input data file BURN.DAT. Input data names, formats and descriptions are shown in Table 2. Input data files for Benchmark Problems 2.1, 2.2, and 2.3 are given in Figure 29.

Output Data

The output data from this program is contained in file BURNUP.OUT. The output data for Benchmark Problems 2.1, 2.2 and 2.3 is shown in Figure 30.

Figure 28

Fortran Program BURNUP Source Code

```
      PROGRAM BURNUP
      IMPLICIT REAL*8 (A-H,O-Z)
      CHARACTER*4 TITLE
      DIMENSION TITLE(20)
      OPEN(2,FILE='BURNUP.OUT')
      OPEN(5,FILE='BURN.DAT')
      IN=5
      IOUT=2
    5 CONTINUE
      READ(IN,10)  TITLE
   10 FORMAT(20A4)
      IF( TITLE(1).EQ.'END ') GO TO 1000
      WRITE(IOUT,20)  TITLE
   20 FORMAT(//,1X,20A4)
      READ(IN,22) IRTYPE
   22 FORMAT(I1)
      IF(IRTYPE.EQ.2) GO TO 30
      WRITE(IOUT,25)
   25 FORMAT(/,1X,'REACTOR TYPE IS PWR',/)
      GO TO 40
   30 WRITE(IOUT,35)
   35 FORMAT(/,1X,'REACTOR TYPE IS BWR',/)
   40 CONTINUE
      READ(IN,50) NRP,U235P
   50 FORMAT(I10,F10.3)
      WRITE(IOUT,60) NRP,U235P
   60 FORMAT(1X,I5,1X,'IRRADIATION PERIODS',8X,'INITIALLY',
     &F10.3,1X,'PERCENT U235')
      IF(NRP.GT.100) GO TO 1000
      BT=0.0D0
      BV=0.0D0
      TFKEEP=0.0D0
      U238KP=0.0D0
      P239KP=0.0D0
      DO 500 IP=1,NRP
      WRITE(IOUT,70) IP
   70 FORMAT(//,1X,'REPORT FOR PERIOD',I5,/)
      READ(IN,80) PL,DUR,VOIDP
   80 FORMAT(3F10.2)
      WRITE(IOUT,90) PL,DUR
   90 FORMAT(1X,'POWER LEVEL',F10.2,1X,'MW/MTU',8X,
     &'DURATION=',F10.2,1X,'DAYS')
      IF(IRTYPE.EQ.2) WRITE(IOUT,95) VOIDP
   95 FORMAT(1X,'VOID PERCENTAGE=',F10.2)
      B=PL*DUR*0.001D0
      BV=BV+B*VOIDP
      BT=BT+B
      BAV=BV/BT
      WRITE(IOUT,100) B,BT
  100 FORMAT(1X,'PERIOD BURNUP=',E12.3,1X,'MWD/KGU',2X,'TOTAL BURNUP=',
     &E12.3,1X,'MWD/KGU')
      IF(IRTYPE.EQ.2) GO TO 300
      Q=200.0D0+5.2342D0*U235P**(-1.0858D0)*BT**(0.11559D0*DLOG(BT))
      WRITE(IOUT,105) Q
  105 FORMAT(1X,'Q VALUE=',F10.3,
     &1X,'MEV/FISSION')
```

Figure 28

Fortran Program BURNUP Source Code (continued)

```
      TFNUM=5.3930D23*BT/Q
      FNU238=1.7038D20*U235P**(-0.17202D0)*BT**1.0574D0
      FNP239=2.7165D20*U235P**(-0.90385D0)*BT**1.6125D0
      FU238=(FNU238-U238KP)/(TFNUM-TFKEEP)
      FP239=(FNP239-P239KP)/(TFNUM-TFKEEP)
      FU235=1.0D0-FU238-FP239
      TFKEEP=TFNUM
      U238KP=FNU238
      P239KP=FNP239
      PU235=FU235*PL
      PU238=FU238*PL
      PP239=FP239*PL
      WRITE(IOUT,110) PU235
  110 FORMAT(1X,'U235 ISOTOPIC POWER=',1X,F10.3,1X,'MW/MTU')
      WRITE(IOUT,120) PP239
  120 FORMAT(1X,'PU239 ISOTOPIC POWER=',F10.3,1X,'MW/MTU')
      WRITE(IOUT,130) PU238
  130 FORMAT(1X,'U238 ISOTOPIC POWER=',1X,F10.3,1X,'MW/MTU')
      PSI=TFNUM*235.0439/(U235P*6.02252E+24)
      WRITE(IOUT,135) PSI
  135 FORMAT(1X,'PSI=',F12.4)
      GO TO 500
  300 CONTINUE
      IF(BAV.LT.0.001D0) BAV=35.
      Q=200.0D0+8.2112D0*U235P**(-0.35234D0)*BAV**
     &0.045316D0*BT**(0.066524D0+0.027002D0*DLOG(BT))
      WRITE(IOUT,105) Q
      TFNUM=5.3930D23*BT/Q
      FNU238=1.7923D20*U235P**(-0.24103D0)*BT**(1.0583D0)
      DNU238=1.5603D20*U235P**(-0.26939D0)*BT**(1.0587D0)
     &-FNU238
      FNP239=1.9941D20*U235P**(-1.0176D0)*BT**(1.7198D0)
      DNP239=1.8505D20*U235P**(-1.1043D0)*BT**(1.7499D0)
     &-FNP239
      FNU238=FNU238+DNU238*(BAV  -20.0D0)/30.0D0
      FNP239=FNP239+DNP239*(BAV  -20.0D0)/30.0D0
      FU238=(FNU238-U238KP)/(TFNUM-TFKEEP)
      FP239=(FNP239-P239KP)/(TFNUM-TFKEEP)
      FU235=1.0D0-FU238-FP239
      TFKEEP=TFNUM
      U238KP=FNU238
      P239KP=FNP239
      PU235=FU235*PL
      PU238=FU238*PL
      PP239=FP239*PL
      PSI=TFNUM*235.0439/(U235P*6.02252E24)
      WRITE(IOUT,110) PU235
      WRITE(IOUT,120) PP239
      WRITE(IOUT,130) PU238
      WRITE(IOUT,135) PSI
  500 CONTINUE
      GO TO 5
 1000 CONTINUE
      STOP
      END
```

TABLE 2

PROGRAM BURNUP INPUT DATA (BURN.DAT) DESCRIPTION

CARD	VARIABLE	FORMAT	DESCRIPTION
1	TITLE	20A4	PROBLEM TITLE
2	IRTYPE	I1	1 = REACTOR TYPE IS PWR 2 = REACTOR TYPE IS BWR
3	NRP	I10	IRRIDIATION PERIODS
3	U235P	F10.3	INITIAL PERCENTAGE U235
4	PL	F10.2	REACTOR POWER LEVEL (MW/KG)
4	DUR	F10.2	DURATION (DAYS)
4	VOIDP	F10.2	VOID PERCENTAGE IF REACTOR TYPE IS BWR

Figure 29

Program BURNUP Input Data (BURN.DAT)

```
TEST PROBLEM
1
          24          3.3
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
        37.5      36.6667
PROBLEM 2.1.1
1
           1          1.5
         41.         370.
PROBLEM 2.1.2
1
           2          2.5
         43.         370.
         38.         260.
PROBLEM 2.1.3
1
           3          3.5
       28.5          370.
         45.         260.
         42.         300.
PROBLEM 2.1.4
1
           1          3.2
      31.25        1080.
PROBLEM 2.1.4A
1
          10          3.2
      31.25         108.
      31.25         108.
      31.25         108.
      31.25         108.
      31.25         108.
      31.25         108.
      31.25         108.
      31.25         108.
      31.25         108.
      31.25         108.
PROBLEM 2.1.5
1
           6          3.2
         34.         150.
         34.         150.
         41.         150.
         41.         150.
       37.5          150.
       37.5          150.
```

Figure 29

Program BURNUP Input Data (BURN.DAT) (continued)

```
PROBLEM 2.2.1
2
          1        1.1
        30.       370.        40.
PROBLEM 2.2.2
2
          2        2.5
        30.       370.        40.
        27.       260.        30.
PROBLEM 2.2.3
2
          6        2.5
        20.       185.        35.
        20.       185.        35.
        30.       130.        35.
        30.       130.        35.
        30.       150.        35.
        30.       150.        35.
PROBLEM 2.2.3A
2
          3        2.5
        20.       370.        35.
        30.       260.        35.
        30.       300.        35.
PROBLEM 2.2.4
2
          1        2.7
        25.      1080.        35.
PROBLEM 2.2.5
2
          6        2.7
        27.       150.        20.
        31.       150.        50.
        29.       150.        20.
        33.       150.        50.
        28.       150.        20.
        32.       150.        50.
PROBLEM 2.2.6
2
          6        2.7
        31.       150.        50.
        27.       150.        20.
        33.       150.        50.
        29.       150.        20.
        32.       150.        50.
        28.       150.        20.
PROBLEM 2.3.1
1
          3      2.556
    28.462       310.
    31.827       321.
    28.929       305.
PROBLEM 2.3.2
1
          3      2.556
    29.041       310.
    32.475       321.
    29.518       305.
PROBLEM 2.3.3
1
          3      2.556
    27.054       310.
    30.253       321.
    27.498       305.
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT)

```
TEST PROBLEM

REACTOR TYPE IS PWR

   24 IRRADIATION PERIODS        INITIALLY     3.300 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .138E+01 MWD/KGU
Q VALUE=    201.449 MEV/FISSION
U235 ISOTOPIC POWER=      33.949 MW/MTU
PU239 ISOTOPIC POWER=      1.572 MW/MTU
U238 ISOTOPIC POWER=       1.979 MW/MTU
PSI=        .0435

REPORT FOR PERIOD    2

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .275E+01 MWD/KGU
Q VALUE=    201.611 MEV/FISSION
U235 ISOTOPIC POWER=      32.117 MW/MTU
PU239 ISOTOPIC POWER=      3.240 MW/MTU
U238 ISOTOPIC POWER=       2.144 MW/MTU
PSI=        .0870

REPORT FOR PERIOD    3

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .413E+01 MWD/KGU
Q VALUE=    201.806 MEV/FISSION
U235 ISOTOPIC POWER=      30.834 MW/MTU
PU239 ISOTOPIC POWER=      4.452 MW/MTU
U238 ISOTOPIC POWER=       2.213 MW/MTU
PSI=        .1304

REPORT FOR PERIOD    4

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .550E+01 MWD/KGU
Q VALUE=    202.003 MEV/FISSION
U235 ISOTOPIC POWER=      29.752 MW/MTU
PU239 ISOTOPIC POWER=      5.486 MW/MTU
U238 ISOTOPIC POWER=       2.261 MW/MTU
PSI=        .1737

REPORT FOR PERIOD    5

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .688E+01 MWD/KGU
Q VALUE=    202.200 MEV/FISSION
U235 ISOTOPIC POWER=      28.787 MW/MTU
PU239 ISOTOPIC POWER=      6.414 MW/MTU
U238 ISOTOPIC POWER=       2.299 MW/MTU
PSI=        .2169
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
REPORT FOR PERIOD    6

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .825E+01 MWD/KGU
Q VALUE=   202.395 MEV/FISSION
U235 ISOTOPIC POWER=      27.902 MW/MTU
PU239 ISOTOPIC POWER=      7.268 MW/MTU
U238 ISOTOPIC POWER=       2.330 MW/MTU
PSI=        .2600

REPORT FOR PERIOD    7

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .963E+01 MWD/KGU
Q VALUE=   202.590 MEV/FISSION
U235 ISOTOPIC POWER=      27.076 MW/MTU
PU239 ISOTOPIC POWER=      8.067 MW/MTU
U238 ISOTOPIC POWER=       2.357 MW/MTU
PSI=        .3030

REPORT FOR PERIOD    8

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .110E+02 MWD/KGU
Q VALUE=   202.783 MEV/FISSION
U235 ISOTOPIC POWER=      26.296 MW/MTU
PU239 ISOTOPIC POWER=      8.823 MW/MTU
U238 ISOTOPIC POWER=       2.381 MW/MTU
PSI=        .3460

REPORT FOR PERIOD    9

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .124E+02 MWD/KGU
Q VALUE=   202.975 MEV/FISSION
U235 ISOTOPIC POWER=      25.553 MW/MTU
PU239 ISOTOPIC POWER=      9.544 MW/MTU
U238 ISOTOPIC POWER=       2.403 MW/MTU
PSI=        .3889

REPORT FOR PERIOD   10

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .138E+02 MWD/KGU
Q VALUE=   203.167 MEV/FISSION
U235 ISOTOPIC POWER=      24.841 MW/MTU
PU239 ISOTOPIC POWER=     10.236 MW/MTU
U238 ISOTOPIC POWER=       2.423 MW/MTU
PSI=        .4317

REPORT FOR PERIOD   11

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .151E+02 MWD/KGU
Q VALUE=   203.359 MEV/FISSION
U235 ISOTOPIC POWER=      24.155 MW/MTU
PU239 ISOTOPIC POWER=     10.904 MW/MTU
U238 ISOTOPIC POWER=       2.441 MW/MTU
PSI=        .4744
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
REPORT FOR PERIOD   12

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .165E+02 MWD/KGU
Q VALUE=   203.551 MEV/FISSION
U235 ISOTOPIC POWER=      23.491 MW/MTU
PU239 ISOTOPIC POWER=     11.551 MW/MTU
U238 ISOTOPIC POWER=       2.459 MW/MTU
PSI=        .5170

REPORT FOR PERIOD   13

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .179E+02 MWD/KGU
Q VALUE=   203.743 MEV/FISSION
U235 ISOTOPIC POWER=      22.846 MW/MTU
PU239 ISOTOPIC POWER=     12.179 MW/MTU
U238 ISOTOPIC POWER=       2.475 MW/MTU
PSI=        .5596

REPORT FOR PERIOD   14

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .193E+02 MWD/KGU
Q VALUE=   203.935 MEV/FISSION
U235 ISOTOPIC POWER=      22.218 MW/MTU
PU239 ISOTOPIC POWER=     12.791 MW/MTU
U238 ISOTOPIC POWER=       2.491 MW/MTU
PSI=        .6020

REPORT FOR PERIOD   15

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .206E+02 MWD/KGU
Q VALUE=   204.127 MEV/FISSION
U235 ISOTOPIC POWER=      21.605 MW/MTU
PU239 ISOTOPIC POWER=     13.389 MW/MTU
U238 ISOTOPIC POWER=       2.506 MW/MTU
PSI=        .6444

REPORT FOR PERIOD   16

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .220E+02 MWD/KGU
Q VALUE=   204.320 MEV/FISSION
U235 ISOTOPIC POWER=      21.006 MW/MTU
PU239 ISOTOPIC POWER=     13.974 MW/MTU
U238 ISOTOPIC POWER=       2.520 MW/MTU
PSI=        .6868

REPORT FOR PERIOD   17

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .234E+02 MWD/KGU
Q VALUE=   204.513 MEV/FISSION
U235 ISOTOPIC POWER=      20.418 MW/MTU
PU239 ISOTOPIC POWER=     14.548 MW/MTU
U238 ISOTOPIC POWER=       2.534 MW/MTU
PSI=        .7290
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
REPORT FOR PERIOD   18

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .248E+02 MWD/KGU
Q VALUE=   204.707 MEV/FISSION
U235 ISOTOPIC POWER=      19.841 MW/MTU
PU239 ISOTOPIC POWER=     15.111 MW/MTU
U238 ISOTOPIC POWER=       2.548 MW/MTU
PSI=        .7711

REPORT FOR PERIOD   19

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .261E+02 MWD/KGU
Q VALUE=   204.901 MEV/FISSION
U235 ISOTOPIC POWER=      19.275 MW/MTU
PU239 ISOTOPIC POWER=     15.665 MW/MTU
U238 ISOTOPIC POWER=       2.561 MW/MTU
PSI=        .8132

REPORT FOR PERIOD   20

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .275E+02 MWD/KGU
Q VALUE=   205.096 MEV/FISSION
U235 ISOTOPIC POWER=      18.717 MW/MTU
PU239 ISOTOPIC POWER=     16.210 MW/MTU
U238 ISOTOPIC POWER=       2.574 MW/MTU
PSI=        .8552

REPORT FOR PERIOD   21

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .289E+02 MWD/KGU
Q VALUE=   205.292 MEV/FISSION
U235 ISOTOPIC POWER=      18.167 MW/MTU
PU239 ISOTOPIC POWER=     16.747 MW/MTU
U238 ISOTOPIC POWER=       2.586 MW/MTU
PSI=        .8971

REPORT FOR PERIOD   22

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .303E+02 MWD/KGU
Q VALUE=   205.488 MEV/FISSION
U235 ISOTOPIC POWER=      17.625 MW/MTU
PU239 ISOTOPIC POWER=     17.277 MW/MTU
U238 ISOTOPIC POWER=       2.598 MW/MTU
PSI=        .9389

REPORT FOR PERIOD   23

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .316E+02 MWD/KGU
Q VALUE=   205.685 MEV/FISSION
U235 ISOTOPIC POWER=      17.090 MW/MTU
PU239 ISOTOPIC POWER=     17.800 MW/MTU
U238 ISOTOPIC POWER=       2.610 MW/MTU
PSI=        .9807
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
REPORT FOR PERIOD   24

POWER LEVEL      37.50 MW/MTU          DURATION=      36.67 DAYS
PERIOD BURNUP=     .138E+01 MWD/KGU  TOTAL BURNUP=     .330E+02 MWD/KGU
Q VALUE=   205.883 MEV/FISSION
U235 ISOTOPIC POWER=      16.561 MW/MTU
PU239 ISOTOPIC POWER=     18.317 MW/MTU
U238 ISOTOPIC POWER=       2.622 MW/MTU
PSI=       1.0223

PROBLEM 2.1.1

REACTOR TYPE IS PWR

    1 IRRADIATION PERIODS          INITIALLY     1.500 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      41.00 MW/MTU          DURATION=     370.00 DAYS
PERIOD BURNUP=     .152E+02 MWD/KGU  TOTAL BURNUP=     .152E+02 MWD/KGU
Q VALUE=   207.923 MEV/FISSION
U235 ISOTOPIC POWER=      22.322 MW/MTU
PU239 ISOTOPIC POWER=     15.742 MW/MTU
U238 ISOTOPIC POWER=       2.936 MW/MTU
PSI=       1.0237

PROBLEM 2.1.2

REACTOR TYPE IS PWR

    2 IRRADIATION PERIODS          INITIALLY     2.500 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      43.00 MW/MTU          DURATION=     370.00 DAYS
PERIOD BURNUP=     .159E+02 MWD/KGU  TOTAL BURNUP=     .159E+02 MWD/KGU
Q VALUE=   204.689 MEV/FISSION
U235 ISOTOPIC POWER=      29.670 MW/MTU
PU239 ISOTOPIC POWER=     10.546 MW/MTU
U238 ISOTOPIC POWER=       2.784 MW/MTU
PSI=        .6544

REPORT FOR PERIOD    2

POWER LEVEL      38.00 MW/MTU          DURATION=     260.00 DAYS
PERIOD BURNUP=     .988E+01 MWD/KGU  TOTAL BURNUP=     .258E+02 MWD/KGU
Q VALUE=   206.561 MEV/FISSION
U235 'SOTOPIC POWER=      17.171 MW/MTU
PU239 ISOTOPIC POWER=     18.124 MW/MTU
U238 ISOTOPIC POWER=       2.705 MW/MTU
PSI=       1.0511
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
PROBLEM 2.1.3

REACTOR TYPE IS PWR

    3 IRRADIATION PERIODS        INITIALLY     3.500 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      28.50 MW/MTU        DURATION=    370.00 DAYS
PERIOD BURNUP=    .105E+02 MWD/KGU  TOTAL BURNUP=    .105E+02 MWD/KGU
Q VALUE=   202.551 MEV/FISSION
U235 ISOTOPIC POWER=     22.850 MW/MTU
PU239 ISOTOPIC POWER=     3.967 MW/MTU
U238 ISOTOPIC POWER=      1.683 MW/MTU
PSI=       .3131

REPORT FOR PERIOD    2

POWER LEVEL      45.00 MW/MTU        DURATION=    260.00 DAYS
PERIOD BURNUP=    .117E+02 MWD/KGU  TOTAL BURNUP=    .222E+02 MWD/KGU
Q VALUE=   204.085 MEV/FISSION
U235 ISOTOPIC POWER=     28.723 MW/MTU
PU239 ISOTOPIC POWER=    13.356 MW/MTU
U238 ISOTOPIC POWER=      2.920 MW/MTU
PSI=       .6555

REPORT FOR PERIOD    3

POWER LEVEL      42.00 MW/MTU        DURATION=    300.00 DAYS
PERIOD BURNUP=    .126E+02 MWD/KGU  TOTAL BURNUP=    .348E+02 MWD/KGU
Q VALUE=   205.769 MEV/FISSION
U235 ISOTOPIC POWER=     21.290 MW/MTU
PU239 ISOTOPIC POWER=    17.848 MW/MTU
U238 ISOTOPIC POWER=      2.861 MW/MTU
PSI=      1.0183

PROBLEM 2.1.4

REACTOR TYPE IS PWR

    1 IRRADIATION PERIODS        INITIALLY     3.200 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      31.25 MW/MTU        DURATION=   1080.00 DAYS
PERIOD BURNUP=    .338E+02 MWD/KGU  TOTAL BURNUP=    .338E+02 MWD/KGU
Q VALUE=   206.194 MEV/FISSION
U235 ISOTOPIC POWER=     19.420 MW/MTU
PU239 ISOTOPIC POWER=     9.790 MW/MTU
U238 ISOTOPIC POWER=      2.040 MW/MTU
PSI=      1.0766
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
PROBLEM 2.1.4A

REACTOR TYPE IS PWR

   10 IRRADIATION PERIODS        INITIALLY     3.200 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      31.25 MW/MTU        DURATION=    108.00 DAYS
PERIOD BURNUP=    .338E+01 MWD/KGU  TOTAL BURNUP=    .338E+01 MWD/KGU
Q VALUE=   201.756 MEV/FISSION
U235 ISOTOPIC POWER=     27.163 MW/MTU
PU239 ISOTOPIC POWER=     2.338 MW/MTU
U238 ISOTOPIC POWER=      1.749 MW/MTU
PSI=       .1100

REPORT FOR PERIOD    2

POWER LEVEL      31.25 MW/MTU        DURATION=    108.00 DAYS
PERIOD BURNUP=    .338E+01 MWD/KGU  TOTAL BURNUP=    .675E+01 MWD/KGU
Q VALUE=   202.256 MEV/FISSION
U235 ISOTOPIC POWER=     24.515 MW/MTU
PU239 ISOTOPIC POWER=     4.835 MW/MTU
U238 ISOTOPIC POWER=      1.900 MW/MTU
PSI=       .2195

REPORT FOR PERIOD    3

POWER LEVEL      31.25 MW/MTU        DURATION=    108.00 DAYS
PERIOD BURNUP=    .338E+01 MWD/KGU  TOTAL BURNUP=    .101E+02 MWD/KGU
Q VALUE=   202.750 MEV/FISSION
U235 ISOTOPIC POWER=     22.620 MW/MTU
PU239 ISOTOPIC POWER=     6.663 MW/MTU
U238 ISOTOPIC POWER=      1.967 MW/MTU
PSI=       .3285

REPORT FOR PERIOD    4

POWER LEVEL      31.25 MW/MTU        DURATION=    108.00 DAYS
PERIOD BURNUP=    .338E+01 MWD/KGU  TOTAL BURNUP=    .135E+02 MWD/KGU
Q VALUE=   203.239 MEV/FISSION
U235 ISOTOPIC POWER=     21.001 MW/MTU
PU239 ISOTOPIC POWER=     8.233 MW/MTU
U238 ISOTOPIC POWER=      2.016 MW/MTU
PSI=       .4369

REPORT FOR PERIOD    5

POWER LEVEL      31.25 MW/MTU        DURATION=    108.00 DAYS
PERIOD BURNUP=    .338E+01 MWD/KGU  TOTAL BURNUP=    .169E+02 MWD/KGU
Q VALUE=   203.726 MEV/FISSION
U235 ISOTOPIC POWER=     19.543 MW/MTU
PU239 ISOTOPIC POWER=     9.652 MW/MTU
U238 ISOTOPIC POWER=      2.055 MW/MTU
PSI=       .5448
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
REPORT FOR PERIOD    6

POWER LEVEL      31.25 MW/MTU          DURATION=    108.00 DAYS
PERIOD BURNUP=     .338E+01 MWD/KGU  TOTAL BURNUP=     .203E+02 MWD/KGU
Q VALUE=   204.213 MEV/FISSION
U235 ISOTOPIC POWER=      18.193 MW/MTU
PU239 ISOTOPIC POWER=     10.969 MW/MTU
U238 ISOTOPIC POWER=       2.089 MW/MTU
PSI=        .6522

REPORT FOR PERIOD    7

POWER LEVEL      31.25 MW/MTU          DURATION=    108.00 DAYS
PERIOD BURNUP=     .338E+01 MWD/KGU  TOTAL BURNUP=     .236E+02 MWD/KGU
Q VALUE=   204.703 MEV/FISSION
U235 ISOTOPIC POWER=      16.920 MW/MTU
PU239 ISOTOPIC POWER=     12.211 MW/MTU
U238 ISOTOPIC POWER=       2.119 MW/MTU
PSI=        .7591

REPORT FOR PERIOD    8

POWER LEVEL      31.25 MW/MTU          DURATION=    108.00 DAYS
PERIOD BURNUP=     .338E+01 MWD/KGU  TOTAL BURNUP=     .270E+02 MWD/KGU
Q VALUE=   205.196 MEV/FISSION
U235 ISOTOPIC POWER=      15.707 MW/MTU
PU239 ISOTOPIC POWER=     13.396 MW/MTU
U238 ISOTOPIC POWER=       2.147 MW/MTU
PSI=        .8655

REPORT FOR PERIOD    9

POWER LEVEL      31.25 MW/MTU          DURATION=    108.00 DAYS
PERIOD BURNUP=     .338E+01 MWD/KGU  TOTAL BURNUP=     .304E+02 MWD/KGU
Q VALUE=   205.693 MEV/FISSION
U235 ISOTOPIC POWER=      14.541 MW/MTU
PU239 ISOTOPIC POWER=     14.536 MW/MTU
U238 ISOTOPIC POWER=       2.173 MW/MTU
PSI=        .9713

REPORT FOR PERIOD   10

POWER LEVEL      31.25 MW/MTU          DURATION=    108.00 DAYS
PERIOD BURNUP=     .338E+01 MWD/KGU  TOTAL BURNUP=     .338E+02 MWD/KGU
Q VALUE=   206.194 MEV/FISSION
U235 ISOTOPIC POWER=      13.411 MW/MTU
PU239 ISOTOPIC POWER=     15.640 MW/MTU
U238 ISOTOPIC POWER=       2.199 MW/MTU
PSI=       1.0766
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
PROBLEM 2.1.5

REACTOR TYPE IS PWR

    6 IRRADIATION PERIODS        INITIALLY     3.200 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      34.00 MW/MTU         DURATION=    150.00 DAYS
PERIOD BURNUP=     .510E+01 MWD/KGU  TOTAL BURNUP=     .510E+01 MWD/KGU
Q VALUE=   202.012 MEV/FISSION
U235 ISOTOPIC POWER=      28.770 MW/MTU
PU239 ISOTOPIC POWER=      3.280 MW/MTU
U238 ISOTOPIC POWER=       1.951 MW/MTU
PSI=        .1661

REPORT FOR PERIOD    2

POWER LEVEL      34.00 MW/MTU         DURATION=    150.00 DAYS
PERIOD BURNUP=     .510E+01 MWD/KGU  TOTAL BURNUP=     .102E+02 MWD/KGU
Q VALUE=   202.761 MEV/FISSION
U235 ISOTOPIC POWER=      25.076 MW/MTU
PU239 ISOTOPIC POWER=      6.799 MW/MTU
U238 ISOTOPIC POWER=       2.125 MW/MTU
PSI=        .3309

REPORT FOR PERIOD    3

POWER LEVEL      41.00 MW/MTU         DURATION=    150.00 DAYS
PERIOD BURNUP=     .615E+01 MWD/KGU  TOTAL BURNUP=     .164E+02 MWD/KGU
Q VALUE=   203.650 MEV/FISSION
U235 ISOTOPIC POWER=      26.722 MW/MTU
PU239 ISOTOPIC POWER=     11.611 MW/MTU
U238 ISOTOPIC POWER=       2.667 MW/MTU
PSI=        .5281

REPORT FOR PERIOD    4

POWER LEVEL      41.00 MW/MTU         DURATION=    150.00 DAYS
PERIOD BURNUP=     .615E+01 MWD/KGU  TOTAL BURNUP=     .225E+02 MWD/KGU
Q VALUE=   204.539 MEV/FISSION
U235 ISOTOPIC POWER=      23.444 MW/MTU
PU239 ISOTOPIC POWER=     14.805 MW/MTU
U238 ISOTOPIC POWER=       2.751 MW/MTU
PSI=        .7235

REPORT FOR PERIOD    5

POWER LEVEL      37.50 MW/MTU         DURATION=    150.00 DAYS
PERIOD BURNUP=     .563E+01 MWD/KGU  TOTAL BURNUP=     .281E+02 MWD/KGU
Q VALUE=   205.361 MEV/FISSION
U235 ISOTOPIC POWER=      18.854 MW/MTU
PU239 ISOTOPIC POWER=     16.070 MW/MTU
U238 ISOTOPIC POWER=       2.576 MW/MTU
PSI=        .9008
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
REPORT FOR PERIOD    6

POWER LEVEL      37.50 MW/MTU          DURATION=    150.00 DAYS
PERIOD BURNUP=    .563E+01 MWD/KGU  TOTAL BURNUP=    .338E+02 MWD/KGU
Q VALUE=   206.194 MEV/FISSION
U235 ISOTOPIC POWER=      16.545 MW/MTU
PU239 ISOTOPIC POWER=     18.327 MW/MTU
U238 ISOTOPIC POWER=       2.628 MW/MTU
PSI=       1.0766

PROBLEM 2.2.1

REACTOR TYPE IS BWR

    1 IRRADIATION PERIODS        INITIALLY     1.100 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      30.00 MW/MTU          DURATION=    370.00 DAYS
VOID PERCENTAGE=      40.00
PERIOD BURNUP=    .111E+02 MWD/KGU  TOTAL BURNUP=    .111E+02 MWD/KGU
Q VALUE=   212.879 MEV/FISSION
U235 ISOTOPIC POWER=      15.787 MW/MTU
PU239 ISOTOPIC POWER=     12.034 MW/MTU
U238 ISOTOPIC POWER=       2.178 MW/MTU
PSI=        .9977

PROBLEM 2.2.2

REACTOR TYPE IS BWR

    2 IRRADIATION PERIODS        INITIALLY     2.500 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      30.00 MW/MTU          DURATION=    370.00 DAYS
VOID PERCENTAGE=      40.00
PERIOD BURNUP=    .111E+02 MWD/KGU  TOTAL BURNUP=    .111E+02 MWD/KGU
Q VALUE=   209.644 MEV/FISSION
U235 ISOTOPIC POWER=      23.360 MW/MTU
PU239 ISOTOPIC POWER=      4.905 MW/MTU
U238 ISOTOPIC POWER=       1.734 MW/MTU
PSI=        .4458

REPORT FOR PERIOD    2

POWER LEVEL      27.00 MW/MTU          DURATION=    260.00 DAYS
VOID PERCENTAGE=      30.00
PERIOD BURNUP=    .702E+01 MWD/KGU  TOTAL BURNUP=    .181E+02 MWD/KGU
Q VALUE=   210.639 MEV/FISSION
U235 ISOTOPIC POWER=      15.558 MW/MTU
PU239 ISOTOPIC POWER=      9.652 MW/MTU
U238 ISOTOPIC POWER=       1.790 MW/MTU
PSI=        .7242
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
PROBLEM 2.2.3

REACTOR TYPE IS BWR

    6 IRRADIATION PERIODS        INITIALLY     2.500 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      20.00 MW/MTU        DURATION=    185.00 DAYS
VOID PERCENTAGE=     35.00
PERIOD BURNUP=    .370E+01 MWD/KGU  TOTAL BURNUP=    .370E+01 MWD/KGU
Q VALUE=   207.981 MEV/FISSION
U235 ISOTOPIC POWER=     17.426 MW/MTU
PU239 ISOTOPIC POWER=     1.468 MW/MTU
U238 ISOTOPIC POWER=      1.106 MW/MTU
PSI=        .1498

REPORT FOR PERIOD    2

POWER LEVEL      20.00 MW/MTU        DURATION=    185.00 DAYS
VOID PERCENTAGE=     35.00
PERIOD BURNUP=    .370E+01 MWD/KGU  TOTAL BURNUP=    .740E+01 MWD/KGU
Q VALUE=   208.891 MEV/FISSION
U235 ISOTOPIC POWER=     15.346 MW/MTU
PU239 ISOTOPIC POWER=     3.446 MW/MTU
U238 ISOTOPIC POWER=      1.208 MW/MTU
PSI=        .2982

REPORT FOR PERIOD    3

POWER LEVEL      30.00 MW/MTU        DURATION=    130.00 DAYS
VOID PERCENTAGE=     35.00
PERIOD BURNUP=    .390E+01 MWD/KGU  TOTAL BURNUP=    .113E+02 MWD/KGU
Q VALUE=   209.620 MEV/FISSION
U235 ISOTOPIC POWER=     20.478 MW/MTU
PU239 ISOTOPIC POWER=     7.642 MW/MTU
U238 ISOTOPIC POWER=      1.880 MW/MTU
PSI=        .4538

REPORT FOR PERIOD    4

POWER LEVEL      30.00 MW/MTU        DURATION=    130.00 DAYS
VOID PERCENTAGE=     35.00
PERIOD BURNUP=    .390E+01 MWD/KGU  TOTAL BURNUP=    .152E+02 MWD/KGU
Q VALUE=   210.224 MEV/FISSION
U235 ISOTOPIC POWER=     18.147 MW/MTU
PU239 ISOTOPIC POWER=     9.925 MW/MTU
U238 ISOTOPIC POWER=      1.928 MW/MTU
PSI=        .6087

REPORT FOR PERIOD    5

POWER LEVEL      30.00 MW/MTU        DURATION=    150.00 DAYS
VOID PERCENTAGE=     35.00
PERIOD BURNUP=    .450E+01 MWD/KGU  TOTAL BURNUP=    .197E+02 MWD/KGU
Q VALUE=   210.826 MEV/FISSION
U235 ISOTOPIC POWER=     15.830 MW/MTU
PU239 ISOTOPIC POWER=    12.202 MW/MTU
U238 ISOTOPIC POWER=      1.967 MW/MTU
PSI=        .7867
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
REPORT FOR PERIOD    6

POWER LEVEL      30.00 MW/MTU          DURATION=    150.00 DAYS
VOID PERCENTAGE=      35.00
PERIOD BURNUP=     .450E+01 MWD/KGU  TOTAL BURNUP=    .242E+02 MWD/KGU
Q VALUE=   211.358 MEV/FISSION
U235 ISOTOPIC POWER=      13.497 MW/MTU
PU239 ISOTOPIC POWER=     14.501 MW/MTU
U238 ISOTOPIC POWER=       2.002 MW/MTU
PSI=        .9640

PROBLEM 2.2.3A

REACTOR TYPE IS BWR

    3 IRRADIATION PERIODS        INITIALLY     2.500 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      20.00 MW/MTU          DURATION=    370.00 DAYS
VOID PERCENTAGE=      35.00
PERIOD BURNUP=     .740E+01 MWD/KGU  TOTAL BURNUP=    .740E+01 MWD/KGU
Q VALUE=   208.891 MEV/FISSION
U235 ISOTOPIC POWER=      16.391 MW/MTU
PU239 ISOTOPIC POWER=      2.453 MW/MTU
U238 ISOTOPIC POWER=       1.157 MW/MTU
PSI=        .2982

REPORT FOR PERIOD    2

POWER LEVEL      30.00 MW/MTU          DURATION=    260.00 DAYS
VOID PERCENTAGE=      35.00
PERIOD BURNUP=     .780E+01 MWD/KGU  TOTAL BURNUP=    .152E+02 MWD/KGU
Q VALUE=   210.224 MEV/FISSION
U235 ISOTOPIC POWER=      19.315 MW/MTU
PU239 ISOTOPIC POWER=      8.781 MW/MTU
U238 ISOTOPIC POWER=       1.904 MW/MTU
PSI=        .6087

REPORT FOR PERIOD    3

POWER LEVEL      30.00 MW/MTU          DURATION=    300.00 DAYS
VOID PERCENTAGE=      35.00
PERIOD BURNUP=     .900E+01 MWD/KGU  TOTAL BURNUP=    .242E+02 MWD/KGU
Q VALUE=   211.358 MEV/FISSION
U235 ISOTOPIC POWER=      14.666 MW/MTU
PU239 ISOTOPIC POWER=     13.350 MW/MTU
U238 ISOTOPIC POWER=       1.985 MW/MTU
PSI=        .9640
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
PROBLEM 2.2.4

REACTOR TYPE IS BWR

    1 IRRADIATION PERIODS        INITIALLY     2.700 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      25.00 MW/MTU        DURATION=   1080.00 DAYS
VOID PERCENTAGE=      35.00
PERIOD BURNUP=     .270E+02 MWD/KGU  TOTAL BURNUP=    .270E+02 MWD/KGU
Q VALUE=   211.350 MEV/FISSION
U235 ISOTOPIC POWER=      16.056 MW/MTU
PU239 ISOTOPIC POWER=      7.396 MW/MTU
U238 ISOTOPIC POWER=       1.547 MW/MTU
PSI=        .9959

PROBLEM 2.2.5

REACTOR TYPE IS BWR

    6 IRRADIATION PERIODS        INITIALLY     2.700 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      27.00 MW/MTU        DURATION=    150.00 DAYS
VOID PERCENTAGE=      20.00
PERIOD BURNUP=     .405E+01 MWD/KGU  TOTAL BURNUP=    .405E+01 MWD/KGU
Q VALUE=   207.669 MEV/FISSION
U235 ISOTOPIC POWER=      23.344 MW/MTU
PU239 ISOTOPIC POWER=      2.065 MW/MTU
U238 ISOTOPIC POWER=       1.591 MW/MTU
PSI=        .1520

REPORT FOR PERIOD    2

POWER LEVEL      31.00 MW/MTU        DURATION=    150.00 DAYS
VOID PERCENTAGE=      50.00
PERIOD BURNUP=     .465E+01 MWD/KGU  TOTAL BURNUP=    .870E+01 MWD/KGU
Q VALUE=   208.920 MEV/FISSION
U235 ISOTOPIC POWER=      23.979 MW/MTU
PU239 ISOTOPIC POWER=      5.311 MW/MTU
U238 ISOTOPIC POWER=       1.710 MW/MTU
PSI=        .3246

REPORT FOR PERIOD    3

POWER LEVEL      29.00 MW/MTU        DURATION=    150.00 DAYS
VOID PERCENTAGE=      20.00
PERIOD BURNUP=     .435E+01 MWD/KGU  TOTAL BURNUP=    .131E+02 MWD/KGU
Q VALUE=   209.581 MEV/FISSION
U235 ISOTOPIC POWER=      19.251 MW/MTU
PU239 ISOTOPIC POWER=      7.811 MW/MTU
U238 ISOTOPIC POWER=       1.938 MW/MTU
PSI=        .4854
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
REPORT FOR PERIOD    4

POWER LEVEL      33.00 MW/MTU          DURATION=    150.00 DAYS
VOID PERCENTAGE=      50.00
PERIOD BURNUP=    .495E+01 MWD/KGU  TOTAL BURNUP=    .180E+02 MWD/KGU
Q VALUE=   210.338 MEV/FISSION
U235 ISOTOPIC POWER=      19.986 MW/MTU
PU239 ISOTOPIC POWER=     11.075 MW/MTU
U238 ISOTOPIC POWER=       1.939 MW/MTU
PSI=        .6671

REPORT FOR PERIOD    5

POWER LEVEL      28.00 MW/MTU          DURATION=    150.00 DAYS
VOID PERCENTAGE=      20.00
PERIOD BURNUP=    .420E+01 MWD/KGU  TOTAL BURNUP=    .222E+02 MWD/KGU
Q VALUE=   210.801 MEV/FISSION
U235 ISOTOPIC POWER=      14.160 MW/MTU
PU239 ISOTOPIC POWER=     11.883 MW/MTU
U238 ISOTOPIC POWER=       1.957 MW/MTU
PSI=        .8210

REPORT FOR PERIOD    6

POWER LEVEL      32.00 MW/MTU          DURATION=    150.00 DAYS
VOID PERCENTAGE=      50.00
PERIOD BURNUP=    .480E+01 MWD/KGU  TOTAL BURNUP=    .270E+02 MWD/KGU
Q VALUE=   211.364 MEV/FISSION
U235 ISOTOPIC POWER=      14.817 MW/MTU
PU239 ISOTOPIC POWER=     15.237 MW/MTU
U238 ISOTOPIC POWER=       1.947 MW/MTU
PSI=        .9958

PROBLEM 2.2.6

REACTOR TYPE IS BWR

    6 IRRADIATION PERIODS        INITIALLY     2.700 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      31.00 MW/MTU          DURATION=    150.00 DAYS
VOID PERCENTAGE=      50.00
PERIOD BURNUP=    .465E+01 MWD/KGU  TOTAL BURNUP=    .465E+01 MWD/KGU
Q VALUE=   208.157 MEV/FISSION
U235 ISOTOPIC POWER=      27.096 MW/MTU
PU239 ISOTOPIC POWER=      2.341 MW/MTU
U238 ISOTOPIC POWER=       1.564 MW/MTU
PSI=        .1741

REPORT FOR PERIOD    2

POWER LEVEL      27.00 MW/MTU          DURATION=    150.00 DAYS
VOID PERCENTAGE=      20.00
PERIOD BURNUP=    .405E+01 MWD/KGU  TOTAL BURNUP=    .870E+01 MWD/KGU
Q VALUE=   208.920 MEV/FISSION
U235 ISOTOPIC POWER=      20.228 MW/MTU
PU239 ISOTOPIC POWER=      5.032 MW/MTU
U238 ISOTOPIC POWER=       1.740 MW/MTU
PSI=        .3246
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
REPORT FOR PERIOD    3

POWER LEVEL      33.00 MW/MTU          DURATION=    150.00 DAYS
VOID PERCENTAGE=      50.00
PERIOD BURNUP=     .495E+01 MWD/KGU  TOTAL BURNUP=    .137E+02 MWD/KGU
Q VALUE=   209.799 MEV/FISSION
U235 ISOTOPIC POWER=      22.513 MW/MTU
PU239 ISOTOPIC POWER=      8.597 MW/MTU
U238 ISOTOPIC POWER=       1.889 MW/MTU
PSI=        .5072

REPORT FOR PERIOD    4

POWER LEVEL      29.00 MW/MTU          DURATION=    150.00 DAYS
VOID PERCENTAGE=      20.00
PERIOD BURNUP=     .435E+01 MWD/KGU  TOTAL BURNUP=    .180E+02 MWD/KGU
Q VALUE=   210.338 MEV/FISSION
U235 ISOTOPIC POWER=      16.724 MW/MTU
PU239 ISOTOPIC POWER=     10.286 MW/MTU
U238 ISOTOPIC POWER=       1.989 MW/MTU
PSI=        .6671

REPORT FOR PERIOD    5

POWER LEVEL      32.00 MW/MTU          DURATION=    150.00 DAYS
VOID PERCENTAGE=      50.00
PERIOD BURNUP=     .480E+01 MWD/KGU  TOTAL BURNUP=    .228E+02 MWD/KGU
Q VALUE=   210.952 MEV/FISSION
U235 ISOTOPIC POWER=      16.888 MW/MTU
PU239 ISOTOPIC POWER=     13.195 MW/MTU
U238 ISOTOPIC POWER=       1.917 MW/MTU
PSI=        .8425

REPORT FOR PERIOD    6

POWER LEVEL      28.00 MW/MTU          DURATION=    150.00 DAYS
VOID PERCENTAGE=      20.00
PERIOD BURNUP=     .420E+01 MWD/KGU  TOTAL BURNUP=    .270E+02 MWD/KGU
Q VALUE=   211.364 MEV/FISSION
U235 ISOTOPIC POWER=      12.089 MW/MTU
PU239 ISOTOPIC POWER=     13.923 MW/MTU
U238 ISOTOPIC POWER=       1.988 MW/MTU
PSI=        .9958

PROBLEM 2.3.1

REACTOR TYPE IS PWR

    3 IRRADIATION PERIODS        INITIALLY     2.556 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      28.46 MW/MTU          DURATION=    310.00 DAYS
PERIOD BURNUP=     .882E+01 MWD/KGU  TOTAL BURNUP=    .882E+01 MWD/KGU
Q VALUE=   203.268 MEV/FISSION
U235 ISOTOPIC POWER=      21.964 MW/MTU
PU239 ISOTOPIC POWER=      4.735 MW/MTU
U238 ISOTOPIC POWER=       1.762 MW/MTU
PSI=        .3574
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
REPORT FOR PERIOD    2

POWER LEVEL      31.83 MW/MTU          DURATION=    321.00 DAYS
PERIOD BURNUP=     .102E+02 MWD/KGU  TOTAL BURNUP=     .190E+02 MWD/KGU
Q VALUE=   205.154 MEV/FISSION
U235 ISOTOPIC POWER=      18.224 MW/MTU
PU239 ISOTOPIC POWER=     11.429 MW/MTU
U238 ISOTOPIC POWER=       2.174 MW/MTU
PSI=        .7642

REPORT FOR PERIOD    3

POWER LEVEL      28.93 MW/MTU          DURATION=    305.00 DAYS
PERIOD BURNUP=     .882E+01 MWD/KGU  TOTAL BURNUP=     .279E+02 MWD/KGU
Q VALUE=   206.793 MEV/FISSION
U235 ISOTOPIC POWER=      12.256 MW/MTU
PU239 ISOTOPIC POWER=     14.600 MW/MTU
U238 ISOTOPIC POWER=       2.073 MW/MTU
PSI=       1.1095

PROBLEM 2.3.2

REACTOR TYPE IS PWR

    3 IRRADIATION PERIODS        INITIALLY     2.556 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      29.04 MW/MTU          DURATION=    310.00 DAYS
PERIOD BURNUP=     .900E+01 MWD/KGU  TOTAL BURNUP=     .900E+01 MWD/KGU
Q VALUE=   203.302 MEV/FISSION
U235 ISOTOPIC POWER=      22.348 MW/MTU
PU239 ISOTOPIC POWER=      4.892 MW/MTU
U238 ISOTOPIC POWER=       1.801 MW/MTU
PSI=        .3646

REPORT FOR PERIOD    2

POWER LEVEL      32.48 MW/MTU          DURATION=    321.00 DAYS
PERIOD BURNUP=     .104E+02 MWD/KGU  TOTAL BURNUP=     .194E+02 MWD/KGU
Q VALUE=   205.226 MEV/FISSION
U235 ISOTOPIC POWER=      18.441 MW/MTU
PU239 ISOTOPIC POWER=     11.812 MW/MTU
U238 ISOTOPIC POWER=       2.222 MW/MTU
PSI=        .7795

REPORT FOR PERIOD    3

POWER LEVEL      29.52 MW/MTU          DURATION=    305.00 DAYS
PERIOD BURNUP=     .900E+01 MWD/KGU  TOTAL BURNUP=     .284E+02 MWD/KGU
Q VALUE=   206.900 MEV/FISSION
U235 ISOTOPIC POWER=      12.303 MW/MTU
PU239 ISOTOPIC POWER=     15.095 MW/MTU
U238 ISOTOPIC POWER=       2.120 MW/MTU
PSI=       1.1315
```

Figure 30

Program BURNUP Output Data File (BURNUP.OUT) (continued)

```
PROBLEM 2.3.3

REACTOR TYPE IS PWR

    3 IRRADIATION PERIODS        INITIALLY     2.556 PERCENT U235

REPORT FOR PERIOD    1

POWER LEVEL      27.05 MW/MTU        DURATION=    310.00 DAYS
PERIOD BURNUP=    .839E+01 MWD/KGU  TOTAL BURNUP=    .839E+01 MWD/KGU
Q VALUE=   203.187 MEV/FISSION
U235 ISOTOPIC POWER=     21.023 MW/MTU
PU239 ISOTOPIC POWER=     4.361 MW/MTU
U238 ISOTOPIC POWER=      1.670 MW/MTU
PSI=        .3399

REPORT FOR PERIOD    2

POWER LEVEL      30.25 MW/MTU        DURATION=    321.00 DAYS
PERIOD BURNUP=    .971E+01 MWD/KGU  TOTAL BURNUP=    .181E+02 MWD/KGU
Q VALUE=   204.981 MEV/FISSION
U235 ISOTOPIC POWER=     17.677 MW/MTU
PU239 ISOTOPIC POWER=    10.518 MW/MTU
U238 ISOTOPIC POWER=      2.058 MW/MTU
PSI=        .7270

REPORT FOR PERIOD    3

POWER LEVEL      27.50 MW/MTU        DURATION=    305.00 DAYS
PERIOD BURNUP=    .839E+01 MWD/KGU  TOTAL BURNUP=    .265E+02 MWD/KGU
Q VALUE=   206.535 MEV/FISSION
U235 ISOTOPIC POWER=     12.113 MW/MTU
PU239 ISOTOPIC POWER=    13.424 MW/MTU
U238 ISOTOPIC POWER=      1.961 MW/MTU
PSI=       1.0560
```

The computer program BURNUP implements the five-step method outlined below to estimate the relative power from ^{235}U, ^{238}U, and ^{239}Pu. This method is based on the observation that $P_{i\alpha}/Q_i = N'_{i\alpha}$, where $N'_{i\alpha}$ is the number of fissions of nuclide i in time period α.

Step 1. Beginning with the first irradiation period, estimate the cumulative number of fissions, N_α, by all nuclides through the end of the irradiation period by the following expression:

$$N_\alpha = \frac{5.3930 \times 10^{23}}{\bar{Q}_\alpha} B_\alpha \tag{3.2.9}$$

where N_α is the total number of fissions per kilogram of uranium, B_α is the fuel burnup in units of MWD/kgU, and $\bar{Q}_\alpha$ is the burnup averaged energy in MeV for all fissions of all isotopes through the end of irradiation period α. The constant in Equation 3.2.9 is obtained as follows:

$$5.3930 \times 10^{23} = \frac{1 \text{ MeV}}{1.60209 \times 10^{-13} \text{ watt-sec}} \cdot \frac{86400 \text{ sec}}{\text{day}} \cdot \frac{10^6 \text{ watts}}{1 \text{ MW}} \tag{3.2.10}$$

Tables 3-24 and 3-25 provide correlations that can be used to estimate the value of $\bar{Q}_\alpha$ for pressurized water reactors and boiling water reactors, respectively.

Step 2. Estimate the cumulative number of fissions by ^{238}U and ^{239}Pu through the end of irradiation period α using the correlations given in Tables 3-24 and 3-25 for PWRs and BWRs, respectively.

Table 3-24

Correlations for Average MeV/Fission and Total ^{238}U and ^{239}Pu Atoms Fissioned for PWRs

Average MeV/fission:

$$\bar{Q}_\alpha = 200 + 5.2342\, E^{-1.0858}\, B_\alpha^{\ .11559 \ln B_\alpha}$$

Total atoms fissioned per kgU:

for ^{238}U

$$N_{i\alpha} = 1.7038 \times 10^{20}\, E^{-.17202}\, B_\alpha^{\ 1.0574}$$

for ^{239}Pu

$$N_{i\alpha} = 2.7165 \times 10^{20}\, E^{-.90385}\, B_\alpha^{\ 1.6125}$$

E = ^{235}U enrichment in weight percent

B_α = burnup in MWD/kgU at the end of time period α

Note: These correlations are based on results of CorSTAR analyses of 15x15 Westinghouse fuel assemblies using a version of the code LEOPARD. The correlations were developed for the following range of parameters:

$$1.5 \leq E \leq 3.5$$

$$1 \leq B_\alpha \leq 5 + 10 \cdot E$$

Table 3-25

Correlations for Average MeV/Fission and Total ^{238}U and ^{239}Pu Atoms Fissioned for BWRs

Average MeV/fission:

$$\bar{Q}_\alpha = 200 + 8.2112E^{(-.35234)} V_\alpha^{(.045316)} B_\alpha^{(.066524 + .027002 \ln B_\alpha)}$$

Total atoms fissioned per kgU:*

for ^{238}U

$$N_{i\alpha} = 1.7923 \times 10^{20} E^{-.24103} B_\alpha^{1.0583} \quad (V=20\%)$$

$$N_{i\alpha} = 1.5603 \times 10^{20} E^{-.26939} B_\alpha^{1.0587} \quad (V=50\%)$$

for ^{239}Pu

$$N_{i\alpha} = 1.9941 \times 10^{20} E^{-1.0176} B_\alpha^{1.7198} \quad (V=20\%)$$

$$N_{i\alpha} = 1.8505 \times 10^{20} E^{-1.1043} B_\alpha^{1.7499} \quad (V=50\%)$$

E = ^{235}U enrichment in weight percent

B_α = burnup in MWD/kgU at time α

V_α = exposure average void percentage at time α

If V_α is not known, use V_α = 35% as the best estimate and V_α = 50% for a conservative estimate

Note: These correlations are based on results of CorSTAR analyses of 8x8 General Electric fuel assemblies using a version of the code LEOPARD. The correlations were developed for the following range of parameters:

$$1.1 \leq E \leq 3.5$$

$$1 \leq B_\alpha \leq 5 + 10 \cdot E$$

* To estimate the number of atoms fissioned for average void percentages between 20% and 50%, use linear interpolation.

Step 3. Calculate the cumulative number of ^{235}U fissions through the end of irradiation period α by subtracting the total number of ^{238}U and ^{239}Pu fissions calculated in Step 2 above from the total number of all fissions of all nuclides calculated in Step 1.

Step 4. For each of the nuclides, ^{235}U, ^{238}U, and ^{239}Pu, calculate the number of fissions that occur during irradiation period α by subtracting the total number of fissions that occurred through the end of time step $\alpha - 1$ from the total number that occurred through the end of time step α.

$$N_{i\alpha}' = N_{i\alpha} - N_{i\alpha-1} \tag{3.2.11}$$

Step 5. Repeat steps 1 through 4 for each irradiation period.

18. FORTRAN PROGRAM CELLTRAN

The CELLTRAN program simulates the radionuclide transport from groundwater through the environment and food chain to man. It was developed to check the calculations of the PATH1/DOSHEM code.

Theory

The theoretical aspects of this program are discussed in Section 4.2 of Reference 3 (attached for the readers convenience at the end of this section).

Program

The CELLTRAN program includes four executable codes and numerous input and output files. The relationship between the various codes and files is illustrated in Figure 31. CELLTRAN.EXE calculates the environmental transport of radionuclides and generates a file of radionuclides in the sediment, groundwater, surface water, and soil. CELLPOST.EXE processes the radionuclide amount file written by the CELLTRAN program into a form suitable for input to the DOSECAL2 program. DOSECAL2.EXE calculates the dose to the maximum exposed individual by radionuclide, organ and pathway based on radionuclide concentrations in the soil and water. DOSEFAC.EXE calculates inhalation and ingestion dose factors for selected radionuclides for seven organs. The output from this program forms the basis for one of the input files (DOSE.DAT) to the DOSECAL2 program.

Listings of the Fortran source codes for these programs are shown in Figures 32 through 35.

Input Data

Data is input to the various programs via data files as shown in Figure 31. A description of the input data files that are prepared by the user is provided in Tables 3 through 6. Example data sets for CELL.DAT, CPOST.DAT, DOSEFAC.DAT and DOSE.DAT are shown in Figures 36 through 39.

Output Data

Output data files generated by the programs include CELL.OUT, IP.OUT, CONC.DAT, DOSEFAC.OUT, and DOSECAL.OUT. Example outputs are shown in Figures 40 through 44. Note that Figure 44 shows only a small portion of the output file (4 of the 82 time periods).

Figure 31

CELLTRAN Program Codes and Files

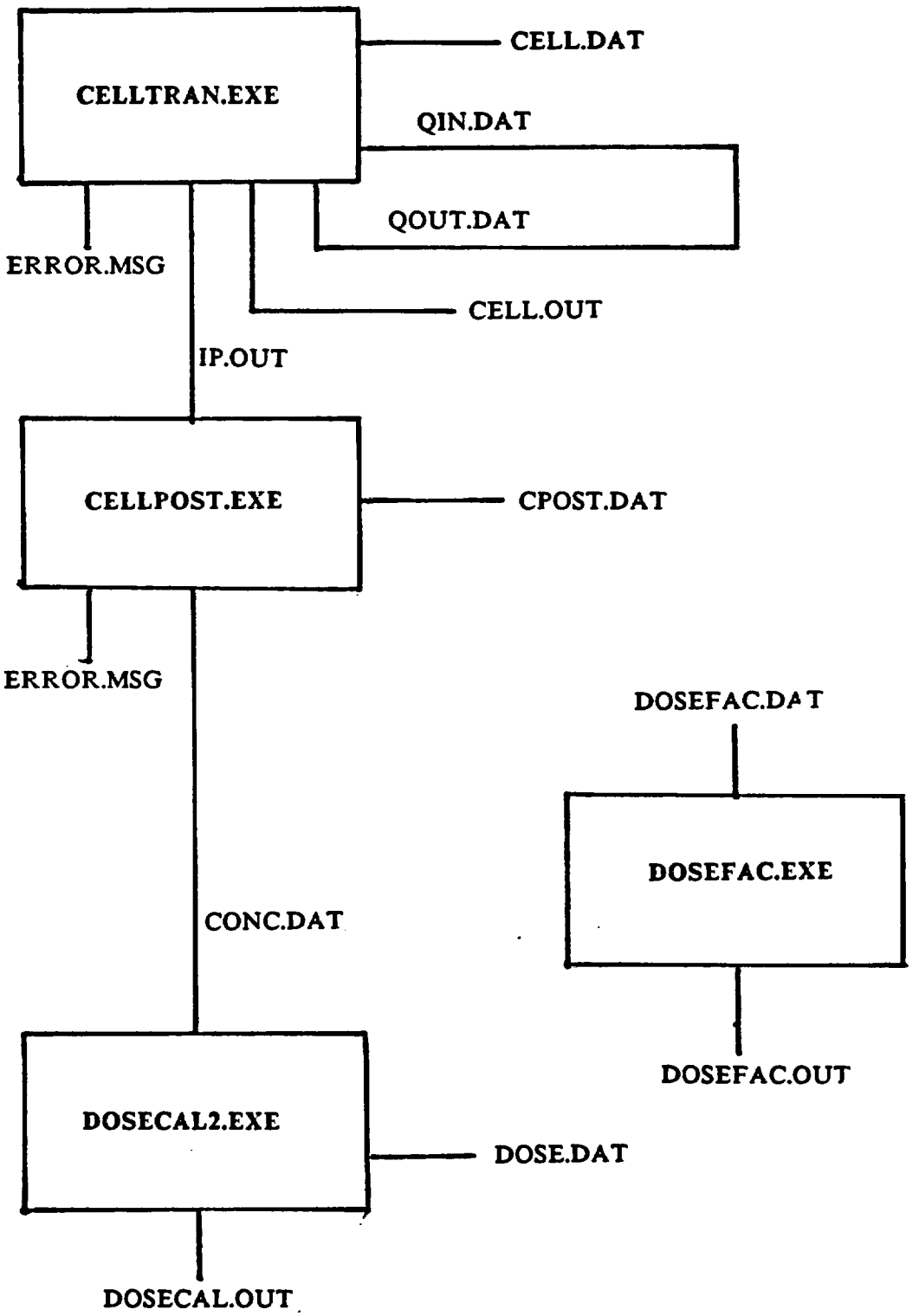


TABLE 3

CELLTRAN PROGRAM INPUT DATA (CELL.DAT) DESCRIPTION

CARD	VARIABLE	FORMAT	DESCRIPTION
1	ITER	I5	NUMBER OF ITERATIONS (CASES) **NOTE: COMPLETE SET OF DATA CARDS 2-21 REQUIRED FOR EACH ITERATION
2	IPINV	I5	LOGICAL: 1 TO WRITE TO IP.OUT FILE
2	IOUT	I5	UNIT SPEC FOR THE OUTPUT FILE
2	IPRNT	I5	LOGICAL: 1 TO WRITE TO CELL.OUT FILE AFTER WRITING TO QOUT.DAT FILE
2	QDATI	I5	LOGICAL: 1 TO OPEN QIN.DAT FILE & WRITE TO QIN.DAT FILE
2	QDATO	I5	LOGICAL: 1 TO OPEN QOUT.DAT FILE & WRITE TO QOUT.DAT FILE
2	IPINV	I5	LOGICAL: 1 TO WRITE TO IP.OUT FILE
3	TITLE	20A4	PROBLEM TITLE
4	NZONES	I5	NUMBER OF ZONES
5	ICHAIN	I5	LOGICAL: 1 = NO CHAIN DECAY, 2 = CHAIN DECAY
6	NTIMES	I5	NUMBER OF CALCULATION TIMES
7	TIME(IT)	E10.3	CALCULATION TIMES IN YEARS (INCREASING ORDER) IT=1,NTIMES
8	SOLID(IZ,ICOM)	E10.3	MASS OF SOLID (KG) IN EACH CELL IZ=1,NZONES; ICOM=1,4 (1=SEDIMENT,2=SURFACE WATER,3=GROUNDWATER,4=SOIL)
8	ALIQ(IZ,ICOM)	E10.3	MASS OF LIQUID (L) IN EACH CELL IZ=1,NZONES; ICOM=1,4 (1=SEDIMENT,2=SURFACE WATER,3=GROUNDWATER,4=SOIL)
9	IZO	I5	ORIGIN ZONE **NOTE: REREAD UNTIL IZO=0 (BLANK CARD #10 IS READ)

TABLE 3

CELLTRAN PROGRAM INPUT DATA (CELL.DAT) DESCRIPTION (continued)

CARD	VARIABLE	FORMAT	DESCRIPTION
9	ICO	I5	ORIGIN COMPARTMENT **NOTE: REREAD UNTIL IZO=0 (BLANK CARD #10 IS READ)
9	IZD	I5	DESTINATION ZONE (=0 IF SINK) **NOTE: REREAD UNTIL IZO=0 (BLANK CARD #10 IS READ)
9	ICD	I5	DESTINATION COMPARTMENT (=0 IF SINK) **NOTE: REREAD UNTIL IZO=0 (BLANK CARD #10 IS READ)
9	ST	E10.3	SOLID TRANSFER RATE (KG/YEAR) BETWEEN CELLS **NOTE: REREAD UNTIL IZO=0 (BLANK CARD #10 IS READ)
9	ALT	E10.3	LIQUID TRANSFER RATE (L/YEAR) BETWEEN CELLS **NOTE: REREAD UNTIL IZO=0 (BLANK CARD #10 IS READ)
10			BLANK CARD
11	IZOR	I5	DEFINES ZONES & COMPARTMENTS **NOTE: READ IF QDATO=1
11	ICOR	I5	DEFINES ZONES & COMPARTMENTS **NOTE: READ IF QDATO=1
11	IZDEST	I5	DEFINES ZONES & COMPARTMENTS **NOTE: READ IF QDATO=1
11	ICDEST	I5	DEFINES ZONES & COMPARTMENTS **NOTE: READ IF QDATO=1
12	NCINV	I5	DEFINES ZONES & COMPARTMENTS **NOTE: READ IF IPINV=1
13	INVIZ(IV)	I5	DEFINES ZONES & COMPARTMENTS **NOTE: READ IF IPINV=1, IV=1,NCINV
13	INVIC(IV)	I5	DEFINES ZONES & COMPARTMENTS **NOTE: READ IF IPINV=1, IV=1,NCINV
14	RNAME	A8	RADIONUCLIDE NAME

TABLE 3

CELLTRAN PROGRAM INPUT DATA (CELL.DAT) DESCRIPTION (continued)

CARD	VARIABLE	FORMAT	DESCRIPTION
15	RHALF	E10.3	RADIOACTIVE HALF LIFE (YEARS)
16	DRPHY(IZ,ICOM)	E10.3	PHYSICAL DECAY RATE (YEARS) ICOM=1,4; IZ=1,NZONES
17	IZ	I5	ZONE NUMBER FOR ICONST **NOTE: NOT READ IF (QDATI.NE.1 & IR=2). REREAD IF (IZ=0 & IR=1)
17	ICOM	I5	COMPARTMENT NUMBER FOR ICONST **NOTE: NOT READ IF (QDATI.NE.1 & IR=2). REREAD IF (IZ=0 & IR=1)
17	ICONST	I5	LOGICAL: 1 IF CONSTANT EXTERNAL INPUT RATES **NOTE: NOT READ IF (QDATI.NE.1 & IR=2). REREAD IF (IZ=0 & IR=1)
18	Q(ICELL,IT)	E10.3	RADIONUCLIDE EXTERNAL INPUT RATE (ATOMS/YEAR). =1 IF CONSTANT **NOTE: NOT READ IF(QDATI.NE.1 & IR=2) & NOT READ + NOT REREAD IF(IZ=0 & IR=2) OR ICONST=1
19	QC	E10.3	RADIONUCLIDE EXTERNAL INPUT RATE (ATOMS/YEAR). =1 IF CONSTANT **NOTE: NOT READ IF (QDATI.NE.1 & IR=2) OR IF (IZ=0 & IR=2)
20	AI(IZ,ICOM)	E10.3	INITIAL RADIONUCLIDE CONCENTRATION (ATOMS) ICOM=1,4; IZ=1,NZONES
21	KD(IZ,ICOM)	E10.3	DISTRIBUTION COEFFICIENT (L/KG) ICOM=1,4; IZ=1,NZONES

TABLE 4

PROGRAM CELLPOST INPUT DATA (CPOST.DAT) DESCRIPTION

CARD	VARIABLE	FORMAT	DESCRIPTION
1	NR	I5	NUMBER OF RADIONUCLIDES
1	NT	I5	NUMBER OF TIME PERIODS

TABLE 5

PROGRAM DOSEFAC INPUT DATA (DOSEFAC.DAT) DESCRIPTION

CARD	VARIABLE	FORMAT	DESCRIPTION
1	TI	F10.0	INTAKE TIME (YR)
1	TC	F10.0	DOSE COMMITMENT TIME (YR)
2	OMASS(IO),IO=1,7	F10.0	MASS OF ORGAN IO (GM)
3	NAME(IR)	1X,A8	NAME OF RADIONUCLIDE IR
4	RHALF	E10.3	RADIONUCLIDE HALF-LIFE (YR)
5	ISOL	I5	1 IF RADIONUCLIDE IN SOLUBLE FORM 2 IF RADIONUCLIDE IN INSOLUBLE FORM
6	FTB	E10.3	FRACTION OF INGESTED RADIONUCLIDE TRANSFERED TO BLOOD
7	BHALF(IO),IO=1,7	E10.3	RADIONUCLIDE BIOLOGICAL HALF-LIFE IN ORGAN IO (DAYS)
7	FO(IO),IO=1,7	E10.3	FRACTION OF INGESTED RADIONUCLIDE REACHING ORGAN IO
7	E(IO),IO=1,7	E10.3	EFFECTIVE ENERGY DEPOSITED BY RADIONUCLIDE DECAY IN ORGAN IO (MEV/DISINTEGRATION)

NOTE: IO = 1 (TOTAL BODY)
2 (BONE)
3 (THYROID)
4 (LIVER)
5 (KIDNEYS)
6 (LUNGS)
7 (GI-LLI)

CARDS 3 THROUGH 7 READ FOR EACH RADIONUCLIDE UNTIL RADIONUCLIDE NAME = END

TABLE 6

DOSECAL2 PROGRAM INPUT DATA (DOSE.DAT) DESCRIPTION

CARD	VARIABLE	FORMAT	DESCRIPTION
1	IOUT	I5	OUTPUT FILE NUMBER
2	SI	F10.2	SPRINKLER IRRIGATION (L/SQ.METER)
3	DLV	F10.2	DENSITY OF LEAFY VEGETABLES (KG/SQ.METER)
4	TI	F10.2	IRRIGATION TIME (DAYS)
5	WHL	F10.2W	WEATHERING HALF-LIFE (DAYS)
6	FRD	F10.2	RADIONUCLIDE DEPOSITED ON LEAVES (FRAC.)
7	HVC	F10.2	HUMAN VEGETABLE CONSUMPTION (KG/YR)
8	HWC	F10.2	HUMAN WATER CONSUMPTION (L/YR)
9	DCPC	F10.2	DAIRY COW PLANT CONSUMPTION (KG/DAY)
10	BCPC	F10.2	BEEF CATTLE PLANT CONSUMPTION (KG/DAY)
11	DCDR	F10.2	DAIRY COW DRINKING RATE (L/DAY)
12	BCDR	F10.2	BEEF CATTLE DRINKING RATE (L/DAY)
13	HMTC	F10.2	MEAT CONSUMPTION BY HUMANS (KG/YR)
14	HMLC	F10.2	MILK CONSUMPTION BY HUMANS (KG/YR)
15	HFC	F10.2	FISH CONSUMPTION BY HUMANS (KG/YR)
16	AS	F10.2	AIR SUBMERSION (HR/YR)
17	SE	F10.2	SOIL EXPOSURE (HR/YR)
18	SWIM	F10.2	TIME SPENT SWIMMING (HR/YR)

TABLE 6

DOSECAL2 PROGRAM INPUT DATA (DOSE.DAT) DESCRIPTION (continued)

CARD	VARIABLE	FORMAT	DESCRIPTION
19	SRF	F10.2	SOIL RESUSPENSION FACTOR (UG/CUBIC METER)
20	HBR	F10.2	HUMAN BREATIONG RATE (CUBIC METERS/YR)
21	ET	F10.2	EXPOSURE TIME FOR HUMANS (YR)
22	DCT	F10.2	DOSE COMMITMENT TIME (YR)
23	SD	F10.2	SOIL DEPTH (CM)
24	SDEN	F10.2	SOIL DENSITY (GM/CUBIC METER)
25	CRFWF(IR)	E10.3	CONCENTRATION RATIO FOR FISH ((CI/KG)FISH/(CI/L)WATER) IR=1,NR
26	CRVEG(IR)	E10.3	CONCENTRATION RATIO FOR VEGETATION ((CI/KG)VEG/(CI/KG)SOIL) IR=1,NR
27	CRMILK(IR)	E10.3	CONCENTRATION RATIO FOR MILK ((CI/L)MILK/(CI/DAY)INTAKE IR=1,NR
28	CRMEAT(IR)	E10.3	CONCENTRATION RATIO FOR MEAT ((CI/KG)MEAT/(CI/DAY)INTAKE IR=1,NR
29	DFEA(IP,IR)	E10.3	EXTERNAL DOSE FAC. AIR SUBMERSION (REM/HR PER UCI/CU.METER) IP=1 FOR SKIN, IP=2 FOR TOTAL BODY IR=1,NR
29	DFEW(IP,IR)	E10.3	EXTERNAL DOSE FAC. WATER IMMERSION (REM/HR PER UCI/CU.METER) IP=1 FOR SKIN, IP=2 FOR TOTAL BODY IR=1,NR
29	DFEG(IP,IR)	E10.3	EXTERNAL DOSE FAC. GROUND EXPOSURE (REM/HR PER UCI/SQ.METER) IP=1 FOR SKIN, IP=2 FOR TOTAL BODY IR=1,NR

TABLE 6

DOSECAL2 PROGRAM INPUT DATA (DOSE.DAT) DESCRIPTION (continued)

CARD	VARIABLE	FORMAT	DESCRIPTION
30	DFINH(IO,IR)	E10.3	INHALATION DOSE (REM) IO=1,7 SEE NOTE IR=1,NR
31	DFING(IO,IR)	E10.3	INGESTION DOSE (REM) IO=1,7 SEE NOTE IR=1,NR

NOTE:

IO = 1(TOTAL BODY)
IO = 2(BONE)
IO = 3(THYROID)
IO = 4(LIVER)
IO = 5(KIDNEYS)
IO = 6(LUNGS)
IO = 7(GI-LLI)

Figure 32

Fortran Program CELLTRAN Source Code

```
      PROGRAM CELLTRAN
C*    //VKDCELL1   JOB  (WDC9,361,A,10,10,0),'DOUG VOGT'
C*    /*TITLE=VOGT AR702N 654-8096
C*    //STEP1 EXEC FORVCOMP
C*    //COMP.SYSIN DD *
C     UPGRADED VERSION OF CELLTRAN BEGUN 013084MTM
C     PROGRAM CONVERTED TO DOUBLE PRECISION ON 021684MTM
C     PROGRAM TO CALCULATE THE AMOUNT OF RADIONUCLIDES IN THE SEDIMENT,
C     SURFACE WATER, GROUNDWATER AND SOIL COMPARTMENTS OF UP TO 2 ZONES.
C     FOUR COMPARTMENTS/ZONE * 2 ZONES = 8 CELLS.  THE PARTITIONING OF A
C     RADIONUCLIDE BETWEEN THE SOLID AND LIQUID COMPONENTS OF A CELL IS
C     DETERMINED BY THE DISTRIBUTION COEFFICIENT FOR THE RADIONUCLIDE
C     IN THAT CELL.  THE RADIONUCLIDES CAN BE TRANSFERED BETWEEN CELLS
C     ALONG WITH THE ASSOCIATED SOLID AND LIQUID TRANSFERS.  THE
C     RADIONUCLIDES CAN BE REMOVED FROM THE CELL EITHER THROUGH
C     RADIOACTIVE DECAY OR TRANSFER TO A SINK.  THE RADIONUCLIDE INPUT
C     RATE TO EACH CELL CAN BE EITHER SPECIFIED AS A CONSTANT OR A TIME
C     DEPENDENT VALUE.  ANY NUMBER OF RADIONUCLIDES MAY BE TREATED.
C     IF THE USER SPECIFIES THAT THE RADIONUCLIDES ARE MEMBERS OF A
C     DECAY CHAIN, THEN THE INPUT RATE FOR A RADIONUCLIDE IN A CELL
C     WILL BE AUGMENTED BY AN AMOUNT EQUAL TO THE PRODUCT OF THE PARENT
C     RADIONUCLIDE AMOUNT AND THE PARENT DECAY RATE.  THE MAXIMUM NUMBER
C     OF CALCULATION TIMES IS CURRENTLY 82.
C*
C*    PROGRAM REVISIONS BY DICK CHAPMAN (RAC) STARTED 4/25/86 TO ADAPT
C*    THE CODE TO MS-DOS FORTRAN. COMMENTS INDICATED BY C*,CODE ADDITIONS
C*    PRECEEDED BY C*,DATE, AND INITIALS, AND FOLLOWED BY C**.
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*4 KD
C     010584MTM
      CHARACTER*4 CNAME
C     010584MTM
      CHARACTER*8 RNAME,QUIT
      INTEGER QDATI,QDATO,QI,QO
C     010584MTM
C     REAL*8 RNAME,QUIT
      DIMENSION KD(1,4),AI(1,4),AICL(4),BKEEP(4,4),A(4,82)
      DIMENSION B(4,4),H(4,4),ROOTR(4),ROOTI(4),ANS(4,4)
      DIMENSION TITLE(20),TIME(82),SOLID(1,4),ALIQ(1,4),CNAME(4),
     &STRANS(4,5),ALTRAN(4,5),Q(4,82),Y(4)
      DIMENSION DRPHY(1,4)
C     013084MTM
      DIMENSION INVIZ(2),INVIC(2),INVCL(2)
      COMMON/A/IOUT
      DATA CNAME/'SED.','S.W.','G.W.','SOIL'/
      DATA QUIT/'END     '/
      IN=5
C     010584MTM
C     QI=7
C     010584MTM
      QI=9
      QO=8
C*    050886RAC
      OPEN (QI,FILE='QIN.DAT')
      OPEN (QO,FILE='QOUT.DAT')
C     013084MTM
      IP=10
      IZERO=0
C     010584MTM
      MITER=4
C     010584MTM
C     CALL OPEN(IN,'CELL    DAT',2)
C*    042586RAC
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
      OPEN(IN,FILE='CELL.DAT')
      IOUT=6
C*    OPEN(IOUT,FILE='CELL.OUT')
C*    060486RAC
      OPEN(IOUT,FILE='ERROR.MSG')
C**
C*    042886RAC
      OPEN (IP,FILE='IP.OUT')
C**
C     010584MTM
C*    READ(IN,5) ITER
C*    042886RAC
      READ(IN,30) ITER
C**
C     010584MTM
C*    IF(ITER.GT.MITER) GO TO 1080
C*    042586RAC
      IF(ITER.LE.MITER) GO TO 3
      WRITE(IOUT,1090) ITER,MITER
 1090 FORMAT(//,1X,'NUMBER OF ITERATIONS(',I2,') GREATER THAN THE MAXIMU
     &M ALLOWED(',I2,')')
      GO TO 3000
    3 CONTINUE
C**
C*    042886RAC
      CLOSE(IOUT)
C**
C     010584MTM
      DO 2000 ICASE=1,ITER
      REWIND QI
      REWIND QO
      ISW=QI
      QI=QO
      QO=ISW
C     013084MTM
C     READ(IN,5) IOUT,IPRNT,QDATI,QDATO
C     013084MTM
      READ(IN,5) IOUT,IPRNT,QDATI,QDATO,IPINV
C     013084MTM
C   5 FORMAT(4I5)
C     013084MTM
    5 FORMAT(5I5)
C*    042886RAC
      OPEN(IOUT,FILE='CELL.OUT')
C**
C     011684MTM
      WRITE(IOUT,7) ICASE
C     011684MTM
    7 FORMAT(///,1X,'ITERATION NUMBER',I2,1X,'FOR CELLTRAN',/)
C     010584MTM
C*    IF(QDATI.EQ.1) CALL OPEN(QI,'QIN     DAT',2)
C*    042586RAC
C*    IF(QDATI.EQ.1)OPEN(QI,FILE='QIN.DAT')
C**
C     010584MTM
C*    IF(QDATO.EQ.1) CALL OPEN(QO,'QOUT    DAT',2)
C*    042586RAC
C*    IF(QDATO.EQ.1)OPEN(QO,FILE='QOUT.DAT')
C**
      MAXZ=1
      MAXT=82
C     READ IN THE PROBLEM TITLE
      READ(IN,10) TITLE
   10 FORMAT(20A4)
      WRITE(IOUT,20) TITLE
   20 FORMAT(1X,20A4)
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
C     READ IN NUMBER OF ZONES
      READ(IN,30) NZONES
   30 FORMAT(I5)
      IF(NZONES.GT.MAXZ) GO TO 1000
      WRITE(IOUT,35) NZONES
   35 FORMAT(/,1X,'NUMBER OF ZONES=',I5)
C     PROGRAM ASSUMES 4 COMPARTMENTS PER ZONE
      NCELLS=4*NZONES
C     DETERMINE WHETHER RADIONUCLIDES ARE TO BE CONSIDERED MEMBERS OF
C     A CHAIN(ICHAIN=1,NO CHAIN DECAY; ICHAIN=2,CHAIN DECAY).
      READ(IN,30) ICHAIN
      IF(ICHAIN.EQ.2) GO TO 50
      WRITE(IOUT,40)
   40 FORMAT(/,1X,'NO CHAIN DECAY')
      GO TO 70
   50 WRITE(IOUT,60)
   60 FORMAT(/,1X,'CHAIN DECAY ASSUMED')
   70 CONTINUE
C     INPUT CALCULATION TIMES(YEARS)
      READ(IN,30) NTIMES
      IF(NTIMES.GT.MAXT) GO TO 1020
      WRITE(IOUT,80) NTIMES
   80 FORMAT(/,1X,'NUMBER OF CALCULATION TIMES=',I5)
C     TIMES MUST BE INPUT IN INCREASING ORDER AND CORRESPOND TO THE
C     TIMES SPECIFIED FOR RADIONUCLIDE INPUT RATES.
      READ(IN,90) (TIME(IT),IT=1,NTIMES)
   90 FORMAT(E10.3)
      WRITE(IOUT,100)
  100 FORMAT(/,1X,'CALCULATION TIMES(YEARS)',/)
      WRITE(IOUT,110) (TIME(IT),IT=1,NTIMES)
  110 FORMAT(1X,8E10.3)
C     013084MTM
      IF(IPINV.EQ.1) WRITE(IP,115) (TIME(IT),IT=1,NTIMES)
C     013084MTM
  115 FORMAT(8E10.3)
C     INPUT THE MASS OF SOLID(KG) AND THE AMOUNT OF LIQUID(L) IN
C     EACH CELL IDENTIFIED BY (ZONE-COMPARTMENT)
C     COMPARTMENT 1=SEDIMENT
C                 2=SURFACE WATER
C                 3=GROUNDWATER
C                 4=SOIL
      READ(IN,120) ((SOLID(IZ,ICOM),ALIQ(IZ,ICOM),ICOM=1,4),
     &IZ=1,NZONES)
  120 FORMAT(2E10.3)
      WRITE(IOUT,130)
  130 FORMAT(//,7X,'MASS OF SOLID AND AMOUNT OF LIQUID',/,12X,
     &'FOR EACH ZONE-COMPARTMENT',//,16X,'SOLID(KG)',3X,'LIQUID(L)',/)
      WRITE(IOUT,140) ((IZ,CNAME(ICOM),SOLID(IZ,ICOM),
     &ALIQ(IZ,ICOM),ICOM=1,4),IZ=1,NZONES)
  140 FORMAT(1X,'ZONE',I2,'-',A4,2X,E10.3,2X,E10.3)
C     INPUT TRANSFER RATES FOR SOLID(KG/YEAR) AND LIQUID(L/YEAR) BETWEEN
C     COMPARTMENTS OR FROM A COMPARTMENT TO A SINK(IZD,ICD=0).
C     TRANSFERS ARE ALLOWED BETWEEN COMPARTMENTS OF DIFFERENT ZONES.
C     TERMINATE INPUT WITH A BLANK CARD.
C     (IZO,ICO)=ORIGIN(ZONE,COMPARTMENT)
C     (IZD,ICD)=DESTINATION(ZONE,COMPARTMENT)
C     ZERO OUT TRANSFER MATRICES
      NCP1=NCELLS+1
      DO 145 IO=1,NCELLS
      DO 145 ID=1,NCP1
      STRANS(IO,ID)=1.0D-6
      ALTRAN(IO,ID)=1.0D-6
  145 CONTINUE
  150 CONTINUE
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
      READ(IN,160) IZO,ICO,IZD,ICD,ST,ALT
  160 FORMAT(4I5,2E10.3)
      IF(IZO.EQ.0) GO TO 185
      IF(IZO.LT.0.OR.IZO.GT.NZONES) GO TO 1040
      IF(ICO.LT.1.OR.ICO.GT.4) GO TO 1040
      IF(IZD.LT.0.OR.IZD.GT.NZONES) GO TO 1040
      IF(ICD.LT.0.OR.ICD.GT.4) GO TO 1040
      IF(IZD.EQ.0.AND.ICD.NE.0) GO TO 1040
      IF(ICD.EQ.0.AND.IZD.NE.0) GO TO 1040
      ICELLO=(IZO-1)*4+ICO
      IF(IZD.EQ.0) GO TO 170
      ICELLD=(IZD-1)*4+ICD
      GO TO 180
  170 ICELLD=NZONES*4+1
  180 CONTINUE
      STRANS(ICELLO,ICELLD)=ST
      ALTRAN(ICELLO,ICELLD)=ALT
      GO TO 150
  185 CONTINUE
C     OUTPUT RELATIONSHIP BETWEEN ZONES,COMPARTMENTS AND CELLS.
      WRITE(IOUT,190)
  190 FORMAT(//,1X,'RELATIONSHIP BETWEEN ZONES, COMPARTMENTS AND CELLS',
     &/)
      DO 210 IZ=1,NZONES
      DO 210 ICOM=1,4
      ICELL=(IZ-1)*4+ICOM
      WRITE(IOUT,200) ICELL,IZ,ICOM
  200 FORMAT(1X,'CELL',I2,' - ZONE',I2,', COMPARTMENT',I2)
  210 CONTINUE
      WRITE(IOUT,211) NCP1
  211 FORMAT(1X,'CELL',I2,' - SINK')
C     PRINT OUT SOLID AND LIQUID TRANSFER MATRICES.
      WRITE(IOUT,220)
  220 FORMAT(//////,44X,'TRANSFER OF SOLID BETWEEN CELLS',/,54X,
     &'(KG/YEAR)',//,53X,'ORIGIN CELLS',/)
      WRITE(IOUT,230) (ICELL,ICELL=1,NCELLS)
  230 FORMAT(16X,I2,7(10X,I2))
      WRITE(IOUT,240)
  240 FORMAT(////,1X,'DESTINATION',/,4X,'CELLS',/)
      DO 260 ICELLD=1,NCP1
      WRITE(IOUT,250) ICELLD,(STRANS(ICELLO,ICELLD),
     &ICELLO=1,NCELLS)
C     011084MTM
C 250 FORMAT(//////,5X,I2,5X,8(E11.5,1X),)
  250 FORMAT(//////,5X,I2,5X,8(E11.5,1X))
  260 CONTINUE
      WRITE(IOUT,270)
  270 FORMAT(//////,44X,'TRANSFER OF LIQUID BETWEEN CELLS',/,55X,
     &'(L/YEAR)',//,53X,'ORIGIN CELLS',/)
      WRITE(IOUT,230) (ICELL,ICELL=1,NCELLS)
      WRITE(IOUT,240)
      DO 280 ICELLD=1,NCP1
      WRITE(IOUT,250) ICELLD,(ALTRAN(ICELLO,ICELLD),
     &ICELLO=1,NCELLS)
  280 CONTINUE
C     INPUT INFORMATION FOR RADIONUCLIDES
C     IF THE RADIONUCLIDES ARE PART OF A DECAY CHAIN, RADIONUCLIDE DATA
C     MUST BE INPUT IN THE ORDER OF THE DECAY.
      IF(QDATO.NE.1) GO TO 282
      READ(IN,5) IZOR,ICOR,IZDEST,ICDEST
      ICLOR=(IZOR-1)*4+ICOR
  282 CONTINUE
C     013084MTM
      IF(IPINV.NE.1) GO TO 284
C     013084MTM
      READ(IN,5) NCINV
C     013084MTM
      DO 283 IV=1,NCINV
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
C       013084MTM
        READ(IN,5) INVIZ(IV),INVIC(IV)
C       013084MTM
        INVCL(IV)=4*(INVIZ(IV)-1)+INVIC(IV)
C       013084MTM
  283   CONTINUE
C       013084MTM
  284   CONTINUE
        IFIRST=1
  285   CONTINUE
        READ(IN,290) RNAME
C       011184
C 290   FORMAT(1X,A8)
C       011184MTM
  290   FORMAT(A8)
C       010584MTM
C       IF(RNAME.EQ.QUIT) GO TO 2000
C       010584MTM
        IF(RNAME.NE.QUIT) GO TO 295
C       010584MTM
        REWIND 8
C       010584MTM
        GO TO 2000
C       010584MTM
  295   CONTINUE
        WRITE(IOUT,300) RNAME
C       011084MTM
C 300   FORMAT(//////,1X'*****    ANALYSES FOR RADIONUCLIDE',2X,A8,1X,'***
C       011084MTM
C      &**')
C       011084MTM
  300   FORMAT(//////,1X,'*****    ANALYSES FOR RADIONUCLIDE',2X,A8,1X,'**
       &***')
C       READ IN RADIONUCLIDE HALF-LIFE IN YEARS
        READ(IN,310) RHALF
  310   FORMAT(E10.3)
        DRATE=0.69315/RHALF
        WRITE(IOUT,320) RHALF,DRATE
  320   FORMAT(/,1X,'RADIOACTIVE HALF-LIFE=',E10.3,1X,'YEARS',/,
       &1X,'RADIOACTIVE DECAY RATE=',E10.3,1X,'YEARS**-1')
C       READ IN PHYSICAL DECAY RATES FOR THE
C       RADIONUCLIDE FOR EACH ZONE-COMPARTMENT COMBINATION
        READ(IN,441) ((DRPHY(IZ,ICOM),ICOM=1,4),IZ=1,NZONES)
        WRITE(IOUT,321)
  321   FORMAT(//,15X,'PHYSICAL',/,16X,'DECAY',/,17X,'RATE',/,
       &13X,'(YEARS**-1)',/)
        WRITE(IOUT,443) ((IZ,CNAME(ICOM),DRPHY(IZ,ICOM),ICOM=1,4),
       &IZ=1,NZONES)
C       ZERO OUT RADIONUCLIDE INPUT RATES
        DO 330 ICELL=1,NCELLS
        DO 330 IT=1,NTIMES
        Q(ICELL,IT)=0.
  330   CONTINUE
C       READ IN RADIONUCLIDE EXTERNAL INPUT RATES(ATOMS/YEAR).
C       MUST END INPUT WITH A BLANK CARD.
C       IF ICONST=1,THE EXTERNAL INPUT RATE FOR THE RADIONUCLIDE IS
C       CONSTANT OVER THE TOTAL CALCULATION PERIOD.
  334   IR=0
  335   IR=IR+1
C       011684MTM
C       IF(IR.EQ.3) GO TO 365
        IF(QDATI.NE.1.AND.IR.EQ.2) GO TO 365
        IF(IR.EQ.1) INPUT=IN
        IF(IR.EQ.2) INPUT=QI
  336   CONTINUE
        READ(INPUT,337) IZ,ICOM,ICONST
  337   FORMAT(3I5)
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
C       0116B4MTM
C       IF(IZ.EQ.0.AND.IR.EQ.1) GO TO 360
C       0116B4MTM
        IF(IZ.EQ.0.AND.IR.EQ.1) GO TO 335
        IF(IZ.EQ.0.AND.IR.EQ.2) GO TO 365
        IF(IZ.LT.1.OR.IZ.GT.NZONES) GO TO 1060
        IF(ICOM.LT.1.OR.ICOM.GT.4) GO TO 1060
        ICELL=(IZ-1)*4+ICOM
        IF(ICONST.EQ.1) GO TO 340
        DO 336 IT=1,NTIMES
        READ(INPUT,90) Q(ICELL,IT)
  338   CONTINUE
C       0116B4MTM
C       GO TO 360
C       0116B4MTM
        GO TO 336
  340   READ(IN,90) QC
        DO 350 IT=1,NTIMES
        Q(ICELL,IT)=QC
  350   CONTINUE
        GO TO 336
C       0116B4MTM
C 360   GO TO 335
  365   CONTINUE
        WRITE(IOUT,370) RNAME
  370   FORMAT(//,45X,A8,1X,'EXTERNAL INPUT RATES',/,54X,
       &'(ATOMS/YR)',//,57X,'CELL',/)
        WRITE(IOUT,230) (ICELL,ICELL=1,NCELLS)
        WRITE(IOUT,380)
  380   FORMAT(4X,'TIME',/,4X,'(YR)',/)
        DO 400 IT=1,NTIMES
        WRITE(IOUT,390) TIME(IT),(Q(ICELL,IT),ICELL=1,NCELLS)
  390   FORMAT(E10.3,1X,8(E10.3,2X))
  400   CONTINUE
        IF(IFIRST.EQ.1) GO TO 440
        IF(ICHAIN.NE.2) GO TO 440
        DO 410 ICELL=1,NCELLS
        DO 410 IT=1,NTIMES
C       ADD EFFECTIVE INPUT RATE DUE TO DECAY OF PARENT RADIONUCLIDE.
        Q(ICELL,IT)=Q(ICELL,IT)+A(ICELL,IT)*DOLD
  410   CONTINUE
        WRITE(IOUT,420) RNAME
  420   FORMAT(//,46X,A8,1X,'TOTAL INPUT RATES',/,54X,
       &'(ATOMS/YR)',//,57X,'CELL',/)
        WRITE(IOUT,230) (ICELL,ICELL=1,NCELLS)
        WRITE(IOUT,380)
        DO 430 IT=1,NTIMES
        WRITE(IOUT,390) TIME(IT),(Q(ICELL,IT),ICELL=1,NCELLS)
  430   CONTINUE
  440   CONTINUE
C       INPUT INITIAL RADIONUCLIDE CONCENTRATIONS(ATOMS)
        READ(IN,441) ((AI(IZ,ICOM),ICOM=1,4),IZ=1,NZONES)
  441   FORMAT(4E10.3)
        WRITE(IOUT,442)
  442   FORMAT(//,18X,'INITIAL',/,15X,'RADIONUCLIDE',/,18X,'AMOUNT',/,
       &18X,'(ATOMS)',/)
        WRITE(IOUT,443) ((IZ,CNAME(ICOM),AI(IZ,ICOM),ICOM=1,4),IZ=1,
       &NZONES)
  443   FORMAT(1X,'ZONE',I2,'-',A4,2X,E10.3)
        DO 450 IZ=1,NZONES
        DO 450 ICOM=1,4
        ICELL=(IZ-1)*4+ICOM
        AICL(ICELL)=AI(IZ,ICOM)
  450   CONTINUE
C       INPUT THE DISTRIBUTION COEFFICIENTS(L/KG).
        READ(IN,441) ((KD(IZ,ICOM),ICOM=1,4),IZ=1,NZONES)
        WRITE(IOUT,460)
  460   FORMAT(//,15X,'KD(L/KG)',/)
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
      WRITE(IOUT,443) ((IZ,CNAME(ICOM),KD(IZ,ICOM),
     &ICOM=1,4),IZ=1,NZONES)
C     013084MTM
      IF(IPINV.NE.1) GO TO 465
C     013084MTM
      WRITE(IP,461) RNAME,NTIMES,DRATE
C     013084MTM
  461 FORMAT(A8,I5,E10.3)
C     013084MTM
      DO 464 IV=1,NCINV
C     013084MTM
      IZZ=INVIZ(IV)
C     013084MTM
      ICC=INVIC(IV)
C     013084MTM
      WRITE(IP,462) IZZ,ICC,KD(IZZ,ICC),SOLID(IZZ,ICC),ALIQ(IZZ,ICC)
C     013084MTM
  462 FORMAT(2I5,3E10.3)
C     013084MTM
  464 CONTINUE
C     013084MTM
  465 CONTINUE
C     CALCULATE THE INTERCELL TRANSFER MATRIX.
C     B(IO,ID)=TRANSFER MATRIX ELEMENT FOR ORIGIN CELL IO AND
C              DESTINATION CELL ID(YEAR**-1)
      DO 480 IZO=1,NZONES
      DO 479 ICO=1,4
      DO 478 IZD=1,NZONES
      DO 477 ICD=1,4
      IF(IZO.EQ.IZD.AND.ICD.EQ.ICO) GO TO 477
      ICELLO=(IZO-1)*4+ICO
      ICELLD=(IZD-1)*4+ICD
      IF(KD(IZO,ICO).LT.1.0D-10) KD(IZO,ICO)=1.0D-10
      B(ICELLD,ICELLO)=(1.0/(SOLID(IZO,ICO)+ALIQ(IZO,ICO)/
     &KD(IZO,ICO)))*STRANS(ICELLO,ICELLD)+(1.0/(SOLID(IZO,ICO)*
     &KD(IZO,ICO)+ALIQ(IZO,ICO)))*ALTRAN(ICELLO,ICELLD)
  477 CONTINUE
  478 CONTINUE
  479 CONTINUE
  480 CONTINUE
      N=NCP1
      DO 500 IZOD=1,NZONES
      DO 500 ICOD=1,4
      ICLOD=(IZOD-1)*4+ICOD
      B(ICLOD,ICLOD)=-((1.0/(SOLID(IZOD,ICOD)+ALIQ(IZOD,ICOD)/
     &KD(IZOD,ICOD)))*STRANS(ICLOD,N)+(1.0/(SOLID(IZOD,ICOD)*KD(IZOD,ICO
     &D)+ALIQ(IZOD,ICOD)))*ALTRAN(ICLOD,N)+DRATE+DRPHY(IZOD,ICOD))
      IF(QDATO.EQ.1.AND.IZOD.EQ.IZOR.AND.ICOD.EQ.ICOR) BT=-B(ICLOD,
     &ICLOD)-DRATE-DRPHY(IZOD,ICOD)
      DO 490 ICLP=1,NCELLS
      IF(ICLOD.EQ.ICLP) GO TO 490
      B(ICLOD,ICLOD)=B(ICLOD,ICLOD)-B(ICLP,ICLOD)
  490 CONTINUE
  500 CONTINUE
      DOLD=DRATE
C     PRINT OUT TRANSFER MATRIX
      WRITE(IOUT,510)
  510 FORMAT(//,53X,'TRANSFER MATRIX',/,55X,'(YEAR**-1)',//,54X,'ORIGIN
     & CELLS',/)
      WRITE(IOUT,230) (ICELL,ICELL=1,NCELLS)
      WRITE(IOUT,240)
      DO 520 ICELLD=1,NCELLS
      WRITE(IOUT,250) ICELLD,(B(ICELLD,ICELLO),ICELLO=1,NCELLS)
  520 CONTINUE
C     FIND THE EIGENVALUES AND EIGENVECTOR FOR MATRIX B(IO,ID).
      CALL RILMAT(B,H,ROOTR,ROOTI,NCELLS,NCELLS,IPRNT,NCAL)
      IF(IPRNT.EQ.1) WRITE(IOUT,521) NCAL
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
  521 FORMAT(/,1X,'NCAL=',I5)
C     MATRIX B NOW CONTAINS THE REAL COMPONENTS OF THE EIGENVECTORS.
C     NOW FIND THE INVERSE OF B.
C     CONSTRUCT A DIAGONAL MATRIX OF ONE'S AND SAVE B IN BKEEP.
      DO 540 I=1,NCELLS
      DO 540 J=1,NCELLS
      BKEEP(I,J)=B(I,J)
      IF(I.EQ.J) GO TO 530
      ANS(I,J)=0.0D0
      GO TO 540
  530 ANS(I,J)=1.0D0
  540 CONTINUE
      CALL MATEQ(B,ANS,D,NCELLS,NCELLS,NCELLS)
C     MATRIX ANS NOW CONTAINS THE INVERSE OF B.
      DO 560 I=1,NCELLS
      Y(I)=0.0D0
      DO 560 J=1,NCELLS
      Y(I)=Y(I)+ANS(I,J)*AICL(J)
  560 CONTINUE
      TL=TIME(1)
      DO 600 IT=1,NTIMES
      DO 590 I=1,NCELLS
      X=ROOTR(I)*(TIME(IT)-TL)
      Y(I)=Y(I)*EXPON(X)
      YY1=0.0D0
      YY2=0.0D0
      DO 580 J=1,NCELLS
      IF(IT.NE.1) GO TO 570
      Q1=Q(J,1)
      Q2=Q1
      GO TO 575
  570 Q1=Q(J,IT-1)
      Q2=Q(J,IT)
  575 CONTINUE
      YY1=ANS(I,J)*Q1+YY1
      YY2=ANS(I,J)*Q2+YY2
  580 CONTINUE
      IF(IT.EQ.1) GO TO 586
      IF(DABS(X).LT.0.01D0) GO TO 585
      Y(I)=Y(I)+(YY1+(YY2-YY1)/((TIME(IT)-TL)*ROOTR(I)))*
     &(EXPON(X)-1.0D0)/ROOTR(I)-(YY2-YY1)/ROOTR(I)
      GO TO 586
  585 Y(I)=Y(I)+(YY1+(YY2-YY1)/((TIME(IT)-TL)*ROOTR(I)))*(TIME(IT)-TL)*
     &(1.0D0+0.5D0*
     &X+.166666666666667D0*X**2+0.416666666666667D-1*X**3+
     &0.833333333333333D-2*X**4+0.138888888888889D-2*X**5+
     &.198412698 4D-3*X**6)-(YY2-YY1)/ROOTR(I)
  586 CONTINUE
  590 CONTINUE
      DO 595 I=1,NCELLS
      A(I,IT)=0.0D0
      DO 595 J=1,NCELLS
      A(I,IT)=A(I,IT)+BKEEP(I,J)*Y(J)
  595 CONTINUE
      TL=TIME(IT)
  600 CONTINUE
C     PRINT RADIONUCLIDE AMOUNTS FOR EACH CELL AS A FUNCTION OF TIME.
      WRITE(IOUT,610) RNAME
  610 FORMAT(//////,51X,A8,' AMOUNTS',/,56X,'(ATOMS)',//,57X,'CELL',/)
      WRITE(IOUT,230) (ICELL,ICELL=1,NCELLS)
      WRITE(IOUT,380)
      IF(QDATO.EQ.1) WRITE(QO,6101) IZDEST,ICDEST,IZERO
 6101 FORMAT(3I5)
      IF(QDATO.EQ.1.AND.IPRNT.EQ.1) WRITE(IOUT,611) IZDEST,ICDEST,IZERO
  611 FORMAT(1X,3I5)
      DO 620 IT=1,NTIMES
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
      IF(QDATO.NE.1) GO TO 616
      QOUTP=BT*A(ICLOR,IT)
      WRITE(QD,6111) QOUTP
 6111 FORMAT(E10.3)
      IF(IPRNT.EQ.1) WRITE(IOUT,612) QOUTP
  612 FORMAT(1X,E10.3)
  616 CONTINUE
      WRITE(IOUT,390) TIME(IT),(A(ICELL,IT),ICELL=1,NCELLS)
  620 CONTINUE
      IF(QDATO.EQ.1) WRITE(QD,621)
  621 FORMAT('            ')
C     013084MTM
      IF(IPINV.NE.1) GO TO 710
C     013084MTM
      DO 700 IT=1,NTIMES
C     013084MTM
      DO 690 IV=1,NCINV
C     013084MTM
      ICX=INVCL(IV)
C     013084MTM
      WRITE(IP,630) A(ICX,IT)
C     013084MTM
  630 FORMAT(E10.3)
C     013084MTM
  690 CONTINUE
C     013084MTM
  700 CONTINUE
C     013084MTM
  710 CONTINUE
      IFIRST=0
      GO TO 285
 1000 WRITE(IOUT,1010) NZONES,MAXZ
 1010 FORMAT(//,1X,'NUMBER OF ZONES(',I2,') GREATER THAN THE MAXIMUM ALL
     &OWED(',I2,')')
C     010584MTM
C     GO TO 2000
C     010584MTM
      GO TO 3000
 1020 WRITE(IOUT,1030) NTIMES,MAXT
 1030 FORMAT(//,1X,'NUMBER OF TIMES(',I2,') GREATER THAN THE MAXIMUM ALL
     &OWED(',I2,')')
C     010584MTM
C     GO TO 2000
C     010584MTM
      GO TO 3000
 1040 WRITE(IOUT,1050) IZO,ICO,IZD,ICD
 1050 FORMAT(//,1X,'ERROR IN ZONE-COMPARTMENT SPECIFICATION FOR SOLID AN
     &D LIQUID TRANSFERS',/,1X,'IZO=',I5,1X,'ICO=',I5,1X,'IZD=',I5,1X,
     &'ICD=',I5)
C     010584MTM
C     GO TO 2000
      GO TO 3000
 1060 WRITE(IOUT,1070) IZ,ICOM
 1070 FORMAT(//,1X,'ERROR IN ZONE-COMPARTMENT SPECIFICATION FOR RADIONUC
     &LIDE INPUT RATES',1X,'IZ=',I5,1X,'ICOM=',I5)
C     0100584MTM
      GO TO 3000
C     010584MTM
C* 1080 WRITE(6,1090) ITER,MITER
C     010584MTM
C* 1090 FORMAT(//,1X,'NUMBER OF ITERATIONS(',I2,') GREATER THAN THE MAXIMU
C*     &M ALLOWED(',I2,')')
C     010584MTM
C*      GO TO 3000
 2000 CONTINUE
C     011084MTM
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
 3000 CONTINUE
C     013084MTM
      REWIND IP
      STOP
      END
      FUNCTION EXPON(X)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/A/IOUT
      IF(X.LT.-50.) GO TO 10
      IF(X.GT.50.) GO TO 20
      EXPON=DEXP(X)
      GO TO 30
   10 EXPON=0.0D0
      GO TO 30
   20 WRITE(IOUT,25) X
   25 FORMAT(//,1X,'OVERFLOW',F10.2,1X,'GT 50')
      STOP
   30 CONTINUE
      RETURN
      END
      SUBROUTINE RILMAT(A,H,ROOTR,ROOTI,M,ID,IP,NCAL)
      REAL*8 A(4,4), H(4,4),HLR(4,4),HLI(4,4),
     > ROOTR(4),ROOTI(4),VECTR(4),VECTI(4),RTR(4), MULTR(4),
     > MULTI(4),ABIG, ABS1,RI,SUM,VTI,BIG,TEMPI, VTR,EPS,TEMPR,TEMP,RR
      LOGICAL INTH(4),TWICE
      INTEGER INT(4),R,RP1,RP2
      IRET = 1
   10 CONTINUE
      N=M
      IF (N-2) 20,20,50
   20 IF (IRET.EQ.0) GO TO 40
      DO 30I=1,N
         DO 30J=1,N
   30       H(I,J)=A(I,J)
   40 CALL EIGQR (A, M, ROOTR, ROOTI, IP, ID, NCAL)
      GO TO 190
C
C     REDUCE MATRIX A TO UPPER HESSENBERG FORM
C
   50 NM2=N-2
      DO 160R=1,NM2
         RP1=R+1
         RP2=R+2
         ABIG=0.D0
         INT(R)=RP1
         DO 60I=RP1,N
            ABS1=DABS(A(I,R))
            IF (ABS1.LE.ABIG) GO TO 60
            INT(R)=I
            ABIG=ABS1
   60       CONTINUE
         INTER=INT(R)
         IF (ABIG.EQ.0.D0) GO TO 160
         IF (INTER.EQ.RP1) GO TO 90
         DO 70I=R,N
            TEMP=A(RP1,I)
            A(RP1,I)=A(INTER,I)
   70       A(INTER,I)=TEMP
         DO 80I=1,N
            TEMP=A(I,RP1)
            A(I,RP1)=A(I,INTER)
   80       A(I,INTER)=TEMP
   90    DO 100I=RP2,N
            MULTR(I)=A(I,R)/A(RP1,R)
  100       A(I,R)=MULTR(I)
         DO 120I=1,RP1
            TEMP=0.D0
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
            DO 110J=RP2,N
  110          TEMP=TEMP+A(I,J)*MULTR(J)
  120       A(I,RP1)=A(I,RP1)+TEMP
         DO 140I=RP2,N
            TEMP=0.D0
         DO 130J=RP2,N
  130       TEMP=TEMP+A(I,J)*MULTR(J)
  140    A(I,RP1)=A(I,RP1)+TEMP-MULTR(I)*A(RP1,RP1)
         DO 150I=RP2,N
            DO 150J=RP2,N
  150          A(I,J)=A(I,J)-MULTR(I)*A(RP1,J)
  160    CONTINUE
      IF (IRET.EQ.0) GO TO 180
C     SAVE A IN H
      DO 170I=1,N
         DO 170J=1,N
  170       H(I,J)=A(I,J)
C
C      CALCULATE EIGENVALUES
C
  180 CALL EIGQR (A, M, ROOTR, ROOTI, IP,ID, NCAL)
  190 IF (NCAL.EQ.0.OR.IRET.EQ.0) GO TO 510
C
C      CALCULATE VECTORS
C
      EPS=0.D0
      DO 200 I=1,N
  200    EPS=EPS+DABS(H(1,I))
      DO 220 I=2,N
         SUM=0.D0
         IM1=I-1
         DO 210J=IM1,N
  210       SUM=SUM+DABS(A(I,J))
  220    IF (SUM.GT.EPS) EPS=SUM
C*      EPS=DSQRT((DFLOAT(N)))*EPS*1.D-19
C*
      EPS=DSQRT((DBLE(N)))*EPS*1.D-19
C**
      IF (EPS.EQ.0.D0) EPS=1.D-19
      N=M
      NM1=N-1
      ITAG1=0
      ITAG2=0
      NMT = NCAL
  230 DO 470 L = 1,NCAL
         LMT=L-ITAG1
         DO 250I=1,N
            DO 240J=1,N
               HLR(I,J)=H(I,J)
  240          HLI(I,J)=0.D0
            HLR(I,I)=HLR(I,I)-ROOTR(L)
  250       HLI(I,I)=-1.D0*ROOTI(L)
         DO 290I=1,NM1
            MULTR(I)=0.D0
            MULTI(I)=0.D0
            INTH(I)=.FALSE.
            IP1=I+1
            IF ((HLR(I+1,I))**2+(HLI(I+1,I))**2.LE.(HLR(I,I))**2+(HLI(I,
     >       I))**2) GO TO 270
            INTH(I)=.TRUE.
            DO 260J=1,N
               TEMPR=HLR(I+1,J)
               TEMPI=HLI(I+1,J)
               HLR(I+1,J)=HLR(I,J)
               HLI(I+1,J)=HLI(I,J)
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
            HLR (I,J)=TEMPR
260         HLI(I,J)=TEMPI
270      IF (HLR(I,I).EQ.0.D0.AND.HLI(I,I).EQ.0.D0) GO TO 290
         MULTR(I)=-(HLR(I+1,I)*HLR(I,I)+HLI(I+1,I)*HLI(I, I))/(HLR(I,
     >     I) **2+HLI(I,I)**2)
         MULTI(I)=(HLR(I+1,I)*HLI(I,I)-HLI(I+1,I)*HLR(I, I))/(HLR(I,
     >     I) **2+HLI(I,I)**2)
         DO 280J=IP1,N
            TEMPR=HLR(I+1,J)+MULTR(I)*HLR(I,J)-MULTI(I)* HLI(I,J)
            TEMPI=HLI(I+1,J)+MULTR(I)*HLI(I,J)+MULTI(I)* HLR(I,J)
            HLR(I+1,J)=TEMPR
280         HLI(I+1,J)=TEMPI
290      CONTINUE
      DO 300I=1,N
         VECTR(I)=1.D0
300      VECTI(I)=0.D0
      TWICE=.FALSE.
310   IF (HLR(N,N).EQ.0.D0.AND.HLI(N,N).EQ.0.D0 ) HLR(N,N) =EPS
      TEMPR=(VECTR(N)*HLR(N,N)+VECTI(N)*HLI(N,N))/(HLR(N, N)**2 +
     >  HLI(N,N)**2)
      TEMPI=(VECTI(N)*HLR(N,N)-VECTR(N)*HLI(N,N))/(HLR(N, N)** 2+
     >  HLI(N,N)**2)
      VECTR(N)=TEMPR
      VECTI(N)=TEMPI
      DO 330I=1,NM1
         K=N-I
         DO 320J=K,NM1
            TEMPR=VECTR(K)-HLR(K,J+1)*VECTR(J+1)+HLI(K,J+ 1)*VECTI(J+
     >        1)
            TEMPI=VECTI(K)-HLR(K,J+1)*VECTI(J+1)-HLI(K,J+ 1)*VECTR(J+
     >        1)
            VECTR(K)=TEMPR
320         VECTI(K)=TEMPI
         IF (HLR(K,K).EQ.0.D0.AND.HLI(K,K).EQ.0.D0) HLR(K,K)=EPS
         TEMPR=(VECTR(K)*HLR(K,K)+VECTI(K)*HLI(K,K))/ (HLR(K,K)**2+
     >     HLI(K,K)**2)
         TEMPI=(VECTI(K)*HLR(K,K)-VECTR(K)*HLI(K,K))/ (HLR(K,K)**2+
     >     HLI(K,K)**2)
         VECTR(K)=TEMPR
330      VECTI(K)=TEMPI
      BIG=0.D0
      DO 340I=1,N
         SUM=DABS(VECTR(I))+DABS(VECTI(I))
340      IF (SUM.GT.BIG) BIG=SUM
      DO 350I=1,N
         VECTR(I)=VECTR(I)/BIG
350      VECTI(I)=VECTI(I)/BIG
      IF (TWICE) GO TO 380
      DO 370I=1,NM1
         IF (.NOT.INTH(I)) GO TO 360
         TEMPR=VECTR(I)
         TEMPI=VECTI(I)
         VECTR(I)=VECTR(I+1)
         VECTI(I)=VECTI(I+1)
         VECTR(I+1)=TEMPR
         VECTI(I+1)=TEMPI
360      VTR=VECTR(I+1)+MULTR(I)*VECTR(I)-MULTI(I)* VECTI(I)
         VTI=VECTI(I)+MULTI(I)*VECTR(I)+MULTR(I)*VECTI(I)
         VECTR(I+1)=VTR
370      VECTI(I+1)=VTI
      TWICE=.TRUE.
      GO TO 310
380   IF (N.EQ.2) GO TO 410
      NM2=N-2
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
          DO 400I=1,NM2
             N1I=N-I-1
             NI1=N-I+1
             DO 390J=NI1,N
                VECTR(J)=H(J,N1I)*VECTR(N1I+1)+VECTR(J)
  390           VECTI(J)=H(J,N1I)*VECTI(N1I+1)+VECTI(J)
             INDEX=INT(N1I)
             TEMPR=VECTR(N1I+1)
             TEMPI=VECTI(N1I+1)
             VECTR(N1I+1)=VECTR(INDEX)
             VECTI(N1I+1)=VECTI(INDEX)
             VECTR(INDEX)=TEMPR
  400        VECTI(INDEX)=TEMPI
  410     DO 420I=1,N
             IF (VECTI(I).NE.0.D0) GO TO 430
  420        CONTINUE
          GO TO 450
  430     ITAG1=ITAG1+1
          IF (VECTI(I).LT.0.D0) GO TO 470
          ITAG2=ITAG2+1
          NMT = NCAL-2*ITAG2
C       ITAG1 TELLS HOW MANY COMPLEX VECTORS, ITAG2 HOW MANY STORED IN A
          DO 440I=1,N
             A(I,NMT+1)=VECTR(I)
             A(I,NMT+2)=VECTI(I)
  440        CONTINUE
          RTR(NMT+1)=ROOTR(L)
          RTR(NMT+2)=ROOTI(L)
          GO TO 470
  450     DO 460I=1,N
             A(I,LMT)=VECTR(I)
  460        CONTINUE
          RTR(LMT)=ROOTR(L)
  470     CONTINUE
C      PUT REAL PARTS OF EIGENVECTORS IN A, IMAGINARY PARTS IN H
       DO 480 I=1,N
          DO 480JJ=1,NMT
          ROOTR(JJ)=RTR(JJ)
          ROOTI(JJ)=0.D0
  480     H(I,JJ)=0.D0
       IF (NMT.EQ.NCAL) GO TO 510
       NMTP1=NMT+1
       NM1 = NCAL - 1
       DO 490I=1,N
          DO 490J=NMTP1,NM1,2
          ROOTI(J)=-RTR(J+1)
          ROOTI(J+1)=RTR(J+1)
          H(I,J)=-A(I,J+1)
  490     H(I,J+1)=A(I,J+1)
       DO 500 I=1,N
          DO 500 J=NMTP1,NM1,2
             ROOTR(J)=RTR(J)
             ROOTR(J+1)=ROOTR(J)
  500        A(I,J+1)=A(I,J)
  510  RETURN
       END
       SUBROUTINE DQRT(A,N,R,SIG,D,ID)
       REAL*8 A(4,4),PSI(2),G(3),SIG,DEN,XK,AL, C,D,E,R,GMAX,
     > G1,G2
C      022284MTM
C*     ERRSET SUBROUTINE USED FOR EXTENDED ERROR HANDLING ON IBM
C*     MAINFRAMES. NOT AVAILACLE ON THE PC.
C*     CALL ERRSET(208,256,-1,1,0,208)
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
      N1=N-1
      IA=N-2
      IP=IA
      IF (N-3) 410,50,10
   10 DO 40J=3,N1
         J1=N-J
         IF (DABS(A(J1+1,J1))-D) 50,50,20
   20    DEN=A(J1+1,J1+1)*(A(J1+1,J1+1)-SIG)+A(J1+1,J1+2)* A(J1+2, J1+1)
     >      +R
         IF (DEN) 30,40,30
   30    IF (DABS(A(J1+1,J1)*A(J1+2,J1+1)*(DABS(A(J1+1,J1+1)+A(J1+2,J1+
     >     2)-SIG)+DABS(A(J1+3,J1+2)))/DEN)-D) 50,50,40
   40    IP=J1
   50 DO 60J=1,IP
         J1=IP-J+1
         IF (DABS(A(J1+1,J1))-D) 70,70,60
   60    IQ=J1
   70 DO 400I=IP,N1
         IF (I-IP) 90,80,90
   80    G(1)=A(IP,IP)*(A(IP,IP)-SIG)+A(IP,IP+1)*A(IP+1,IP)+ R
         G(2)=A(IP+1,IP)*(A(IP,IP)+A(IP+1,IP+1)-SIG)
         G(3)=A(IP+1,IP)*A(IP+2,IP+1)
         A(IP+2,IP)=0.D0
         GO TO 120
   90    G(1)=A(I,I-1)
         G(2)=A(I+1,I-1)
         IF (I-IA) 100,100,110
  100    G(3)=A(I+2,I-1)
         GO TO 120
  110    G(3)=0.D0
  120    CONTINUE
         IF (G(1).EQ.0.D0.AND.G(2).EQ.0.D0.AND.G(3).EQ.0.D0) GO TO 190
         GMAX = G(1)
         IF (DABS(G(2)).GT.DABS(GMAX)) GO TO 130
         G1 = G(2)
         GO TO 140
  130    GMAX = G(2)
         G1 = G(1)
  140    IF (DABS(G(3)).GT.DABS(GMAX)) GO TO 150
         G2 = G(3)
         GO TO 160
  150    G2 = GMAX
         GMAX = G(3)
  160    CONTINUE
C     011184MTM
C        XK = DABS(GMAX)*DSQRT( (G1/GMAX)**2 + (G2/MAX)**2 + 1.D0)
C     011184MTM
         XK = DABS(GMAX)*DSQRT( (G1/GMAX)**2 + (G2/GMAX)**2+1.D0)
         IF (G(1).GE.0.D0) GO TO 170
         XK = -XK
  170    CONTINUE
         IF (XK) 180,200,180
  180    AL=G(1)/XK+1.D0
         PSI(1)=G(2)/(G(1)+XK)
         PSI(2)=G(3)/(G(1)+XK)
         GO TO 210
  190    XK = 0.D0
  200    AL=2.D0
         PSI(1)=0.D0
         PSI(2)=0.D0
  210    IF (I-IQ) 220,250,220
  220    IF (I-IP) 240,230,240
  230    A(I,I-1)=-A(I,I-1)
         GO TO 250
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
240     A(I,I-1)=-XK
250     DO 300J=I,N
           IF (I-IA) 260,260,270
260        C=PSI(2)*A(I+2,J)
           GO TO 280
270     C=0.0
280     E=AL*(A(I,J)+PSI(1)*A(I+1,J)+C)
        A(I,J)=A(I,J)-E
        A(I+1,J)=A(I+1,J)-PSI(1)*E
        IF (I-IA) 290,290,300
290     A(I+2,J)=A(I+2,J)-PSI(2)*E
300     CONTINUE
      IF (I-IA) 310,310,320
310   L=I+2
      GO TO 330
320   L=N
330   DO 380J=IQ,L
        IF (I-IA) 340,340,350
340     C=PSI(2)*A(J,I+2)
        GO TO 360
350     C=0.0
360     E=AL*(A(J,I)+PSI(1)*A(J,I+1)+C)
        A(J,I)=A(J,I)-E
        A(J,I+1)=A(J,I+1)-PSI(1)*E
        IF (I-IA) 370,370,380
370     A(J,I+2)=A(J,I+2)-PSI(2)*E
380     CONTINUE
      IF (I-N+3) 390,390,400
390   E=AL*PSI(2)*A(I+3,I+2)
      A(I+3,I)=-E
      A(I+3,I+1)=-PSI(1)*E
      A(I+3,I+2)=A(I+3,I+2)-PSI(2)*E
400   CONTINUE
410   RETURN
      END
         SUBROUTINE EIGQR (A,M,ROOTR,ROOTI,IPRNT,ID, NCAL)
C
C        PROGRAM TO CALL QR TRANSFORMATION
C
      REAL*8 A(4,4)
      REAL*8 ROOTR(4),ROOTI(4),AA,B,C,DD,E,F,G, H,R,SIG,X,S,
     >  ZERO,XNN,XN2,Z1,Z2,VQ,SQ,D
      COMMON/A/IOUT
      N=M
      NCAL = N
      IF (IPRNT) 10,20,10
 10   WRITE(IOUT,10000)
 20   ZERO=0.D0
      JJ=1
 30   XNN=0.D0
      XN2=0.D0
      AA=0.D0
      B=0.D0
      C=0.D0
      DD=0.D0
      R=0.D0
      SIG=0.D0
      ITER=0
 40   IF (N-2) 50,90,100
 50   IF (IPRNT) 60,70,60
 60   WRITE(IOUT,10100)A(1,1)
 70   ROOTR(1)=A(1,1)
      ROOTI(1)=0.D0
 80   RETURN
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
   90 JJ=-1
  100 X=(A(N-1,N-1)-A(N,N))**2
      S=4.D0*A(N,N-1)*A(N-1,N)
      ITER=ITER+1
      IF (X.EQ.0.D0.OR.DABS(S/X).GT.1.D-16) GO TO 150
  110 IF (DABS(A(N-1,N-1))-DABS(A(N,N))) 130,130,120
  120 E=A(N-1,N-1)
      G=A(N,N)
      GO TO 140
  130 G=A(N-1,N-1)
      E=A(N,N)
  140 F=0.D0
      H=0.D0
      GO TO 200
  150 S=X+S
      X=A(N-1,N-1)+A(N,N)
      IF (S) 190,160,160
  160 SQ=DSQRT(S)
      F=0.D0
      H=0.D0
      IF (X) 170,170,180
  170 E=(X-SQ)/2.0D0
      G=(X+SQ)/2.0D0
      GO TO 200
  180 G=(X-SQ)/2.0D0
      E=(X+SQ)/2.0D0
      GO TO 200
  190 F=DSQRT(-S)/2.0D0
      E=X/2.0D0
      G=E
      H=-F
  200 CONTINUE
      IF (JJ) 220,210,210
  210 D=1.0D-17*(DABS(G)+F)
      IF (DABS(A(N-1,N-2)).GT.D) GO TO 250
  220 IF (IPRNT) 230,240,230
  230 WRITE(IOUT,10100)E,F,ITER
      WRITE(IOUT,10100)G,H
  240 ROOTR(N)=E
      ROOTI(N)=F
      ROOTR(N-1)=G
      ROOTI(N-1)=H
      N=N-2
      IF (JJ) 80,30,30
  250 IF (DABS(A(N,N-1)).GT.1.0D-17*DABS(A(N,N))) GO TO 290
  260 IF (IPRNT) 270,280,270
  270 WRITE(IOUT,10100)A(N,N),ZERO,ITER
  280 ROOTR(N)=A(N,N)
      ROOTI(N)=0.D0
      N=N-1
      GO TO 30
  290 IF (DABS(DABS(XNN/A(N,N-1))-1.D0)-1.D-13) 310,310,300
  300 IF (DABS(DABS(XN2/A(N-1,N-2))-1.D0)-1.D-13) 310,310,400
  310 VQ=DABS(A(N,N-1))-DABS(A(N-1,N-2))
C     011084MTM THE FOLLOWING LINE HAS BEEN REMOVED SINCE IT WAS
C     GARBLED IN TRANSMISSION FROM THE MICROCOMPUTER AT TEKNEKRON.
C     LINE REMOVED
C     011084MTM
      IF(ITER-15) 450,320,350
  320 IF (VQ) 330,330,340
  330 R=A(N-1,N-2)**2*1.D0
      SIG=2.D0*A(N-1,N-2)
      GO TO 500
  340 R=A(N,N-1)**2
      SIG=2.D0*A(N,N-1)
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
      GO TO 500
  350 IF (VQ) 380,380,360
  360 IF (IPRNT) 370,240,370
  370 WRITE(IOUT,10200)A(N-1,N-2)
      GO TO 230
  380 IF (IPRNT) 390,280,390
  390 WRITE(IOUT,10200)A(N,N-1)
      GO TO 270
  400 IF (ITER.LE.50) GO TO 420
      NCAL = M - N
      MNC = M - NCAL + 1
      DO 410 K = 1,NCAL
         II = MNC + K - 1
         ROOTR(K) = ROOTR(II)
  410    ROOTI(K) = ROOTI(II)
      GO TO 80
  420 IF (ITER.GT.5) GO TO 450
  430 Z1= (E-AA)**2+(F-B)**2 - 0.25D0*(E*E + F*F)
      Z2= (G-C)**2+(H-DD)**2 - 0.25D0*(G*G + H*H)
      IF (Z1) 440,440,470
  440 IF (Z2) 450,450,460
  450 R=E*G-F*H
      SIG=E+G
      GO TO 500
  460 R=E*E
      SIG=E+E
      GO TO 500
  470 IF (Z2) 480,480,490
  480 R=G*G
      SIG=G+G
      GO TO 500
  490 R=0.D0
      SIG=0.D0
  500 XNN=A(N,N-1)
      XN2=A(N-1,N-2)
      CALL DQRT(A,N,R,SIG,D,ID)
      AA=E
      B=F
      C=G
      DD=H
      GO TO 100
10000 FORMAT(////1X,9HREAL PART, 14X,14HIMAGINARY PART,26X,
     > 13HTAKEN AS ZERO,6X,4HITER//)
10100 FORMAT(1X,E13.6,13X,E13.6,36X,I3)
10200 FORMAT(64X,E13.6)
      END
      SUBROUTINE MATEQ(A,B,D,III,JJJ,ID)
      REAL*8 A,B,R,S,D
      DIMENSION A(4,4),B(4,4)
      KK=III
      NV=IABS(JJJ)
      D=1.0D0
      IF (JJJ.LT.0) D=0.0D0
      KKM=KK-1
      DO 90I=1,KKM
         S=0.0D0
         DO 10J=I,KK
            R=DABS(A(J,I))
            IF (R.LT.S) GO TO 10
            S=R
            L=J
   10       CONTINUE
```

Figure 32

Fortran Program CELLTRAN Source Code (continued)

```
      IF (L.EQ.I) GO TO 50
      DO 20 J=I,KK
         S=A(I,J)
         A(I,J)=A(L,J)
20       A(L,J)=S
      IF (NV.LE.0) GO TO 40
      DO 30 J=1,NV
         S=B(I,J)
         B(I,J)=B(L,J)
30       B(L,J)=S
40    D=-D
50    IF (A(I,I).EQ.0.) GO TO 90
      IPO=I+1
      DO 80J=IPO,KK
         IF (A(J,I).EQ.0.) GO TO 80
         S=A(J,I)/A(I,I)
         A(J,I)=0.0D0
         DO 60 K=IPO,KK
            A(J,K)=A(J,K)-A(I,K)*S
60       CONTINUE
         IF (NV.LE.0) GO TO 80
         DO 70 K=1,NV
            B(J,K)=B(J,K)-B(I,K)*S
70       CONTINUE
80       CONTINUE
90    CONTINUE
      DO 100I=1,KK
100      D=D*A(I,I)
      IF (NV.LE.0) GO TO 130
      KMO = KK-1
      DO 120K=1,NV
         B(KK,K)=B(KK,K)/A(KK,KK)
         DO 120I=1,KMO
            N=KK-I
         DO 110J=N,KMO
110         B(N,K)=B(N,K)-A(N,J+1)*B(J+1,K)
120      B(N,K)=B(N,K)/A(N,N)
130 CONTINUE
    RETURN
    END
C*  /*
C*  //STEP2 EXEC FORVLKSM,NAME='WDC9VKD.CELLTRAN.LOAD',
C*  //   DISK=FILE03
C*  /*
C*  ?
```

Figure 33

Fortran Program CELLPOST Source Code

```
      PROGRAM CELLPOST
C*    //VKDCELLP   JOB  (WDC9,361,A,10,10,0),'DOUG VOGT'
C*    /*TITLE=VOGT AR702N 654-8096
C*    //STEP1 EXEC FORVCOMP
C*    //COMP.SYSIN DD *
C*    PROGRAM REVISIONS BY DICK CHAPMAN (RAC) STARTED 5/21/86 TO ADAPT
C*    THE CODE TO MS-DOS FORTRAN. COMMENTS INDICATED BY C*, CODE ADDITIONS
C*    PRECEEDED BY C*, DATE, AND INITIALS, AND FOLLOWED BY C**.
C**
C***  PROGRAM TO POST-PROCESS THE RADIONUCLIDE AMOUNT FILE WRITTEN
C***  BY CELLTRAN.  THE OUTPUT OF THIS POST-PROCESSOR IS USED FOR INPUT
C***  TO THE DOSECAL PROGRAM.
      CHARACTER*8 RNAME
      DIMENSION CS(7,82),CW(7,82),RNAME(7),TIME(82)
      IN=5
      INPUT=1
      ID=9
      IOUT=6
C*    060386RAC
      OPEN(IN,FILE='CPOST.DAT')
      OPEN(INPUT,FILE='IP.OUT')
      OPEN(ID,FILE='CONC.DAT')
      OPEN(IOUT,FILE='ERROR.MSG')
C**
      READ(IN,10) NR,NT
   10 FORMAT(2I5)
      READ(INPUT,15) (TIME(IT),IT=1,NT)
   15 FORMAT(8E10.3)
      DO 100 IR=1,NR
      READ(INPUT,20) RNAME(IR),NTIMES,DRATE
   20 FORMAT(A8,I5,E10.3)
      IF(NTIMES.NE.NT) GO TO 1000
      READ(INPUT,30) ID1,ID2,F1L,ALSOL,ALWAT
      READ(INPUT,30) ID1,ID2,F1S,ASSOL,ASWAT
   30 FORMAT(2I5,3E10.3)
      DO 50 IT=1,NT
      READ(INPUT,40) ATWAT
      READ(INPUT,40) ATSOIL
   40 FORMAT(E10.3)
      AS=ATSOIL*F1S/(F1S+ASWAT/ASSOL)
      CS(IR,IT)=8.5646E-13*DRATE*AS/ASSOL
      CW(IR,IT)=8.5646E-13*DRATE*ATWAT/ALWAT
   50 CONTINUE
  100 CONTINUE
      WRITE(ID,105) NR,NT
  105 FORMAT(2I5)
      WRITE(ID,107) (TIME(IT),IT=1,NT)
  107 FORMAT(8E10.3)
      WRITE(ID,110) (RNAME(IR),IR=1,NR)
  110 FORMAT(10A8)
      DO 500 IT=1,NT
      WRITE(ID,120) (CS(IR,IT),IR=1,NR)
  120 FORMAT(8E10.3)
      WRITE(ID,120) (CW(IR,IT),IR=1,NR)
  500 CONTINUE
      GO TO 2000
 1000 WRITE(IOUT,1010) NTIMES,NT
 1010 FORMAT(/,1X,'ERROR***NTIMES(',I3,1X,') NOT EQUAL TO NT(',I3,1X,')'
     &)
 2000 CONTINUE
C     013084MTM
      REWIND 9
      STOP
      END
C*    060386RAC
C*    /*
C*    //STEP2 EXEC FORVLKSM,NAME='WDC9VKD.CELLPOST.LOAD',
C*    //  DISK=FILE03
C*    /*
C*    ?
C**
```

Figure 34

Fortran Program DOSECAL2 Source Code

```
C       UPGRADE OF DOSECAL 011BB4MTM
C       PROGRAM TO CALCULATE THE DOSE TO THE MAXIMUM EXPOSED
C       INDIVIDUAL BY RADIONUCLIDE, ORGAN AND PATHWAY BASED UPON
C       RADIONUCLIDE CONCENTRATIONS IN SOIL AND WATER COMPARTMENTS
C*      PROGRAM REVISIONS BY DICK CHAPMAN (RAC) STARTED 5/21/86 TO ADAPT
C*      THE CODE TO MS-DOS FORTRAN. COMMENTS INDICATED BY C*, CODE ADDITIONS
C*      PRECEEDED BY C*, DATE AND INITIALS, AND FOLLOWED BY C**.
C*****
C*****
C       GLOSSARY OF USAGE AND EXPOSURE PARAMETERS(INPUT)
C*****
C*****
C       SI  =SPRINKLER IRRIGATION(L/M**2)
C       DLV =DENSITY OF LEAFY VEGETABLES(KG/M**2)
C       TI  =IRRIGATION TIME(DAYS)
C       WHL =WEATHERING HALF-LIFE FOR RADIONUCLIDES DEPOSITED
C            ON PLANT LEAVES(DAYS)
C       FRD =FRACTION OF RADIONUCLIDE DEPOSITED ON LEAVES
C       HVC =HUMAN VEGETABLE CONSUMPTION(KG/YR)
C       HWC =HUMAN WATER CONSUMPTION(L/YR)
C       DCPC=DAIRY COW PLANT CONSUMPTION(KG/DAY)
C       BCPC=BEEF CATTLE PLANT CONSUMPTION(KG/DAY)
C       DCDR=DAIRY COW DRINKING RATE(L/DAY)
C       BCDR=BEEF CATTLE DRINKING RATE(L/DAY)
C       HMTC=HUMAN MEAT CONSUMPTION(KG/YR)
C       HMLC=HUMAN MILK CONSUMPTION(L/YR)
C       HFC =HUMAN FISH CONSUMPTION(KG/YR)
C       AS  =AIR SUBMERSION(HR/YR)
C       SE  =SOIL EXPOSURE(HR/YR)
C       SWIM=TIME SPENT SWIMMING(HR/YR)
C       SRF =SOIL RESUSPENSION FACTOR(MICROGRAMS/M**3)
C       HBR =HUMAN BREATHING RATE(M**3/YR)
C       ET  =EXPOSURE TIME FOR HUMANS(YR)
C       DCT =DOSE COMMITMENT TIME(YR)-NOT DIRECTLY USED IN THE
C            CALCULATION.  IMPLICIT IN THE INHILATION AND INGESTION
C            DOSE FACTORS.
C       SD  =SOIL DEPTH(CM)
C       SDEN=SOIL DENSITY(GM/CM**3)
C       CONCS(IR)=SOIL CONCENTRATION OF RADIONUCLIDE IR(MICROCURIES/KG)
C       CONCW(IR)=WATER CONCENTRATION OF RADIONUCLIDE IR(MICROCURIES/L)
C*****
C*****
C       GLOSSARY OF CONCENTRATION RATIOS(INPUT)
C*****
C*****
C       CRFWF(IR) =CONCENTRATION RATIO FOR FRESH WATER FISH FOR
C                  RADIONUCLIDE IR((CI/KG)FISH/(CI/L)WATER)
C       CRVEG(IR) =CONCENTRATION RATIO FOR VEGETATION FOR RADIONUCLIDE IR
C                  ((CI/KG)VEGETATION/(CI/KG) SOIL)
C       CRMILK(IR)=CONCENTRATION RATIO FOR MILK FOR RADIONUCLIDE IR
C                  ((CI/L)MILK/(CI/DAY)INTAKE)
C       CRMEAT(IR)=CONCENTRATION RATIO FOR MEAT FOR RADIONUCLIDE IR
C                  ((CI/KG)MEAT/(CI/DAY)INTAKE)
C*****
C*****
C       GLOSSARY OF DOSE FACTORS(INPUT)
C*****
C*****
C       DFEG(IP,IR) =GROUND EXPOSURE EXTERNAL DOSE FACTOR FOR RADIONUCLIDE
C                    IR AND IP=1(SKIN) OR IP=2(TOTAL BODY)
C                    ((REM/HR)/(MICROCURIE/M**2))
C       DFEW(IP,IR) =WATER IMMERSION EXTERNAL DOSE FACTOR FOR RADIONUCLIDE
C                    IR AND IP=1(SKIN) OR IP=2(TOTAL BODY)
C                    ((REM/HR)/(MICROCURIE/M**3))
```

Figure 34

Fortran Program DOSECAL2 Source Code (continued)

```
C     DFEA(IP,IR) =AIR SUBMERSION EXTERNAL DOSE FACTOR FOR RADIONUCLIDE
C                  IR AND IP=1(SKIN) OR IP=2(TOTAL BODY)
C                  ((REM/HR)/(MICROCURIE/M**3))
C     DFINH(IO,IR)=INHALATION DOSE FACTOR FOR RADIONUCLIDE IR AND ORGAN
C                  IO(REM/((MICROCURIE/YR))
C     DFING(IO,IR)=INGESTION DOSE FACTOR FOR RADIONUCLIDE IR AND ORGAN
C                  IO(REM/((MICROCURIE/YR))
C     IO=1(TOTAL BODY)
C     IO=2(BONE)
C     IO=3(THYROID)
C     IO=4(LIVER)
C     IO=5(KIDNEYS)
C     IO=6(LUNGS)
C     IO=7(GI-LLI)
C     INHALATION AND INGESTION DOSE FACTORS ARE BASED UPON AN
C     EXPOSURE FOR (ET) YEARS AND A COMMITMENT FOR (ET) YEARS
C*****
C*****
C*****
C     TYPE AND DIMENSION SECTION
C*****
C*****
C*****
      REAL*8 NAME
      DIMENSION NAME(10)
      DIMENSION CONCS(10),CONCW(10),DINHT(7),DINGT(7),DT(7,10),DTT(7),
     &CRFWF(10),CRVEG(10),CRMILK(10),CRMEAT(10),DFEG(2,10),DFEW(2,10),
     &DFEA(2,10),DFINH(7,10),DFING(7,10),DEXTT(2)
C*    050586RAC
C*    DIMENSION TIME(33),DINH(7,10),DING(7,10),DEXT(2,10)
      DIMENSION TIME(82),DINH(7,10),DING(7,10),DEXT(2,10)
C**
C*****
C*****
C*****
C     INPUT SECTION
C*****
C*****
C*****
      IN=5
      INPUT=7
C*    052186RAC
C*    CALL OPEN(IN,'DOSE    DAT',2)
C*    CALL OPEN(INPUT,'CONC    DAT',2)
      OPEN(IN,FILE='DOSE.DAT')
      OPEN(INPUT,FILE='CONC.DAT')
C**
      READ(IN,5) IOUT
C*    052286RAC
      OPEN (IOUT,FILE='DOSECAL.OUT')
C**
    5 FORMAT(I5)
      READ(INPUT,10) NR,NT
   10 FORMAT(2I5)
      WRITE(IOUT,11) NR,NT
   11 FORMAT(1X,'NUMBER OF RADIONUCLIDES=',I5,1X,'NUMBER OF TIMES=',I5)
      READ(INPUT,111) (TIME(IT),IT=1,NT)
  111 FORMAT(8E10.3)
      READ(INPUT,12) (NAME(IR),IR=1,NR)
   12 FORMAT(10A8)
      WRITE(IOUT,13)
   13 FORMAT(//,1X,'***RADIONUCLIDES***',/)
      WRITE(IOUT,14) (NAME(IR),IR=1,NR)
   14 FORMAT(1X,10A8)
      DO 1000 IT=1,NT
```

Figure 34

Fortran Program DOSECAL2 Source Code (continued)

```
C*****
C*****
C     READ IN USAGE AND EXPOSURE PARAMETERS
C*****
C*****
      IF(IT.GT.1) GO TO 391
      READ(IN,15) SI,DLV,TI,WHL,FRD,HVC,HWC,DCPC,BCPC,
     &DCDR,BCDR,HMTC,HMLC,HFC,AS,SE,SWIM,SRF,HBR,ET,
     &DCT,SD,SDEN
   15 FORMAT(F10.2)
C*****
C*****
C     PRINT OUT USAGE AND EXPOSURE PARAMETERS
C*****
C*****
      WRITE(IOUT,16)
   16 FORMAT(//,1X,'USAGE AND EXPOSURE PARAMETERS',/)
      WRITE(IOUT,17) SI
   17 FORMAT(1X,'SPRINKLER IRRIGATION=',F10.2,1X,'L/M**2')
      WRITE(IOUT,18) DLV
   18 FORMAT(1X,'DENSITY OF LEAFY VEGETABLES=',F10.2,1X,'KG/M**2')
      WRITE(IOUT,19) TI
   19 FORMAT(1X,'IRRIGATION TIME=',F10.2,1X,'DAYS')
      WRITE(IOUT,20) WHL
   20 FORMAT(1X,'WEATHERING HALF-LIFE=',F10.2,1X,'DAYS')
      WRITE(IOUT,21) FRD
   21 FORMAT(1X,'FRACTION OF RADIONUCLIDE DEPOSITED ON LEAVES=',1X,F10.2
     &)
      WRITE(IOUT,22) HVC
   22 FORMAT(1X,'HUMAN VEGETABLE CONSUMPTION=',F10.2,1X,'KG/YR')
      WRITE(IOUT,23) HWC
   23 FORMAT(1X,'HUMAN WATER CONSUMPTION=',F10.2,1X,'L/YR')
      WRITE(IOUT,24) DCPC
   24 FORMAT(1X,'DAIRY COW PLANT CONSUMPTION=',F10.2,1X,'KG/DAY')
      WRITE(IOUT,25) BCPC
   25 FORMAT(1X,'BEEF CATTLE PLANT CONSUMPTION=',F10.2,1X,'KG/DAY')
      WRITE(IOUT,26) DCDR
   26 FORMAT(1X,'DAIRY COW DRINKING RATE=',F10.2,1X,'L/DAY')
      WRITE(IOUT,27) BCDR
   27 FORMAT(1X,'BEEF CATTLE DRINKING RATE=',F10.2,1X,'L/DAY')
      WRITE(IOUT,28) HMTC
   28 FORMAT(1X,'MEAT CONSUMPTION BY HUMANS=',F10.2,1X,'KG/YR')
      WRITE(IOUT,29) HMLC
   29 FORMAT(1X,'MILK CONSUMPTION BY HUMANS=',F10.2,1X,'L/YR')
      WRITE(IOUT,30) HFC
   30 FORMAT(1X,'FISH CONSUMPTION BY HUMANS=',F10.2,1X,'KG/YR')
      WRITE(IOUT,31) AS
   31 FORMAT(1X,'AIR SUBMERSION=',F10.2,1X,'HR/YR')
      WRITE(IOUT,32) SE
   32 FORMAT(1X,'SOIL EXPOSURE=',F10.2,1X,'HR/YR')
      WRITE(IOUT,33) SWIM
   33 FORMAT(1X,'TIME SPENT SWIMMING=',F10.2,1X,'HR/YR')
      WRITE(IOUT,34) SRF
   34 FORMAT(1X,'SOIL RESUSPENSION FACTOR=',E10.2,1X,'UG/M**3')
      WRITE(IOUT,35) HBR
   35 FORMAT(1X,'HUMAN BREATHING RATE=',F10.2,1X,'M**3/YR')
      WRITE(IOUT,36) ET
   36 FORMAT(1X,'EXPOSURE TIME FOR HUMANS=',F10.2,1X,'YR')
      WRITE(IOUT,37) DCT
   37 FORMAT(1X,'DOSE COMMITMENT TIME=',F10.2,1X,'YR')
      WRITE(IOUT,38) SD
   38 FORMAT(1X,'SOIL DEPTH=',F10.2,1X,'CM')
      WRITE(IOUT,39) SDEN
   39 FORMAT(1X,'SOIL DENSITY=',F10.2,1X,'GM/CM**3')
  391 CONTINUE
```

Figure 34

Fortran Program DOSECAL2 Source Code (continued)

```
C*****
C*****
C     READ IN SOIL AND WATER RADIONUCLIDE CONCENTRATIONS
C*****
C*****
      READ(INPUT,40) (CONCS(IR),IR=1,NR)
   40 FORMAT(6E10.3)
      READ(INPUT,40) (CONCW(IR),IR=1,NR)
C*****
C*****
C     PRINT OUT SOIL AND WATER RADIONUCLIDE CONCENTRATIONS
C*****
C*****
      WRITE(IOUT,41)
   41 FORMAT(//,1X,'SOIL AND WATER RADIONUCLIDE CONCENTRATIONS',/)
      DO 50 IR=1,NR
      WRITE(IOUT,42) NAME(IR),CONCS(IR),CONCW(IR)
   42 FORMAT(1X,A8,2X,'SOIL CONCENTRATION=',2X,E10.3,1X,'MICROCURIES/KG'
     &,/,11X,'WATER CONCENTRATION=',1X,E10.3,1X,'MICROCURIES/L')
   50 CONTINUE
      IF(IT.GT.1) GO TO 69
C*****
C*****
C     READ IN CONCENTRATION RATIO TABLES
C*****
C*****
      READ(IN,40) (CRFWF(IR),IR=1,NR)
      READ(IN,40) (CRVEG(IR),IR=1,NR)
      READ(IN,40) (CRMILK(IR),IR=1,NR)
      READ(IN,40) (CRMEAT(IR),IR=1,NR)
C*****
C*****
C     PRINT OUT CONCENTRATION RATIO TABLES
C*****
C*****
      WRITE(IOUT,51)
   51 FORMAT(//,1X,'CONCENTRATION RATIOS',/)
      DO 60 IR=1,NR
      WRITE(IOUT,52) NAME(IR),CRFWF(IR),CRVEG(IR),CRMILK(IR),CRMEAT(IR)
   52 FORMAT(1X,A8,2X,'RATIO FOR FISH=',7X,E10.3,1X,'((CI/KG)FISH/(CI/L)
     &WATER)',/,11X,'RATIO FOR VEGETATION=',1X,E10.3,1X,'((CI/KG)VEGETATI
     &ON/(CI/KG)SOIL)',/,11X,'RATIO FOR MILK=',7X,E10.3,1X,'((CI/L)MILK/(
     &CI/DAY)INTAKE)',/,11X,'RATIO FOR MEAT=',7X,E10.3,1X,'((CI/KG)MEAT/
     &(CI/DAY)INTAKE)')
   60 CONTINUE
C*****
C*****
C     READ IN DOSE FACTOR TABLES
C*****
C*****
      READ(IN,61) ((DFEG(IP,IR),IP=1,2),(DFEW(IP,IR),IP=1,2),
     &(DFEA(IP,IR),IP=1,2),IR=1,NR)
   61 FORMAT(6E10.3)
      READ(IN,62) ((DFINH(IO,IR),IO=1,7),IR=1,NR)
   62 FORMAT(7E10.3)
      READ(IN,62) ((DFING(IO,IR),IO=1,7),IR=1,NR)
C*****
C*****
C     PRINT OUT DOSE FACTOR TABLES
C*****
C*****
```

Figure 34

Fortran Program DOSECAL2 Source Code (continued)

```
      WRITE(IOUT,63)
   63 FORMAT(///,37X,'EXTERNAL DOSE FACTORS',//,18X,
     &'GROUND EXPOSURE',9X,'WATER IMMERSION',10X,'AIR SUBMERSION',/,
     &16X,'(REM/HR PER UCI/M**2)',3X,2('(REM/HR PER UCI/M**3)',3X),/,1X,
     &'RADIONUCLIDE',4X,'SKIN',5X,'TOTAL BODY',5X,'SKIN',5X,'TOTAL BODY'
     &,5X,'SKIN',5X,'TOTAL BODY',/)
C*    WRITE(IOUT,64) (NAME(IR),(DFEG(IP,IR),IP=1,2),(DFEW(IP,IR),IP=1,2)
C*   &,(DFEA(IP,IR),IP=1,2),IR=1,NR)
C*    052286RAC
      DO 110 IR=1,NR
  110 WRITE(IOUT,64) NAME(IR),(DFEG(IP,IR),IP=1,2),(DFEW(IP,IR),IP=1,2),
     &(DFEA(IP,IR),IP=1,2)
C**
   64 FORMAT(1X,A8,6X,6(E9.3,3X))
      WRITE(IOUT,65)
   65 FORMAT(///,37X,'INHALATION DOSE FACTORS')
      WRITE(IOUT,66)
   66 FORMAT(43X,'(REM/(UCI/YR))',//,1X,'RADIONUCLIDE',2X,'TOTAL BODY',
     &5X,'BONE',6X,'THYROID',6X,'LIVER',6X,'KIDNEYS',6X,'LUNGS',6X,
     &'GI-LLI',/)
C*    052286RAC
C*    WRITE(IOUT,67) (NAME(IR),(DFINH(ID,IR),ID=1,7),IR=1,NR)
      DO 120 IR=1,NR
  120 WRITE(IOUT,67) NAME(IR),(DFINH(ID,IR),ID=1,7)
C**
   67 FORMAT(1X,A8,6X,7(E9.3,3X))
      WRITE(IOUT,68)
   68 FORMAT(///,37X,'INGESTION DOSE FACTORS')
      WRITE(IOUT,66)
C*    052286RAC
      DO 130 IR=1,NR
  130 WRITE(IOUT,67) NAME(IR),(DFING(ID,IR),ID=1,7)
C*    WRITE(IOUT,67) (NAME(IR),(DFING(ID,IR),ID=1,7),IR=1,NR)
C**
C*****
C*****
C*****
C     RADIONUCLIDE INTAKE AND EXPOSURE CALCULATION
C*****
C*****
C*****
C     CONVERT FROM WEATHERING HALF-LIFE IN DAYS(WHL) TO WEATHERING
C     RATE(WR) IN YR(**-1)
      WR=253.172/WHL
C     CONVERT IRRIGATION TIME FROM DAYS(TI) TO YEARS(TIYR)
      TIYR=TI/365.25
   69 WRITE(IOUT,691) TIME(IT)
  691 FORMAT(//,1X,'TIME=',E10.3,1X,'YEARS',/)
C     BEGIN LOOP OVER RADIONUCLIDES
      DO 500 IR=1,NR
C     CALCULATE HUMAN INTAKE(HIDW)(MICROCURIES/YR) OF RADIONUCLIDE
C     IR DUE TO DRINKING WATER
      HIDW=HWC*CONCW(IR)
C     CALCULATE HUMAN INTAKE(HIF)(MICROCURIES/YR) OF RADIONUCLIDE IR
C     DUE TO FISH CONSUMPTION
      HIF=HFC*CRFWF(IR)*CONCW(IR)
C     CALCULATE RADIONUCLIDE IR DEPOSITION(DR)(MICROCURIES/KG) ON
C     VEGETATION DUE TO SPRINKLER IRRIGATION
      DR=FRD*CONCW(IR)*SI/DLV
C     (PC) IS THE VEGETATION RADIONUCLIDE IR CONCENTRATION
C     (MICROCURIES/KG) DUE TO BOTH UPTAKE FROM SOIL AND DEPOSITION
C     BY SPRINKLER IRRIGATION
      COEFF=WR*TIYR
      IF(COEFF.LT.50.) GO TO 70
      PC=CRVEG(IR)*CONCS(IR)+DR/WR
      GO TO 75
```

Figure 34

Fortran Program DOSECAL2 Source Code (continued)

```
   70 PC=CRVEG(IR)*CONCS(IR)+(DR/WR)*(1.-EXP(-WR*TIYR))
   75 CONTINUE
C     (PI) IS THE ANNUAL HUMAN INTAKE OF RADIONUCLIDE IR DUE TO
C     EATING VEGETABLES
      PI=HVC*PC
C     (HIM) AND (HIB) ARE THE RADIONUCLIDE INGESTION RATES FOR HUMANS
C     (MICROCURIES/YR) DUE TO MILK AND BEEF CONSUMPTION RESPECTIVELY
      HIM=(DCPC*PC+DCDR*CONCW(IR))*CRMILK(IR)*HMLC
      HIB=(BCPC*PC+BCDR*CONCW(IR))*CRMEAT(IR)*HMTC
C     (HINGES) IS THE TOTAL ANNUAL HUMAN INGESTION OF RADIONUCLIDE
C     IR
      HINGES= HIDW+HIF+HIM+HIB+PI
C     CALCULATE THE AIR CONCENTRATION (AC)(MICROCURIES/M**3) OF
C     RADIONUCLIDE IR
C     THE FACTOR 1.0E-9 IS USED TO CONVERT THE SOIL RESUSPENSION
C     FACTOR FROM (UG/M**3) TO (KG/M**3)
      AC=CONCS(IR)*SRF*1.0E-9
C     CALCULATE EXPOSURES TO RADIONUCLIDE IR DUE TO INHALATION,
C     AIR SUBMERSION,GROUND EXPOSURE AND SWIMMING
      HINHAL=AC*HBR
      HEXTA=8766.*ET*AC
C     THE FACTOR 1.0E+3 IS USED TO CONVERT THE SOIL DENSITY FROM
C     (GM/CM**3) TO (KG/M**3).  THE FACTOR 1.0E-2 IS USED TO CONVERT
C     THE SOIL DEPTH FROM (CM) TO (M)
      HEXTG=SE*ET*CONCS(IR)*(1.0E+3*SDEN)*(1.0E-2*SD)
C     THE FACTOR 1.0E+3 IS USED TO CONVERT THE RADIONUCLIDE
C     CONCENTRATION IN WATER FROM (MICROCURIES/L) TO (MICROCURIES/M**3)
      HEXTS=SWIM*ET*CONCW(IR)*1.0E+03
C*****
C*****
C*****
C     DOSE CALCULATIONS
C*****
C*****
C*****
      DO 100 IP=1,2
      DEXT(IP,IR)=HEXTA*DFEA(IP,IR)+HEXTG*DFEG(IP,IR)+HEXTS*DFEW(IP,IR)
  100 CONTINUE
      DO 200 ID=1,7
      DINH(ID,IR)=HINHAL*DFINH(ID,IR)
      DING(ID,IR)=HINGES*DFING(ID,IR)
  200 CONTINUE
  500 CONTINUE
C     END LOOP OVER RADIONUCLIDES
      DO 600 IP=1,2
      DEXTT(IP)=0.
      DO 550 IR=1,NR
      DEXTT(IP)=DEXTT(IP)+DEXT(IP,IR)
  550 CONTINUE
  600 CONTINUE
      DO 700 ID=1,7
      DINHT(ID)=0.
      DINGT(ID)=0.
      DO 650 IR=1,NR
      DINHT(ID)=DINHT(ID)+DINH(ID,IR)
      DINGT(ID)=DINGT(ID)+DING(ID,IR)
  650 CONTINUE
  700 CONTINUE
      DO 800 IR=1,NR
      DT(1,IR)=DEXT(2,IR)+DINH(1,IR)+DING(1,IR)
      DO 750 ID=2,7
      DT(ID,IR)=DINH(ID,IR)+DING(ID,IR)
  750 CONTINUE
  800 CONTINUE
```

Figure 34

Fortran Program DOSECAL2 Source Code (continued)

```
      DO 900 ID=1,7
      DTT(ID)=0.
      DO 850 IR=1,NR
      DTT(ID)=DTT(ID)+DT(ID,IR)
  850 CONTINUE
  900 CONTINUE
C*****
C*****
C     PRINT OUT CALCULATED DOSES
C*****
C*****
      WRITE(IOUT,901)
  901 FORMAT(////,12X,'EXTERNAL DOSE',/,16X,'(REM)',//,1X,'RADIONUCLIDE'
     &,4X,'SKIN',5X,'TOTAL BODY')
C*    052286RAC
C*    WRITE(IOUT,902) (NAME(IR),(DEXT(IP,IR),IP=1,2),IR=1,NR)
      DO 140 IR=1,NR
  140 WRITE(IOUT,902) NAME(IR),(DEXT(IP,IR),IP=1,2)
C**
  902 FORMAT(1X,A8,6X,2(E9.3,3X))
      WRITE(IOUT,903) (DEXTT(IP),IP=1,2)
  903 FORMAT(4X,'TOTAL',6X,2(E9.3,3X))
      WRITE(IOUT,904)
  904 FORMAT(//,46X,'INHALATION DOSE')
      WRITE(IOUT,905)
  905 FORMAT(51X,'(REM)',//,1X,'RADIONUCLIDE',4X,'SKIN',5X,'TOTAL BODY'
     &,6X,'BONE',6X,'THYROID',6X,'LIVER',6X,'KIDNEYS',6X,'LUNGS',6X,
     &'GI-LLI',/)
C*    052286RAC
C*    WRITE(IOUT,906) (NAME(IR),(DINH(ID,IR),ID=1,7),IR=1,NR)
      DO 150 IR=1,NR
  150 WRITE(IOUT,906) NAME(IR),(DINH(ID,IR),ID=1,7)
C**
  906 FORMAT(1X,A8,18X,7(E9.3,3X))
      WRITE(IOUT,907) (DINHT(ID),ID=1,7)
  907 FORMAT(4X,'TOTAL',18X,7(E9.3,3X))
      WRITE(IOUT,908)
  908 FORMAT(//,46X,'INGESTION DOSE')
      WRITE(IOUT,905)
C*    052286RAC
C*    WRITE(IOUT,906) (NAME(IR),(DING(ID,IR),ID=1,7),IR=1,NR)
      DO 160 IR=1,NR
  160 WRITE(IOUT,906) NAME(IR),(DING(ID,IR),ID=1,7)
C**
      WRITE(IOUT,907) (DINGT(ID),ID=1,7)
      WRITE(IOUT,909)
  909 FORMAT(//,49X,'TOTAL DOSE')
      WRITE(IOUT,905)
C*    052286RAC
C*    WRITE(IOUT,910) (NAME(IR),DEXT(1,IR),(DT(ID,IR),ID=1,7),IR=1,NR)
      DO 170 IR=1,NR
  170 WRITE(IOUT,910) NAME(IR),DEXT(1,IR),(DT(ID,IR),ID=1,7)
C**
  910 FORMAT(1X,A8,6X,8(E9.3,3X))
      WRITE(IOUT,911) DEXTT(1),(DTT(ID),ID=1,7)
  911 FORMAT(4X,'TOTAL',6X,8(E9.3,3X))
 1000 CONTINUE
      STOP
      END
```

Figure 35

Fortran Program DOSEFAC Source Code

```
      PROGRAM DOSEFAC
C     PROGRAM TO CALCULATE INHALATION AND INGESTION DOSE FACTORS
C     FOR SELECTED RADIONUCLIDES FOR 7 ORGANS
C*    PROGRAM REVISIONS BY DICK CHAPMAN (RAC) STARTED 5/21/86 TO ADAPT
C*    THE CODE TO MS-DOS FORTRAN. COMMENTS INDICATED BY C*, CODE ADDITIONS
C*    PRECEEDED BY C*, DATE, AND INITIALS, AND FOLLOWED BY C**.
C*****
C*****
C     GLOSSARY OF INPUT VARIABLES
C*****
C*****
C     NAME(IR)=NAME OF RADIONUCLIDE IR
C     RHALF=RADIONUCLIDE HALF-LIFE(YR)
C     ISOL=1(RADIONUCLIDE IN SOLUBLE FORM)
C     ISOL=2(RADIONUCLIDE IN INSOLUBLE FORM)
C     TI=INTAKE TIME(YR)
C     TC=DOSE COMMITMENT TIME(YR)
C     OMASS(IO)=MASS OF ORGAN IO(GM)
C     IO=1(TOTAL BODY)
C       =2(BONE)
C       =3(THYROID)
C       =4(LIVER)
C       =5(KIDNEYS)
C       =6(LUNGS)
C       =7(GI-LLI)
C     BHALF(IO)=RADIONUCLIDE BIOLOGICAL HALF-LIFE IN ORGAN IO(DAYS)
C     FO(IO)=FRACTION OF INGESTED RADIONUCLIDE REACHING ORGAN IO
C     FTB=FRACTION OF INGESTED RADIONUCLIDE TRANSFERED TO BLOOD
C     FB(IO)=FRACTION OF RADIONUCLIDE TRANSFERED FROM THE BLOOD
C            TO ORGAN IO(USED IN THE CALCULATION OF INHALATION
C            DOSE FACTORS)
C     FB(IO)=FO(IO)/FTB
C     E(IO)=EFFECTIVE ENERGY DEPOSITED BY RADIONUCLIDE DECAY IN
C           ORGAN IO(MEV/DISINTEGRATION)
C     DFINH(IR,IO)=INHALATION DOSE FACTOR FOR RADIONUCLIDE IR AND
C                  ORGAN IO(REM/(UCI/YR))
C     DFING(IR,IO)=INGESTION DOSE FACTOR FOR RADIONUCLIDE IR AND
C                  ORGAN IO(REM/(UCI/YR))
C*    CHARACTER*8 NAME,QUIT
C*    052186RAC
      CHARACTER*8 NAME(20),QUIT
C**
C*    DIMENSION NAME(20)
      DIMENSION OMASS(7),BHALF(7),FO(7),FB(7),E(7),
     &DFINH(20,7),DFING(20,7)
      DATA QUIT/'END     '/
      IN=5
      IOUT=2
C*    CALL OPEN(5,'DOSEFAC DAT',2)
C*    052186RAC
      OPEN(IN,FILE='DOSEFAC.DAT')
      OPEN(IOUT,FILE='DOSEFAC.OUT')
C**
```

Figure 35

Fortran Program DOSEFAC Source Code (continued)

```
      IR=0
      READ(IN,5) TI,TC
    5 FORMAT(2F10.0)
      WRITE(IOUT,8) TI,TC
    8 FORMAT(1X,'INTAKE TIME=',F10.2,2X,'YEARS',/,1X,
     &'COMMITMENT TIME=',F10.2,2X,'YEARS',/)
      READ(IN,10) (OMASS(IO),IO=1,7)
   10 FORMAT(7F10.0)
      WRITE(IOUT,12) (OMASS(IO),IO=1,7)
   12 FORMAT(3X,'ORGAN',7X,'MASS(GM)',/,
     &        1X,'TOTAL BODY',3X,F8.1,/,
     &        4X,'BONE',6X,F8.1,/,
     &        2X,'THYROID',5X,F8.1,/,
     &        3X,'LIVER',6X,F8.1,/,
     &        2X,'KIDNEYS',5X,F8.1,/,
     &        3X,'LUNGS',6X,F8.1,/,
     &        2X,'GI-LLI',6X,F8.1,//)
   20 IR=IR+1
      READ(IN,30) NAME(IR)
   30 FORMAT(1X,A8)
      IF(NAME(IR).EQ.QUIT) GO TO 110
      WRITE(IOUT,30) NAME(IR)
      READ(IN,40) RHALF
   40 FORMAT(E10.3)
      WRITE(IOUT,50) RHALF
   50 FORMAT(/,1X,'RADIOACTIVE DECAY HALF LIFE=',E10.3,2X,'YEARS')
      READ(IN,55) ISOL
   55 FORMAT(I5)
      IF(ISOL.EQ.1) WRITE(IOUT,56)
   56 FORMAT(1X,'SOLUBLE FORM')
      IF(ISOL.EQ.2) WRITE(IOUT,57)
   57 FORMAT(1X,'INSOLUBLE FORM')
      READ(IN,40) FTB
      WRITE(IOUT,58) FTB
   58 FORMAT(/,1X,'FRACTION OF RADIONUCLIDE TRANSFERED TO THE BLOOD=',E1
     &0.3)
      READ(IN,60) (BHALF(IO),FO(IO),E(IO),IO=1,7)
   60 FORMAT(3E10.3)
      DO 65 IO=1,7
      FB(IO)=FO(IO)/FTB
   65 CONTINUE
      WRITE(IOUT,70) (BHALF(IO),FO(IO),FB(IO),E(IO),IO=1,5),BHALF(6),
     &E(6),E(7)
   70 FORMAT(/,3X,'ORGAN',6X,'BIOLOGICAL HALF-LIFE',3X,
     &'FRACTION REACHING ORGAN',3X,'FRACTION FROM BLOOD',3X,
     &'EFFECTIVE ENERGY',/,21X,'(DAYS)',41X,'TO ORGAN',7X,'(MEV/DISINTEG
     &RATION)',//,1X,'TOTAL BODY',8X,E10.3,15X,E10.3,13X,E10.3,10X,  E10
     &.3,/,4X,'BONE',11X,E10.3,15X,E10.3,13X,E10.3,10X,E10.3,/,2X,'THYRO
     &ID',10X,E10.3,15X,E10.3,13X,E10.3,10X,E10.3,/,3X,'LIVER',11X,E10.3
     &,15X,E10.3,13X,E10.3,10X,E10.3,/,2X,'KIDNEYS',10X,E10.3,15X,E10.3,
     &13X,E10.3,10X,E10.3,/,3X,'LUNGS',11X,E10.3,15X,10('-'),13X,10('-')
     &,10X,E10.3,/,2X,'GI-LLI',11X,10('-'),15X,10('-'),13X,10('-'),10X,
     &E10.3,/)
      DO 100 IO=1,7
      IF(IO.EQ.7) GO TO 90
      BHALF(IO)=BHALF(IO)/365.25
      IF(BHALF(IO).LT.3.17E-8) BHALF(IO)=3.17E-8
      D=0.69315*(RHALF+BHALF(IO))/(RHALF*BHALF(IO))
      P=D*TC
```

Figure 35

Fortran Program DOSEFAC Source Code (continued)

```
      IF(P.GE.50.) GO TO 71
      E1=EXP(-P)
      GO TO 72
   71 E1=0.
   72 P=D*(TC-TI)
      IF(P.GE.50.) GO TO 73
      E2=EXP(-P)
      GO TO 74
   73 E2=0.
   74 CONTINUE
      IF(IO.EQ.6) GO TO 80
      DFING(IR,IO)=0.0187E6*(FO(IO)*E(IO)/(OMASS(IO)*D**2))*
     &(TI*D+E1-E2)
      DFINH(IR,IO)=0.0187E6*0.25*(FB(IO)*E(IO)/(OMASS(IO)*D**2))*
     &(TI*D+E1-E2)/FLOAT(ISOL)
      IF(ISOL.EQ.1) DFINH(IR,IO)=DFINH(IR,IO)+0.5*DFING(IR,IO)
      GO TO 100
   80 DFING(IR,IO)=0.
      DFINH(IR,IO)=(.0187E6*0.125*(ISOL-1)*E(IO)/(OMASS(IO)*D**2))*
     &(TI*D+E1-E2)
      GO TO 100
   90 P=(0.541/365.25)*0.69315/RHALF
C     0.541 IS THE TIME IN DAYS FOR TRAVEL FROM THE MOUTH TO THE LLI
      IF(P.GE.50.) GO TO 91
      EX=EXP(-P)
      GO TO 92
   91 EX=0.
   92 CONTINUE
      DFING(IR,IO)=2.56E+1*TI*0.75*AMAX1(1.-FTB,0.05)*E(IO)*EX/OMASS(IO)
      DFINH(IR,IO)=(0.50+(ISOL-1)*0.125)*DFING(IR,IO)/
     &(AMAX1(1.-FTB,0.05)*(ISOL-1)+2-ISOL)
  100 CONTINUE
      GO TO 20
  110 NR=IR-1
      WRITE(IOUT,120)
  120 FORMAT(//,42X,'INHALATION DOSE FACTORS')
      WRITE(IOUT,130)
  130 FORMAT(46X,'(REM/(UCI/YR))',//,48X,'***ORGAN***',//,17X,
     &'TOTAL BODY',5X,'BONE',5X,'THYROID',5X,'LIVER',5X,'KIDNEYS',
     &5X,'LUNGS',5X,'GI-LLI',/,2X,'RADIONUCLIDE',/)
C*    WRITE(IOUT,140) (NAME(IR),(DFINH(IR,IO),IO=1,7),IR=1,NR)
C*    052186RAC
      DO 135 IR=1,NR
  135 WRITE(IOUT,140) NAME(IR),(DFINH(IR,IO),IO=1,7)
C**
  140 FORMAT(5X,A8,4X,E10.3,6(1X,E10.3))
      WRITE(IOUT,150)
  150 FORMAT(//,43X,'INGESTION DOSE FACTORS')
      WRITE(IOUT,130)
C*    WRITE(IOUT,140) (NAME(IR),(DFING(IR,IO),IO=1,7),IR=1,NR)
C*    052186RAC
      DO 155 IR=1,NR
  155 WRITE(IOUT,140) NAME(IR),(DFING(IR,IO),IO=1,7)
C**
      STOP
      END
```

Figure 36

Program CELLTRAN Input Data (CELL.DAT)

```
     2
     1     0     0     1     0
ZONE 1 SIMULATION FOR BMP 3.0
     1          ZONES
     2          CHAIN DECAY
    82
      0.0E0
     0.1E-2
     0.2E-2
     0.3E-2
     0.4E-2
     0.5E-2
     0.6E-2
     0.7E-2
     0.8E-2
     0.9E-2
     0.1E-1
     0.2E-1
     0.3E-1
     0.4E-1
     0.5E-1
     0.6E-1
     0.7E-1
     0.8E-1
     0.9E-1
     0.1E+0
     0.2E+0
     0.3E+0
     0.4E+0
     0.5E+0
     0.6E+0
     0.7E+0
     0.8E+0
     0.9E+0
     0.1E+1
     0.2E+1
     0.3E+1
     0.4E+1
     0.5E+1
     0.6E+1
     0.7E+1
     0.8E+1
     0.9E+1
     0.1E+2
     0.2E+2
     0.3E+2
     0.4E+2
     0.5E+2
     0.6E+2
     0.7E+2
     0.8E+2
     0.9E+2
     0.1E+3
     0.2E+3
     0.3E+3
     0.4E+3
     0.5E+3
     0.6E+3
     0.7E+3
     0.8E+3
     0.9E+3
     0.1E+4
```

Figure 36

Program CELLTRAN Input Data (CELL.DAT) (continued)

```
     0.2E+4
     0.3E+4
     0.4E+4
     0.5E+4
     0.6E+4
     0.7E+4
     0.8E+4
     0.9E+4
     0.1E+5
     0.2E+5
     0.3E+5
     0.4E+5
     0.5E+5
     0.6E+5
     0.7E+5
     0.8E+5
     0.9E+5
     0.1E+6
     0.2E+6
     0.3E+6
     0.4E+6
     0.5E+6
     0.6E+6
     0.7E+6
     0.8E+6
     0.9E+6
    1.39E10     5.33E9
     3.44E6    1.33E10
    9.68E12    1.48E12
    1.12E11    2.00E10
     1     1     1     2     1.39E9     5.33E8
     1     2     1     1     1.39E9     5.33E8
     1     2     1     4     1.12E8    4.00E10
     1     3     1     2      0.0E0    2.16E12
     1     4     1     2     1.12E8    4.00E10
     1     4     1     3      0.0E0    9.60E10
     1     2     0     0     3.00E9    1.16E13

     1     2     1     2
242PU
    3.763E5
      0.0E0      0.0E0      0.0E0      0.0E0
     1     3     1
    3.80E23

      0.0E0      0.0E0      0.0E0      0.0E0
      5.0E4      1.0E5      5.0E3      1.0E3
238U
    4.468E9
      0.0E0      0.0E0      0.0E0      0.0E0
     1     3     1
    7.52E27

      0.0E0      0.0E0      0.0E0      0.0E0
      5.0E3      1.0E4      5.0E2      1.0E1
234U
    2.445E5
      0.0E0      0.0E0      0.0E0      0.0E0
     1     3     1
    2.88E23

      0.0E0      0.0E0      0.0E0      0.0E0
      5.0E3      1.0E4      5.0E2      1.0E1
```

Figure 36

Program CELLTRAN Input Data (CELL.DAT) (continued)

```
230TH
     7.7E4
     0.0E0      0.0E0      0.0E0      0.0E0
    1    3     1
   1.04E23

     0.0E0      0.0E0      0.0E0      0.0E0
     5.0E4      1.0E5      5.0E4      1.0E4
226RA
   1600.E0
     0.0E0      0.0E0      0.0E0      0.0E0
    1    3     1
   2.16E21

     0.0E0      0.0E0      0.0E0      0.0E0
     5.0E3      5.0E4      5.0E3      1.0E1
222RN
 0.1048E-1
   6070.E0    364.E+3      0.0E0    51.4E+0
    1    3     1
   1.41E16

     0.0E0      0.0E0      0.0E0      0.0E0
     0.0E0      0.0E0      0.0E0      0.0E0
210PB
   22.3E+0
     0.0E0      0.0E0      0.0E0      0.0E0
    1    3     1
    3.0E19

     0.0E0      0.0E0      0.0E0      0.0E0
     5.0E3      1.0E4      5.0E2      1.0E1
END
    1    0     1    0    1
ZONE 2 SIMULATION FOR BMP 3.0
    1          ZONES
    2          CHAIN DECAY
   B2
     0.0E0
    0.1E-2
    0.2E-2
    0.3E-2
    0.4E-2
    0.5E-2
    0.6E-2
    0.7E-2
    0.8E-2
    0.9E-2
    0.1E-1
    0.2E-1
    0.3E-1
    0.4E-1
    0.5E-1
    0.6E-1
    0.7E-1
    0.8E-1
    0.9E-1
    0.1E+0
    0.2E+0
    0.3E+0
    0.4E+0
    0.5E+0
    0.6E+0
    0.7E+0
    0.8E+0
    0.9E+0
```

Figure 36

Program CELLTRAN Input Data (CELL.DAT) (continued)

```
 0.1E+1
 0.2E+1
 0.3E+1
 0.4E+1
 0.5E+1
 0.6E+1
 0.7E+1
 0.8E+1
 0.9E+1
 0.1E+2
 0.2E+2
 0.3E+2
 0.4E+2
 0.5E+2
 0.6E+2
 0.7E+2
 0.8E+2
 0.9E+2
 0.1E+3
 0.2E+3
 0.3E+3
 0.4E+3
 0.5E+3
 0.6E+3
 0.7E+3
 0.8E+3
 0.9E+3
 0.1E+4
 0.2E+4
 0.3E+4
 0.4E+4
 0.5E+4
 0.6E+4
 0.7E+4
 0.8E+4
 0.9E+4
 0.1E+5
 0.2E+5
 0.3E+5
 0.4E+5
 0.5E+5
 0.6E+5
 0.7E+5
 0.8E+5
 0.9E+5
 0.1E+6
 0.2E+6
 0.3E+6
 0.4E+6
 0.5E+6
 0.6E+6
 0.7E+6
 0.8E+6
 0.9E+6
5.23E10   2.01E10
 1.91E8   2.87E12
1.56E13   2.39E12
1.10E11   1.98E10
 1    1    1    2    5.23E9    2.01E9
 1    1    0    0    2.74E9    1.05E9
 1    2    1    1    5.23E9    2.01E9
 1    2    1    4    3.16E6   4.76E10
 1    4    1    2    1.58E6   2.38E10
 1    4    1    3     0.0E0   9.50E10
 1    3    1    2     0.0E0   2.16E12
 1    2    0    0    9.13E8   1.38E13

 2
 1    2
 1    4
```

Figure 36

Program CELLTRAN Input Data (CELL.DAT) (continued)

```
242PU
   3.763E5
     0.0E0      0.0E0      0.0E0      0.0E0

     0.0E0      0.0E0      0.0E0      0.0E0
     5.0E4      1.0E5      5.0E3      1.0E3
238U
   4.468E9
     0.0E0      0.0E0      0.0E0      0.0E0

     0.0E0      0.0E0      0.0E0      0.0E0
     5.0E3      1.0E4      5.0E2      1.0E1
234U
   2.445E5
     0.0E0      0.0E0      0.0E0      0.0E0

     0.0E0      0.0E0      0.0E0      0.0E0
     5.0E3      1.0E4      5.0E2      1.0E1
230TH
     7.7E4
     0.0E0      0.0E0      0.0E0      0.0E0

     0.0E0      0.0E0      0.0E0      0.0E0
     5.0E4      1.0E5      5.0E4      1.0E4
226RA
   1600.E0
     0.0E0      0.0E0      0.0E0      0.0E0

     0.0E0      0.0E0      0.0E0      0.0E0
     5.0E3      5.0E4      5.0E3      1.0E1
222RN
 0.1048E-1
   6070.E0    364.E+3      0.0E0    51.4E+0

     0.0E0      0.0E0      0.0E0      0.0E0
     0.0E0      0.0E0      0.0E0      0.0E0
210PB
   22.3E+0
     0.0E0      0.0E0      0.0E0      0.0E0

     0.0E0      0.0E0      0.0E0      0.0E0
     5.0E3      1.0E4      5.0E2      1.0E1
END
```

Figure 37

Program CELLPOST Input Data (CPOST.DAT)

```
7    62
```

Figure 38

Program DOSEFAC Input Data (DOSEFAC.DAT)

```
      70.        70.
   70000.      7000.        20.      1800.       310.      1000.      150.
242PU
  3.763E5
   2
  0.30E-4
   650.E2  0.300E-4      51.E0
   365.E2   1.35E-5      2.5E2
     0.E0      0.E0       0.E0
   146.E2   1.35E-5      51.E0
   320.E2  0.600E-6      51.E0
 365.25E0      0.E0      51.E0
                         .51E0
238U
  4.468E9
   2
  0.10E-1
   100.E0    0.01E0      43.E0
   300.E0   1.10E-3     220.E0
     0.E0      0.E0       0.E0
     0.E0      0.E0       0.E0
    15.E0   1.10E-3      43.E0
   120.E0      0.E0      43.E0
                         .43E0
234U
  2.445E5
   2
   0.01E0
   100.E0    0.01E0      49.E0
   300.E0   0.11E-2      2.4E2
     0.E0      0.E0       0.E0
     0.E0      0.E0       0.E0
    15.E0   0.11E-2      49.E0
   120.E0      0.E0      49.E0
                         .48E0
230TH
    7.7E4
   2
   0.1E-3
   570.E2    0.1E-3     0.48E2
   365.E2    0.7E-4    0.242E3
     0.E0      0.E0       0.E0
   570.E2    0.5E-5     0.48E2
   220.E2    0.5E-5     0.48E2
  1.461E3      0.E0     0.48E2
                        0.47E0
226RA
    1.6E3
   2
    0.3E0
    8.1E3     0.3E0     0.11E3
   164.E2    0.03E0     0.11E3
     0.E0      0.E0       0.E0
     0.E0      0.E0       0.E0
     0.E0      0.E0       0.E0
   120.E0      0.E0     0.11E3
                         3.7E0
210PB
   22.3E0
   2
   0.08E0
   1.46E3    0.08E0      5.2E0
   3.65E3    0.02E0      29.E0
     0.E0      0.E0       0.E0
   1.95E3   0.64E-2      10.E0
   5.31E2    0.01E0      10.E0
   120.E0      0.E0     25.07E0
                        0.460E0
END
```

Figure 39

Program DOSECAL2 Input Data (DOSE.DAT)

```
    2
400.
5.2
62.
14.
.25
190.
370.
50.
50.
60.
50.
95.
100.
6.9
8760.
2920.
15.
3.5
8000.
70.
70.
2.5
2.8
   3.5E+00   2.0E+00   2.0E+00   30.E+00   50.E+00     0.0E0  100.E+00
    2.5E-4    2.5E-3    2.5E-3    4.2E-3    1.4E-3     0.0E0    6.8E-2
    2.5E-8    6.0E-4    6.0E-4    2.5E-6    2.0E-4     0.0E0    1.0E-5
    5.0E-3    5.0E-3    5.0E-3    5.0E-3    9.9E-4     0.0E0    9.9E-4
   1.60E-8   1.10E-9   3.60E-9  1.10E-10   1.60E-6   5.10E-8
   6.32E-7   3.52E-7   9.32E-7   7.36E-8   8.11E-4   3.38E-5
   5.08E-7   7.32E-9   1.24E-8   1.18E-9   5.28E-6   5.18E-7
   1.00E-7   7.82E-9   4.41E-9   1.22E-9   1.88E-6   5.45E-7
   1.55E-5   1.28E-5   5.03E-6   3.26E-6   2.89E-3   1.51E-3
     0.0E0     0.0E0     0.0E0     0.0E0     0.0E0     0.0E0
   1.70E-8   1.30E-8   3.60E-7   3.00E-9   3.36E-4   2.69E-6
   7.63E+3   3.02E+5   0.00E+0   4.33E+4   3.26E+4   1.18E+4   2.83E+0
   7.90E+1   1.34E+3   0.00E+0   0.00E+0   3.11E+2   3.31E+3   2.39E+0
   9.00E+1   1.46E+3   0.00E+0   0.00E+0   3.54E+2   3.78E+3   2.67E+0
   7.09E+3   2.63E+5   0.00E+0   1.17E+4   5.70E+4   4.16E+4   2.61E+0
   1.55E+4   1.54E+4   0.00E+0   5.35E-1   1.52E+1   8.47E+3   2.06E+1
     0.0E0     0.0E0     0.0E0     0.0E0     0.0E0     0.0E0     0.0E0
   1.28E+2   3.71E+3   0.00E+0   1.00E+3   3.34E+3   1.90E+3   2.55E+0
   9.16E-1   3.63E+1   0.00E+0   5.13E+0   3.92E+0   0.00E+0   4.57E+0
   3.16E+0   5.27E+1   0.00E+0   0.00E+0   1.22E+1   0.00E+0   3.85E+0
   3.60E+0   5.75E+1   0.00E+0   0.00E+0   1.39E+1   0.00E+0   4.30E+0
   2.84E+0   1.02E+2   0.00E+0   5.84E+0   2.85E+1   0.00E+0   4.21E+0
   1.16E+4   1.54E+4   0.00E+0   4.01E-1   1.14E+1   0.00E+0   2.32E+1
     0.0E0     0.0E0     0.0E0     0.0E0     0.0E0     0.0E0     0.0E0
   3.54E+1   9.26E+2   0.00E+0   2.79E+2   8.35E+2   0.00E+0   3.79E+0
```

Figure 40

Program CELLTRAN Output File (CELL.OUT)

```
ITERATION NUMBER 2 FOR CELLTRAN

ZONE 2 SIMULATION FOR BMP 3.0

NUMBER OF ZONES=     1

CHAIN DECAY ASSUMED

NUMBER OF CALCULATION TIMES=    82

CALCULATION TIMES(YEARS)

  .000E+00  .100E-02  .200E-02  .300E-02  .400E-02  .500E-02  .600E-02  .700E-02
  .800E-02  .900E-02  .100E-01  .200E-01  .300E-01  .400E-01  .500E-01  .600E-01
  .700E-01  .800E-01  .900E-01  .100E+00  .200E+00  .300E+00  .400E+00  .500E+00
  .600E+00  .700E+00  .800E+00  .900E+00  .100E+01  .200E+01  .300E+01  .400E+01
  .500E+01  .600E+01  .700E+01  .800E+01  .900E+01  .100E+02  .200E+02  .300E+02
  .400E+02  .500E+02  .600E+02  .700E+02  .800E+02  .900E+02  .100E+03  .200E+03
  .300E+03  .400E+03  .500E+03  .600E+03  .700E+03  .800E+03  .900E+03  .100E+04
  .200E+04  .300E+04  .400E+04  .500E+04  .600E+04  .700E+04  .800E+04  .900E+04
  .100E+05  .200E+05  .300E+05  .400E+05  .500E+05  .600E+05  .700E+05  .800E+05
  .900E+05  .100E+06  .200E+06  .300E+06  .400E+06  .500E+06  .600E+06  .700E+06
  .800E+06  .900E+06

      MASS OF SOLID AND AMOUNT OF LIQUID
           FOR EACH ZONE-COMPARTMENT

                SOLID(KG)    LIQUID(L)

ZONE 1-SED.     .523E+11     .201E+11
ZONE 1-S.W.     .191E+09     .287E+13
ZONE 1-G.W.     .156E+14     .239E+13
ZONE 1-SOIL     .110E+12     .198E+11

RELATIONSHIP BETWEEN ZONES, COMPARTMENTS AND CELLS

CELL 1 - ZONE 1, COMPARTMENT 1
CELL 2 - ZONE 1, COMPARTMENT 2
CELL 3 - ZONE 1, COMPARTMENT 3
CELL 4 - ZONE 1, COMPARTMENT 4
CELL 5 - SINK
```

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

TRANSFER OF SOLID BETWEEN CELLS
(KG/YEAR)

ORIGIN CELLS

DESTINATION CELLS	1	2	3	4
1	.10000E-05	.52300E+10	.10000E-05	.10000E-05
2	.52300E+10	.10000E-05	.00000E+00	.15800E+07
3	.10000E-05	.10000E-05	.10000E-05	.00000E+00
4	.10000E-05	.31600E+07	.10000E-05	.10000E-05
5	.27400E+10	.91300E+09	.10000E-05	.10000E-05

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

TRANSFER OF LIQUID BETWEEN CELLS
(L/YEAR)

ORIGIN CELLS

DESTINATION CELLS	1	2	3	4
1	.10000E-05	.20100E+10	.10000E-05	.10000E-05
2	.20100E+10	.10000E-05	.21600E+13	.23800E+11
3	.10000E-05	.10000E-05	.10000E-05	.95000E+11
4	.10000E-05	.47600E+11	.10000E-05	.10000E-05
5	.10500E+10	.13800E+14	.10000E-05	.10000E-05

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

```
*****    ANALYSES FOR RADIONUCLIDE  242PU    *****

RADIOACTIVE HALF-LIFE=  .376E+06 YEARS
RADIOACTIVE DECAY RATE=  .184E-05 YEARS**-1

                PHYSICAL
                 DECAY
                  RATE
              (YEARS**-1)

ZONE 1-SED.     .000E+00
ZONE 1-S.W.     .000E+00
ZONE 1-G.W.     .000E+00
ZONE 1-SOIL     .000E+00
```

242PU EXTERNAL INPUT RATES (ATOMS/YR)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.000E+00	.502E+16	.000E+00	.000E+00
.200E-02	.000E+00	.147E+17	.000E+00	.000E+00
.300E-02	.000E+00	.257E+17	.000E+00	.000E+00
.400E-02	.000E+00	.370E+17	.000E+00	.000E+00
.500E-02	.000E+00	.484E+17	.000E+00	.000E+00
.600E-02	.000E+00	.598E+17	.000E+00	.000E-00
.700E-02	.000E+00	.712E+17	.000E+00	.000E+00
.800E-02	.000E+00	.827E+17	.000E+00	.000E+00
.900E-02	.000E+00	.941E+17	.000E+00	.000E+00
.100E-01	.000E+00	.106E+18	.000E+00	.000E+00
.200E-01	.000E+00	.220E+18	.000E+00	.000E+00
.300E-01	.000E+00	.335E+18	.000E+00	.000E+00
.400E-01	.000E+00	.449E+18	.000E+00	.000E+00
.500E-01	.000E+00	.564E+18	.000E+00	.000E+00
.600E-01	.000E+00	.678E+18	.000E+00	.000E+00
.700E-01	.000E+00	.793E+18	.000E+00	.000E+00
.800E-01	.000E+00	.908E+18	.000E+00	.000E+00
.900E-01	.000E+00	.102E+19	.000E+00	.000E+00
.100E+00	.000E+00	.114E+19	.000E+00	.000E+00
.200E+00	.000E+00	.229E+19	.000E+00	.000E+00
.300E+00	.000E+00	.344E+19	.000E+00	.000E+00
.400E+00	.000E+00	.459E+19	.000E+00	.000E+00
.500E+00	.000E+00	.575E+19	.000E+00	.000E+00
.600E+00	.000E+00	.692E+19	.000E+00	.000E+00
.700E+00	.000E+00	.808E+19	.000E+00	.000E+00
.800E+00	.000E+00	.925E+19	.000E+00	.000E+00
.900E+00	.000E+00	.104E+20	.000E+00	.000E+00
.100E+01	.000E+00	.116E+20	.000E+00	.000E+00
.200E+01	.000E+00	.235E+20	.000E+00	.000E+00
.300E+01	.000E+00	.358E+20	.000E+00	.000E+00
.400E+01	.000E+00	.483E+20	.000E+00	.000E+00
.500E+01	.000E+00	.610E+20	.000E+00	.000E+00
.600E+01	.000E+00	.741E+20	.000E+00	.000E+00
.700E+01	.000E+00	.873E+20	.000E+00	.000E+00
.800E+01	.000E+00	.101E+21	.000E+00	.000E+00
.900E+01	.000E+00	.114E+21	.000E+00	.000E+00
.100E+02	.000E+00	.128E+21	.000E+00	.000E+00

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.200E+02	.000E+00	.274E+21	.000E+00	.000E+00
.300E+02	.000E+00	.429E+21	.000E+00	.000E+00
.400E+02	.000E+00	.588E+21	.000E+00	.000E+00
.500E+02	.000E+00	.750E+21	.000E+00	.000E+00
.600E+02	.000E+00	.912E+21	.000E+00	.000E+00
.700E+02	.000E+00	.108E+22	.000E+00	.000E+00
.800E+02	.000E+00	.124E+22	.000E+00	.000E+00
.900E+02	.000E+00	.140E+22	.000E+00	.000E+00
.100E+03	.000E+00	.157E+22	.000E+00	.000E+00
.200E+03	.000E+00	.320E+22	.000E+00	.000E+00
.300E+03	.000E+00	.483E+22	.000E+00	.000E+00
.400E+03	.000E+00	.646E+22	.000E+00	.000E+00
.500E+03	.000E+00	.809E+22	.000E+00	.000E+00
.600E+03	.000E+00	.971E+22	.000E+00	.000E+00
.700E+03	.000E+00	.113E+23	.000E+00	.000E+00
.800E+03	.000E+00	.129E+23	.000E+00	.000E+00
.900E+03	.000E+00	.145E+23	.000E+00	.000E+00
.100E+04	.000E+00	.161E+23	.000E+00	.000E+00
.200E+04	.000E+00	.317E+23	.000E+00	.000E+00
.300E+04	.000E+00	.467E+23	.000E+00	.000E+00
.400E+04	.000E+00	.609E+23	.000E+00	.000E+00
.500E+04	.000E+00	.745E+23	.000E+00	.000E+00
.600E+04	.000E+00	.875E+23	.000E+00	.000E+00
.700E+04	.000E+00	.999E+23	.000E+00	.000E+00
.800E+04	.000E+00	.112E+24	.000E+00	.000E+00
.900E+04	.000E+00	.123E+24	.000E+00	.000E+00
.100E+05	.000E+00	.134E+24	.000E+00	.000E+00
.200E+05	.000E+00	.219E+24	.000E+00	.000E+00
.300E+05	.000E+00	.272E+24	.000E+00	.000E+00
.400E+05	.000E+00	.306E+24	.000E+00	.000E+00
.500E+05	.000E+00	.328E+24	.000E+00	.000E+00
.600E+05	.000E+00	.341E+24	.000E+00	.000E+00
.700E+05	.000E+00	.350E+24	.000E+00	.000E+00
.800E+05	.000E+00	.355E+24	.000E+00	.000E+00
.900E+05	.000E+00	.359E+24	.000E+00	.000E+00
.100E+06	.000E+00	.361E+24	.000E+00	.000E+00
.200E+06	.000E+00	.365E+24	.000E+00	.000E+00
.300E+06	.000E+00	.365E+24	.000E+00	.000E+00
.400E+06	.000E+00	.365E+24	.000E+00	.000E+00
.500E+06	.000E+00	.365E+24	.000E+00	.000E+00
.600E+06	.000E+00	.365E+24	.000E+00	.000E+00
.700E+06	.000E+00	.365E+24	.000E+00	.000E+00
.800E+06	.000E+00	.365E+24	.000E+00	.000E+00
.900E+06	.000E+00	.365E+24	.000E+00	.000E+00

	INITIAL RADIONUCLIDE AMOUNT (ATOMS)
ZONE 1-SED.	.000E+00
ZONE 1-S.W.	.000E+00
ZONE 1-G.W.	.000E+00
ZONE 1-SOIL	.000E+00

	KD(L/KG)
ZONE 1-SED.	.500E+05
ZONE 1-S.W.	.100E+06
ZONE 1-G.W.	.500E+04
ZONE 1-SOIL	.100E+04

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

TRANSFER MATRIX
(YEAR**-1)

ORIGIN CELLS

DESTINATION CELLS	1	2	3	4
1	-.15239E+00	.23805E+02	.64113E-19	.90984E-17
2	.10000E+00	-.28606E+02	.27691E-04	.23069E-03
3	.19121E-16	.45517E-14	-.29533E-04	.86348E-03
4	.19121E-16	.16550E-01	.64113E-19	-.10960E-02

242PU AMOUNTS
(ATOMS)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.198E+11	.249E+13	.296E+01	.137E+08
.200E-02	.175E+12	.122E+14	.500E+02	.122E+09
.300E-02	.677E+12	.318E+14	.283E+03	.471E+09
.400E-02	.177E+13	.618E+14	.981E+03	.123E+10
.500E-02	.370E+13	.102E+15	.258E+04	.257E+10
.600E-02	.671E+13	.153E+15	.564E+04	.467E+10
.700E-02	.110E+14	.213E+15	.109E+05	.768E+10
.800E-02	.169E+14	.283E+15	.192E+05	.118E+11
.900E-02	.246E+14	.362E+15	.316E+05	.171E+11
.100E-01	.342E+14	.450E+15	.491E+05	.238E+11
.200E-01	.284E+15	.178E+16	.848E+06	.198E+12

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.300E-01	.933E+15	.377E+16	.427E+07	.650E-12
.400E-01	.212E+16	.627E+16	.131E+08	.147E+13
.500E-01	.394E+16	.914E+16	.310E+08	.275E+13
.600E-01	.648E+16	.123E+17	.620E+08	.452E+13
.700E-01	.979E+16	.157E+17	.111E+09	.683E+13
.800E-01	.139E+17	.192E+17	.182E+09	.971E+13
.900E-01	.189E+17	.228E+17	.280E+09	.132E+14
.100E+00	.247E+17	.266E+17	.411E+09	.173E+14
.200E+00	.134E+18	.664E+17	.474E+10	.939E+14
.300E+00	.337E+18	.107E+18	.186E+11	.237E+15
.400E+00	.633E+18	.148E+18	.477E+11	.449E+15
.500E+00	.102E+19	.190E+18	.980E+11	.728E+15
.600E+00	.151E+19	.232E+18	.175E+12	.108E+16
.700E+00	.208E+19	.275E+18	.286E+12	.150E+16
.800E+00	.275E+19	.318E+18	.436E+12	.199E+16
.900E+00	.351E+19	.361E+18	.631E+12	.255E+16
.100E+01	.436E+19	.405E+18	.878E+12	.318E+16
.200E+01	.179E+20	.867E+18	.760E+13	.137E+17
.300E+01	.402E+20	.137E+19	.268E+14	.321E+17
.400E+01	.709E+20	.192E+19	.656E+14	.593E+17
.500E+01	.110E+21	.250E+19	.132E+15	.957E+17
.600E+01	.156E+21	.311E+19	.234E+15	.142E+18
.700E+01	.210E+21	.376E+19	.380E+15	.199E+18
.800E+01	.271E+21	.445E+19	.580E+15	.266E+18
.900E+01	.339E+21	.515E+19	.843E+15	.345E+18
.100E+02	.413E+21	.589E+19	.118E+16	.436E+18
.200E+02	.146E+22	.146E+20	.111E+17	.210E+19
.300E+02	.289E+22	.251E+20	.420E+17	.533E+19
.400E+02	.455E+22	.364E+20	.108E+18	.103E+20
.500E+02	.634E+22	.484E+20	.226E+18	.172E+20
.600E+02	.822E+22	.606E+20	.410E+18	.260E+20
.700E+02	.101E+23	.732E+20	.679E+18	.367E+20
.800E+02	.121E+23	.856E+20	.105E+19	.494E+20
.900E+02	.140E+23	.980E+20	.154E+19	.639E+20
.100E+03	.160E+23	.111E+21	.216E+19	.804E+20
.200E+03	.356E+23	.236E+21	.193E+20	.346E+21
.300E+03	.553E+23	.362E+21	.666E+20	.781E+21
.400E+03	.749E+23	.488E+21	.158E+21	.137E+22
.500E+03	.945E+23	.613E+21	.306E+21	.209E+22
.600E+03	.114E+24	.738E+21	.521E+21	.293E+22
.700E+03	.133E+24	.861E+21	.812E+21	.388E+22
.800E+03	.152E+24	.984E+21	.119E+22	.493E+22
.900E+03	.172E+24	.111E+22	.166E+22	.606E+22
.100E+04	.191E+24	.123E+22	.223E+22	.726E+22
.200E+04	.379E+24	.243E+22	.143E+23	.219E+23
.300E+04	.559E+24	.359E+22	.397E+23	.386E+23
.400E+04	.730E+24	.468E+22	.786E+23	.555E+23
.500E+04	.894E+24	.573E+22	.131E+24	.718E+23
.600E+04	.105E+25	.673E+22	.195E+24	.876E+23
.700E+04	.120E+25	.769E+22	.270E+24	.103E+24
.800E+04	.135E+25	.862E+22	.356E+24	.117E+24
.900E+04	.148E+25	.947E+22	.451E+24	.131E+24
.100E+05	.161E+25	.103E+23	.555E+24	.144E+24
.200E+05	.263E+25	.169E+23	.190E+25	.246E+24
.300E+05	.327E+25	.210E+23	.351E+25	.311E+24
.400E+05	.368E+25	.236E+23	.511E+25	.352E+24
.500E+05	.395E+25	.253E+23	.655E+25	.379E+24
.600E+05	.411E+25	.263E+23	.778E+25	.396E+24
.700E+05	.421E+25	.270E+23	.879E+25	.406E+24
.800E+05	.428E+25	.274E+23	.961E+25	.413E+24
.900E+05	.432E+25	.277E+23	.103E+26	.418E+24
.100E+06	.435E+25	.278E+23	.108E+26	.420E+24
.200E+06	.440E+25	.281E+23	.123E+26	.425E+24
.300E+06	.440E+25	.281E+23	.124E+26	.425E+24
.400E+06	.440E+25	.281E+23	.124E+26	.425E+24
.500E+06	.440E+25	.281E+23	.124E+26	.425E+24
.600E+06	.440E+25	.281E+23	.124E+26	.425E+24
.700E+06	.440E+25	.281E+23	.124E+26	.425E+24
.800E+06	.440E+25	.281E+23	.124E+26	.425E+24
.900E+06	.440E+25	.281E+23	.124E+26	.425E+24

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

```
*****    ANALYSES FOR RADIONUCLIDE  238U     *****

RADIOACTIVE HALF-LIFE=  .447E+10 YEARS
RADIOACTIVE DECAY RATE=  .155E-09 YEARS**-1

                PHYSICAL
                 DECAY
                  RATE
              (YEARS**-1)

ZONE 1-SED.     .000E+00
ZONE 1-S.W.     .000E+00
ZONE 1-G.W.     .000E+00
ZONE 1-SOIL     .000E+00
```

238U EXTERNAL INPUT RATES (ATOMS/YR)

TIME (YR)	CELL 1	CELL 2	CELL 3	CELL 4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.000E+00	.102E+22	.000E+00	.000E+00
.200E-02	.000E+00	.305E+22	.000E+00	.000E+00
.300E-02	.000E+00	.537E+22	.000E+00	.000E+00
.400E-02	.000E+00	.780E+22	.000E+00	.000E+00
.500E-02	.000E+00	.102E+23	.000E+00	.000E+00
.600E-02	.000E+00	.127E+23	.000E+00	.000E+00
.700E-02	.000E+00	.152E+23	.000E+00	.000E+00
.800E-02	.000E+00	.176E+23	.000E+00	.000E+00
.900E-02	.000E+00	.201E+23	.000E+00	.000E+00
.100E-01	.000E+00	.226E+23	.000E+00	.000E+00
.200E-01	.000E+00	.472E+23	.000E+00	.000E+00
.300E-01	.000E+00	.718E+23	.000E+00	.000E+00
.400E-01	.000E+00	.965E+23	.000E+00	.000E+00
.500E-01	.000E+00	.121E+24	.000E+00	.000E+00
.600E-01	.000E+00	.146E+24	.000E+00	.000E+00
.700E-01	.000E+00	.170E+24	.000E+00	.000E+00
.800E-01	.000E+00	.195E+24	.000E+00	.000E+00
.900E-01	.000E+00	.220E+24	.000E+00	.000E+00
.100E+00	.000E+00	.245E+24	.000E+00	.000E+00
.200E+00	.000E+00	.492E+24	.000E+00	.000E+00
.300E+00	.000E+00	.740E+24	.000E+00	.000E+00
.400E+00	.000E+00	.988E+24	.000E+00	.000E+00
.500E+00	.000E+00	.124E+25	.000E+00	.000E+00
.600E+00	.000E+00	.149E+25	.000E+00	.000E+00
.700E+00	.000E+00	.174E+25	.000E+00	.000E+00
.800E+00	.000E+00	.199E+25	.000E+00	.000E+00
.900E+00	.000E+00	.224E+25	.000E+00	.000E+00
.100E+01	.000E+00	.249E+25	.000E+00	.000E+00
.200E+01	.000E+00	.504E+25	.000E+00	.000E+00
.300E+01	.000E+00	.764E+25	.000E+00	.000E+00
.400E+01	.000E+00	.103E+26	.000E+00	.000E+00
.500E+01	.000E+00	.130E+26	.000E+00	.000E+00
.600E+01	.000E+00	.157E+26	.000E+00	.000E+00
.700E+01	.000E+00	.185E+26	.000E+00	.000E+00
.800E+01	.000E+00	.213E+26	.000E+00	.000E+00
.900E+01	.000E+00	.242E+26	.000E+00	.000E+00
.100E+02	.000E+00	.270E+26	.000E+00	.000E+00
.200E+02	.000E+00	.570E+26	.000E+00	.000E+00
.300E+02	.000E+00	.883E+26	.000E+00	.000E+00
.400E+02	.000E+00	.120E+27	.000E+00	.000E+00
.500E+02	.000E+00	.152E+27	.000E+00	.000E+00

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.600E+02	.000E+00	.184E+27	.000E+00	.000E+00
.700E+02	.000E+00	.216E+27	.000E+00	.000E+00
.800E+02	.000E+00	.248E+27	.000E+00	.000E+00
.900E+02	.000E+00	.280E+27	.000E+00	.000E+00
.100E+03	.000E+00	.311E+27	.000E+00	.000E+00
.200E+03	.000E+00	.620E+27	.000E+00	.000E+00
.300E+03	.000E+00	.915E+27	.000E+00	.000E+00
.400E+03	.000E+00	.120E+28	.000E+00	.000E+00
.500E+03	.000E+00	.147E+28	.000E+00	.000E+00
.600E+03	.000E+00	.173E+28	.000E+00	.000E+00
.700E+03	.000E+00	.198E+28	.000E+00	.000E+00
.800E+03	.000E+00	.221E+28	.000E+00	.000E+00
.900E+03	.000E+00	.244E+28	.000E+00	.000E+00
.100E+04	.000E+00	.266E+28	.000E+00	.000E+00
.200E+04	.000E+00	.438E+28	.000E+00	.000E+00
.300E+04	.000E+00	.549E+28	.000E+00	.000E+00
.400E+04	.000E+00	.621E+28	.000E+00	.000E+00
.500E+04	.000E+00	.668E+28	.000E+00	.000E+00
.600E+04	.000E+00	.697E+28	.000E+00	.000E+00
.700E+04	.000E+00	.717E+28	.000E+00	.000E+00
.800E+04	.000E+00	.729E+28	.000E+00	.000E+00
.900E+04	.000E+00	.737E+28	.000E+00	.000E+00
.100E+05	.000E+00	.743E+28	.000E+00	.000E+00
.200E+05	.000E+00	.752E+28	.000E+00	.000E+00
.300E+05	.000E+00	.752E+28	.000E+00	.000E+00
.400E+05	.000E+00	.752E+28	.000E+00	.000E+00
.500E+05	.000E+00	.752E+28	.000E+00	.000E+00
.600E+05	.000E+00	.752E+28	.000E+00	.000E+00
.700E+05	.000E+00	.752E+28	.000E+00	.000E+00
.800E+05	.000E+00	.752E+28	.000E+00	.000E+00
.900E+05	.000E+00	.752E+28	.000E+00	.000E+00
.100E+06	.000E+00	.752E+28	.000E+00	.000E+00
.200E+06	.000E+00	.752E+28	.000E+00	.000E+00
.300E+06	.000E+00	.752E+28	.000E+00	.000E+00
.400E+06	.000E+00	.752E+28	.000E+00	.000E+00
.500E+06	.000E+00	.752E+28	.000E+00	.000E+00
.600E+06	.000E+00	.752E+28	.000E+00	.000E+00
.700E+06	.000E+00	.752E+28	.000E+00	.000E+00
.800E+06	.000E+00	.752E+28	.000E+00	.000E+00
.900E+06	.000E+00	.752E+28	.000E+00	.000E+00

238U TOTAL INPUT RATES (ATOMS/YR)

TIME (YR)	CELL 1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.364E+05	.102E+22	.545E-05	.253E+02
.200E-02	.323E+06	.305E+22	.920E-04	.225E+03
.300E-02	.125E+07	.537E+22	.520E-03	.868E+03
.400E-02	.326E+07	.780E+22	.181E-02	.227E+04
.500E-02	.682E+07	.102E+23	.474E-02	.474E+04
.600E-02	.124E+08	.127E+23	.104E-01	.860E+04
.700E-02	.203E+08	.152E+23	.201E-01	.141E+05
.800E-02	.312E+08	.176E+23	.354E-01	.217E+05
.900E-02	.453E+08	.201E+23	.582E-01	.315E+05
.100E-01	.630E+08	.226E+23	.905E-01	.438E+05
.200E-01	.524E+09	.472E+23	.156E+01	.365E+06
.300E-01	.172E+10	.718E+23	.786E+01	.120E+07
.400E-01	.390E+10	.965E+23	.242E+02	.272E+07
.500E-01	.726E+10	.121E+24	.571E+02	.506E+07
.600E-01	.119E+11	.146E+24	.114E+03	.832E+07
.700E-01	.180E+11	.170E+24	.204E+03	.126E+08

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.800E-01	.256E+11	.195E+24	.334E+03	.179E+08
.900E-01	.348E+11	.220E+24	.516E+03	.243E+08
.100E+00	.456E+11	.245E+24	.757E+03	.318E+08
.200E+00	.247E+12	.492E+24	.872E+04	.173E+09
.300E+00	.620E+12	.740E+24	.342E+05	.437E+09
.400E+00	.117E+13	.988E+24	.878E+05	.826E+09
.500E+00	.188E+13	.124E+25	.181E+06	.134E+10
.600E+00	.278E+13	.149E+25	.323E+06	.198E+10
.700E+00	.384E+13	.174E+25	.527E+06	.276E+10
.800E+00	.507E+13	.199E+25	.803E+06	.366E+10
.900E+00	.647E+13	.224E+25	.116E+07	.469E+10
.100E+01	.804E+13	.249E+25	.162E+07	.586E+10
.200E+01	.329E+14	.504E+25	.140E+08	.252E+11
.300E+01	.740E+14	.764E+25	.493E+08	.592E+11
.400E+01	.131E+15	.103E+26	.121E+09	.109E+12
.500E+01	.202E+15	.130E+26	.243E+09	.176E+12
.600E+01	.288E+15	.157E+26	.430E+09	.261E+12
.700E+01	.387E+15	.185E+26	.700E+09	.366E+12
.800E+01	.500E+15	.213E+26	.107E+10	.491E+12
.900E+01	.625E+15	.242E+26	.155E+10	.636E+12
.100E+02	.761E+15	.270E+26	.217E+10	.804E+12
.200E+02	.269E+16	.570E+26	.204E+11	.387E+13
.300E+02	.532E+16	.883E+26	.773E+11	.982E+13
.400E+02	.838E+16	.120E+27	.199E+12	.190E+14
.500E+02	.117E+17	.152E+27	.416E+12	.317E+14
.600E+02	.151E+17	.184E+27	.756E+12	.478E+14
.700E+02	.187E+17	.216E+27	.125E+13	.676E+14
.800E+02	.223E+17	.248E+27	.193E+13	.909E+14
.900E+02	.258E+17	.280E+27	.283E+13	.118E+15
.100E+03	.295E+17	.311E+27	.397E+13	.148E+15
.200E+03	.657E+17	.620E+27	.355E+14	.637E+15
.300E+03	.102E+18	.915E+27	.123E+15	.144E+16
.400E+03	.138E+18	.120E+28	.291E+15	.252E+16
.500E+03	.174E+18	.147E+28	.563E+15	.385E+16
.600E+03	.210E+18	.173E+28	.959E+15	.540E+16
.700E+03	.245E+18	.198E+28	.150E+16	.715E+16
.800E+03	.281E+18	.221E+28	.219E+16	.908E+16
.900E+03	.316E+18	.244E+28	.306E+16	.112E+17
.100E+04	.352E+18	.266E+28	.410E+16	.134E+17
.200E+04	.698E+18	.438E+28	.264E+17	.404E+17
.300E+04	.103E+19	.549E+28	.731E+17	.712E+17
.400E+04	.135E+19	.621E+28	.145E+18	.102E+18
.500E+04	.165E+19	.668E+28	.240E+18	.132E+18
.600E+04	.194E+19	.697E+28	.359E+18	.161E+18
.700E+04	.221E+19	.717E+28	.497E+18	.189E+18
.800E+04	.248E+19	.729E+28	.655E+18	.216E+18
.900E+04	.272E+19	.737E+28	.831E+18	.241E+18
.100E+05	.297E+19	.743E+28	.102E+19	.265E+18
.200E+05	.485E+19	.752E+28	.349E+19	.453E+18
.300E+05	.603E+19	.752E+28	.647E+19	.573E+18
.400E+05	.678E+19	.752E+28	.941E+19	.649E+18
.500E+05	.727E+19	.752E+28	.121E+20	.699E+18
.600E+05	.756E+19	.752E+28	.143E+20	.729E+18
.700E+05	.776E+19	.752E+28	.162E+20	.749E+18
.800E+05	.787E+19	.752E+28	.177E+20	.760E+18
.900E+05	.796E+19	.752E+28	.189E+20	.769E+18
.100E+06	.801E+19	.752E+28	.198E+20	.774E+18
.200E+06	.810E+19	.752E+28	.227E+20	.783E+18
.300E+06	.810E+19	.752E+28	.229E+20	.783E+18
.400E+06	.810E+19	.752E+28	.229E+20	.783E+18
.500E+06	.810E+19	.752E+28	.229E+20	.783E+18
.600E+06	.810E+19	.752E+28	.229E+20	.783E+18
.700E+06	.810E+19	.752E+28	.229E+20	.783E+18
.800E+06	.810E+19	.752E+28	.229E+20	.783E+18
.900E+06	.810E+19	.752E+28	.229E+20	.783E+18

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

```
                 INITIAL
              RADIONUCLIDE
                 AMOUNT
                 (ATOMS)

ZONE 1-SED.     .000E+00
ZONE 1-S.W.     .000E+00
ZONE 1-G.W.     .000E+00
ZONE 1-SOIL     .000E+00

              KD(L/KG)

ZONE 1-SED.     .500E+04
ZONE 1-S.W.     .100E+05
ZONE 1-G.W.     .500E+03
ZONE 1-SOIL     .100E+02

                                                    TRANSFER MATRIX
                                                      (YEAR**-1)

                                                     ORIGIN  CELLS

                 1            2            3            4


DESTINATION
   CELLS



     1      -.15239E+00  .10942E+02  .64211E-19  .98272E-17



     2       .10000E+00 -.15755E+02  .27684E-03  .21268E-01



     3       .19123E-16  .20923E-14 -.27684E-03  .84837E-01



     4       .19123E-16  .16569E-01  .64211E-19 -.10610E+00
```

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

238U AMOUNTS (ATOMS).

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.185E+16	.507E+18	.596E+08	.281E+13
.200E-02	.166E+17	.252E+19	.101E+10	.251E+14
.300E-02	.648E+17	.666E+19	.575E+10	.981E+14
.400E-02	.171E+18	.131E+20	.201E+11	.259E+15
.500E-02	.360E+18	.218E+20	.532E+11	.545E+15
.600E-02	.657E+18	.328E+20	.117E+12	.994E+15
.700E-02	.109E+19	.462E+20	.228E+12	.165E+16
.800E-02	.167E+19	.617E+20	.403E+12	.254E+16
.900E-02	.244E+19	.795E+20	.666E+12	.370E+16
.100E-01	.342E+19	.994E+20	.104E+13	.518E+16
.200E-01	.295E+20	.411E+21	.186E+14	.447E+17
.300E-01	.999E+20	.904E+21	.959E+14	.151E+18
.400E-01	.233E+21	.155E+22	.302E+15	.353E+18
.500E-01	.444E+21	.234E+22	.728E+15	.673E+18
.600E-01	.747E+21	.324E+22	.148E+16	.113E+19
.700E-01	.115E+22	.423E+22	.269E+16	.175E+19
.800E-01	.167E+22	.531E+22	.450E+16	.253E+19
.900E-01	.231E+22	.646E+22	.705E+16	.350E+19
.100E+00	.308E+22	.767E+22	.105E+17	.467E+19
.200E+00	.188E+23	.218E+23	.135E+18	.285E+20
.300E+00	.505E+23	.373E+23	.564E+18	.768E+20
.400E+00	.989E+23	.532E+23	.151E+19	.151E+21
.500E+00	.164E+24	.694E+23	.319E+19	.250E+21
.600E+00	.246E+24	.857E+23	.582E+19	.375E+21
.700E+00	.344E+24	.102E+24	.963E+19	.526E+21
.800E+00	.459E+24	.119E+24	.146E+20	.702E+21
.900E+00	.590E+24	.135E+24	.216E+20	.904E+21
.100E+01	.737E+24	.152E+24	.302E+20	.113E+22
.200E+01	.308E+25	.328E+24	.264E+21	.480E+22
.300E+01	.695E+25	.517E+24	.915E+21	.110E+23
.400E+01	.123E+26	.718E+24	.219E+22	.196E+23
.500E+01	.189E+26	.931E+24	.431E+22	.306E+23
.600E+01	.268E+26	.115E+25	.745E+22	.439E+23
.700E+01	.360E+26	.139E+25	.118E+23	.595E+23
.800E+01	.462E+26	.163E+25	.176E+23	.772E+23
.900E+01	.575E+26	.188E+25	.250E+23	.971E+23
.100E+02	.699E+26	.214E+25	.341E+23	.119E+24
.200E+02	.237E+27	.510E+25	.257E+24	.434E+24
.300E+02	.455E+27	.847E+25	.803E+24	.871E+24
.400E+02	.699E+27	.120E+26	.175E+25	.138E+25
.500E+02	.956E+27	.157E+26	.314E+25	.192E+25
.600E+02	.122E+28	.194E+26	.500E+25	.249E+25
.700E+02	.148E+28	.231E+26	.734E+25	.306E+25
.800E+02	.175E+28	.268E+26	.102E+26	.364E+25
.900E+02	.202E+28	.306E+26	.135E+26	.423E+25
.100E+03	.228E+28	.342E+26	.173E+26	.480E+25
.200E+03	.488E+28	.703E+26	.807E+26	.104E+26
.300E+03	.736E+28	.105E+27	.189E+27	.159E+26
.400E+03	.976E+28	.138E+27	.338E+27	.211E+26
.500E+03	.120E+29	.170E+27	.527E+27	.260E+26
.600E+03	.142E+29	.200E+27	.750E+27	.308E+26
.700E+03	.163E+29	.229E+27	.101E+28	.354E+26
.800E+03	.183E+29	.256E+27	.129E+28	.396E+26
.900E+03	.202E+29	.283E+27	.161E+28	.438E+26
.100E+04	.221E+29	.309E+27	.195E+28	.479E+26
.200E+04	.365E+29	.510E+27	.625E+28	.794E+26
.300E+04	.459E+29	.640E+27	.114E+29	.998E+26

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.400E+04	.520E+29	.725E+27	.166E+29	.113E+27
.500E+04	.560E+29	.780E+27	.213E+29	.122E+27
.600E+04	.584E+29	.814E+27	.254E+29	.127E+27
.700E+04	.601E+29	.837E+27	.286E+29	.131E+27
.800E+04	.611E+29	.851E+27	.316E+29	.133E+27
.900E+04	.618E+29	.861E+27	.339E+29	.134E+27
.100E+05	.623E+29	.868E+27	.357E+29	.136E+27
.200E+05	.631E+29	.879E+27	.415E+29	.137E+27
.300E+05	.631E+29	.879E+27	.420E+29	.137E+27
.400E+05	.631E+29	.879E+27	.420E+29	.137E+27
.500E+05	.631E+29	.879E+27	.420E+29	.137E+27
.600E+05	.631E+29	.879E+27	.420E+29	.137E+27
.700E+05	.631E+29	.879E+27	.420E+29	.137E+27
.800E+05	.631E+29	.879E+27	.420E+29	.137E+27
.900E+05	.631E+29	.879E+27	.420E+29	.137E+27
.100E+06	.631E+29	.879E+27	.420E+29	.137E+27
.200E+06	.631E+29	.879E+27	.420E+29	.137E+27
.300E+06	.631E+29	.879E+27	.420E+29	.137E+27
.400E+06	.631E+29	.879E+27	.420E+29	.137E+27
.500E+06	.631E+29	.879E+27	.420E+29	.137E+27
.600E+06	.631E+29	.879E+27	.420E+29	.137E+27
.700E+06	.631E+29	.879E+27	.420E+29	.137E+27
.800E+06	.631E+29	.879E+27	.420E+29	.137E+27
.900E+06	.631E+29	.879E+27	.420E+29	.137E+27

***** ANALYSES FOR RADIONUCLIDE 234U *****

RADIOACTIVE HALF-LIFE= .245E+06 YEARS
RADIOACTIVE DECAY RATE= .283E-05 YEARS**-1

	PHYSICAL DECAY RATE (YEARS**-1)
ZONE 1-SED.	.000E+00
ZONE 1-S.W.	.000E+00
ZONE 1-G.W.	.000E+00
ZONE 1-SOIL	.000E+00

234U EXTERNAL INPUT RATES (ATOMS/YR)

TIME (YR)	CELL 1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.000E+00	.391E+17	.000E+00	.000E+00
.200E-02	.000E+00	.117E+18	.000E+00	.000E+00
.300E-02	.000E+00	.206E+18	.000E+00	.000E+00
.400E-02	.000E+00	.299E+18	.000E+00	.000E+00
.500E-02	.000E+00	.392E+18	.000E+00	.000E+00
.600E-02	.000E+00	.487E+18	.000E+00	.000E+00
.700E-02	.000E+00	.581E+18	.000E+00	.000E+00
.800E-02	.000E+00	.675E+18	.000E+00	.000E+00
.900E-02	.000E+00	.770E+18	.000E+00	.000E+00
.100E-01	.000E+00	.864E+18	.000E+00	.000E+00
.200E-01	.000E+00	.181E+19	.000E+00	.000E+00

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.300E-01	.000E+00	.275E+19	.000E+00	.000E+00
.400E-01	.000E+00	.370E+19	.000E+00	.000E+00
.500E-01	.000E+00	.464E+19	.000E+00	.000E+00
.600E-01	.000E+00	.558E+19	.000E+00	.000E+00
.700E-01	.000E+00	.653E+19	.000E+00	.000E+00
.800E-01	.000E+00	.747E+19	.000E+00	.000E+00
.900E-01	.000E+00	.842E+19	.000E+00	.000E+00
.100E+00	.000E+00	.937E+19	.000E+00	.000E+00
.200E+00	.000E+00	.188E+20	.000E+00	.000E+00
.300E+00	.000E+00	.283E+20	.000E+00	.000E+00
.400E+00	.000E+00	.378E+20	.000E+00	.000E+00
.500E+00	.000E+00	.474E+20	.000E+00	.000E+00
.600E+00	.000E+00	.569E+20	.000E+00	.000E+00
.700E+00	.000E+00	.665E+20	.000E+00	.000E+00
.800E+00	.000E+00	.761E+20	.000E+00	.000E+00
.900E+00	.000E+00	.857E+20	.000E+00	.000E+00
.100E+01	.000E+00	.954E+20	.000E+00	.000E+00
.200E+01	.000E+00	.193E+21	.000E+00	.000E+00
.300E+01	.000E+00	.293E+21	.000E+00	.000E+00
.400E+01	.000E+00	.394E+21	.000E+00	.000E+00
.500E+01	.000E+00	.497E+21	.000E+00	.000E+00
.600E+01	.000E+00	.602E+21	.000E+00	.000E+00
.700E+01	.000E+00	.709E+21	.000E+00	.000E+00
.800E+01	.000E+00	.816E+21	.000E+00	.000E+00
.900E+01	.000E+00	.925E+21	.000E+00	.000E+00
.100E+02	.000E+00	.104E+22	.000E+00	.000E+00
.200E+02	.000E+00	.218E+22	.000E+00	.000E+00
.300E+02	.000E+00	.338E+22	.000E+00	.000E+00
.400E+02	.000E+00	.460E+22	.000E+00	.000E+00
.500E+02	.000E+00	.583E+22	.000E+00	.000E+00
.600E+02	.000E+00	.705E+22	.000E+00	.000E+00
.700E+02	.000E+00	.828E+22	.000E+00	.000E+00
.800E+02	.000E+00	.950E+22	.000E+00	.000E+00
.900E+02	.000E+00	.107E+23	.000E+00	.000E+00
.100E+03	.000E+00	.119E+23	.000E+00	.000E+00
.200E+03	.000E+00	.237E+23	.000E+00	.000E+00
.300E+03	.000E+00	.351E+23	.000E+00	.000E+00
.400E+03	.000E+00	.459E+23	.000E+00	.000E+00
.500E+03	.000E+00	.563E+23	.000E+00	.000E+00
.600E+03	.000E+00	.662E+23	.000E+00	.000E+00
.700E+03	.000E+00	.757E+23	.000E+00	.000E+00
.800E+03	.000E+00	.848E+23	.000E+00	.000E+00
.900E+03	.000E+00	.935E+23	.000E+00	.000E+00
.100E+04	.000E+00	.102E+24	.000E+00	.000E+00
.200E+04	.000E+00	.168E+24	.000E+00	.000E+00
.300E+04	.000E+00	.211E+24	.000E+00	.000E+00
.400E+04	.000E+00	.238E+24	.000E+00	.000E+00
.500E+04	.000E+00	.256E+24	.000E+00	.000E+00
.600E+04	.000E+00	.268E+24	.000E+00	.000E+00
.700E+04	.000E+00	.275E+24	.000E+00	.000E+00
.800E+04	.000E+00	.280E+24	.000E+00	.000E+00
.900E+04	.000E+00	.283E+24	.000E+00	.000E+00
.100E+05	.000E+00	.285E+24	.000E+00	.000E+00
.200E+05	.000E+00	.289E+24	.000E+00	.000E+00
.300E+05	.000E+00	.289E+24	.000E+00	.000E+00
.400E+05	.000E+00	.289E+24	.000E+00	.000E+00
.500E+05	.000E+00	.289E+24	.000E+00	.000E+00
.600E+05	.000E+00	.289E+24	.000E+00	.000E+00
.700E+05	.000E+00	.289E+24	.000E+00	.000E+00
.800E+05	.000E+00	.289E+24	.000E+00	.000E+00
.900E+05	.000E+00	.289E+24	.000E+00	.000E+00
.100E+06	.000E+00	.289E+24	.000E+00	.000E+00
.200E+06	.000E+00	.289E+24	.000E+00	.000E+00
.300E+06	.000E+00	.289E+24	.000E+00	.000E+00
.400E+06	.000E+00	.289E+24	.000E+00	.000E+00
.500E+06	.000E+00	.289E+24	.000E+00	.000E+00
.600E+06	.000E+00	.289E+24	.000E+00	.000E+00
.700E+06	.000E+00	.289E+24	.000E+00	.000E+00
.800E+06	.000E+00	.289E+24	.000E+00	.000E+00
.900E+06	.000E+00	.289E+24	.000E+00	.000E+00

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

234U TOTAL INPUT RATES (ATOMS/YR)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.287E+06	.391E+17	.924E-02	.435E+03
.200E-02	.257E+07	.117E+18	.156E+00	.390E+04
.300E-02	.100E+08	.206E+18	.892E+00	.152E+05
.400E-02	.265E+08	.299E+18	.312E+01	.401E+05
.500E-02	.558E+08	.392E+18	.825E+01	.845E+05
.600E-02	.102E+09	.487E+18	.182E+02	.154E+06
.700E-02	.169E+09	.581E+18	.353E+02	.255E+06
.800E-02	.260E+09	.675E+18	.625E+02	.393E+06
.900E-02	.379E+09	.770E+18	.103E+03	.574E+06
.100E-01	.531E+09	.864E+18	.161E+03	.804E+06
.200E-01	.458E+10	.181E+19	.288E+04	.694E+07
.300E-01	.155E+11	.275E+19	.149E+05	.235E+08
.400E-01	.361E+11	.370E+19	.469E+05	.547E+08
.500E-01	.689E+11	.464E+19	.113E+06	.104E+09
.600E-01	.116E+12	.558E+19	.230E+06	.176E+09
.700E-01	.179E+12	.653E+19	.418E+06	.271E+09
.800E-01	.259E+12	.747E+19	.698E+06	.393E+09
.900E-01	.359E+12	.842E+19	.109E+07	.544E+09
.100E+00	.478E+12	.937E+19	.163E+07	.724E+09
.200E+00	.292E+13	.188E+20	.209E+08	.443E+10
.300E+00	.784E+13	.283E+20	.875E+08	.119E+11
.400E+00	.153E+14	.378E+20	.234E+09	.234E+11
.500E+00	.254E+14	.474E+20	.495E+09	.388E+11
.600E+00	.381E+14	.569E+20	.904E+09	.582E+11
.700E+00	.534E+14	.665E+20	.149E+10	.816E+11
.800E+00	.712E+14	.761E+20	.230E+10	.109E+12
.900E+00	.915E+14	.857E+20	.335E+10	.140E+12
.100E+01	.114E+15	.954E+20	.469E+10	.176E+12
.200E+01	.478E+15	.193E+21	.410E+11	.745E+12
.300E+01	.108E+16	.293E+21	.142E+12	.170E+13
.400E+01	.190E+16	.394E+21	.340E+12	.304E+13
.500E+01	.293E+16	.497E+21	.668E+12	.475E+13
.600E+01	.416E+16	.602E+21	.116E+13	.681E+13
.700E+01	.558E+16	.709E+21	.183E+13	.923E+13
.800E+01	.717E+16	.816E+21	.273E+13	.120E+14
.900E+01	.893E+16	.925E+21	.387E+13	.151E+14
.100E+02	.108E+17	.104E+22	.529E+13	.185E+14
.200E+02	.368E+17	.218E+22	.399E+14	.673E+14
.300E+02	.706E+17	.338E+22	.125E+15	.135E+15
.400E+02	.108E+18	.460E+22	.271E+15	.214E+15
.500E+02	.148E+18	.583E+22	.488E+15	.299E+15
.600E+02	.189E+18	.705E+22	.776E+15	.386E+15
.700E+02	.230E+18	.828E+22	.114E+16	.475E+15
.800E+02	.272E+18	.950E+22	.158E+16	.565E+15
.900E+02	.313E+18	.107E+23	.209E+16	.656E+15
.100E+03	.354E+18	.119E+23	.268E+16	.745E+15
.200E+03	.757E+18	.237E+23	.125E+17	.162E+16
.300E+03	.114E+19	.351E+23	.293E+17	.246E+16
.400E+03	.151E+19	.459E+23	.525E+17	.327E+16
.500E+03	.187E+19	.563E+23	.817E+17	.404E+16
.600E+03	.221E+19	.662E+23	.116E+18	.473E+16
.700E+03	.253E+19	.757E+23	.156E+18	.549E+16
.800E+03	.284E+19	.848E+23	.201E+18	.615E+16
.900E+03	.313E+19	.935E+23	.249E+18	.680E+16
.100E+04	.342E+19	.102E+24	.302E+18	.743E+16
.200E+04	.567E+19	.168E+24	.969E+18	.123E+17

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

```
.300E+04   .712E+19   .211E+24   .177E+19   .155E+17
.400E+04   .806E+19   .238E+24   .257E+19   .175E+17
.500E+04   .868E+19   .256E+24   .330E+19   .189E+17
.600E+04   .906E+19   .268E+24   .393E+19   .197E+17
.700E+04   .932E+19   .275E+24   .446E+19   .203E+17
.800E+04   .948E+19   .280E+24   .490E+19   .206E+17
.900E+04   .959E+19   .283E+24   .525E+19   .209E+17
.100E+05   .967E+19   .285E+24   .553E+19   .210E+17
.200E+05   .979E+19   .289E+24   .644E+19   .213E+17
.300E+05   .979E+19   .289E+24   .652E+19   .213E+17
.400E+05   .979E+19   .289E+24   .652E+19   .213E+17
.500E+05   .979E+19   .289E+24   .652E+19   .213E+17
.600E+05   .979E+19   .289E+24   .652E+19   .213E+17
.700E+05   .979E+19   .289E+24   .652E+19   .213E+17
.800E+05   .979E+19   .289E+24   .652E+19   .213E+17
.900E+05   .979E+19   .289E+24   .652E+19   .213E+17
.100E+06   .979E+19   .289E+24   .652E+19   .213E+17
.200E+06   .979E+19   .289E+24   .652E+19   .213E+17
.300E+06   .979E+19   .289E+24   .652E+19   .213E+17
.400E+06   .979E+19   .289E+24   .652E+19   .213E+17
.500E+06   .979E+19   .289E+24   .652E+19   .213E+17
.600E+06   .979E+19   .289E+24   .652E+19   .213E+17
.700E+06   .979E+19   .289E+24   .652E+19   .213E+17
.800E+06   .979E+19   .289E+24   .652E+19   .213E+17
.900E+06   .979E+19   .289E+24   .652E+19   .213E+17

                 INITIAL
              RADIONUCLIDE
                 AMOUNT
                 (ATOMS)

ZONE 1-SED.     .000E+00
ZONE 1-S.W.     .000E+00
ZONE 1-G.W.     .000E+00
ZONE 1-SOIL     .000E+00

              KD(L/KG)

ZONE 1-SED.     .500E+04
ZONE 1-S.W.     .100E+05
ZONE 1-G.W.     .500E+03
ZONE 1-SOIL     .100E+02

                                                  TRANSFER MATRIX
                                                    (YEAR**-1)

                                                   ORIGIN  CELLS

                  1          2          3          4


DESTINATION
   CELLS


     1      -.15239E+00  .10942E+02  .64211E-19  .98232E-17
```

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

2	.10000E+00	-.15755E+02	.27684E-03	.2126BE-01
3	.19123E-16	.20923E-14	-.27967E-03	.B4B37E-01
4	.19123E-16	.16569E-01	.64211E-19	-.10611E+00

234U AMOUNTS (ATOMS)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.710E+11	.194E+14	.228E+04	.108E+09
.200E-02	.636E+12	.967E+14	.387E+05	.964E+09
.300E-02	.248E+13	.256E+15	.221E+06	.376E+10
.400E-02	.655E+13	.502E+15	.772E+06	.992E+10
.500E-02	.138E+14	.837E+15	.204E+07	.209E+11
.600E-02	.252E+14	.126E+16	.449E+07	.381E+11
.700E-02	.417E+14	.177E+16	.873E+07	.631E+11
.800E-02	.642E+14	.237E+16	.155E+08	.973E+11
.900E-02	.938E+14	.305E+16	.255E+08	.142E+12
.100E-01	.131E+15	.381E+16	.399E+08	.199E+12
.200E-01	.113E+16	.157E+17	.711E+09	.171E+13
.300E-01	.383E+16	.347E+17	.367E+10	.580E+13
.400E-01	.892E+16	.596E+17	.116E+11	.135E+14
.500E-01	.170E+17	.896E+17	.279E+11	.258E+14
.600E-01	.286E+17	.124E+18	.568E+11	.434E+14
.700E-01	.442E+17	.162E+18	.103E+12	.670E+14
.800E-01	.641E+17	.203E+18	.172E+12	.971E+14
.900E-01	.886E+17	.247E+18	.270E+12	.134E+15
.100E+00	.118E+18	.294E+18	.402E+12	.179E+15
.200E+00	.719E+18	.832E+18	.517E+13	.109E+16
.300E+00	.193E+19	.143E+19	.216E+14	.294E+16
.400E+00	.378E+19	.203E+19	.578E+14	.576E+16
.500E+00	.627E+19	.265E+19	.122E+15	.956E+16
.600E+00	.939E+19	.328E+19	.223E+15	.143E+17
.700E+00	.131E+20	.390E+19	.368E+15	.201E+17
.800E+00	.175E+20	.454E+19	.567E+15	.269E+17
.900E+00	.225E+20	.518E+19	.827E+15	.346E+17
.100E+01	.282E+20	.582E+19	.116E+16	.433E+17
.200E+01	.118E+21	.126E+20	.101E+17	.184E+18
.300E+01	.266E+21	.198E+20	.350E+17	.420E+18
.400E+01	.469E+21	.275E+20	.840E+17	.750E+18
.500E+01	.724E+21	.356E+20	.165E+18	.117E+19
.600E+01	.103E+22	.442E+20	.285E+18	.168E+19
.700E+01	.138E+22	.532E+20	.452E+18	.228E+19
.800E+01	.177E+22	.624E+20	.674E+18	.296E+19
.900E+01	.220E+22	.721E+20	.956E+18	.372E+19
.100E+02	.268E+22	.823E+20	.131E+19	.456E+19

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.200E+02	.908E+22	.195E+21	.986E+19	.166E+20
.300E+02	.174E+23	.324E+21	.307E+20	.333E+20
.400E+02	.268E+23	.461E+21	.670E+20	.528E+20
.500E+02	.366E+23	.602E+21	.120E+21	.738E+20
.600E+02	.467E+23	.743E+21	.192E+21	.954E+20
.700E+02	.569E+23	.886E+21	.281E+21	.117E+21
.800E+02	.671E+23	.103E+22	.389E+21	.140E+21
.900E+02	.773E+23	.117E+22	.516E+21	.162E+21
.100E+03	.874E+23	.131E+22	.661E+21	.184E+21
.200E+03	.186E+24	.269E+22	.309E+22	.399E+21
.300E+03	.282E+24	.402E+22	.723E+22	.608E+21
.400E+03	.373E+24	.528E+22	.130E+23	.807E+21
.500E+03	.461E+24	.650E+22	.202E+23	.997E+21
.600E+03	.544E+24	.766E+22	.287E+23	.118E+22
.700E+03	.624E+24	.877E+22	.385E+23	.135E+22
.800E+03	.701E+24	.983E+22	.495E+23	.152E+22
.900E+03	.774E+24	.109E+23	.616E+23	.168E+22
.100E+04	.846E+24	.118E+23	.746E+23	.184E+22
.200E+04	.140E+25	.196E+23	.240E+24	.304E+22
.300E+04	.176E+25	.246E+23	.439E+24	.383E+22
.400E+04	.199E+25	.278E+23	.637E+24	.433E+22
.500E+04	.214E+25	.299E+23	.817E+24	.466E+22
.600E+04	.225E+25	.313E+23	.975E+24	.488E+22
.700E+04	.231E+25	.321E+23	.111E+25	.501E+22
.800E+04	.235E+25	.327E+23	.122E+25	.511E+22
.900E+04	.237E+25	.331E+23	.130E+25	.516E+22
.100E+05	.239E+25	.333E+23	.137E+25	.520E+22
.200E+05	.242E+25	.338E+23	.160E+25	.527E+22
.300E+05	.242E+25	.338E+23	.162E+25	.527E+22
.400E+05	.242E+25	.338E+23	.162E+25	.527E+22
.500E+05	.242E+25	.338E+23	.162E+25	.527E+22
.600E+05	.242E+25	.338E+23	.162E+25	.527E+22
.700E+05	.242E+25	.338E+23	.162E+25	.527E+22
.800E+05	.242E+25	.338E+23	.162E+25	.527E+22
.900E+05	.242E+25	.338E+23	.162E+25	.527E+22
.100E+06	.242E+25	.338E+23	.162E+25	.527E+22
.200E+06	.242E+25	.338E+23	.162E+25	.527E+22
.300E+06	.242E+25	.338E+23	.162E+25	.527E+22
.400E+06	.242E+25	.338E+23	.162E+25	.527E+22
.500E+06	.242E+25	.338E+23	.162E+25	.527E+22
.600E+06	.242E+25	.338E+23	.162E+25	.527E+22
.700E+06	.242E+25	.338E+23	.162E+25	.527E+22
.800E+06	.242E+25	.338E+23	.162E+25	.527E+22
.900E+06	.242E+25	.338E+23	.162E+25	.527E+22

***** ANALYSES FOR RADIONUCLIDE 230TH *****

RADIOACTIVE HALF-LIFE= .770E+05 YEARS
RADIOACTIVE DECAY RATE= .900E-05 YEARS**-1

	PHYSICAL DECAY RATE (YEARS**-1)
ZONE 1-SED.	.000E+00
ZONE 1-S.W.	.000E+00
ZONE 1-G.W.	.000E+00
ZONE 1-SOIL	.000E+00

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

230TH EXTERNAL INPUT RATES (ATOMS/YR)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.000E+00	.137E+15	.000E+00	.000E+00
.200E-02	.000E+00	.402E+15	.000E+00	.000E+00
.300E-02	.000E+00	.702E+15	.000E+00	.000E+00
.400E-02	.000E+00	.101E+16	.000E+00	.000E+00
.500E-02	.000E+00	.132E+16	.000E+00	.000E+00
.600E-02	.000E+00	.164E+16	.000E+00	.000E+00
.700E-02	.000E+00	.195E+16	.000E+00	.000E+00
.800E-02	.000E+00	.226E+16	.000E+00	.000E+00
.900E-02	.000E+00	.258E+16	.000E+00	.000E+00
.100E-01	.000E+00	.289E+16	.000E+00	.000E+00
.200E-01	.000E+00	.602E+16	.000E+00	.000E+00
.300E-01	.000E+00	.916E+16	.000E+00	.000E+00
.400E-01	.000E+00	.123E+17	.000E+00	.000E+00
.500E-01	.000E+00	.154E+17	.000E+00	.000E+00
.600E-01	.000E+00	.186E+17	.000E+00	.000E+00
.700E-01	.000E+00	.217E+17	.000E+00	.000E+00
.800E-01	.000E+00	.248E+17	.000E+00	.000E+00
.900E-01	.000E+00	.280E+17	.000E+00	.000E+00
.100E+00	.000E+00	.311E+17	.000E+00	.000E+00
.200E+00	.000E+00	.626E+17	.000E+00	.000E+00
.300E+00	.000E+00	.941E+17	.000E+00	.000E+00
.400E+00	.000E+00	.126E+18	.000E+00	.000E+00
.500E+00	.000E+00	.157E+18	.000E+00	.000E+00
.600E+00	.000E+00	.189E+18	.000E+00	.000E+00
.700E+00	.000E+00	.221E+18	.000E+00	.000E+00
.800E+00	.000E+00	.253E+18	.000E+00	.000E+00
.900E+00	.000E+00	.285E+18	.000E+00	.000E+00
.100E+01	.000E+00	.317E+18	.000E+00	.000E+00
.200E+01	.000E+00	.644E+18	.000E+00	.000E+00
.300E+01	.000E+00	.979E+18	.000E+00	.000E+00
.400E+01	.000E+00	.132E+19	.000E+00	.000E+00
.500E+01	.000E+00	.167E+19	.000E+00	.000E+00
.600E+01	.000E+00	.203E+19	.000E+00	.000E+00
.700E+01	.000E+00	.239E+19	.000E+00	.000E+00
.800E+01	.000E+00	.276E+19	.000E+00	.000E+00
.900E+01	.000E+00	.313E+19	.000E+00	.000E+00
.100E+02	.000E+00	.351E+19	.000E+00	.000E+00
.200E+02	.000E+00	.751E+19	.000E+00	.000E+00
.300E+02	.000E+00	.118E+20	.000E+00	.000E+00
.400E+02	.000E+00	.161E+20	.000E+00	.000E+00
.500E+02	.000E+00	.206E+20	.000E+00	.000E+00
.600E+02	.000E+00	.250E+20	.000E+00	.000E+00
.700E+02	.000E+00	.295E+20	.000E+00	.000E+00
.800E+02	.000E+00	.340E+20	.000E+00	.000E+00
.900E+02	.000E+00	.385E+20	.000E+00	.000E+00
.100E+03	.000E+00	.430E+20	.000E+00	.000E+00
.200E+03	.000E+00	.881E+20	.000E+00	.000E+00
.300E+03	.000E+00	.133E+21	.000E+00	.000E+00
.400E+03	.000E+00	.179E+21	.000E+00	.000E+00
.500E+03	.000E+00	.224E+21	.000E+00	.000E+00
.600E+03	.000E+00	.269E+21	.000E+00	.000E+00
.700E+03	.000E+00	.315E+21	.000E+00	.000E+00
.800E+03	.000E+00	.360E+21	.000E+00	.000E+00

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.900E+03	.000E+00	.406E+21	.000E+00	.000E+00
.100E+04	.000E+00	.451E+21	.000E+00	.000E+00
.200E+04	.000E+00	.906E+21	.000E+00	.000E+00
.300E+04	.000E+00	.136E+22	.000E+00	.000E+00
.400E+04	.000E+00	.181E+22	.000E+00	.000E+00
.500E+04	.000E+00	.225E+22	.000E+00	.000E+00
.600E+04	.000E+00	.269E+22	.000E+00	.000E+00
.700E+04	.000E+00	.312E+22	.000E+00	.000E+00
.800E+04	.000E+00	.354E+22	.000E+00	.000E+00
.900E+04	.000E+00	.396E+22	.000E+00	.000E+00
.100E+05	.000E+00	.438E+22	.000E+00	.000E+00
.200E+05	.000E+00	.823E+22	.000E+00	.000E+00
.300E+05	.000E+00	.116E+23	.000E+00	.000E+00
.400E+05	.000E+00	.146E+23	.000E+00	.000E+00
.500E+05	.000E+00	.171E+23	.000E+00	.000E+00
.600E+05	.000E+00	.194E+23	.000E+00	.000E+00
.700E+05	.000E+00	.213E+23	.000E+00	.000E+00
.800E+05	.000E+00	.231E+23	.000E+00	.000E+00
.900E+05	.000E+00	.246E+23	.000E+00	.000E+00
.100E+06	.000E+00	.259E+23	.000E+00	.000E+00
.200E+06	.000E+00	.326E+23	.000E+00	.000E+00
.300E+06	.000E+00	.344E+23	.000E+00	.000E+00
.400E+06	.000E+00	.349E+23	.000E+00	.000E+00
.500E+06	.000E+00	.350E+23	.000E+00	.000E+00
.600E+06	.000E+00	.350E+23	.000E+00	.000E+00
.700E+06	.000E+00	.350E+23	.000E+00	.000E+00
.800E+06	.000E+00	.350E+23	.000E+00	.000E+00
.900E+06	.000E+00	.350E+23	.000E+00	.000E+00

230TH TOTAL INPUT RATES (ATOMS/YR)

TIME (YR)	CELL 1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.201E+06	.137E+15	.647E-02	.305E+03
.200E-02	.180E+07	.402E+15	.110E+00	.273E+04
.300E-02	.704E+07	.702E+15	.625E+00	.107E+05
.400E-02	.186E+08	.101E+16	.219E+01	.281E+05
.500E-02	.391E+08	.132E+16	.578E+01	.592E+05
.600E-02	.714E+08	.164E+16	.127E+02	.108E+06
.700E-02	.118E+09	.195E+16	.247E+02	.179E+06
.800E-02	.182E+09	.226E+16	.438E+02	.276E+06
.900E-02	.266E+09	.258E+16	.724E+02	.403E+06
.100E-01	.372E+09	.289E+16	.113E+03	.563E+06
.200E-01	.321E+10	.602E+16	.201E+04	.486E+07
.300E-01	.108E+11	.916E+16	.104E+05	.164E+08
.400E-01	.253E+11	.123E+17	.328E+05	.383E+08
.500E-01	.482E+11	.154E+17	.791E+05	.731E+08
.600E-01	.812E+11	.186E+17	.161E+06	.123E+09
.700E-01	.125E+12	.217E+17	.293E+06	.190E+09
.800E-01	.182E+12	.248E+17	.489E+06	.275E+09
.900E-01	.251E+12	.280E+17	.765E+06	.381E+09
.100E+00	.335E+12	.311E+17	.114E+07	.507E+09
.200E+00	.204E+13	.626E+17	.147E+08	.310E+10
.300E+00	.548E+13	.941E+17	.612E+08	.833E+10
.400E+00	.107E+14	.126E+18	.164E+09	.163E+11
.500E+00	.178E+14	.157E+18	.346E+09	.271E+11
.600E+00	.266E+14	.189E+18	.631E+09	.407E+11
.700E+00	.373E+14	.221E+18	.104E+10	.570E+11

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.800E+00	.497E+14	.253E+18	.161E+10	.761E+11
.900E+00	.639E+14	.285E+18	.234E+10	.980E+11
.100E+01	.799E+14	.317E+18	.328E+10	.123E+12
.200E+01	.335E+15	.644E+18	.286E+11	.521E+12
.300E+01	.755E+15	.979E+18	.994E+11	.119E+13
.400E+01	.133E+16	.132E+19	.238E+12	.213E+13
.500E+01	.205E+16	.167E+19	.467E+12	.332E+13
.600E+01	.291E+16	.203E+19	.809E+12	.477E+13
.700E+01	.390E+16	.239E+19	.128E+13	.646E+13
.800E+01	.502E+16	.276E+19	.191E+13	.839E+13
.900E+01	.625E+16	.313E+19	.271E+13	.105E+14
.100E+02	.759E+16	.351E+19	.370E+13	.129E+14
.200E+02	.257E+17	.751E+19	.280E+14	.471E+14
.300E+02	.494E+17	.118E+20	.872E+14	.945E+14
.400E+02	.759E+17	.161E+20	.190E+15	.150E+15
.500E+02	.104E+18	.206E+20	.341E+15	.209E+15
.600E+02	.132E+18	.250E+20	.543E+15	.271E+15
.700E+02	.161E+18	.295E+20	.798E+15	.333E+15
.800E+02	.190E+18	.340E+20	.110E+16	.396E+15
.900E+02	.219E+18	.385E+20	.146E+16	.459E+15
.100E+03	.248E+18	.430E+20	.187E+16	.521E+15
.200E+03	.529E+18	.881E+20	.876E+16	.113E+16
.300E+03	.801E+18	.133E+21	.205E+17	.172E+16
.400E+03	.106E+19	.179E+21	.367E+17	.229E+16
.500E+03	.131E+19	.224E+21	.572E+17	.283E+16
.600E+03	.154E+19	.269E+21	.814E+17	.334E+16
.700E+03	.177E+19	.315E+21	.109E+18	.384E+16
.800E+03	.199E+19	.360E+21	.140E+18	.431E+16
.900E+03	.220E+19	.406E+21	.175E+18	.476E+16
.100E+04	.240E+19	.451E+21	.212E+18	.520E+16
.200E+04	.397E+19	.906E+21	.680E+18	.863E+16
.300E+04	.500E+19	.136E+22	.124E+19	.109E+17
.400E+04	.565E+19	.181E+22	.180E+19	.123E+17
.500E+04	.608E+19	.225E+22	.232E+19	.132E+17
.600E+04	.637E+19	.269E+22	.276E+19	.138E+17
.700E+04	.654E+19	.312E+22	.314E+19	.142E+17
.800E+04	.666E+19	.354E+22	.345E+19	.145E+17
.900E+04	.673E+19	.396E+22	.370E+19	.146E+17
.100E+05	.678E+19	.438E+22	.389E+19	.147E+17
.200E+05	.687E+19	.823E+22	.454E+19	.149E+17
.300E+05	.687E+19	.116E+23	.460E+19	.149E+17
.400E+05	.687E+19	.146E+23	.460E+19	.149E+17
.500E+05	.687E+19	.171E+23	.460E+19	.149E+17
.600E+05	.687E+19	.194E+23	.460E+19	.149E+17
.700E+05	.687E+19	.213E+23	.460E+19	.149E+17
.800E+05	.687E+19	.231E+23	.460E+19	.149E+17
.900E+05	.687E+19	.246E+23	.460E+19	.149E+17
.100E+06	.687E+19	.259E+23	.460E+19	.149E+17
.200E+06	.687E+19	.326E+23	.460E+19	.149E+17
.300E+06	.687E+19	.344E+23	.460E+19	.149E+17
.400E+06	.687E+19	.349E+23	.460E+19	.149E+17
.500E+06	.687E+19	.350E+23	.460E+19	.149E+17
.600E+06	.687E+19	.350E+23	.460E+19	.149E+17
.700E+06	.687E+19	.350E+23	.460E+19	.149E+17
.800E+06	.687E+19	.350E+23	.460E+19	.149E+17
.900E+06	.687E+19	.350E+23	.460E+19	.149E+17

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

```
                 INITIAL
              RADIONUCLIDE
                 AMOUNT
                 (ATOMS)

ZONE 1-SED.     .000E+00
ZONE 1-S.W.     .000E+00
ZONE 1-G.W.     .000E+00
ZONE 1-SOIL     .000E+00

              KD(L/KG)

ZONE 1-SED.     .500E+05
ZONE 1-S.W.     .100E+06
ZONE 1-G.W.     .500E+05
ZONE 1-SOIL     .100E+05

                                                    TRANSFER MATRIX
                                                      (YEAR**-1)

                                                    ORIGIN  CELLS

                 1            2            3            4


DESTINATION
   CELLS



     1      -.15240E+00  .23805E+02  .64104E-19  .90917E-17



     2       .10000E+00 -.28606E+02  .27692E-05  .35999E-04



     3       .19121E-16  .45517E-14 -.11771E-04  .86362E-04



     4       .19121E-16  .16550E-01  .64104E-19 -.13136E-03
```

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

TIME (YR)	230TH AMOUNTS (ATOMS) CELL 1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.540E+09	.679E+11	.797E-02	.375E+06
.200E-02	.479E+10	.332E+12	.133E+00	.333E+07
.300E-02	.185E+11	.868E+12	.767E+00	.129E+08
.400E-02	.484E+11	.169E+13	.268E+01	.336E+08
.500E-02	.101E+12	.279E+13	.704E+01	.703E+08
.600E-02	.183E+12	.417E+13	.154E+02	.127E+09
.700E-02	.302E+12	.582E+13	.298E+02	.210E+09
.800E-02	.463E+12	.774E+13	.526E+02	.322E+09
.900E-02	.672E+12	.990E+13	.864E+02	.467E+09
.100E-01	.936E+12	.123E+14	.135E+03	.651E+09
.200E-01	.777E+13	.487E+14	.233E+04	.541E+10
.300E-01	.255E+14	.103E+15	.117E+05	.178E+11
.400E-01	.579E+14	.172E+15	.362E+05	.403E+11
.500E-01	.108E+15	.250E+15	.857E+05	.751E+11
.600E-01	.177E+15	.336E+15	.172E+06	.124E+12
.700E-01	.268E+15	.429E+15	.307E+06	.187E+12
.800E-01	.381E+15	.525E+15	.505E+06	.266E+12
.900E-01	.517E+15	.625E+15	.781E+06	.361E+12
.100E+00	.677E+15	.728E+15	.115E+07	.473E+12
.200E+00	.366E+16	.181E+16	.138E+08	.257E+13
.300E+00	.921E+16	.293E+16	.553E+08	.649E+13
.400E+00	.173E+17	.407E+16	.146E+09	.123E+14
.500E+00	.280E+17	.519E+16	.310E+09	.199E+14
.600E+00	.412E+17	.634E+16	.571E+09	.295E+14
.700E+00	.570E+17	.751E+16	.957E+09	.410E+14
.800E+00	.753E+17	.869E+16	.150E+10	.544E+14
.900E+00	.961E+17	.988E+16	.223E+10	.698E+14
.100E+01	.119E+18	.111E+17	.319E+10	.871E+14
.200E+01	.489E+18	.238E+17	.376E+11	.374E+15
.300E+01	.110E+19	.376E+17	.154E+12	.862E+15
.400E+01	.194E+19	.524E+17	.429E+12	.163E+16
.500E+01	.300E+19	.683E+17	.964E+12	.263E+16
.600E+01	.428E+19	.853E+17	.188E+13	.390E+16
.700E+01	.576E+19	.103E+18	.333E+13	.546E+16
.800E+01	.744E+19	.122E+18	.548E+13	.733E+16
.900E+01	.930E+19	.141E+18	.851E+13	.951E+16
.100E+02	.113E+20	.162E+18	.126E+14	.120E+17
.200E+02	.401E+20	.402E+18	.198E+15	.583E+17
.300E+02	.797E+20	.690E+18	.860E+15	.149E+18
.400E+02	.125E+21	.100E+19	.243E+16	.289E+18
.500E+02	.175E+21	.133E+19	.542E+16	.483E+18
.600E+02	.227E+21	.167E+19	.104E+17	.733E+18
.700E+02	.280E+21	.201E+19	.178E+17	.104E+19
.800E+02	.333E+21	.235E+19	.284E+17	.140E+19
.900E+02	.387E+21	.270E+19	.426E+17	.182E+19
.100E+03	.442E+21	.305E+19	.611E+17	.230E+19
.200E+03	.989E+21	.653E+19	.642E+18	.102E+20
.300E+03	.153E+22	.100E+20	.225E+19	.238E+20
.400E+03	.209E+22	.136E+20	.539E+19	.431E+20
.500E+03	.263E+22	.170E+20	.106E+20	.680E+20
.600E+03	.318E+22	.205E+20	.182E+20	.983E+20
.700E+03	.373E+22	.241E+20	.287E+20	.134E+21
.800E+03	.428E+22	.275E+20	.425E+20	.175E+21
.900E+03	.484E+22	.311E+20	.599E+20	.221E+21
.100E+04	.538E+22	.346E+20	.812E+20	.273E+21
.200E+04	.109E+23	.697E+20	.578E+21	.106E+22
.300E+04	.164E+23	.105E+21	.167E+22	.230E+22
.400E+04	.218E+23	.139E+21	.343E+22	.392E+22
.500E+04	.271E+23	.173E+21	.586E+22	.588E+22

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.600E+04	.324E+23	.207E+21	.892E+22	.813E+22
.700E+04	.376E+23	.240E+21	.125E+23	.106E+23
.800E+04	.426E+23	.273E+21	.167E+23	.133E+23
.900E+04	.477E+23	.305E+21	.213E+23	.162E+23
.100E+05	.527E+23	.337E+21	.264E+23	.192E+23
.200E+05	.991E+23	.634E+21	.926E+23	.529E+23
.300E+05	.140E+24	.894E+21	.183E+24	.872E+23
.400E+05	.176E+24	.112E+22	.290E+24	.119E+24
.500E+05	.206E+24	.132E+22	.410E+24	.146E+24
.600E+05	.234E+24	.149E+22	.537E+24	.171E+24
.700E+05	.256E+24	.164E+22	.669E+24	.192E+24
.800E+05	.278E+24	.178E+22	.803E+24	.211E+24
.900E+05	.296E+24	.190E+22	.935E+24	.227E+24
.100E+06	.312E+24	.200E+22	.107E+25	.241E+24
.200E+06	.392E+24	.251E+22	.205E+25	.312E+24
.300E+06	.414E+24	.265E+22	.255E+25	.333E+24
.400E+06	.420E+24	.269E+22	.277E+25	.339E+24
.500E+06	.421E+24	.270E+22	.285E+25	.340E+24
.600E+06	.421E+24	.270E+22	.287E+25	.340E+24
.700E+06	.421E+24	.270E+22	.288E+25	.340E+24
.800E+06	.421E+24	.270E+22	.288E+25	.340E+24
.900E+06	.421E+24	.270E+22	.288E+25	.340E+24

***** ANALYSES FOR RADIONUCLIDE 226RA *****

RADIOACTIVE HALF-LIFE= .160E+04 YEARS
RADIOACTIVE DECAY RATE= .433E-03 YEARS**-1

	PHYSICAL DECAY RATE (YEARS**-1)
ZONE 1-SED.	.000E+00
ZONE 1-S.W.	.000E+00
ZONE 1-G.W.	.000E+00
ZONE 1-SOIL	.000E+00

226RA EXTERNAL INPUT RATES (ATOMS/YR)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.000E+00	.267E+14	.000E+00	.000E+00
.200E-02	.000E+00	.841E+14	.000E+00	.000E+00
.300E-02	.000E+00	.147E+15	.000E+00	.000E+00
.400E-02	.000E+00	.212E+15	.000E+00	.000E+00
.500E-02	.000E+00	.278E+15	.000E+00	.000E+00
.600E-02	.000E+00	.343E+15	.000E+00	.000E+00
.700E-02	.000E+00	.409E+15	.000E+00	.000E+00
.800E-02	.000E+00	.475E+15	.000E+00	.000E+00
.900E-02	.000E+00	.541E+15	.000E+00	.000E+00
.100E-01	.000E+00	.607E+15	.000E+00	.000E+00
.200E-01	.000E+00	.126E+16	.000E+00	.000E+00
.300E-01	.000E+00	.192E+16	.000E+00	.000E+00
.400E-01	.000E+00	.258E+16	.000E+00	.000E+00
.500E-01	.000E+00	.324E+16	.000E+00	.000E+00

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.600E-01	.000E+00	.390E+16	.000E+00	.000E+00
.700E-01	.000E+00	.456E+16	.000E+00	.000E+00
.800E-01	.000E+00	.522E+16	.000E+00	.000E+00
.900E-01	.000E+00	.588E+16	.000E+00	.000E+00
.100E+00	.000E+00	.654E+16	.000E+00	.000E+00
.200E+00	.000E+00	.131E+17	.000E+00	.000E+00
.300E+00	.000E+00	.198E+17	.000E+00	.000E+00
.400E+00	.000E+00	.264E+17	.000E+00	.000E+00
.500E+00	.000E+00	.331E+17	.000E+00	.000E+00
.600E+00	.000E+00	.398E+17	.000E+00	.000E+00
.700E+00	.000E+00	.465E+17	.000E+00	.000E+00
.800E+00	.000E+00	.532E+17	.000E+00	.000E+00
.900E+00	.000E+00	.600E+17	.000E+00	.000E+00
.100E+01	.000E+00	.667E+17	.000E+00	.000E+00
.200E+01	.000E+00	.135E+18	.000E+00	.000E+00
.300E+01	.000E+00	.206E+18	.000E+00	.000E+00
.400E+01	.000E+00	.278E+18	.000E+00	.000E+00
.500E+01	.000E+00	.351E+18	.000E+00	.000E+00
.600E+01	.000E+00	.426E+18	.000E+00	.000E+00
.700E+01	.000E+00	.502E+18	.000E+00	.000E+00
.800E+01	.000E+00	.579E+18	.000E+00	.000E+00
.900E+01	.000E+00	.658E+18	.000E+00	.000E+00
.100E+02	.000E+00	.737E+18	.000E+00	.000E+00
.200E+02	.000E+00	.158E+19	.000E+00	.000E+00
.300E+02	.000E+00	.247E+19	.000E+00	.000E+00
.400E+02	.000E+00	.338E+19	.000E+00	.000E+00
.500E+02	.000E+00	.431E+19	.000E+00	.000E+00
.600E+02	.000E+00	.524E+19	.000E+00	.000E+00
.700E+02	.000E+00	.617E+19	.000E+00	.000E+00
.800E+02	.000E+00	.711E+19	.000E+00	.000E+00
.900E+02	.000E+00	.804E+19	.000E+00	.000E+00
.100E+03	.000E+00	.898E+19	.000E+00	.000E+00
.200E+03	.000E+00	.183E+20	.000E+00	.000E+00
.300E+03	.000E+00	.276E+20	.000E+00	.000E+00
.400E+03	.000E+00	.369E+20	.000E+00	.000E+00
.500E+03	.000E+00	.461E+20	.000E+00	.000E+00
.600E+03	.000E+00	.553E+20	.000E+00	.000E+00
.700E+03	.000E+00	.645E+20	.000E+00	.000E+00
.800E+03	.000E+00	.736E+20	.000E+00	.000E+00
.900E+03	.000E+00	.827E+20	.000E+00	.000E+00
.100E+04	.000E+00	.918E+20	.000E+00	.000E+00
.200E+04	.000E+00	.181E+21	.000E+00	.000E+00
.300E+04	.000E+00	.268E+21	.000E+00	.000E+00
.400E+04	.000E+00	.354E+21	.000E+00	.000E+00
.500E+04	.000E+00	.439E+21	.000E+00	.000E+00
.600E+04	.000E+00	.522E+21	.000E+00	.000E+00
.700E+04	.000E+00	.604E+21	.000E+00	.000E+00
.800E+04	.000E+00	.685E+21	.000E+00	.000E+00
.900E+04	.000E+00	.764E+21	.000E+00	.000E+00
.100E+05	.000E+00	.843E+21	.000E+00	.000E+00
.200E+05	.000E+00	.157E+22	.000E+00	.000E+00
.300E+05	.000E+00	.221E+22	.000E+00	.000E+00
.400E+05	.000E+00	.277E+22	.000E+00	.000E+00
.500E+05	.000E+00	.326E+22	.000E+00	.000E+00
.600E+05	.000E+00	.369E+22	.000E+00	.000E+00
.700E+05	.000E+00	.406E+22	.000E+00	.000E+00
.800E+05	.000E+00	.439E+22	.000E+00	.000E+00
.900E+05	.000E+00	.468E+22	.000E+00	.000E+00
.100E+06	.000E+00	.493E+22	.000E+00	.000E+00
.200E+06	.000E+00	.620E+22	.000E+00	.000E+00
.300E+06	.000E+00	.654E+22	.000E+00	.000E+00
.400E+06	.000E+00	.663E+22	.000E+00	.000E+00
.500E+06	.000E+00	.665E+22	.000E+00	.000E+00
.600E+06	.000E+00	.666E+22	.000E+00	.000E+00
.700E+06	.000E+00	.666E+22	.000E+00	.000E+00
.800E+06	.000E+00	.666E+22	.000E+00	.000E+00
.900E+06	.000E+00	.666E+22	.000E+00	.000E+00

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

226RA TOTAL INPUT RATES (ATOMS/YR)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.486E+04	.287E+14	.718E-07	.338E+01
.200E-02	.431E+05	.841E+14	.119E-05	.300E+02
.300E-02	.167E+06	.147E+15	.691E-05	.116E+03
.400E-02	.435E+06	.212E+15	.241E-04	.303E+03
.500E-02	.910E+06	.278E+15	.633E-04	.633E+03
.600E-02	.165E+07	.343E+15	.139E-03	.115E+04
.700E-02	.272E+07	.409E+15	.268E-03	.189E+04
.800E-02	.416E+07	.475E+15	.473E-03	.290E+04
.900E-02	.605E+07	.541E+15	.778E-03	.421E+04
.100E-01	.842E+07	.607E+15	.121E-02	.586E+04
.200E-01	.700E+08	.126E+16	.210E-01	.487E+05
.300E-01	.230E+09	.192E+16	.106E+00	.160E+06
.400E-01	.521E+09	.258E+16	.326E+00	.363E+06
.500E-01	.970E+09	.324E+16	.771E+00	.676E+06
.600E-01	.160E+10	.390E+16	.155E+01	.111E+07
.700E-01	.241E+10	.456E+16	.276E+01	.168E+07
.800E-01	.343E+10	.522E+16	.455E+01	.239E+07
.900E-01	.466E+10	.588E+16	.703E+01	.325E+07
.100E+00	.610E+10	.654E+16	.103E+02	.426E+07
.200E+00	.329E+11	.131E+17	.124E+03	.231E+08
.300E+00	.829E+11	.198E+17	.498E+03	.584E+08
.400E+00	.156E+12	.264E+17	.132E+04	.111E+09
.500E+00	.252E+12	.331E+17	.279E+04	.180E+09
.600E+00	.371E+12	.398E+17	.514E+04	.265E+09
.700E+00	.513E+12	.465E+17	.862E+04	.369E+09
.800E+00	.678E+12	.532E+17	.135E+05	.490E+09
.900E+00	.865E+12	.600E+17	.201E+05	.628E+09
.100E+01	.107E+13	.667E+17	.287E+05	.784E+09
.200E+01	.440E+13	.135E+18	.338E+06	.337E+10
.300E+01	.990E+13	.206E+18	.139E+07	.794E+10
.400E+01	.175E+14	.278E+18	.387E+07	.146E+11
.500E+01	.270E+14	.351E+18	.868E+07	.236E+11
.600E+01	.385E+14	.426E+18	.169E+08	.351E+11
.700E+01	.519E+14	.502E+18	.300E+08	.492E+11
.800E+01	.670E+14	.579E+18	.493E+08	.660E+11
.900E+01	.837E+14	.658E+18	.766E+08	.857E+11
.100E+02	.102E+15	.737E+18	.114E+09	.108E+12
.200E+02	.361E+15	.158E+19	.179E+10	.525E+12
.300E+02	.717E+15	.247E+19	.774E+10	.134E+13
.400E+02	.113E+16	.338E+19	.219E+11	.261E+13
.500E+02	.158E+16	.431E+19	.488E+11	.435E+13
.600E+02	.204E+16	.524E+19	.933E+11	.660E+13
.700E+02	.252E+16	.617E+19	.160E+12	.935E+13
.800E+02	.300E+16	.711E+19	.255E+12	.126E+14
.900E+02	.349E+16	.804E+19	.383E+12	.164E+14
.100E+03	.398E+16	.898E+19	.550E+12	.207E+14
.200E+03	.889E+16	.183E+20	.578E+13	.921E+14
.300E+03	.138E+17	.276E+20	.202E+14	.215E+15
.400E+03	.188E+17	.369E+20	.485E+14	.388E+15
.500E+03	.237E+17	.461E+20	.950E+14	.612E+15
.600E+03	.286E+17	.553E+20	.164E+15	.885E+15
.700E+03	.336E+17	.645E+20	.258E+15	.121E+16
.800E+03	.385E+17	.736E+20	.382E+15	.158E+16
.900E+03	.435E+17	.827E+20	.539E+15	.199E+16
.100E+04	.484E+17	.918E+20	.731E+15	.246E+16
.200E+04	.979E+17	.181E+21	.520E+16	.955E+16

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.300E+04	.147E+18	.268E+21	.150E+17	.207E+17
.400E+04	.196E+18	.354E+21	.309E+17	.353E+17
.500E+04	.244E+18	.439E+21	.527E+17	.530E+17
.600E+04	.291E+18	.522E+21	.803E+17	.732E+17
.700E+04	.338E+18	.604E+21	.113E+18	.956E+17
.800E+04	.384E+18	.685E+21	.150E+18	.120E+18
.900E+04	.429E+18	.764E+21	.192E+18	.146E+18
.100E+05	.475E+18	.843E+21	.237E+18	.173E+18
.200E+05	.892E+18	.157E+22	.833E+18	.476E+18
.300E+05	.126E+19	.221E+22	.165E+19	.785E+18
.400E+05	.158E+19	.277E+22	.261E+19	.107E+19
.500E+05	.185E+19	.326E+22	.369E+19	.132E+19
.600E+05	.210E+19	.369E+22	.484E+19	.154E+19
.700E+05	.231E+19	.406E+22	.602E+19	.173E+19
.800E+05	.250E+19	.439E+22	.722E+19	.190E+19
.900E+05	.267E+19	.468E+22	.842E+19	.204E+19
.100E+06	.281E+19	.493E+22	.960E+19	.217E+19
.200E+06	.353E+19	.620E+22	.164E+20	.281E+19
.300E+06	.373E+19	.654E+22	.230E+20	.300E+19
.400E+06	.378E+19	.663E+22	.249E+20	.305E+19
.500E+06	.379E+19	.665E+22	.256E+20	.306E+19
.600E+06	.379E+19	.666E+22	.259E+20	.306E+19
.700E+06	.379E+19	.666E+22	.259E+20	.306E+19
.800E+06	.379E+19	.666E+22	.260E+20	.306E+19
.900E+06	.379E+19	.666E+22	.260E+20	.306E+19

	INITIAL RADIONUCLIDE AMOUNT (ATOMS)
ZONE 1-SED.	.000E+00
ZONE 1-S.W.	.000E+00
ZONE 1-G.W.	.000E+00
ZONE 1-SOIL	.000E+00

	KD(L/KG)
ZONE 1-SED.	.500E+04
ZONE 1-S.W.	.500E+05
ZONE 1-G.W.	.500E+04
ZONE 1-SOIL	.100E+02

TRANSFER MATRIX
(YEAR**-1)

ORIGIN CELLS

DESTINATION CELLS	1	2	3	4
1	-.15282E+00	.21055E+02	.64113E-19	.98232E-17

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

2	.10000E+00	-.25859E+02	.27691E-04	.21268E-01
3	.19123E-16	.40258E-14	-.46091E-03	.84837E-01
4	.19123E-16	.16554E-01	.64113E-19	-.10654E+00

226RA AMOUNTS (ATOMS)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.100E+09	.142E+11	.167E+01	.787E+05
.200E-02	.888E+09	.697E+11	.281E+02	.699E+06
.300E-02	.343E+10	.182E+12	.159E+03	.270E+07
.400E-02	.898E+10	.355E+12	.553E+03	.706E+07
.500E-02	.188E+11	.588E+12	.145E+04	.148E+08
.600E-02	.341E+11	.879E+12	.318E+04	.268E+08
.700E-02	.562E+11	.123E+13	.616E+04	.442E+08
.800E-02	.862E+11	.163E+13	.109E+05	.678E+08
.900E-02	.125E+12	.209E+13	.179E+05	.986E+08
.100E-01	.175E+12	.261E+13	.278E+05	.137E+09
.200E-01	.146E+13	.104E+14	.482E+06	.115E+10
.300E-01	.481E+13	.221E+14	.244E+07	.379E+10
.400E-01	.110E+14	.371E+14	.754E+07	.864E+10
.500E-01	.206E+14	.544E+14	.179E+08	.162E+11
.600E-01	.340E+14	.736E+14	.358E+08	.267E+11
.700E-01	.515E+14	.943E+14	.641E+08	.406E+11
.800E-01	.736E+14	.116E+15	.106E+09	.579E+11
.900E-01	.100E+15	.139E+15	.163E+09	.789E+11
.100E+00	.132E+15	.162E+15	.241E+09	.104E+12
.200E+00	.726E+15	.411E+15	.282E+10	.572E+12
.300E+00	.184E+16	.671E+15	.111E+11	.146E+13
.400E+00	.349E+16	.933E+15	.287E+11	.276E+13
.500E+00	.567E+16	.120E+16	.592E+11	.449E+13
.600E+00	.837E+16	.147E+16	.106E+12	.663E+13
.700E+00	.116E+17	.174E+16	.173E+12	.920E+13
.800E+00	.153E+17	.201E+16	.263E+12	.122E+14
.900E+00	.196E+17	.229E+16	.381E+12	.156E+14
.100E+01	.244E+17	.257E+16	.529E+12	.194E+14
.200E+01	.100E+18	.549E+16	.449E+13	.809E+14
.300E+01	.225E+18	.871E+16	.154E+14	.184E+15
.400E+01	.397E+18	.122E+17	.369E+14	.330E+15
.500E+01	.614E+18	.158E+17	.725E+14	.516E+15

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.600E+01	.875E+18	.197E+17	.126E+15	.743E+15
.700E+01	.118E+19	.238E+17	.200E+15	.101E+16
.800E+01	.152E+19	.281E+17	.298E+15	.132E+16
.900E+01	.190E+19	.326E+17	.424E+15	.166E+16
.100E+02	.231E+19	.373E+17	.580E+15	.204E+16
.200E+02	.813E+19	.923E+17	.449E+16	.771E+16
.300E+02	.160E+20	.157E+18	.143E+17	.159E+17
.400E+02	.252E+20	.228E+18	.318E+17	.257E+17
.500E+02	.350E+20	.302E+18	.579E+17	.365E+17
.600E+02	.452E+20	.377E+18	.933E+17	.478E+17
.700E+02	.556E+20	.454E+18	.138E+18	.595E+17
.800E+02	.662E+20	.531E+18	.193E+18	.714E+17
.900E+02	.768E+20	.608E+18	.258E+18	.833E+17
.100E+03	.875E+20	.685E+18	.332E+18	.954E+17
.200E+03	.194E+21	.146E+19	.161E+19	.216E+18
.300E+03	.300E+21	.223E+19	.384E+19	.337E+18
.400E+03	.406E+21	.300E+19	.697E+19	.458E+18
.500E+03	.511E+21	.376E+19	.110E+20	.579E+18
.600E+03	.616E+21	.452E+19	.158E+20	.700E+18
.700E+03	.721E+21	.528E+19	.214E+20	.821E+18
.800E+03	.825E+21	.604E+19	.278E+20	.942E+18
.900E+03	.929E+21	.679E+19	.349E+20	.106E+19
.100E+04	.103E+22	.755E+19	.427E+20	.118E+19
.200E+04	.205E+22	.149E+20	.154E+21	.240E+19
.300E+04	.305E+22	.221E+20	.314E+21	.362E+19
.400E+04	.403E+22	.293E+20	.509E+21	.487E+19
.500E+04	.500E+22	.363E+20	.732E+21	.613E+19
.600E+04	.595E+22	.432E+20	.978E+21	.739E+19
.700E+04	.688E+22	.500E+20	.124E+22	.865E+19
.800E+04	.781E+22	.567E+20	.153E+22	.992E+19
.900E+04	.871E+22	.632E+20	.182E+22	.112E+20
.100E+05	.961E+22	.698E+20	.213E+22	.125E+20
.200E+05	.179E+23	.130E+21	.558E+22	.247E+20
.300E+05	.252E+23	.183E+21	.933E+22	.358E+20
.400E+05	.316E+23	.229E+21	.132E+23	.457E+20
.500E+05	.372E+23	.270E+21	.172E+23	.543E+20
.600E+05	.421E+23	.306E+21	.210E+23	.619E+20
.700E+05	.464E+23	.336E+21	.249E+23	.685E+20
.800E+05	.501E+23	.364E+21	.286E+23	.743E+20
.900E+05	.534E+23	.388E+21	.321E+23	.794E+20
.100E+06	.563E+23	.408E+21	.355E+23	.839E+20
.200E+06	.708E+23	.514E+21	.590E+23	.106E+21
.300E+06	.747E+23	.542E+21	.703E+23	.112E+21
.400E+06	.757E+23	.549E+21	.749E+23	.114E+21
.500E+06	.759E+23	.551E+21	.766E+23	.114E+21
.600E+06	.761E+23	.552E+21	.772E+23	.114E+21
.700E+06	.761E+23	.552E+21	.773E+23	.114E+21
.800E+06	.761E+23	.552E+21	.774E+23	.114E+21
.900E+06	.761E+23	.552E+21	.774E+23	.114E+21

***** ANALYSES FOR RADIONUCLIDE 222RN *****

RADIOACTIVE HALF-LIFE= .105E-01 YEARS
RADIOACTIVE DECAY RATE= .661E+02 YEARS**-1

	PHYSICAL DECAY RATE (YEARS**-1)
ZONE 1-SED.	.607E+04
ZONE 1-S.W.	.364E+06
ZONE 1-G.W.	.000E+00
ZONE 1-SOIL	.514E+02

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

222RN EXTERNAL INPUT RATES (ATOMS/YR)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.000E+00	.490E+11	.000E+00	.000E+00
.200E-02	.000E+00	.981E+11	.000E+00	.000E+00
.300E-02	.000E+00	.147E+12	.000E+00	.000E+00
.400E-02	.000E+00	.196E+12	.000E+00	.000E+00
.500E-02	.000E+00	.245E+12	.000E+00	.000E+00
.600E-02	.000E+00	.294E+12	.000E+00	.000E+00
.700E-02	.000E+00	.343E+12	.000E+00	.000E+00
.800E-02	.000E+00	.392E+12	.000E+00	.000E+00
.900E-02	.000E+00	.440E+12	.000E+00	.000E+00
.100E-01	.000E+00	.489E+12	.000E+00	.000E+00
.200E-01	.000E+00	.975E+12	.000E+00	.000E+00
.300E-01	.000E+00	.146E+13	.000E+00	.000E+00
.400E-01	.000E+00	.194E+13	.000E+00	.000E+00
.500E-01	.000E+00	.243E+13	.000E+00	.000E+00
.600E-01	.000E+00	.291E+13	.000E+00	.000E+00
.700E-01	.000E+00	.339E+13	.000E+00	.000E+00
.800E-01	.000E+00	.388E+13	.000E+00	.000E+00
.900E-01	.000E+00	.436E+13	.000E+00	.000E+00
.100E+00	.000E+00	.484E+13	.000E+00	.000E+00
.200E+00	.000E+00	.967E+13	.000E+00	.000E+00
.300E+00	.000E+00	.145E+14	.000E+00	.000E+00
.400E+00	.000E+00	.193E+14	.000E+00	.000E+00
.500E+00	.000E+00	.242E+14	.000E+00	.000E+00
.600E+00	.000E+00	.290E+14	.000E+00	.000E+00
.700E+00	.000E+00	.338E+14	.000E+00	.000E+00
.800E+00	.000E+00	.386E+14	.000E+00	.000E+00
.900E+00	.000E+00	.435E+14	.000E+00	.000E+00
.100E+01	.000E+00	.483E+14	.000E+00	.000E+00
.200E+01	.000E+00	.966E+14	.000E+00	.000E+00
.300E+01	.000E+00	.145E+15	.000E+00	.000E+00
.400E+01	.000E+00	.193E+15	.000E+00	.000E+00
.500E+01	.000E+00	.241E+15	.000E+00	.000E+00
.600E+01	.000E+00	.290E+15	.000E+00	.000E+00
.700E+01	.000E+00	.338E+15	.000E+00	.000E+00
.800E+01	.000E+00	.386E+15	.000E+00	.000E+00
.900E+01	.000E+00	.434E+15	.000E+00	.000E+00
.100E+02	.000E+00	.483E+15	.000E+00	.000E+00
.200E+02	.000E+00	.965E+15	.000E+00	.000E+00
.300E+02	.000E+00	.145E+16	.000E+00	.000E+00
.400E+02	.000E+00	.193E+16	.000E+00	.000E+00
.500E+02	.000E+00	.241E+16	.000E+00	.000E+00
.600E+02	.000E+00	.289E+16	.000E+00	.000E+00
.700E+02	.000E+00	.337E+16	.000E+00	.000E+00
.800E+02	.000E+00	.386E+16	.000E+00	.000E+00
.900E+02	.000E+00	.434E+16	.000E+00	.000E+00
.100E+03	.000E+00	.482E+16	.000E+00	.000E+00
.200E+03	.000E+00	.962E+16	.000E+00	.000E+00
.300E+03	.000E+00	.144E+17	.000E+00	.000E+00
.400E+03	.000E+00	.192E+17	.000E+00	.000E+00
.500E+03	.000E+00	.239E+17	.000E+00	.000E+00
.600E+03	.000E+00	.286E+17	.000E+00	.000E+00
.700E+03	.000E+00	.333E+17	.000E+00	.000E+00
.800E+03	.000E+00	.380E+17	.000E+00	.000E+00
.900E+03	.000E+00	.427E+17	.000E+00	.000E+00
.100E+04	.000E+00	.474E+17	.000E+00	.000E+00
.200E+04	.000E+00	.933E+17	.000E+00	.000E+00

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.300E+04	.000E+00	.138E+18	.000E+00	.000E+00
.400E+04	.000E+00	.182E+18	.000E+00	.000E+00
.500E+04	.000E+00	.226E+18	.000E+00	.000E+00
.600E+04	.000E+00	.268E+18	.000E+00	.000E+00
.700E+04	.000E+00	.310E+18	.000E+00	.000E+00
.800E+04	.000E+00	.352E+18	.000E+00	.000E+00
.900E+04	.000E+00	.393E+18	.000E+00	.000E+00
.100E+05	.000E+00	.433E+18	.000E+00	.000E+00
.200E+05	.000E+00	.807E+18	.000E+00	.000E+00
.300E+05	.000E+00	.114E+19	.000E+00	.000E+00
.400E+05	.000E+00	.142E+19	.000E+00	.000E+00
.500E+05	.000E+00	.168E+19	.000E+00	.000E+00
.600E+05	.000E+00	.190E+19	.000E+00	.000E+00
.700E+05	.000E+00	.209E+19	.000E+00	.000E+00
.800E+05	.000E+00	.226E+19	.000E+00	.000E+00
.900E+05	.000E+00	.240E+19	.000E+00	.000E+00
.100E+06	.000E+00	.253E+19	.000E+00	.000E+00
.200E+06	.000E+00	.318E+19	.000E+00	.000E+00
.300E+06	.000E+00	.336E+19	.000E+00	.000E+00
.400E+06	.000E+00	.341E+19	.000E+00	.000E+00
.500E+06	.000E+00	.342E+19	.000E+00	.000E+00
.600E+06	.000E+00	.342E+19	.000E+00	.000E+00
.700E+06	.000E+00	.342E+19	.000E+00	.000E+00
.800E+06	.000E+00	.342E+19	.000E+00	.000E+00
.900E+06	.000E+00	.342E+19	.000E+00	.000E+00

222RN TOTAL INPUT RATES (ATOMS/YR)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.433E+05	.490E+11	.724E-03	.341E+02
.200E-02	.385E+06	.981E+11	.122E-01	.303E+03
.300E-02	.149E+07	.147E+12	.689E-01	.117E+04
.400E-02	.389E+07	.196E+12	.239E+00	.306E+04
.500E-02	.814E+07	.245E+12	.629E+00	.640E+04
.600E-02	.148E+08	.294E+12	.138E+01	.116E+05
.700E-02	.244E+08	.344E+12	.267E+01	.191E+05
.800E-02	.374E+08	.393E+12	.470E+01	.294E+05
.900E-02	.543E+08	.441E+12	.774E+01	.427E+05
.100E-01	.757E+08	.490E+12	.120E+02	.595E+05
.200E-01	.632E+09	.979E+12	.209E+03	.497E+06
.300E-01	.209E+10	.147E+13	.106E+04	.164E+07
.400E-01	.476E+10	.196E+13	.326E+04	.374E+07
.500E-01	.890E+10	.245E+13	.774E+04	.700E+07
.600E-01	.147E+11	.294E+13	.155E+05	.116E+08
.700E-01	.223E+11	.343E+13	.278E+05	.176E+08
.800E-01	.319E+11	.393E+13	.458E+05	.251E+08
.900E-01	.434E+11	.442E+13	.708E+05	.342E+08
.100E+00	.571E+11	.491E+13	.104E+06	.449E+08
.200E+00	.315E+12	.985E+13	.122E+07	.248E+09
.300E+00	.799E+12	.148E+14	.482E+07	.631E+09
.400E+00	.151E+13	.197E+14	.124E+08	.120E+10
.500E+00	.246E+13	.247E+14	.256E+08	.194E+10
.600E+00	.362E+13	.296E+14	.459E+08	.287E+10
.700E+00	.502E+13	.346E+14	.749E+08	.399E+10
.800E+00	.664E+13	.395E+14	.114E+09	.528E+10
.900E+00	.849E+13	.445E+14	.165E+09	.676E+10
.100E+01	.106E+14	.494E+14	.229E+09	.842E+10
.200E+01	.433E+14	.990E+14	.194E+10	.350E+11
.300E+01	.974E+14	.149E+15	.669E+10	.799E+11
.400E+01	.172E+15	.198E+15	.160E+11	.143E+12

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.500E+01	.266E+15	.248E+15	.314E+11	.224E+12
.600E+01	.379E+15	.299E+15	.544E+11	.322E+12
.700E+01	.510E+15	.346E+15	.865E+11	.438E+12
.800E+01	.657E+15	.398E+15	.129E+12	.570E+12
.900E+01	.821E+15	.448E+15	.184E+12	.719E+12
.100E+02	.100E+16	.499E+15	.251E+12	.884E+12
.200E+02	.352E+16	.100E+16	.194E+13	.334E+13
.300E+02	.695E+16	.152E+16	.620E+13	.689E+13
.400E+02	.109E+17	.203E+16	.138E+14	.111E+14
.500E+02	.152E+17	.254E+16	.251E+14	.158E+14
.600E+02	.196E+17	.305E+16	.404E+14	.207E+14
.700E+02	.241E+17	.357E+16	.599E+14	.258E+14
.800E+02	.287E+17	.409E+16	.836E+14	.309E+14
.900E+02	.333E+17	.460E+16	.112E+15	.361E+14
.100E+03	.379E+17	.512E+16	.144E+15	.413E+14
.200E+03	.840E+17	.103E+17	.698E+15	.936E+14
.300E+03	.130E+18	.154E+17	.166E+16	.146E+15
.400E+03	.176E+18	.205E+17	.302E+16	.198E+15
.500E+03	.222E+18	.255E+17	.475E+16	.251E+15
.600E+03	.267E+18	.306E+17	.684E+16	.303E+15
.700E+03	.313E+18	.356E+17	.927E+16	.356E+15
.800E+03	.358E+18	.406E+17	.120E+17	.408E+15
.900E+03	.403E+18	.456E+17	.151E+17	.460E+15
.100E+04	.448E+18	.507E+17	.185E+17	.513E+15
.200E+04	.889E+18	.998E+17	.669E+17	.104E+16
.300E+04	.132E+19	.148E+18	.136E+18	.157E+16
.400E+04	.174E+19	.195E+18	.220E+18	.211E+16
.500E+04	.217E+19	.242E+18	.317E+18	.265E+16
.600E+04	.256E+19	.287E+18	.424E+18	.320E+16
.700E+04	.298E+19	.332E+18	.539E+18	.375E+16
.800E+04	.338E+19	.377E+18	.661E+18	.430E+16
.900E+04	.377E+19	.420E+18	.789E+18	.484E+16
.100E+05	.416E+19	.463E+18	.922E+18	.539E+16
.200E+05	.776E+19	.863E+18	.242E+19	.107E+17
.300E+05	.109E+20	.122E+19	.404E+19	.155E+17
.400E+05	.137E+20	.152E+19	.573E+19	.198E+17
.500E+05	.161E+20	.180E+19	.743E+19	.235E+17
.600E+05	.182E+20	.203E+19	.912E+19	.268E+17
.700E+05	.201E+20	.224E+19	.108E+20	.297E+17
.800E+05	.217E+20	.242E+19	.124E+20	.322E+17
.900E+05	.231E+20	.257E+19	.139E+20	.344E+17
.100E+06	.244E+20	.271E+19	.154E+20	.363E+17
.200E+06	.307E+20	.340E+19	.256E+20	.460E+17
.300E+06	.324E+20	.359E+19	.305E+20	.487E+17
.400E+06	.328E+20	.365E+19	.324E+20	.494E+17
.500E+06	.329E+20	.366E+19	.332E+20	.495E+17
.600E+06	.329E+20	.366E+19	.334E+20	.496E+17
.700E+06	.329E+20	.366E+19	.335E+20	.496E+17
.800E+06	.329E+20	.366E+19	.335E+20	.496E+17
.900E+06	.329E+20	.366E+19	.335E+20	.496E+17

	INITIAL RADIONUCLIDE AMOUNT (ATOMS)
ZONE 1-SED.	.000E+00
ZONE 1-S.W.	.000E+00
ZONE 1-G.W.	.000E+00
ZONE 1-SOIL	.000E+00

	KD(L/KG)
ZONE 1-SED.	.000E+00
ZONE 1-S.W.	.000E+00
ZONE 1-G.W.	.000E+00
ZONE 1-SOIL	.000E+00

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

TRANSFER MATRIX
(YEAR**-1)

ORIGIN CELLS

DESTINATION CELLS	1	2	3	4
1	-.61363E+04	.70035E-03	.41841E-18	.50505E-16
2	.10000E+00	-.36407E+06	.90377E+00	.12020E+01
3	.49751E-16	.34843E-18	-.67044E+02	.47980E+01
4	.49751E-16	.16585E-01	.41841E-18	-.12354E+03

222RN AMOUNTS
(ATOMS)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.593E+01	.134E+06	.172E-02	.108E+01
.200E-02	.537E+02	.269E+06	.133E-01	.429E+01
.300E-02	.213E+03	.404E+06	.443E-01	.976E+01
.400E-02	.570E+03	.538E+06	.105E+00	.180E+02
.500E-02	.121E+04	.673E+06	.208E+00	.299E+02
.600E-02	.223E+04	.808E+06	.371E+00	.465E+02
.700E-02	.371E+04	.943E+06	.616E+00	.693E+02
.800E-02	.574E+04	.108E+07	.970E+00	.100E+03
.900E-02	.840E+04	.121E+07	.147E+01	.140E+03
.100E-01	.118E+05	.135E+07	.215E+01	.192E+03

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.200E-01	.102E+06	.269E+07	.398E+02	.211E+04
.300E-01	.336E+06	.404E+07	.195E+03	.774E+04
.400E-01	.769E+06	.537E+07	.594E+03	.194E+05
.500E-01	.144E+07	.674E+07	.138E+04	.390E+05
.600E-01	.238E+07	.808E+07	.269E+04	.680E+05
.700E-01	.362E+07	.942E+07	.466E+04	.108E+06
.800E-01	.517E+07	.108E+08	.739E+04	.159E+06
.900E-01	.705E+07	.121E+08	.110E+05	.223E+06
.100E+00	.926E+07	.135E+08	.155E+05	.299E+06
.200E+00	.512E+08	.270E+08	.133E+06	.188E+07
.300E+00	.130E+09	.406E+08	.379E+06	.486E+07
.400E+00	.246E+09	.541E+08	.787E+06	.932E+07
.500E+00	.400E+09	.679E+08	.138E+07	.153E+08
.600E+00	.590E+09	.814E+08	.218E+07	.227E+08
.700E+00	.818E+09	.949E+08	.322E+07	.316E+08
.800E+00	.108E+10	.108E+09	.450E+07	.419E+08
.900E+00	.138E+10	.122E+09	.607E+07	.538E+08
.100E+01	.172E+10	.136E+09	.793E+07	.671E+08
.200E+01	.706E+10	.272E+09	.486E+08	.282E+09
.300E+01	.159E+11	.409E+09	.144E+09	.644E+09
.400E+01	.280E+11	.545E+09	.319E+09	.115E+10
.500E+01	.434E+11	.681E+09	.594E+09	.180E+10
.600E+01	.618E+11	.820E+09	.992E+09	.260E+10
.700E+01	.830E+11	.957E+09	.153E+10	.353E+10
.800E+01	.107E+12	.109E+10	.224E+10	.461E+10
.900E+01	.134E+12	.123E+10	.314E+10	.581E+10
.100E+02	.163E+12	.137E+10	.424E+10	.715E+10
.200E+02	.574E+12	.276E+10	.309E+11	.270E+11
.300E+02	.113E+13	.417E+10	.964E+11	.557E+11
.400E+02	.178E+13	.557E+10	.212E+12	.901E+11
.500E+02	.247E+13	.698E+10	.383E+12	.128E+12
.600E+02	.319E+13	.839E+10	.614E+12	.168E+12
.700E+02	.393E+13	.980E+10	.908E+12	.209E+12
.800E+02	.467E+13	.112E+11	.126E+13	.250E+12
.900E+02	.542E+13	.127E+11	.168E+13	.292E+12
.100E+03	.617E+13	.141E+11	.217E+13	.334E+12
.200E+03	.137E+14	.282E+11	.105E+14	.757E+12
.300E+03	.212E+14	.423E+11	.249E+14	.118E+13
.400E+03	.287E+14	.564E+11	.451E+14	.161E+13
.500E+03	.361E+14	.703E+11	.710E+14	.203E+13
.600E+03	.435E+14	.842E+11	.102E+15	.245E+13
.700E+03	.509E+14	.981E+11	.138E+15	.288E+13
.800E+03	.583E+14	.112E+12	.180E+15	.330E+13
.900E+03	.656E+14	.126E+12	.226E+15	.373E+13
.100E+04	.729E+14	.140E+12	.276E+15	.415E+13
.200E+04	.145E+15	.277E+12	.998E+15	.841E+13
.300E+04	.215E+15	.411E+12	.203E+16	.127E+14
.400E+04	.284E+15	.543E+12	.329E+16	.171E+14
.500E+04	.353E+15	.676E+12	.473E+16	.215E+14
.600E+04	.420E+15	.803E+12	.632E+16	.259E+14
.700E+04	.486E+15	.931E+12	.804E+16	.303E+14
.800E+04	.551E+15	.106E+13	.986E+16	.348E+14
.900E+04	.615E+15	.118E+13	.118E+17	.392E+14
.100E+05	.679E+15	.131E+13	.138E+17	.437E+14
.200E+05	.126E+16	.246E+13	.361E+17	.865E+14
.300E+05	.178E+16	.350E+13	.603E+17	.126E+15
.400E+05	.223E+16	.439E+13	.855E+17	.160E+15
.500E+05	.263E+16	.521E+13	.111E+18	.190E+15
.600E+05	.297E+16	.592E+13	.136E+18	.217E+15
.700E+05	.327E+16	.654E+13	.161E+18	.240E+15
.800E+05	.354E+16	.710E+13	.185E+18	.261E+15
.900E+05	.377E+16	.757E+13	.208E+18	.279E+15
.100E+06	.397E+16	.801E+13	.230E+18	.294E+15
.200E+06	.500E+16	.103E+14	.381E+18	.372E+15
.300E+06	.527E+16	.110E+14	.454E+18	.394E+15
.400E+06	.535E+16	.112E+14	.484E+18	.400E+15
.500E+06	.536E+16	.113E+14	.495E+18	.401E+15
.600E+06	.537E+16	.113E+14	.499E+18	.401E+15
.700E+06	.537E+16	.113E+14	.500E+18	.401E+15
.800E+06	.537E+16	.113E+14	.500E+18	.401E+15
.900E+06	.537E+16	.113E+14	.500E+18	.401E+15

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

```
*****    ANALYSES FOR RADIONUCLIDE  210PB    *****

RADIOACTIVE HALF-LIFE=  .223E+02 YEARS
RADIOACTIVE DECAY RATE=  .311E-01 YEARS**-1

                PHYSICAL
                 DECAY
                  RATE
              (YEARS**-1)

ZONE 1-SED.     .000E+00
ZONE 1-S.W.     .000E+00
ZONE 1-G.W.     .000E+00
ZONE 1-SOIL     .000E+00

                                                  210PB    EXTERNAL INPUT RATES
                                                           (ATOMS/YR)

                                                              CELL

                 1            2            3            4
   TIME
   (YR)

 .000E+00   .000E+00    .000E+00    .000E+00    .000E+00
 .100E-02   .000E+00    .408E+13    .000E+00    .000E+00
 .200E-02   .000E+00    .122E+14    .000E+00    .000E+00
 .300E-02   .000E+00    .214E+14    .000E+00    .000E+00
 .400E-02   .000E+00    .311E+14    .000E+00    .000E+00
 .500E-02   .000E+00    .409E+14    .000E+00    .000E+00
 .600E-02   .000E+00    .507E+14    .000E+00    .000E+00
 .700E-02   .000E+00    .605E+14    .000E+00    .000E+00
 .800E-02   .000E+00    .704E+14    .000E+00    .000E+00
 .900E-02   .000E+00    .802E+14    .000E+00    .000E+00
 .100E-01   .000E+00    .900E+14    .000E+00    .000E+00
 .200E-01   .000E+00    .188E+15    .000E+00    .000E+00
 .300E-01   .000E+00    .287E+15    .000E+00    .000E+00
 .400E-01   .000E+00    .385E+15    .000E+00    .000E+00
 .500E-01   .000E+00    .483E+15    .000E+00    .000E+00
 .600E-01   .000E+00    .582E+15    .000E+00    .000E+00
 .700E-01   .000E+00    .680E+15    .000E+00    .000E+00
 .800E-01   .000E+00    .779E+15    .000E+00    .000E+00
 .900E-01   .000E+00    .877E+15    .000E+00    .000E+00
 .100E+00   .000E+00    .976E+15    .000E+00    .000E+00
 .200E+00   .000E+00    .196E+16    .000E+00    .000E+00
 .300E+00   .000E+00    .295E+16    .000E+00    .000E+00
 .400E+00   .000E+00    .394E+16    .000E+00    .000E+00
 .500E+00   .000E+00    .494E+16    .000E+00    .000E+00
 .600E+00   .000E+00    .593E+16    .000E+00    .000E+00
 .700E+00   .000E+00    .693E+16    .000E+00    .000E+00
 .800E+00   .000E+00    .793E+16    .000E+00    .000E+00
 .900E+00   .000E+00    .893E+16    .000E+00    .000E+00
 .100E+01   .000E+00    .994E+16    .000E+00    .000E+00
 .200E+01   .000E+00    .201E+17    .000E+00    .000E+00
 .300E+01   .000E+00    .304E+17    .000E+00    .000E+00
 .400E+01   .000E+00    .410E+17    .000E+00    .000E+00
 .500E+01   .000E+00    .516E+17    .000E+00    .000E+00
 .600E+01   .000E+00    .624E+17    .000E+00    .000E+00
 .700E+01   .000E+00    .734E+17    .000E+00    .000E+00
 .800E+01   .000E+00    .844E+17    .000E+00    .000E+00
 .900E+01   .000E+00    .956E+17    .000E+00    .000E+00
 .100E+02   .000E+00    .107E+18    .000E+00    .000E+00
 .200E+02   .000E+00    .222E+18    .000E+00    .000E+00
 .300E+02   .000E+00    .340E+18    .000E+00    .000E+00
 .400E+02   .000E+00    .459E+18    .000E+00    .000E+00
 .500E+02   .000E+00    .577E+18    .000E+00    .000E+00
```

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.600E+02	.000E+00	.695E+18	.000E+00	.000E+00
.700E+02	.000E+00	.814E+18	.000E+00	.000E+00
.800E+02	.000E+00	.932E+18	.000E+00	.000E+00
.900E+02	.000E+00	.105E+19	.000E+00	.000E+00
.100E+03	.000E+00	.117E+19	.000E+00	.000E+00
.200E+03	.000E+00	.234E+19	.000E+00	.000E+00
.300E+03	.000E+00	.351E+19	.000E+00	.000E+00
.400E+03	.000E+00	.467E+19	.000E+00	.000E+00
.500E+03	.000E+00	.583E+19	.000E+00	.000E+00
.600E+03	.000E+00	.698E+19	.000E+00	.000E+00
.700E+03	.000E+00	.813E+19	.000E+00	.000E+00
.800E+03	.000E+00	.928E+19	.000E+00	.000E+00
.900E+03	.000E+00	.104E+20	.000E+00	.000E+00
.100E+04	.000E+00	.116E+20	.000E+00	.000E+00
.200E+04	.000E+00	.228E+20	.000E+00	.000E+00
.300E+04	.000E+00	.337E+20	.000E+00	.000E+00
.400E+04	.000E+00	.445E+20	.000E+00	.000E+00
.500E+04	.000E+00	.551E+20	.000E+00	.000E+00
.600E+04	.000E+00	.655E+20	.000E+00	.000E+00
.700E+04	.000E+00	.758E+20	.000E+00	.000E+00
.800E+04	.000E+00	.859E+20	.000E+00	.000E+00
.900E+04	.000E+00	.959E+20	.000E+00	.000E+00
.100E+05	.000E+00	.106E+21	.000E+00	.000E+00
.200E+05	.000E+00	.197E+21	.000E+00	.000E+00
.300E+05	.000E+00	.277E+21	.000E+00	.000E+00
.400E+05	.000E+00	.348E+21	.000E+00	.000E+00
.500E+05	.000E+00	.409E+21	.000E+00	.000E+00
.600E+05	.000E+00	.463E+21	.000E+00	.000E+00
.700E+05	.000E+00	.510E+21	.000E+00	.000E+00
.800E+05	.000E+00	.551E+21	.000E+00	.000E+00
.900E+05	.000E+00	.586E+21	.000E+00	.000E+00
.100E+06	.000E+00	.618E+21	.000E+00	.000E+00
.200E+06	.000E+00	.777E+21	.000E+00	.000E+00
.300E+06	.000E+00	.820E+21	.000E+00	.000E+00
.400E+06	.000E+00	.832E+21	.000E+00	.000E+00
.500E+06	.000E+00	.835E+21	.000E+00	.000E+00
.600E+06	.000E+00	.835E+21	.000E+00	.000E+00
.700E+06	.000E+00	.835E+21	.000E+00	.000E+00
.800E+06	.000E+00	.836E+21	.000E+00	.000E+00
.900E+06	.000E+00	.836E+21	.000E+00	.000E+00

210PB TOTAL INPUT RATES (ATOMS/YR)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.392E+03	.408E+13	.113E+00	.716E+02
.200E-02	.355E+04	.122E+14	.882E+00	.283E+03
.300E-02	.141E+05	.214E+14	.293E+01	.645E+03
.400E-02	.377E+05	.311E+14	.695E+01	.119E+04
.500E-02	.803E+05	.409E+14	.138E+02	.198E+04
.600E-02	.148E+06	.507E+14	.246E+02	.308E+04
.700E-02	.246E+06	.605E+14	.407E+02	.459E+04
.800E-02	.380E+06	.704E+14	.641E+02	.661E+04
.900E-02	.556E+06	.802E+14	.971E+02	.928E+04
.100E-01	.778E+06	.900E+14	.142E+03	.127E+05
.200E-01	.672E+07	.188E+15	.263E+04	.140E+06
.300E-01	.222E+08	.287E+15	.129E+05	.512E+06
.400E-01	.508E+08	.385E+15	.393E+05	.128E+07
.500E-01	.952E+08	.483E+15	.912E+05	.258E+07
.600E-01	.158E+09	.582E+15	.178E+06	.450E+07
.700E-01	.239E+09	.680E+15	.308E+06	.713E+07

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.800E-01	.342E+09	.779E+15	.489E+06	.105E+08
.900E-01	.466E+09	.877E+15	.726E+06	.147E+08
.100E+00	.613E+09	.976E+15	.103E+07	.198E+08
.200E+00	.339E+10	.196E+16	.877E+07	.124E+09
.300E+00	.861E+10	.295E+16	.250E+08	.322E+09
.400E+00	.163E+11	.394E+16	.520E+08	.617E+09
.500E+00	.264E+11	.494E+16	.913E+08	.101E+10
.600E+00	.390E+11	.593E+16	.144E+09	.150E+10
.700E+00	.541E+11	.693E+16	.213E+09	.209E+10
.800E+00	.716E+11	.793E+16	.298E+09	.277E+10
.900E+00	.914E+11	.893E+16	.401E+09	.356E+10
.100E+01	.114E+12	.994E+16	.525E+09	.444E+10
.200E+01	.467E+12	.201E+17	.321E+10	.186E+11
.300E+01	.105E+13	.304E+17	.955E+10	.426E+11
.400E+01	.185E+13	.410E+17	.211E+11	.762E+11
.500E+01	.287E+13	.516E+17	.393E+11	.119E+12
.600E+01	.408E+13	.624E+17	.656E+11	.172E+12
.700E+01	.549E+13	.734E+17	.102E+12	.234E+12
.800E+01	.708E+13	.844E+17	.148E+12	.305E+12
.900E+01	.885E+13	.956E+17	.208E+12	.384E+12
.100E+02	.108E+14	.107E+18	.281E+12	.473E+12
.200E+02	.380E+14	.222E+18	.204E+13	.179E+13
.300E+02	.749E+14	.340E+18	.638E+13	.369E+13
.400E+02	.117E+15	.459E+18	.140E+14	.596E+13
.500E+02	.163E+15	.577E+18	.253E+14	.846E+13
.600E+02	.211E+15	.695E+18	.406E+14	.111E+14
.700E+02	.260E+15	.814E+18	.600E+14	.138E+14
.800E+02	.309E+15	.932E+18	.836E+14	.166E+14
.900E+02	.359E+15	.105E+19	.111E+15	.193E+14
.100E+03	.408E+15	.117E+19	.143E+15	.221E+14
.200E+03	.905E+15	.234E+19	.692E+15	.501E+14
.300E+03	.140E+16	.351E+19	.164E+16	.781E+14
.400E+03	.190E+16	.467E+19	.298E+16	.106E+15
.500E+03	.239E+16	.583E+19	.469E+16	.134E+15
.600E+03	.288E+16	.698E+19	.676E+16	.162E+15
.700E+03	.337E+16	.813E+19	.916E+16	.190E+15
.800E+03	.385E+16	.928E+19	.119E+17	.218E+15
.900E+03	.434E+16	.104E+20	.149E+17	.247E+15
.100E+04	.482E+16	.116E+20	.183E+17	.275E+15
.200E+04	.958E+16	.226E+20	.660E+17	.556E+15
.300E+04	.142E+17	.337E+20	.134E+18	.840E+15
.400E+04	.188E+17	.445E+20	.217E+18	.113E+16
.500E+04	.233E+17	.551E+20	.313E+18	.142E+16
.600E+04	.278E+17	.655E+20	.418E+18	.171E+16
.700E+04	.321E+17	.758E+20	.532E+18	.201E+16
.800E+04	.365E+17	.859E+20	.652E+18	.230E+16
.900E+04	.407E+17	.959E+20	.778E+18	.259E+16
.100E+05	.449E+17	.106E+21	.910E+18	.289E+16
.200E+05	.836E+17	.197E+21	.239E+19	.572E+16
.300E+05	.118E+18	.277E+21	.399E+19	.830E+16
.400E+05	.146E+18	.348E+21	.565E+19	.106E+17
.500E+05	.174E+18	.409E+21	.733E+19	.126E+17
.600E+05	.197E+18	.463E+21	.900E+19	.144E+17
.700E+05	.216E+18	.510E+21	.106E+20	.159E+17
.800E+05	.234E+18	.551E+21	.122E+20	.172E+17
.900E+05	.250E+18	.586E+21	.137E+20	.184E+17
.100E+06	.263E+18	.618E+21	.152E+20	.194E+17
.200E+06	.331E+18	.777E+21	.252E+20	.246E+17
.300E+06	.349E+18	.820E+21	.300E+20	.261E+17
.400E+06	.354E+18	.832E+21	.320E+20	.264E+17
.500E+06	.355E+18	.835E+21	.327E+20	.265E+17
.600E+06	.355E+18	.835E+21	.330E+20	.265E+17
.700E+06	.355E+18	.835E+21	.331E+20	.265E+17
.800E+06	.355E+18	.836E+21	.331E+20	.265E+17
.900E+06	.355E+18	.836E+21	.331E+20	.265E+17

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

```
                    INITIAL
                 RADIONUCLIDE
                    AMOUNT
                    (ATOMS)

ZONE 1-SED.      .000E+00
ZONE 1-S.W.      .000E+00
ZONE 1-G.W.      .000E+00
ZONE 1-SOIL      .000E+00

                 KD(L/KG)

ZONE 1-SED.      .500E+04
ZONE 1-S.W.      .100E+05
ZONE 1-G.W.      .500E+03
ZONE 1-SOIL      .100E+02

                                                        TRANSFER MATRIX
                                                          (YEAR**-1)

                                                         ORIGIN  CELLS

                   1            2            3            4


DESTINATION
   CELLS


     1      -.18347E+00  .10942E+02  .64211E-19  .98232E-17


     2       .10000E+00 -.15787E+02  .27684E-03  .21268E-01


     3       .19123E-16  .20923E-14 -.31360E-01  .84837E-01


     4       .19123E-16  .16569E-01  .64211E-19 -.13719E+00
```

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

210PB AMOUNTS (ATOMS)

CELL

TIME (YR)	1	2	3	4
.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
.100E-02	.741E+07	.203E+10	.238E+00	.112E+05
.200E-02	.664E+08	.101E+11	.404E+01	.101E+06
.300E-02	.259E+09	.266E+11	.230E+02	.392E+06
.400E-02	.682E+09	.522E+11	.804E+02	.103E+07
.500E-02	.144E+10	.872E+11	.212E+03	.217E+07
.600E-02	.262E+10	.131E+12	.468E+03	.397E+07
.700E-02	.434E+10	.184E+12	.909E+03	.657E+07
.800E-02	.669E+10	.246E+12	.161E+04	.101E+08
.900E-02	.976E+10	.317E+12	.266E+04	.148E+08
.100E-01	.137E+11	.397E+12	.415E+04	.207E+08
.200E-01	.118E+12	.164E+13	.740E+05	.178E+09
.300E-01	.398E+12	.361E+13	.382E+06	.603E+09
.400E-01	.928E+12	.620E+13	.120E+07	.141E+10
.500E-01	.177E+13	.932E+13	.290E+07	.268E+10
.600E-01	.298E+13	.129E+14	.591E+07	.451E+10
.700E-01	.460E+13	.169E+14	.107E+08	.697E+10
.800E-01	.667E+13	.212E+14	.179E+08	.101E+11
.900E-01	.922E+13	.258E+14	.281E+08	.140E+11
.100E+00	.123E+14	.306E+14	.418E+08	.186E+11
.200E+00	.748E+14	.866E+14	.537E+09	.114E+12
.300E+00	.201E+15	.148E+15	.224E+10	.305E+12
.400E+00	.392E+15	.212E+15	.599E+10	.597E+12
.500E+00	.649E+15	.276E+15	.126E+11	.990E+12
.600E+00	.972E+15	.341E+15	.230E+11	.148E+13
.700E+00	.136E+16	.406E+15	.360E+11	.208E+13
.800E+00	.181E+16	.472E+15	.564E+11	.277E+13
.900E+00	.233E+16	.538E+15	.850E+11	.357E+13
.100E+01	.290E+16	.605E+15	.119E+12	.446E+13
.200E+01	.120E+17	.130E+16	.102E+13	.188E+14
.300E+01	.269E+17	.205E+16	.349E+13	.424E+14
.400E+01	.469E+17	.284E+16	.825E+13	.750E+14
.500E+01	.717E+17	.367E+16	.160E+14	.116E+15
.600E+01	.101E+18	.454E+16	.272E+14	.165E+15
.700E+01	.134E+18	.544E+16	.425E+14	.221E+15
.800E+01	.171E+18	.637E+16	.624E+14	.285E+15
.900E+01	.211E+18	.733E+16	.874E+14	.355E+15
.100E+02	.254E+18	.832E+16	.118E+15	.431E+15
.200E+02	.801E+18	.191E+17	.777E+15	.145E+16
.300E+02	.146E+19	.307E+17	.215E+16	.274E+16
.400E+02	.216E+19	.427E+17	.419E+16	.415E+16
.500E+02	.287E+19	.547E+17	.681E+16	.560E+16
.600E+02	.359E+19	.667E+17	.990E+16	.706E+16
.700E+02	.431E+19	.788E+17	.134E+17	.854E+16
.800E+02	.503E+19	.908E+17	.172E+17	.100E+17
.900E+02	.574E+19	.103E+18	.213E+17	.115E+17
.100E+03	.647E+19	.115E+18	.256E+17	.130E+17
.200E+03	.136E+20	.234E+18	.787E+17	.276E+17
.300E+03	.207E+20	.353E+18	.145E+18	.422E+17
.400E+03	.278E+20	.472E+18	.223E+18	.567E+17
.500E+03	.348E+20	.590E+18	.312E+18	.712E+17

Figure 40

Program CELLTRAN Output File (CELL.OUT) (continued)

.600E+03	.418E+20	.707E+18	.414E+18	.855E+17
.700E+03	.488E+20	.824E+18	.526E+18	.999E+17
.800E+03	.558E+20	.941E+18	.648E+18	.114E+18
.900E+03	.626E+20	.106E+19	.780E+18	.128E+18
.100E+04	.698E+20	.118E+19	.923E+18	.143E+18
.200E+04	.13BE+21	.232E+19	.281E+19	.283E+18
.300E+04	.204E+21	.343E+19	.533E+19	.419E+18
.400E+04	.270E+21	.453E+19	.834E+19	.554E+18
.500E+04	.334E+21	.561E+19	.117E+20	.687E+18
.600E+04	.397E+21	.667E+19	.154E+20	.817E+18
.700E+04	.460E+21	.772E+19	.194E+20	.946E+18
.800E+04	.521E+21	.875E+19	.236E+20	.107E-19
.900E+04	.582E+21	.977E+19	.279E+20	.120E+19
.100E+05	.644E+21	.108E+20	.324E+20	.132E+19
.200E+05	.120E+22	.201E+20	.826E+20	.246E+19
.300E+05	.168E+22	.282E+20	.136E+21	.347E+19
.400E+05	.211E+22	.354E+20	.192E+21	.436E+19
.500E+05	.249E+22	.417E+20	.247E+21	.512E+19
.600E+05	.281E+22	.472E+20	.302E+21	.580E+19
.700E+05	.310E+22	.520E+20	.356E+21	.639E+19
.800E+05	.335E+22	.561E+20	.408E+21	.690E+19
.900E+05	.356E+22	.597E+20	.458E+21	.734E+19
.100E+06	.376E+22	.630E+20	.505E+21	.775E+19
.200E+06	.472E+22	.792E+20	.830E+21	.974E+19
.300E+06	.498E+22	.835E+20	.986E+21	.103E+20
.400E+06	.506E+22	.848E+20	.105E+22	.104E+20
.500E+06	.508E+22	.851E+20	.107E+22	.105E+20
.600E+06	.508E+22	.851E+20	.108E+22	.105E+20
.700E+06	.508E+22	.851E+20	.108E+22	.105E+20
.800E+06	.508E+22	.852E+20	.108E+22	.105E+20
.900E+06	.508E+22	.852E+20	.108E+22	.105E+20

Figure 41

Program CELLTRAN Output File (IP.OUT)

```
 .000E+00  .100E-02  .200E-02  .300E-02  .400E-02  .500E-02  .600E-02  .700E-02
 .800E-02  .900E-02  .100E-01  .200E-01  .300E-01  .400E-01  .500E-01  .600E-01
 .700E-01  .800E-01  .900E-01  .100E+00  .200E+00  .300E+00  .400E+00  .500E+00
 .600E+00  .700E+00  .800E+00  .900E+00  .100E+01  .200E+01  .300E+01  .400E+01
 .500E+01  .600E+01  .700E+01  .800E+01  .900E+01  .100E+02  .200E+02  .300E+02
 .400E+02  .500E+02  .600E+02  .700E+02  .800E+02  .900E+02  .100E+03  .200E+03
 .300E+03  .400E+03  .500E+03  .600E+03  .700E+03  .800E+03  .900E+03  .100E+04
 .200E+04  .300E+04  .400E+04  .500E+04  .600E+04  .700E+04  .800E+04  .900E+04
 .100E+05  .200E+05  .300E+05  .400E+05  .500E+05  .600E+05  .700E+05  .800E+05
 .900E+05  .100E+06  .200E+06  .300E+06  .400E+06  .500E+06  .600E+06  .700E+06
 .800E+06  .900E+06
242PU      82  .184E-05
   1    2  .100E+06  .191E+09  .287E+13
   1    4  .100E+04  .110E+12  .198E+11
 .000E+00
 .000E+00
 .249E+13
 .137E+08
 .122E+14
 .122E+09
 .318E+14          .255E+16          .236E+21          .103E+23
 .471E+09          .405E+18          .346E+21          .144E+24
 .618E+14          .318E+16          .362E+21          .169E+23
 .123E+10          .867E+18          .781E+21          .246E+24
 .102E+15          .137E+17          .488E+21          .210E+23
 .257E+10          .137E+19          .137E+22          .311E+24
 .153E+15          .321E+17          .613E+21          .236E+23
 .467E+10          .192E+19          .209E+22          .352E+24
 .213E+15          .593E+17          .738E+21          .253E+23
 .768E+10          .250E+19          .293E+22          .379E+24
 .283E+15          .957E+17          .861E+21          .263E+23
 .118E+11          .311E+19          .388E+22          .396E+24
 .362E+15          .142E+18          .984E+21          .270E+23
 .171E+11          .376E+19          .493E+22          .406E+24
 .450E+15          .199E+18          .111E+22          .274E+23
 .238E+11          .445E+19          .606E+22          .413E+24
 .178E+16          .266E+18          .123E+22          .277E+23
 .198E+12          .515E+19          .726E+22          .418E+24
 .377E+16          .345E+18          .243E+22          .278E+23
 .650E+12          .589E+19          .219E+23          .420E+24
 .627E+16          .436E+18          .359E+22          .281E+23
 .147E+13          .146E+20          .386E+23          .425E+24
 .914E+16          .210E+19          .468E+22          .281E+23
 .275E+13          .251E+20          .555E+23          .425E+24
 .123E+17          .533E+19          .573E+22          .281E+23
 .452E+13          .364E+20          .718E+23          .425E+24
 .157E+17          .103E+20          .673E+22          .281E+23
 .683E+13          .484E+20          .876E+23          .425E+24
 .192E+17          .172E+20          .769E+22          .281E+23
 .971E+13          .606E+20          .103E+24          .425E+24
 .228E+17          .260E+20          .862E+22          .281E+23
 .132E+14          .732E+20          .117E+24          .425E+24
 .266E+17          .367E+20          .947E+22          .281E+23
 .173E+14          .856E+20          .131E+24          .425E+24
 .664E+17          .494E+20                            .281E+23
 .939E+14          .980E+20                            .425E+24
 .107E+18          .639E+20
 .237E+15          .111E+21
 .148E+18          .804E+20
 .449E+15
 .190E+18
 .728E+15
 .232E+18
 .108E+16
 .275E+18
 .150E+16
 .318E+18
 .199E+16
 .361E+18
```

Figure 41

Program CELLTRAN Output File (IP.OUT) (continued)

```
238U        B2  .155E-09
    1    2  .100E+05  .191E+09  .287E+13
    1    4  .100E+02  .110E+12  .198E+11
  .000E+00
  .000E+00
  .507E+18
  .281E+13
  .252E+19
  .251E+14
  .666E+19
  .981E+14
  .131E+20
  .259E+15
  .218E+20                .110E+23                .510E+27
  .545E+15                .718E+24                .794E+26
  .328E+20                .196E+23                .640E+27
  .994E+15                .931E+24                .998E+26
  .462E+20                .306E+23                .725E+27
  .165E+16                .115E+25                .113E+27
  .617E+20                .439E+23                .780E+27
  .254E+16                .139E+25                .122E+27
  .795E+20                .595E+23                .814E+27
  .370E+16                .163E+25                .127E+27
  .994E+20                .772E+23                .837E+27
  .518E+16                .188E+25                .131E+27
  .411E+21                .971E+23                .851E+27
  .447E+17                .214E+25                .133E+27
  .904E+21                .119E+24                .861E+27
  .151E+18                .510E+25                .134E+27
  .155E+22                .434E+24                .868E+27
  .353E+18                .847E+25                .136E+27
  .234E+22                .871E+24                .879E+27
  .673E+18                .120E+26                .137E+27
  .324E+22                .138E+25                .879E+27
  .113E+19                .157E+26                .137E+27
  .423E+22                .192E+25                .879E+27
  .175E+19                .194E+26                .137E+27
  .531E+22                .249E+25                .879E+27
  .253E+19                .231E+26                .137E+27
  .646E+22                .306E+25                .879E+27
  .350E+19                .268E+26                .137E+27
  .767E+22                .364E+25                .879E+27
  .467E+19                .306E+26                .137E+27
  .218E+23                .423E+25                .879E+27
  .285E+20                .342E+26                .137E+27
  .373E+23                .480E+25                .879E+27
  .768E+20                .703E+26                .137E+27
  .532E+23                .104E+26                .879E+27
  .151E+21                .105E+27                .137E+27
  .694E+23                .159E+26                .879E+27
  .250E+21                .138E+27                .137E+27
  .857E+23                .211E+26                .879E+27
  .375E+21                .170E+27                .137E+27
  .102E+24                .260E+26                .879E+27
  .526E+21                .200E+27                .137E+27
  .119E+24                .308E+26                .879E+27
  .702E+21                .229E+27                .137E+27
  .135E+24                .354E+26                .879E+27
  .904E+21                .256E+27                .137E+27
  .152E+24                .396E+26                .879E+27
  .113E+22                .283E+27                .137E+27
  .328E+24                .438E+26                .879E+27
  .480E+22                .309E+27                .137E+27
  .517E+24                .479E+26                .879E+27
                                                  .137E+27
```

Figure 41

Program CELLTRAN Output File (IP.OUT) (continued)

```
234U        82  .283E-05
    1     2  .100E+05  .191E+09  .287E+13
    1     4  .100E+02  .110E+12  .198E+11
  .000E+00
  .000E+00
  .194E+14
  .108E+09
  .967E+14
  .964E+09
  .256E+15                .184E+18                .196E+23
  .376E+10                .198E+20                .304E+22
  .502E+15                .420E+18                .246E+23
  .992E+10                .275E+20                .383E+22
  .837E+15                .750E+18                .278E+23
  .209E+11                .356E+20                .433E+22
  .126E+16                .117E+19                .299E+23
  .381E+11                .442E+20                .466E+22
  .177E+16                .168E+19                .313E+23
  .631E+11                .532E+20                .488E+22
  .237E+16                .228E+19                .321E+23
  .973E+11                .624E+20                .501E+22
  .305E+16                .296E+19                .327E+23
  .142E+12                .721E+20                .511E+22
  .381E+16                .372E+19                .331E+23
  .199E+12                .823E+20                .516E+22
  .157E+17                .456E+19                .333E+23
  .171E+13                .195E+21                .520E+22
  .347E+17                .166E+20                .338E+23
  .580E+13                .324E+21                .527E+22
  .596E+17                .333E+20                .338E+23
  .135E+14                .461E+21                .527E+22
  .896E+17                .528E+20                .338E+23
  .258E+14                .602E+21                .527E+22
  .124E+18                .738E+20                .338E+23
  .434E+14                .743E+21                .527E+22
  .162E+18                .954E+20                .338E+23
  .670E+14                .886E+21                .527E+22
  .203E+18                .117E+21                .338E+23
  .971E+14                .103E+22                .527E+22
  .247E+18                .140E+21                .338E+23
  .134E+15                .117E+22                .527E+22
  .294E+18                .162E+21                .338E+23
  .179E+15                .131E+22                .527E+22
  .832E+18                .184E+21                .338E+23
  .109E+16                .269E+22                .527E+22
  .143E+19                .399E+21                .338E+23
  .294E+16                .402E+22                .527E+22
  .203E+19                .608E+21                .338E+23
  .576E+16                .528E+22                .527E+22
  .265E+19                .807E+21                .338E+23
  .956E+16                .650E+22                .527E+22
  .328E+19                .997E+21                .338E+23
  .143E+17                .766E+22                .527E+22
  .390E+19                .118E+22                .338E+23
  .201E+17                .877E+22                .527E+22
  .454E+19                .135E+22                .338E+23
  .269E+17                .983E+22                .527E+22
  .518E+19                .152E+22                .338E+23
  .346E+'                 .109E+23                .527E+22
  .582                    .168E+22                .338E+23
  .433E                   .118E+23                .527E+22
  .126E+.                 .184E+22
```

Figure 41

Program CELLTRAN Output File (IP.OUT) (continued)

```
230TH        82  .900E-05
    1     2  .100E+06  .191E+09  .287E+13
    1     4  .100E+05  .110E+12  .198E+11
  .000E+00
  .000E+00
  .679E+11
  .375E+06
  .332E+12
  .333E+07
  .868E+12                .374E+15                .697E+20
  .129E+08                .376E+17                .106E+22
  .169E+13                .882E+15                .105E+21
  .336E+08                .524E+17                .230E+22
  .279E+13                .163E+16                .139E+21
  .703E+08                .683E+17                .392E+22
  .417E+13                .263E+16                .173E+21
  .127E+09                .853E+17                .588E+22
  .582E+13                .390E+16                .207E+21
  .210E+09                .103E+18                .813E+22
  .774E+13                .546E+16                .240E+21
  .322E+09                .122E+18                .106E+23
  .990E+13                .733E+16                .273E+21
  .467E+09                .141E+18                .133E+23
  .123E+14                .951E+16                .305E+21
  .651E+09                .162E+18                .162E+23
  .487E+14                .120E+17                .337E+21
  .541E+10                .402E+18                .192E+23
  .103E+15                .583E+17                .634E+21
  .176E+11                .690E+18                .529E+23
  .172E+15                .149E+18                .894E+21
  .403E+11                .100E+19                .872E+23
  .250E+15                .269E+18                .112E+22
  .751E+11                .133E+19                .119E+24
  .336E+15                .483E+18                .132E+22
  .124E+12                .167E+19                .146E+24
  .429E+15                .733E+18                .149E+22
  .187E+12                .201E+19                .171E+24
  .525E+15                .104E+19                .164E+22
  .266E+12                .235E+19                .192E+24
  .625E+15                .140E+19                .178E+22
  .361E+12                .270E+19                .211E+24
  .728E+15                .182E+19                .190E+22
  .473E+12                .305E+19                .227E+24
  .181E+16                .230E+19                .200E+22
  .257E+13                .653E+19                .241E+24
  .293E+16                .102E+20                .251E+22
  .649E+13                .100E+20                .312E+24
  .407E+16                .238E+20                .265E+22
  .123E+14                .136E+20                .333E+24
  .519E+16                .431E+20                .269E+22
  .199E+14                .170E+20                .339E+24
  .634E+16                .680E+20                .270E+22
  .295E+14                .205E+20                .340E+24
  .751E+16                .983E+20                .270E+22
  .410E+14                .241E+20                .340E+24
  .869E+16                .134E+21                .270E+22
  .544E+14                .275E+20                .340E+24
  .988E+16                .175E+21                .270E+22
  .698E+14                .311E+20                .340E+24
  .111E+17                .221E+21                .270E+22
  .871E+14                .346E+20                .340E+24
  .238E+17                .273E+21
```

Figure 41

Program CELLTRAN Output File (IP.OUT) (continued)

```
226RA        82  .433E-03
    1     2  .500E+05  .191E+09  .287E+13
    1     4  .100E+02  .110E+12  .198E+11
  .000E+00
  .000E+00
  .142E+11
  .787E+05
  .697E+11
  .699E+06
  .182E+12                                                .118E+19
  .270E+07                .809E+14                        .149E+20
  .355E+12                .871E+16                        .240E+19
  .706E+07                .184E+15                        .221E+20
  .588E+12                .122E+17                        .362E+19
  .148E+08                .330E+15                        .293E+20
  .879E+12                .158E+17                        .487E+19
  .269E+08                .516E+15                        .363E+20
  .123E+13                .197E+17                        .613E+19
  .442E+08                .743E+15                        .432E+20
  .163E+13                .238E+17                        .739E+19
  .678E+08                .101E+16                        .500E+20
  .209E+13                .281E+17                        .865E+19
  .986E+08                .132E+16                        .567E+20
  .261E+13                .326E+17                        .992E+19
  .137E+09                .166E+16                        .632E+20
  .104E+14                .373E+17                        .112E+20
  .115E+10                .204E+16                        .698E+20
  .221E+14                .923E+17                        .125E+20
  .379E+10                .771E+16                        .130E+21
  .371E+14                .157E+18                        .247E+20
  .864E+10                .159E+17                        .183E+21
  .544E+14                .228E+18                        .358E+20
  .162E+11                .257E+17                        .229E+21
  .736E+14                .302E+18                        .457E+20
  .267E+11                .365E+17                        .270E+21
  .943E+14                .377E+18                        .543E+20
  .406E+11                .478E+17                        .306E+21
  .116E+15                .454E+18                        .619E+20
  .579E+11                .595E+17                        .336E+21
  .139E+15                .531E+18                        .685E+20
  .789E+11                .714E+17                        .364E+21
  .162E+15                .608E+18                        .743E+20
  .104E+12                .833E+17                        .388E+21
  .411E+15                .685E+18                        .794E+20
  .572E+12                .954E+17                        .408E+21
  .671E+15                .146E+19                        .839E+20
  .146E+13                .216E+18                        .514E+21
  .933E+15                .223E+19                        .106E+21
  .276E+13                .337E+18                        .542E+21
  .120E+16                .300E+19                        .112E+21
  .449E+13                .458E+18                        .549E+21
  .147E+16                .376E+19                        .114E+21
  .663E+13                .579E+18                        .551E+21
  .174E+16                .452E+19                        .114E+21
  .920E+13                .700E+18                        .552E+21
  .201E+16                .528E+19                        .114E+21
  .122E+14                .821E+18                        .552E+21
  .229E+16                .604E+19                        .114E+21
  .156E+14                .942E+18                        .552E+21
  .257E+16                .679E+19                        .114E+21
  .194E+14                .106E+19                        .552E+21
  .549E+16                .755E+19                        .114E+21
```

Figure 41

Program CELLTRAN Output File (IP.OUT) (continued)

```
222RN        B2  .661E+02
    1     2  .000E+00  .191E+09  .287E+13
    1     4  .000E+00  .110E+12  .198E+11
  .000E+00
  .000E+00
  .134E+06
  .108E+01
  .269E+06
  .429E+01
  .404E+06                .282E+09
  .976E+01                .409E+09                .277E+12
  .538E+06                .644E+09                .841E+13
  .180E+02                .545E+09                .411E+12
  .673E+06                .115E+10                .127E+14
  .299E+02                .681E+09                .543E+12
  .808E+06                .180E+10                .171E+14
  .465E+02                .820E+09                .676E+12
  .943E+06                .260E+10                .215E+14
  .693E+02                .957E+09                .803E+12
  .108E+07                .353E+10                .259E+14
  .100E+03                .109E+10                .931E+12
  .121E+07                .461E+10                .303E+14
  .140E+03                .123E+10                .106E+13
  .135E+07                .581E+10                .348E+14
  .192E+03                .137E+10                .118E+13
  .269E+07                .715E+10                .392E+14
  .211E+04                .276E+10                .131E+13
  .404E+07                .270E+11                .437E+14
  .774E+04                .417E+10                .246E+13
  .537E+07                .557E+11                .865E+14
  .194E+05                .557E+10                .350E+13
  .674E+07                .901E+11                .126E+15
  .390E+05                .698E+10                .439E+13
  .808E+07                .128E+12                .160E+15
  .680E+05                .839E+10                .521E+13
  .942E+07                .168E+12                .190E+15
  .106E+06                .980E+10                .592E+13
  .108E+08                .209E+12                .217E+15
  .159E+06                .112E+11                .654E+13
  .121E+08                .250E+12                .240E+15
  .223E+06                .127E+11                .710E+13
  .135E+08                .292E+12                .261E+15
  .299E+06                .141E+11                .757E+13
  .270E+08                .334E+12                .279E+15
  .188E+07                .282E+11                .801E+13
  .406E+08                .757E+12                .294E+15
  .486E+07                .423E+11                .103E+14
  .541E+08                .118E+13                .372E+15
  .932E+07                .564E+11                .110E+14
  .679E+08                .161E+13                .394E+15
  .153E+08                .703E+11                .112E+14
  .814E+08                .203E+13                .400E+15
  .227E+08                .842E+11                .113E+14
  .949E+08                .245E+13                .401E+15
  .316E+08                .981E+11                .113E+14
  .108E+09                .288E+13                .401E+15
  .419E+08                .112E+12                .113E+14
  .122E+09                .330E+13                .401E+15
  .538E+08                .126E+12                .113E+14
  .136E+09                .373E+13                .401E+15
  .671E+08                .140E+12                .113E+14
  .272E+09                .415E+13                .401E+15
```

Figure 41

Program CELLTRAN Output File (IP.OUT) (continued)

```
210PB        82  .311E-01
    1     2  .100E+05  .191E+09  .287E+13
    1     4  .100E+02  .110E+12  .198E+11
  .000E+00
  .000E+00
  .203E+10
  .112E+05
  .101E+11
  .101E+06                                  .143E+18
  .266E+11              .188E+14            .232E+19
  .392E+06              .205E+16            .283E+18
  .522E+11              .424E+14            .343E+19
  .103E+07              .284E+16            .419E+18
  .872E+11              .750E+14            .453E+19
  .217E+07              .367E+16            .554E+18
  .131E+12              .116E+15            .561E+19
  .397E+07              .454E+16            .687E+18
  .184E+12              .165E+15            .667E+19
  .657E+07              .544E+16            .817E+18
  .246E+12              .221E+15            .772E+19
  .101E+08              .637E+16            .946E+18
  .317E+12              .285E+15            .875E+19
  .148E+08              .733E+16            .107E+19
  .397E+12              .355E+15            .977E+19
  .207E+08              .832E+16            .120E+19
  .164E+13              .431E+15            .108E+20
  .178E+09              .191E+17            .132E+19
  .361E+13              .145E+16            .201E+20
  .603E+09              .307E+17            .246E+19
  .620E+13              .274E+16            .282E+20
  .141E+10              .427E+17            .347E+19
  .932E+13              .415E+16            .354E+20
  .268E+10              .547E+17            .436E+19
  .129E+14              .560E+16            .417E+20
  .451E+10              .667E+17            .512E+19
  .169E+14              .706E+16            .472E+20
  .697E+10              .788E+17            .580E+19
  .212E+14              .854E+16            .520E+20
  .101E+11              .908E+17            .639E+19
  .258E+14              .100E+17            .561E+20
  .140E+11              .103E+18            .690E+19
  .306E+14              .115E+17            .597E+20
  .186E+11              .115E+18            .734E+19
  .866E+14              .130E+17            .630E+20
  .114E+12              .234E+18            .775E+19
  .148E+15              .276E+17            .792E+20
  .305E+12              .353E+18            .974E+19
  .212E+15              .422E+17            .835E+20
  .597E+12              .472E+18            .103E+20
  .276E+15              .567E+17            .848E+20
  .990E+12              .590E+18            .104E+20
  .341E+15              .712E+17            .851E+20
  .148E+13              .707E+18            .105E+20
  .406E+15              .855E+17            .851E+20
  .208E+13              .824E+18            .105E+20
  .472E+15              .999E+17            .851E+20
  .277E+13              .941E+18            .105E+20
  .538E+15              .114E+18            .852E+20
  .357E+13              .106E+19            .105E+20
  .605E+15              .128E+18            .852E+20
  .446E+13              .118E+19            .105E+20
  .130E+16
```

Figure 42

Program CELLPOST Output File (CONC.DAT)

```
   7   82
 .000E+00  .100E-02  .200E-02  .300E-02  .400E-02  .500E-02  .600E-02  .700E-02
 .800E-02  .900E-02  .100E-01  .200E-01  .300E-01  .400E-01  .500E-01  .600E-01
 .700E-01  .800E-01  .900E-01  .100E+00  .200E+00  .300E+00  .400E+00  .500E+00
 .600E+00  .700E+00  .800E+00  .900E+00  .100E+01  .200E+01  .300E+01  .400E+01
 .500E+01  .600E+01  .700E+01  .800E+01  .900E+01  .100E+02  .200E+02  .300E+02
 .400E+02  .500E+02  .600E+02  .700E+02  .800E+02  .900E+02  .100E+03  .200E+03
 .300E+03  .400E+03  .500E+03  .600E+03  .700E+03  .800E+03  .900E+03  .100E+04
 .200E+04  .300E+04  .400E+04  .500E+04  .600E+04  .700E+04  .800E+04  .900E+04
 .100E+05  .200E+05  .300E+05  .400E+05  .500E+05  .600E+05  .700E+05  .800E+05
 .900E+05  .100E+06  .200E+06  .300E+06  .400E+06  .500E+06  .600E+06  .700E+06
 .800E+06  .900E+06
242PU   238U    234U    230TH   226RA   222RN   210PB
 .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00  .000E+00
 .196E-21  .333E-20  .234E-20  .263E-22  .261E-21  .000E+00  .266E-20
 .137E-17  .235E-16  .164E-16  .182E-18  .183E-17  .264E-17  .188E-16
 .175E-20  .298E-19  .209E-19  .233E-21  .231E-20  .000E+00  .240E-19
 .670E-17  .117E-15  .817E-16  .892E-18  .901E-17  .531E-17  .937E-16
 .675E-20  .116E-18  .814E-19  .904E-21  .894E-20  .000E+00  .932E-19
 .175E-16  .308E-15  .216E-15  .233E-17  .235E-16  .797E-17  .247E-15
 .176E-19  .307E-18  .215E-18  .235E-20  .234E-19  .000E+00  .245E-18
 .339E-16  .606E-15  .424E-15  .454E-17  .459E-16  .106E-16  .484E-15
 .368E-19  .646E-18  .452E-18  .493E-20  .490E-19  .000E+00  .516E-18
 .560E-16  .101E-14  .707E-15  .749E-17  .760E-16  .133E-16  .809E-15
 .669E-19  .118E-17  .825E-18  .890E-20  .888E-19  .000E+00  .944E-18
 .840E-16  .152E-14  .106E-14  .112E-16  .114E-15  .159E-16  .122E-14
 .110E-18  .196E-17  .137E-17  .147E-19  .146E-18  .000E+00  .156E-17
 .117E-15  .214E-14  .149E-14  .156E-16  .159E-15  .186E-16  .171E-14
 .169E-18  .301E-17  .211E-17  .226E-19  .225E-18  .000E+00  .240E-17
 .155E-15  .285E-14  .200E-14  .208E-16  .211E-15  .213E-16  .228E-14
 .245E-18  .439E-17  .307E-17  .327E-19  .327E-18  .000E+00  .352E-17
 .199E-15  .368E-14  .258E-14  .266E-16  .270E-15  .239E-16  .294E-14
 .341E-18  .614E-17  .431E-17  .456E-19  .454E-18  .000E+00  .492E-17
 .247E-15  .460E-14  .322E-14  .330E-16  .337E-15  .266E-16  .368E-14
 .284E-17  .530E-16  .370E-16  .379E-18  .381E-17  .000E+00  .423E-16
 .977E-15  .190E-13  .133E-13  .131E-15  .134E-14  .531E-16  .152E-13
 .931E-17  .179E-15  .126E-15  .125E-17  .126E-16  .000E+00  .143E-15
 .207E-14  .418E-13  .293E-13  .277E-15  .286E-14  .797E-16  .335E-13
 .211E-16  .418E-15  .292E-15  .282E-17  .286E-16  .000E+00  .335E-15
 .344E-14  .717E-13  .503E-13  .462E-15  .479E-14  .106E-15  .575E-13
 .394E-16  .798E-15  .558E-15  .526E-17  .536E-16  .000E+00  .637E-15
 .502E-14  .108E-12  .757E-13  .671E-15  .703E-14  .133E-15  .865E-13
 .647E-16  .134E-14  .939E-15  .869E-17  .884E-16  .000E+00  .107E-14
 .675E-14  .150E-12  .105E-12  .902E-15  .951E-14  .159E-15  .120E-12
 .978E-16  .207E-14  .145E-14  .131E-16  .134E-15  .000E+00  .166E-14
 .862E-14  .196E-12  .137E-12  .115E-14  .122E-13  .186E-15  .157E-12
 .139E-15  .300E-14  .210E-14  .186E-16  .192E-15  .000E+00  .240E-14
 .105E-13  .246E-12  .171E-12  .141E-14  .150E-13  .213E-15  .197E-12
 .189E-15  .415E-14  .290E-14  .253E-16  .261E-15  .000E+00  .333E-14
 .125E-13  .299E-12  .209E-12  .168E-14  .180E-13  .239E-15  .239E-12
 .248E-15  .554E-14  .387E-14  .331E-16  .344E-15  .000E+00  .442E-14
 .146E-13  .355E-12  .248E-12  .196E-14  .209E-13  .266E-15  .284E-12
 .134E-14  .338E-13  .236E-13  .180E-15  .189E-14  .000E+00  .271E-13
 .365E-13  .101E-11  .703E-12  .486E-14  .531E-13  .533E-15  .804E-12
 .339E-14  .910E-13  .636E-13  .455E-15  .484E-14  .000E+00  .725E-13
 .588E-13  .173E-11  .121E-11  .787E-14  .867E-13  .801E-15  .137E-11
 .643E-14  .179E-12  .125E-12  .862E-15  .914E-14  .000E+00  .142E-12
 .813E-13  .246E-11  .171E-11  .109E-13  .121E-12  .107E-14  .197E-11
 .104E-13  .296E-12  .207E-12  .139E-14  .149E-13  .000E+00  .235E-12
 .104E-12  .321E-11  .224E-11  .139E-13  .155E-12  .134E-14  .256E-11
 .155E-13  .445E-12  .310E-12  .207E-14  .220E-13  .000E+00  .352E-12
```

Figure 42

Program CELLPOST Output File (CONC.DAT) (continued)

.127E-12	.396E-11	.277E-11	.170E-13	.190E-12	.161E-14	.316E-11
.215E-13	.624E-12	.435E-12	.287E-14	.305E-13	.000E+00	.495E-12
.151E-12	.472E-11	.329E-11	.202E-13	.225E-12	.187E-14	.377E-11
.285E-13	.832E-12	.582E-12	.381E-14	.404E-13	.000E+00	.659E-12
.175E-12	.550E-11	.383E-11	.233E-13	.260E-12	.213E-14	.438E-11
.365E-13	.107E-11	.749E-12	.489E-14	.517E-13	.000E+00	.849E-12
.198E-12	.624E-11	.437E-11	.265E-13	.296E-12	.241E-14	.499E-11
.455E-13	.134E-11	.937E-12	.610E-14	.642E-13	.000E+00	.106E-11
.222E-12	.703E-11	.492E-11	.298E-13	.332E-12	.268E-14	.561E-11
.196E-12	.569E-11	.398E-11	.262E-13	.268E-12	.000E+00	.447E-11
.476E-12	.152E-10	.106E-10	.639E-13	.709E-12	.537E-14	.121E-10
.460E-12	.130E-10	.909E-11	.618E-13	.609E-12	.000E+00	.101E-10
.752E-12	.239E-10	.167E-10	.101E-12	.113E-11	.807E-14	.190E-10
.849E-12	.232E-10	.162E-10	.114E-12	.109E-11	.000E+00	.178E-10
.105E-11	.332E-10	.232E-10	.141E-12	.158E-11	.108E-13	.264E-10
.137E-11	.363E-10	.253E-10	.184E-12	.171E-11	.000E+00	.276E-10
.137E-11	.431E-10	.301E-10	.183E-12	.204E-11	.134E-13	.341E-10
.203E-11	.520E-10	.364E-10	.273E-12	.246E-11	.000E+00	.392E-10
.171E-11	.532E-10	.373E-10	.229E-12	.255E-11	.162E-13	.421E-10
.285E-11	.705E-10	.494E-10	.383E-12	.334E-11	.000E+00	.526E-10
.206E-11	.643E-10	.449E-10	.277E-12	.308E-11	.189E-13	.505E-10
.381E-11	.915E-10	.641E-10	.514E-12	.437E-11	.000E+00	.678E-10
.244E-11	.754E-10	.527E-10	.328E-12	.363E-11	.215E-13	.591E-10
.494E-11	.115E-09	.805E-10	.666E-12	.550E-11	.000E+00	.844E-10
.283E-11	.870E-10	.609E-10	.379E-12	.421E-11	.243E-13	.680E-10
.625E-11	.141E-09	.987E-10	.841E-12	.676E-11	.000E+00	.103E-09
.323E-11	.990E-10	.695E-10	.435E-12	.482E-11	.270E-13	.772E-10
.301E-10	.515E-09	.359E-09	.409E-11	.255E-10	.000E+00	.345E-09
.802E-11	.236E-09	.165E-09	.108E-11	.119E-10	.544E-13	.177E-09
.763E-10	.103E-08	.721E-09	.104E-10	.527E-10	.000E+00	.652E-09
.138E-10	.392E-09	.274E-09	.185E-11	.203E-10	.823E-13	.285E-09
.148E-09	.164E-08	.114E-08	.203E-10	.851E-10	.000E+00	.987E-09
.200E-10	.555E-09	.389E-09	.269E-11	.295E-10	.110E-12	.396E-09
.246E-09	.228E-08	.160E-08	.338E-10	.121E-09	.000E+00	.133E-08
.266E-10	.726E-09	.508E-09	.357E-11	.390E-10	.138E-12	.508E-09
.372E-09	.295E-08	.206E-08	.514E-10	.158E-09	.000E+00	.168E-08
.333E-10	.897E-09	.627E-09	.449E-11	.487E-10	.165E-12	.619E-09
.526E-09	.363E-08	.253E-08	.729E-10	.197E-09	.000E+00	.203E-08
.402E-10	.107E-08	.748E-09	.540E-11	.587E-10	.193E-12	.731E-09
.708E-09	.432E-08	.303E-08	.981E-10	.236E-09	.000E+00	.238E-08
.470E-10	.124E-08	.870E-09	.631E-11	.686E-10	.221E-12	.843E-09
.915E-09	.501E-08	.351E-08	.128E-09	.276E-09	.000E+00	.274E-08
.538E-10	.142E-08	.988E-09	.725E-11	.786E-10	.251E-12	.956E-09
.115E-08	.569E-08	.398E-08	.161E-09	.316E-09	.000E+00	.309E-08
.609E-10	.158E-08	.111E-08	.819E-11	.885E-10	.278E-12	.107E-08
.496E-08	.123E-07	.864E-08	.715E-09	.715E-09	.000E+00	.657E-08
.130E-09	.325E-08	.227E-08	.175E-10	.189E-09	.556E-12	.217E-08
.112E-07	.188E-07	.132E-07	.167E-08	.112E-08	.000E+00	.100E-07
.199E-09	.486E-08	.339E-08	.269E-10	.288E-09	.834E-12	.328E-08
.196E-07	.250E-07	.175E-07	.302E-08	.152E-08	.000E+00	.135E-07
.268E-09	.638E-08	.446E-08	.365E-10	.388E-09	.111E-11	.438E-08
.299E-07	.308E-07	.216E-07	.476E-08	.192E-08	.000E+00	.169E-07
.337E-09	.786E-08	.549E-08	.457E-10	.486E-09	.139E-11	.548E-08
.420E-07	.365E-07	.255E-07	.689E-08	.232E-08	.000E+00	.203E-07
.405E-09	.925E-08	.647E-08	.551E-10	.584E-09	.166E-11	.656E-08
.556E-07	.420E-07	.292E-07	.939E-08	.272E-08	.000E+00	.238E-07
.473E-09	.106E-07	.741E-08	.647E-10	.682E-09	.194E-11	.765E-08
.706E-07	.469E-07	.329E-07	.123E-07	.312E-08	.000E+00	.271E-07
.540E-09	.118E-07	.830E-08	.739E-10	.780E-09	.221E-11	.873E-08
.868E-07	.519E-07	.364E-07	.155E-07	.351E-08	.000E+00	.304E-07
.609E-09	.131E-07	.921E-08	.835E-10	.877E-09	.249E-11	.984E-08
.104E-06	.568E-07	.398E-07	.191E-07	.391E-08	.000E+00	.340E-07
.675E-09	.143E-07	.997E-08	.929E-10	.976E-09	.276E-11	.110E-07

Figure 42

Program CELLPOST Output File (CONC.DAT) (continued)

.314E-06	.941E-07	.658E-07	.743E-07	.795E-08	.000E+00	.673E-07
.133E-08	.236E-07	.166E-07	.187E-09	.193E-08	.546E-11	.215E-07
.553E-06	.118E-06	.829E-07	.161E-06	.120E-07	.000E+00	.997E-07
.197E-08	.296E-07	.208E-07	.282E-09	.286E-08	.811E-11	.318E-07
.795E-06	.134E-06	.937E-07	.275E-06	.161E-07	.000E+00	.132E-06
.257E-08	.335E-07	.235E-07	.373E-09	.379E-08	.107E-10	.420E-07
.103E-05	.145E-06	.101E-06	.412E-06	.203E-07	.000E+00	.163E-06
.315E-08	.361E-07	.253E-07	.465E-09	.469E-08	.133E-10	.521E-07
.125E-05	.151E-06	.106E-06	.570E-06	.245E-07	.000E+00	.194E-06
.370E-08	.377E-07	.264E-07	.556E-09	.558E-08	.158E-10	.619E-07
.148E-05	.155E-06	.108E-06	.743E-06	.286E-07	.000E+00	.225E-06
.422E-08	.387E-07	.271E-07	.645E-09	.646E-08	.184E-10	.716E-07
.168E-05	.158E-06	.111E-06	.932E-06	.329E-07	.000E+00	.255E-06
.473E-08	.394E-07	.276E-07	.733E-09	.733E-08	.209E-10	.812E-07
.188E-05	.159E-06	.112E-06	.114E-05	.371E-07	.000E+00	.285E-06
.520E-08	.398E-07	.280E-07	.819E-09	.817E-08	.233E-10	.907E-07
.206E-05	.161E-06	.113E-06	.135E-05	.414E-07	.000E+00	.314E-06
.566E-08	.401E-07	.281E-07	.905E-09	.902E-08	.258E-10	.100E-06
.352E-05	.162E-06	.114E-06	.371E-05	.818E-07	.000E+00	.585E-06
.928E-08	.407E-07	.285E-07	.170E-08	.168E-07	.485E-10	.187E-06
.445E-05	.162E-06	.114E-06	.611E-05	.119E-06	.000E+00	.825E-06
.115E-07	.407E-07	.285E-07	.240E-08	.236E-07	.690E-10	.262E-06
.504E-05	.162E-06	.114E-06	.834E-05	.151E-06	.000E+00	.104E-05
.130E-07	.407E-07	.285E-07	.301E-08	.296E-07	.866E-10	.329E-06
.543E-05	.162E-06	.114E-06	.102E-04	.180E-06	.000E+00	.122E-05
.139E-07	.407E-07	.285E-07	.355E-08	.349E-07	.103E-09	.387E-06
.567E-05	.162E-06	.114E-06	.120E-04	.205E-06	.000E+00	.138E-05
.144E-07	.407E-07	.285E-07	.400E-08	.395E-07	.117E-09	.438E-06
.582E-05	.162E-06	.114E-06	.135E-04	.227E-06	.000E+00	.152E-05
.148E-07	.407E-07	.285E-07	.440E-08	.434E-07	.129E-09	.483E-06
.592E-05	.162E-06	.114E-06	.148E-04	.246E-06	.000E+00	.164E-05
.150E-07	.407E-07	.285E-07	.478E-08	.470E-07	.140E-09	.521E-06
.599E-05	.162E-06	.114E-06	.159E-04	.263E-06	.000E+00	.175E-05
.152E-07	.407E-07	.285E-07	.510E-08	.501E-07	.149E-09	.554E-06
.602E-05	.162E-06	.114E-06	.169E-04	.278E-06	.000E+00	.184E-05
.153E-07	.407E-07	.285E-07	.537E-08	.527E-07	.158E-09	.585E-06
.609E-05	.162E-06	.114E-06	.219E-04	.351E-06	.000E+00	.232E-05
.154E-07	.407E-07	.285E-07	.674E-08	.664E-07	.203E-09	.735E-06
.609E-05	.162E-06	.114E-06	.233E-04	.371E-06	.000E+00	.245E-05
.154E-07	.407E-07	.285E-07	.712E-08	.700E-07	.217E-09	.775E-06
.609E-05	.162E-06	.114E-06	.238E-04	.378E-06	.000E+00	.247E-05
.154E-07	.407E-07	.285E-07	.722E-08	.709E-07	.221E-09	.787E-06
.609E-05	.162E-06	.114E-06	.238E-04	.378E-06	.000E+00	.250E-05
.154E-07	.407E-07	.285E-07	.725E-08	.712E-07	.223E-09	.790E-06
.609E-05	.162E-06	.114E-06	.238E-04	.378E-06	.000E+00	.250E-05
.154E-07	.407E-07	.285E-07	.725E-08	.713E-07	.223E-09	.790E-06
.609E-05	.162E-06	.114E-06	.238E-04	.378E-06	.000E+00	.250E-05
.154E-07	.407E-07	.285E-07	.725E-08	.713E-07	.223E-09	.790E-06
.609E-05	.162E-06	.114E-06	.238E-04	.378E-06	.000E+00	.250E-05
.154E-07	.407E-07	.285E-07	.725E-08	.713E-07	.223E-09	.791E-06
.609E-05	.162E-06	.114E-06	.238E-04	.378E-06	.000E+00	.250E-05
.154E-07	.407E-07	.285E-07	.725E-08	.713E-07	.223E-09	.791E-06

Figure 43

Program DOSEFAC Output File (DOSEFAC.OUT)

INTAKE TIME= 70.00 YEARS
COMMITMENT TIME= 70.00 YEARS

ORGAN	MASS(GM)
TOTAL BODY	70000.0
BONE	7000.0
THYROID	20.0
LIVER	1800.0
KIDNEYS	310.0
LUNGS	1000.0
GI-LLI	150.0

242PU

RADIOACTIVE DECAY HALF LIFE= .376E+06 YEARS
INSOLUBLE FORM

FRACTION OF RADIONUCLIDE TRANSFERED TO THE BLOOD= .300E-04

ORGAN	BIOLOGICAL HALF-LIFE (DAYS)	FRACTION REACHING ORGAN	FRACTION FROM BLOOD TO ORGAN	EFFECTIVE ENERGY (MEV/DISINTEGRATION)
TOTAL BODY	.650E+05	.300E-04	.100E+01	.510E+02
BONE	.365E+05	.135E-04	.450E+00	.250E+03
THYROID	.000E+00	.000E+00	.000E+00	.000E+00
LIVER	.145E+05	.135E-04	.450E+00	.510E+02
KIDNEYS	.320E+05	.600E-06	.200E-01	.510E+02
LUNGS	.365E+03	----------	----------	.510E+02
GI-LLI	----------	----------	----------	.510E+00

238U

RADIOACTIVE DECAY HALF LIFE= .447E+10 YEARS
INSOLUBLE FORM

FRACTION OF RADIONUCLIDE TRANSFERED TO THE BLOOD= .100E-01

ORGAN	BIOLOGICAL HALF-LIFE (DAYS)	FRACTION REACHING ORGAN	FRACTION FROM BLOOD TO ORGAN	EFFECTIVE ENERGY (MEV/DISINTEGRATION)
TOTAL BODY	.100E+03	.100E-01	.100E+01	.430E+02
BONE	.300E+03	.110E-02	.110E+00	.220E+03
THYROID	.000E+00	.000E+00	.000E+00	.000E+00
LIVER	.000E+00	.000E+00	.000E+00	.000E+00
KIDNEYS	.150E+02	.110E-02	.110E+00	.430E+02
LUNGS	.120E+03	----------	----------	.430E+02
GI-LLI	----------	----------	----------	.430E+00

Figure 43

Program DOSEFAC Output File (DOSEFAC.OUT) (continued)

234U

RADIOACTIVE DECAY HALF LIFE= .245E+06 YEARS
INSOLUBLE FORM

FRACTION OF RADIONUCLIDE TRANSFERED TO THE BLOOD= .100E-01

ORGAN	BIOLOGICAL HALF-LIFE (DAYS)	FRACTION REACHING ORGAN	FRACTION FROM BLOOD TO ORGAN	EFFECTIVE ENERGY (MEV/DISINTEGRATION)
TOTAL BODY	.100E+03	.100E-01	.100E+01	.490E+02
BONE	.300E+03	.110E-02	.110E+00	.240E+03
THYROID	.000E+00	.000E+00	.000E+00	.000E+00
LIVER	.000E+00	.000E+00	.000E+00	.000E+00
KIDNEYS	.150E+02	.110E-02	.110E+00	.490E+02
LUNGS	.120E+03	----------	----------	.490E+02
GI-LLI	----------	----------	----------	.480E+00

230TH

RADIOACTIVE DECAY HALF LIFE= .770E+05 YEARS
INSOLUBLE FORM

FRACTION OF RADIONUCLIDE TRANSFERED TO THE BLOOD= .100E-03

ORGAN	BIOLOGICAL HALF-LIFE (DAYS)	FRACTION REACHING ORGAN	FRACTION FROM BLOOD TO ORGAN	EFFECTIVE ENERGY (MEV/DISINTEGRATION)
TOTAL BODY	.570E+05	.100E-03	.100E+01	.480E+02
BONE	.365E+05	.700E-04	.700E+00	.242E+03
THYROID	.000E+00	.000E+00	.000E+00	.000E+00
LIVER	.570E+05	.500E-05	.500E-01	.480E+02
KIDNEYS	.220E+05	.500E-05	.500E-01	.480E+02
LUNGS	.146E+04	----------	----------	.480E+02
GI-LLI	----------	----------	----------	.470E+00

226RA

RADIOACTIVE DECAY HALF LIFE= .160E+04 YEARS
INSOLUBLE FORM

FRACTION OF RADIONUCLIDE TRANSFERED TO THE BLOOD= .300E+00

ORGAN	BIOLOGICAL HALF-LIFE (DAYS)	FRACTION REACHING ORGAN	FRACTION FROM BLOOD TO ORGAN	EFFECTIVE ENERGY (MEV/DISINTEGRATION)
TOTAL BODY	.810E+04	.300E+00	.100E+01	.110E+03
BONE	.164E+05	.300E-01	.100E+00	.110E+03
THYROID	.000E+00	.000E+00	.000E+00	.000E+00
LIVER	.000E+00	.000E+00	.000E+00	.000E+00
KIDNEYS	.000E+00	.000E+00	.000E+00	.000E+00
LUNGS	.120E+03	----------	----------	.110E+03
GI-LLI	----------	----------	----------	.370E+01

Figure 43

Program DOSEFAC Output File (DOSEFAC.OUT) (continued)

210PB

RADIOACTIVE DECAY HALF LIFE= .223E+02 YEARS
INSOLUBLE FORM

FRACTION OF RADIONUCLIDE TRANSFERED TO THE BLOOD= .800E-01

ORGAN	BIOLOGICAL HALF-LIFE (DAYS)	FRACTION REACHING ORGAN	FRACTION FROM BLOOD TO ORGAN	EFFECTIVE ENERGY (MEV/DISINTEGRATION)
TOTAL BODY	.146E+04	.800E-01	.100E+01	.520E+01
BONE	.365E+04	.200E-01	.250E+00	.290E+02
THYROID	.000E+00	.000E+00	.000E+00	.000E+00
LIVER	.195E+04	.640E-02	.800E-01	.100E+02
KIDNEYS	.531E+03	.100E-01	.125E+00	.100E+02
LUNGS	.120E+03	----------	----------	.251E+02
GI-LLI	----------	----------	----------	.460E+00

INHALATION DOSE FACTORS
(REM/(UCI/YR))

ORGAN

RADIONUCLIDE	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU	.382E+04	.788E+05	.000E+00	.506E+05	.158E+05	.118E+05	.256E+01
238U	.395E+02	.659E+03	.000E+00	.000E+00	.148E+03	.331E+04	.241E+01
234U	.450E+02	.719E+03	.000E+00	.000E+00	.169E+03	.377E+04	.269E+01
230TH	.355E+04	.119E+06	.000E+00	.690E+04	.345E+05	.416E+05	.263E+01
226RA	.485E+04	.642E+04	.000E+00	.000E+00	.000E+00	.847E+04	.207E+02
210PB	.553E+02	.145E+04	.000E+00	.412E+03	.126E+04	.190E+04	.258E+01

INGESTION DOSE FACTORS
(REM/(UCI/YR))

ORGAN

RADIONUCLIDE	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU	.916E+00	.189E+02	.000E+00	.122E+02	.379E+01	.000E+00	.457E+01
238U	.316E+01	.527E+02	.000E+00	.000E+00	.118E+02	.000E+00	.381E+01
234U	.360E+01	.575E+02	.000E+00	.000E+00	.135E+02	.000E+00	.426E+01
230TH	.284E+01	.949E+02	.000E+00	.552E+01	.276E+02	.000E+00	.421E+01
226RA	.116E+05	.154E+05	.000E+00	.000E+00	.000E+00	.000E+00	.232E+02
210PB	.354E+02	.926E+03	.000E+00	.264E+03	.806E+03	.000E+00	.379E+01

Figure 44

Program DOSECAL2 Output File (DOSECAL.OUT)

```
NUMBER OF RADIONUCLIDES=    7 NUMBER OF TIMES=   82

***RADIONUCLIDES***

242PU   238U    234U    230TH   226RA   222RN   210PB

USAGE AND EXPOSURE PARAMETERS

SPRINKLER IRRIGATION=    400.00 L/M**2
DENSITY OF LEAFY VEGETABLES=      5.20 KG/M**2
IRRIGATION TIME=     62.00 DAYS
WEATHERING HALF-LIFE=     14.00 DAYS
FRACTION OF RADIONUCLIDE DEPOSITED ON LEAVES=        .25
HUMAN VEGETABLE CONSUMPTION=    190.00 KG/YR
HUMAN WATER CONSUMPTION=    370.00 L/YR
DAIRY COW PLANT CONSUMPTION=     50.00 KG/DAY
BEEF CATTLE PLANT CONSUMPTION=     50.00 KG/DAY
DAIRY COW DRINKING RATE=     60.00 L/DAY
BEEF CATTLE DRINKING RATE=     50.00 L/DAY
MEAT CONSUMPTION BY HUMANS=     95.00 KG/YR
MILK CONSUMPTION BY HUMANS=    100.00 L/YR
FISH CONSUMPTION BY HUMANS=      6.90 KG/YR
AIR SUBMERSION=   8760.00 HR/YR
SOIL EXPOSURE=   2920.00 HR/YR
TIME SPENT SWIMMING=     15.00 HR/YR
SOIL RESUSPENSION FACTOR=   .35E+01 UG/M**3
HUMAN BREATHING RATE=   8000.00 M**3/YR
EXPOSURE TIME FOR HUMANS=     70.00 YR
DOSE COMMITMENT TIME=     70.00 YR
SOIL DEPTH=      2.50 CM
SOIL DENSITY=      2.80 GM/CM**3

SOIL AND WATER RADIONUCLIDE CONCENTRATIONS

242PU     SOIL CONCENTRATION=    .000E+00 MICROCURIES/KG
          WATER CONCENTRATION=   .000E+00 MICROCURIES/L
238U      SOIL CONCENTRATION=    .000E+00 MICROCURIES/KG
          WATER CONCENTRATION=   .000E+00 MICROCURIES/L
234U      SOIL CONCENTRATION=    .000E+00 MICROCURIES/KG
          WATER CONCENTRATION=   .000E+00 MICROCURIES/L
230TH     SOIL CONCENTRATION=    .000E+00 MICROCURIES/KG
          WATER CONCENTRATION=   .000E+00 MICROCURIES/L
226RA     SOIL CONCENTRATION=    .000E+00 MICROCURIES/KG
          WATER CONCENTRATION=   .000E+00 MICROCURIES/L
222RN     SOIL CONCENTRATION=    .000E+00 MICROCURIES/KG
          WATER CONCENTRATION=   .000E+00 MICROCURIES/L
210PB     SOIL CONCENTRATION=    .000E+00 MICROCURIES/KG
          WATER CONCENTRATION=   .000E+00 MICROCURIES/L

CONCENTRATION RATIOS

242PU     RATIO FOR FISH=          .350E+01 ((CI/KG)FISH/(CI/L)WATER)
          RATIO FOR VEGETATION=    .250E-03 ((CI/KG)VEGETATION/(CI/KG)SOIL)
          RATIO FOR MILK=          .250E-07 ((CI/L)MILK/(CI/DAY)INTAKE)
          RATIO FOR MEAT=          .500E-02 ((CI/KG)MEAT/(CI/DAY)INTAKE)
238U      RATIO FOR FISH=          .200E+01 ((CI/KG)FISH/(CI/L)WATER)
          RATIO FOR VEGETATION=    .250E-02 ((CI/KG)VEGETATION/(CI/KG)SOIL)
          RATIO FOR MILK=          .600E-03 ((CI/L)MILK/(CI/DAY)INTAKE)
          RATIO FOR MEAT=          .500E-02 ((CI/KG)MEAT/(CI/DAY)INTAKE)
234U      RATIO FOR FISH=          .200E+01 ((CI/KG)FISH/(CI/L)WATER)
          RATIO FOR VEGETATION=    .250E-02 ((CI/KG)VEGETATION/(CI/KG)SOIL)
          RATIO FOR MILK=          .600E-03 ((CI/L)MILK/(CI/DAY)INTAKE)
          RATIO FOR MEAT=          .500E-02 ((CI/KG)MEAT/(CI/DAY)INTAKE)
```

Figure 44

Program DOSECAL2 Output File (DOSECAL.OUT) (continued)

```
230TH     RATIO FOR FISH=          .300E+02 ((CI/KG)FISH/(CI/L)WATER)
          RATIO FOR VEGETATION=    .420E-02 ((CI/KG)VEGETATION/(CI/KG)SOIL)
          RATIO FOR MILK=          .250E-05 ((CI/L)MILK/(CI/DAY)INTAKE)
          RATIO FOR MEAT=          .500E-02 ((CI/KG)MEAT/(CI/DAY)INTAKE)
226RA     RATIO FOR FISH=          .500E+02 ((CI/KG)FISH/(CI/L)WATER)
          RATIO FOR VEGETATION=    .140E-02 ((CI/KG)VEGETATION/(CI/KG)SOIL)
          RATIO FOR MILK=          .200E-03 ((CI/L)MILK/(CI/DAY)INTAKE)
          RATIO FOR MEAT=          .990E-03 ((CI/KG)MEAT/(CI/DAY)INTAKE)
222RN     RATIO FOR FISH=          .000E+00 ((CI/KG)FISH/(CI/L)WATER)
          RATIO FOR VEGETATION=    .000E+00 ((CI/KG)VEGETATION/(CI/KG)SOIL)
          RATIO FOR MILK=          .000E+00 ((CI/L)MILK/(CI/DAY)INTAKE)
          RATIO FOR MEAT=          .000E+00 ((CI/KG)MEAT/(CI/DAY)INTAKE)
210PB     RATIO FOR FISH=          .100E+03 ((CI/KG)FISH/(CI/L)WATER)
          RATIO FOR VEGETATION=    .680E-01 ((CI/KG)VEGETATION/(CI/KG)SOIL)
          RATIO FOR MILK=          .100E-04 ((CI/L)MILK/(CI/DAY)INTAKE)
          RATIO FOR MEAT=          .990E-03 ((CI/KG)MEAT/(CI/DAY)INTAKE)
```

EXTERNAL DOSE FACTORS

RADIONUCLIDE	GROUND EXPOSURE (REM/HR PER UCI/M**2) SKIN	GROUND EXPOSURE TOTAL BODY	WATER IMMERSION (REM/HR PER UCI/M**3) SKIN	WATER IMMERSION TOTAL BODY	AIR SUBMERSION (REM/HR PER UCI/M**3) SKIN	AIR SUBMERSION TOTAL BODY
242PU	.160E-07	.110E-08	.360E-08	.110E-09	.160E-05	.510E-07
238U	.632E-06	.352E-06	.932E-06	.736E-07	.811E-03	.338E-04
234U	.508E-06	.732E-08	.124E-07	.118E-08	.528E-05	.518E-06
230TH	.100E-06	.782E-08	.441E-08	.122E-08	.188E-05	.545E-06
226RA	.155E-04	.128E-04	.503E-05	.326E-05	.289E-02	.151E-02
222RN	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB	.170E-07	.130E-07	.360E-06	.300E-08	.336E-03	.269E-05

INHALATION DOSE FACTORS (REM/(UCI/YR))

RADIONUCLIDE	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU	.763E+04	.302E+06	.000E+00	.433E+05	.326E+05	.118E+05	.283E+01
238U	.790E+02	.134E+04	.000E+00	.000E+00	.311E+03	.331E+04	.239E+01
234U	.900E+02	.146E+04	.000E+00	.000E+00	.354E+03	.378E+04	.267E+01
230TH	.709E+04	.263E+06	.000E+00	.117E+05	.570E+05	.416E+05	.261E+01
226RA	.155E+05	.154E+05	.000E+00	.535E+00	.152E+02	.847E+04	.206E+02
222RN	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB	.128E+03	.371E+04	.000E+00	.100E+04	.334E+04	.190E+04	.255E+01

INGESTION DOSE FACTORS (REM/(UCI/YR))

RADIONUCLIDE	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU	.916E+00	.363E+02	.000E+00	.513E+01	.392E+01	.000E+00	.457E+01
238U	.316E+01	.527E+02	.000E+00	.000E+00	.122E+02	.000E+00	.385E+01
234U	.360E+01	.575E+02	.000E+00	.000E+00	.139E+02	.000E+00	.430E+01
230TH	.284E+01	.102E+03	.000E+00	.584E+01	.285E+02	.000E+00	.421E+01
226RA	.116E+05	.154E+05	.000E+00	.401E+00	.114E+02	.000E+00	.232E+02
222RN	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB	.354E+02	.926E+03	.000E+00	.279E+03	.835E+03	.000E+00	.379E+01

Figure 44

Program DOSECAL2 Output File (DOSECAL.OUT) (continued)

TIME= .000E+00 YEARS

EXTERNAL DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY
242PU	.000E+00	.000E+00
238U	.000E+00	.000E+00
234U	.000E+00	.000E+00
230TH	.000E+00	.000E+00
226RA	.000E+00	.000E+00
222RN	.000E+00	.000E+00
210PB	.000E+00	.000E+00
TOTAL	.000E+00	.000E+00

INHALATION DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
238U		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
234U		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
230TH		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
226RA		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
222RN		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
TOTAL		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00

INGESTION DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
238U		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
234U		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
230TH		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
226RA		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
222RN		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
TOTAL		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00

TOTAL DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
238U	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
234U	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
230TH	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
226RA	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
222RN	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
TOTAL	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00

Figure 44

Program DOSECAL2 Output File (DOSECAL.OUT) (continued)

SOIL AND WATER RADIONUCLIDE CONCENTRATIONS

242PU	SOIL CONCENTRATION=	.196E-21	MICROCURIES/KG
	WATER CONCENTRATION=	.137E-17	MICROCURIES/L
238U	SOIL CONCENTRATION=	.333E-20	MICROCURIES/KG
	WATER CONCENTRATION=	.235E-16	MICROCURIES/L
234U	SOIL CONCENTRATION=	.234E-20	MICROCURIES/KG
	WATER CONCENTRATION=	.164E-16	MICROCURIES/L
230TH	SOIL CONCENTRATION=	.263E-22	MICROCURIES/KG
	WATER CONCENTRATION=	.182E-18	MICROCURIES/L
226RA	SOIL CONCENTRATION=	.261E-21	MICROCURIES/KG
	WATER CONCENTRATION=	.183E-17	MICROCURIES/L
222RN	SOIL CONCENTRATION=	.000E+00	MICROCURIES/KG
	WATER CONCENTRATION=	.264E-17	MICROCURIES/L
210PB	SOIL CONCENTRATION=	.266E-20	MICROCURIES/KG
	WATER CONCENTRATION=	.188E-16	MICROCURIES/L

TIME= .100E-02 YEARS

EXTERNAL DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY
242PU	.522E-20	.161E-21
238U	.230E-16	.183E-17
234U	.231E-18	.206E-19
230TH	.880E-21	.236E-21
226RA	.972E-17	.631E-17
222RN	.000E+00	.000E+00
210PB	.711E-17	.597E-19
TOTAL	.401E-16	.823E-17

INHALATION DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU		.419E-22	.166E-20	.000E+00	.238E-21	.179E-21	.648E-22	.155E-25
238U		.737E-23	.125E-21	.000E+00	.000E+00	.290E-22	.309E-21	.223E-24
234U		.590E-23	.957E-22	.000E+00	.000E+00	.232E-22	.248E-21	.175E-24
230TH		.522E-23	.194E-21	.000E+00	.862E-23	.420E-22	.306E-22	.192E-26
226RA		.113E-21	.113E-21	.000E+00	.391E-26	.111E-24	.619E-22	.151E-24
222RN		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB		.953E-23	.276E-21	.000E+00	.745E-22	.249E-21	.142E-21	.190E-24
TOTAL		.183E-21	.246E-20	.000E+00	.321E-21	.522E-21	.855E-21	.756E-24

INGESTION DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU		.796E-15	.316E-13	.000E+00	.446E-14	.341E-14	.000E+00	.397E-14
238U		.469E-13	.781E-12	.000E+00	.000E+00	.181E-12	.000E+00	.571E-13
234U		.373E-13	.595E-12	.000E+00	.000E+00	.144E-12	.000E+00	.445E-13
230TH		.423E-15	.152E-13	.000E+00	.869E-15	.424E-14	.000E+00	.626E-15
226RA		.195E-10	.259E-10	.000E+00	.675E-15	.192E-13	.000E+00	.390E-13
222RN		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB		.840E-12	.220E-10	.000E+00	.662E-11	.198E-10	.000E+00	.899E-13
TOTAL		.204E-10	.493E-10	.000E+00	.663E-11	.202E-10	.000E+00	.235E-12

Figure 44

Program DOSECAL2 Output File (DOSECAL.OUT) (continued)

TOTAL DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU	.522E-20	.796E-15	.316E-13	.000E+00	.446E-14	.341E-14	.648E-22	.397E-14
238U	.230E-16	.469E-13	.781E-12	.000E+00	.000E+00	.181E-12	.309E-21	.571E-13
234U	.231E-18	.373E-13	.595E-12	.000E+00	.000E+00	.144E-12	.248E-21	.445E-13
230TH	.880E-21	.423E-15	.152E-13	.000E+00	.869E-15	.424E-14	.306E-22	.626E-15
226RA	.972E-17	.195E-10	.259E-10	.000E+00	.675E-15	.192E-13	.619E-22	.390E-13
222RN	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB	.711E-17	.840E-12	.220E-10	.000E+00	.662E-11	.198E-10	.142E-21	.899E-13
TOTAL	.401E-16	.204E-10	.493E-10	.000E+00	.663E-11	.202E-10	.855E-21	.235E-12

SOIL AND WATER RADIONUCLIDE CONCENTRATIONS

242PU	SOIL CONCENTRATION=	.175E-20	MICROCURIES/KG
	WATER CONCENTRATION=	.670E-17	MICROCURIES/L
238U	SOIL CONCENTRATION=	.298E-19	MICROCURIES/KG
	WATER CONCENTRATION=	.117E-15	MICROCURIES/L
234U	SOIL CONCENTRATION=	.209E-19	MICROCURIES/KG
	WATER CONCENTRATION=	.817E-16	MICROCURIES/L
230TH	SOIL CONCENTRATION=	.233E-21	MICROCURIES/KG
	WATER CONCENTRATION=	.892E-18	MICROCURIES/L
226RA	SOIL CONCENTRATION=	.231E-20	MICROCURIES/KG
	WATER CONCENTRATION=	.901E-17	MICROCURIES/L
222RN	SOIL CONCENTRATION=	.000E+00	MICROCURIES/KG
	WATER CONCENTRATION=	.531E-17	MICROCURIES/L
210PB	SOIL CONCENTRATION=	.240E-19	MICROCURIES/KG
	WATER CONCENTRATION=	.937E-16	MICROCURIES/L

TIME= .100E+01 YEARS

EXTERNAL DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY
242PU	.113E-13	.742E-15
238U	.190E-10	.729E-11
234U	.687E-11	.104E-12
230TH	.887E-14	.721E-15
226RA	.160E-10	.129E-10
222RN	.000E+00	.000E+00
210PB	.238E-11	.215E-12
TOTAL	.443E-10	.205E-10

INHALATION DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU		.972E-14	.385E-12	.000E+00	.552E-13	.415E-13	.150E-13	.361E-17
238U		.296E-14	.503E-13	.000E+00	.000E+00	.117E-13	.124E-12	.897E-16
234U		.236E-14	.383E-13	.000E+00	.000E+00	.929E-14	.992E-13	.701E-16
230TH		.121E-14	.449E-13	.000E+00	.200E-14	.974E-14	.711E-14	.446E-18
226RA		.279E-13	.277E-13	.000E+00	.962E-18	.273E-16	.152E-13	.370E-16
222RN		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB		.380E-14	.110E-12	.000E+00	.297E-13	.991E-13	.564E-13	.757E-16
TOTAL		.479E-13	.656E-12	.000E+00	.868E-13	.171E-12	.317E-12	.276E-15

Figure 44

Program DOSECAL2 Output File (DOSECAL.OUT) (continued)

INGESTION DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU		.129E-09	.511E-08	.000E+00	.723E-09	.552E-09	.000E+00	.644E-09
238U		.140E-07	.234E-06	.000E+00	.000E+00	.541E-07	.000E+00	.171E-07
234U		.112E-07	.179E-06	.000E+00	.000E+00	.432E-07	.000E+00	.134E-07
230TH		.692E-10	.249E-08	.000E+00	.142E-09	.694E-09	.000E+00	.103E-09
226RA		.354E-05	.470E-05	.000E+00	.122E-09	.348E-08	.000E+00	.708E-08
222RN		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB		.251E-06	.657E-05	.000E+00	.198E-05	.592E-05	.000E+00	.269E-07
TOTAL		.382E-05	.117E-04	.000E+00	.198E-05	.603E-05	.000E+00	.651E-07

TOTAL DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU	.113E-13	.129E-09	.511E-08	.000E+00	.723E-09	.552E-09	.150E-13	.644E-09
238U	.190E-10	.140E-07	.234E-06	.000E+00	.000E+00	.541E-07	.124E-12	.171E-07
234U	.687E-11	.112E-07	.179E-06	.000E+00	.000E+00	.432E-07	.992E-13	.134E-07
230TH	.887E-14	.692E-10	.249E-08	.000E+00	.142E-09	.694E-09	.711E-14	.103E-09
226RA	.160E-10	.354E-05	.470E-05	.000E+00	.122E-09	.348E-08	.152E-13	.708E-08
222RN	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB	.238E-11	.251E-06	.657E-05	.000E+00	.198E-05	.592E-05	.564E-13	.269E-07
TOTAL	.443E-10	.382E-05	.117E-04	.000E+00	.198E-05	.603E-05	.317E-12	.651E-07

SOIL AND WATER RADIONUCLIDE CONCENTRATIONS

242PU	SOIL CONCENTRATION=	.196E-12	MICROCURIES/KG
	WATER CONCENTRATION=	.476E-12	MICROCURIES/L
238U	SOIL CONCENTRATION=	.569E-11	MICROCURIES/KG
	WATER CONCENTRATION=	.152E-10	MICROCURIES/L
234U	SOIL CONCENTRATION=	.398E-11	MICROCURIES/KG
	WATER CONCENTRATION=	.106E-10	MICROCURIES/L
230TH	SOIL CONCENTRATION=	.262E-13	MICROCURIES/KG
	WATER CONCENTRATION=	.639E-13	MICROCURIES/L
226RA	SOIL CONCENTRATION=	.268E-12	MICROCURIES/KG
	WATER CONCENTRATION=	.709E-12	MICROCURIES/L
222RN	SOIL CONCENTRATION=	.000E+00	MICROCURIES/KG
	WATER CONCENTRATION=	.537E-14	MICROCURIES/L
210PB	SOIL CONCENTRATION=	.447E-11	MICROCURIES/KG
	WATER CONCENTRATION=	.121E-10	MICROCURIES/L

TIME= .100E+03 YEARS

EXTERNAL DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY
242PU	.263E-09	.181E-10
238U	.530E-07	.288E-07
234U	.289E-07	.418E-09
230TH	.230E-09	.180E-10
226RA	.705E-07	.582E-07
222RN	.000E+00	.000E+00
210PB	.116E-08	.578E-09
TOTAL	.154E-06	.880E-07

Figure 44

Program DOSECAL2 Output File (DOSECAL.OUT) (continued)

INHALATION DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU		.246E-09	.972E-08	.000E+00	.139E-08	.105E-08	.380E-09	.911E-13
238U		.126E-10	.213E-09	.000E+00	.000E+00	.495E-10	.527E-09	.381E-12
234U		.100E-10	.163E-09	.000E+00	.000E+00	.394E-10	.421E-09	.298E-12
230TH		.320E-10	.119E-08	.000E+00	.527E-10	.257E-09	.188E-09	.118E-13
226RA		.137E-09	.136E-09	.000E+00	.473E-14	.134E-12	.749E-10	.182E-12
222RN		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB		.111E-10	.321E-09	.000E+00	.865E-10	.289E-09	.164E-09	.221E-12
TOTAL		.448E-09	.117E-07	.000E+00	.153E-08	.168E-08	.176E-08	.118E-11

INGESTION DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU		.355E-07	.141E-05	.000E+00	.199E-06	.152E-06	.000E+00	.177E-06
238U		.316E-05	.527E-04	.000E+00	.000E+00	.122E-04	.000E+00	.385E-05
234U		.253E-05	.404E-04	.000E+00	.000E+00	.976E-05	.000E+00	.302E-05
230TH		.194E-07	.698E-06	.000E+00	.399E-07	.195E-06	.000E+00	.288E-07
226RA		.945E-03	.125E-02	.000E+00	.327E-07	.929E-06	.000E+00	.189E-05
222RN		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB		.453E-04	.129E-02	.000E+00	.388E-03	.116E-02	.000E+00	.527E-05
TOTAL		.100E-02	.264E-02	.000E+00	.389E-03	.119E-02	.000E+00	.142E-04

TOTAL DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU	.263E-09	.357E-07	.141E-05	.000E+00	.200E-06	.153E-06	.380E-09	.177E-06
238U	.530E-07	.319E-05	.527E-04	.000E+00	.000E+00	.122E-04	.527E-09	.385E-05
234U	.265E-07	.253E-05	.404E-04	.000E+00	.000E+00	.976E-05	.421E-09	.302E-05
230TH	.230E-09	.195E-07	.699E-06	.000E+00	.400E-07	.195E-06	.188E-09	.288E-07
226RA	.705E-07	.945E-03	.125E-02	.000E+00	.327E-07	.929E-06	.749E-10	.189E-05
222RN	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB	.116E-08	.493E-04	.129E-02	.000E+00	.388E-03	.116E-02	.164E-09	.527E-05
TOTAL	.154E-06	.100E-02	.264E-02	.000E+00	.389E-03	.119E-02	.176E-08	.142E-04

SOIL AND WATER RADIONUCLIDE CONCENTRATIONS

242PU	SOIL CONCENTRATION=	.496E-08	MICROCURIES/KG
	WATER CONCENTRATION=	.130E-09	MICROCURIES/L
238U	SOIL CONCENTRATION=	.123E-07	MICROCURIES/KG
	WATER CONCENTRATION=	.325E-08	MICROCURIES/L
234U	SOIL CONCENTRATION=	.864E-08	MICROCURIES/KG
	WATER CONCENTRATION=	.227E-08	MICROCURIES/L
230TH	SOIL CONCENTRATION=	.715E-09	MICROCURIES/KG
	WATER CONCENTRATION=	.175E-10	MICROCURIES/L
226RA	SOIL CONCENTRATION=	.715E-09	MICROCURIES/KG
	WATER CONCENTRATION=	.189E-09	MICROCURIES/L
222RN	SOIL CONCENTRATION=	.000E+00	MICROCURIES/KG
	WATER CONCENTRATION=	.556E-12	MICROCURIES/L
210PB	SOIL CONCENTRATION=	.657E-08	MICROCURIES/KG
	WATER CONCENTRATION=	.217E-08	MICROCURIES/L

Figure 44

Program DOSECAL2 Output File (DOSECAL.OUT) (continued)

TIME= .800E+04 YEARS

EXTERNAL DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY
242PU	.385E-06	.264E-07
238U	.147E-05	.799E-06
234U	.807E-06	.117E-07
230TH	.133E-05	.104E-06
226RA	.734E-05	.605E-05
222RN	.000E+00	.000E+00
210PB	.927E-07	.477E-07
TOTAL	.114E-04	.704E-05

INHALATION DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU		.359E-06	.142E-04	.000E+00	.204E-05	.153E-05	.555E-06	.133E-09
238U		.349E-09	.593E-08	.000E+00	.000E+00	.138E-08	.146E-07	.106E-10
234U		.280E-09	.454E-08	.000E+00	.000E+00	.110E-08	.117E-07	.830E-11
230TH		.185E-06	.686E-05	.000E+00	.305E-06	.149E-05	.109E-05	.681E-10
226RA		.143E-07	.142E-07	.000E+00	.493E-12	.140E-10	.780E-08	.190E-10
222RN		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB		.914E-09	.265E-07	.000E+00	.714E-08	.238E-07	.136E-07	.182E-10
TOTAL		.560E-06	.211E-04	.000E+00	.235E-05	.305E-05	.169E-05	.257E-09

INGESTION DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU		.263E-05	.112E-03	.000E+00	.159E-04	.121E-04	.000E+00	.141E-04
238U		.788E-04	.131E-02	.000E+00	.000E+00	.304E-03	.000E+00	.960E-04
234U		.629E-04	.100E-02	.000E+00	.000E+00	.243E-03	.000E+00	.751E-04
230TH		.408E-05	.146E-03	.000E+00	.839E-05	.409E-04	.000E+00	.605E-05
226RA		.783E-01	.104E+00	.000E+00	.271E-05	.769E-04	.000E+00	.157E-03
222RN		.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB		.375E-02	.980E-01	.000E+00	.295E-01	.864E-01	.000E+00	.401E-03
TOTAL		.822E-01	.205E+00	.000E+00	.296E-01	.891E-01	.000E+00	.749E-03

TOTAL DOSE
(REM)

RADIONUCLIDE	SKIN	TOTAL BODY	BONE	THYROID	LIVER	KIDNEYS	LUNGS	GI-LLI
242PU	.385E-06	.322E-05	.126E-03	.000E+00	.179E-04	.137E-04	.555E-06	.141E-04
238U	.147E-05	.796E-04	.131E-02	.000E+00	.000E+00	.304E-03	.146E-07	.960E-04
234U	.807E-06	.629E-04	.100E-02	.000E+00	.000E+00	.243E-03	.117E-07	.751E-04
230TH	.133E-05	.437E-05	.153E-03	.000E+00	.869E-05	.424E-04	.109E-05	.605E-05
226RA	.734E-05	.783E-01	.104E+00	.000E+00	.271E-05	.769E-04	.780E-08	.157E-03
222RN	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
210PB	.927E-07	.375E-02	.980E-01	.000E+00	.295E-01	.864E-01	.136E-07	.401E-03
TOTAL	.114E-04	.822E-01	.205E+00	.000E+00	.296E-01	.891E-01	.169E-05	.749E-03

Figure 44

Program DOSECAL2 Output File (DOSECAL.OUT) (continued)

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SOIL AND WATER RADIONUCLIDE CONCENTRATIONS

242PU     SOIL CONCENTRATION=    .188E-05 MICROCURIES/KG
          WATER CONCENTRATION=   .520E-08 MICROCURIES/L
238U      SOIL CONCENTRATION=    .159E-06 MICROCURIES/KG
          WATER CONCENTRATION=   .398E-07 MICROCURIES/L
234U      SOIL CONCENTRATION=    .112E-06 MICROCURIES/KG
          WATER CONCENTRATION=   .280E-07 MICROCURIES/L
230TH     SOIL CONCENTRATION=    .114E-05 MICROCURIES/KG
          WATER CONCENTRATION=   .819E-09 MICROCURIES/L
226RA     SOIL CONCENTRATION=    .371E-07 MICROCURIES/KG
          WATER CONCENTRATION=   .817E-08 MICROCURIES/L
222RN     SOIL CONCENTRATION=    .000E+00 MICROCURIES/KG
          WATER CONCENTRATION=   .233E-10 MICROCURIES/L
210PB     SOIL CONCENTRATION=    .285E-06 MICROCURIES/KG
          WATER CONCENTRATION=   .907E-07 MICROCURIES/L
```

4.2 CELLTRANS

4.2.1 Code Description

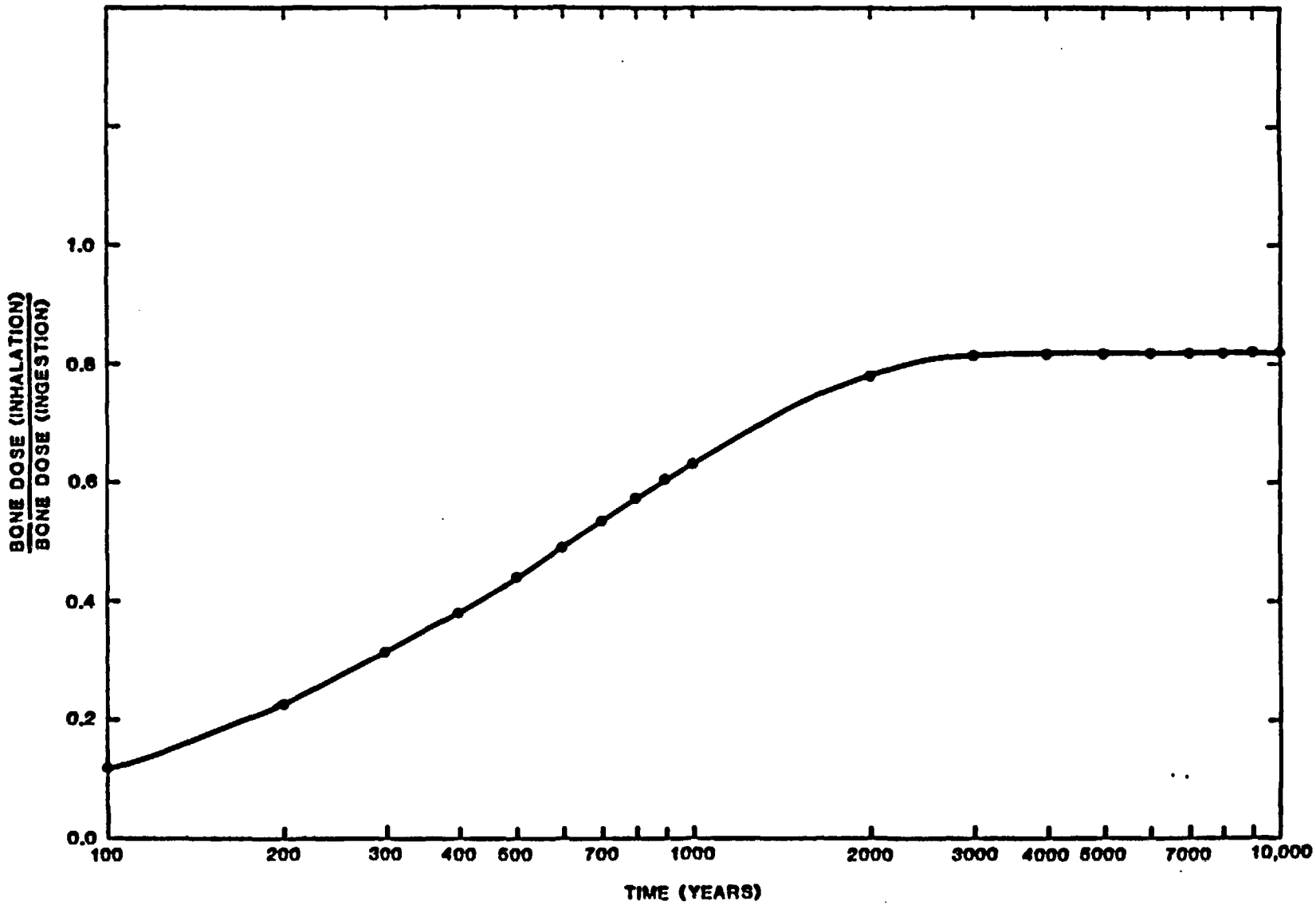
The code CELLTRANS was developed at the outset of this benchmarking effort to check the calculations of PATH1/DOSHEM. The codes differ from one another in the way the linear differential equations of compartment transfer are solved. In CELLTRANS, no compartment transfer is specified for radioactive decay. Instead, decay of a parent is treated as a source term for the daughter. This assumption reduces the order of the transfer matrix by a factor of seven. Furthermore, the radionuclide concentration in a surface-water subzone, when multiplied by the flow out of that subzone, is treated as a source term for the surface-water subzone of the next zone downstream. This means that the transfer matrix can be broken down into a number of 4x4 submatrices, which can be solved rapidly by use of the eigenvalue method. The use of this method means that the calculation can be performed on a microcomputer. In fact, CELLTRANS was developed and tested on a microcomputer before being transferred to the National Institutes of Health (NIH) computing facility used by NRC. The direct integration procedure for solving the compartmental transfer equations, as used in PATH1, is generally too time consuming for a microcomputer.

For a particular zone, the transfer of a radionuclide, A, between subzones can be expressed mathematically as follows:

$$\frac{dA_i}{dt} = \sum_{j=1}^{N} B_{ij} A_j + Q_{Ai} , \qquad (4.2.1)$$

Figure 4-22

Ratio of Inhalation to Ingestion Bone Dose for Benchmark Problem 3.1B



where

A_i = number of atoms of radionuclide A in subzone i

B_{ij}, $i \neq j$ = transfer coefficient (positive or zero) for transfers from subzone j to subzone i (yr^{-1})

Q_{Ai} = input rate of radionuclide A to subzone i (atoms/yr)

N = number of subzones = 4 (groundwater, surface water, sediment, and soil)

In addition to accounting for direct input of radionuclide A to subzone i, the term Q_{Ai} will also reflect the input of radionuclide A due to the radioactive decay of the parent of A occurring in subzone i. If subzone i is the surface-water subzone, the term Q_{Ai} will also include the input of radionuclide A from the surface-water subzone upstream. The transfer coefficient for radionuclide transfer out of subzone i is given by:

$$B_{ii} = -\sum_{\substack{j=1 \\ j \neq i}}^{N} B_{ji} - \lambda_i - \sum_{k=1}^{N_s} S_{ki} \qquad (4.2.2)$$

where

B_{ii} = negative sum of all transfer coefficients (B_{ij}, $i \neq j$ for transfers out of subzone i (yr^{-1}))

λ_i = decay rate for radionuclide A for subzone i (yr^{-1}) (includes both radioactive decay and physical removal from subzone i)

S_{ki} = transfer coefficient for physical transfer of radionuclide A from subzone i to sink k (yr^{-1})

N_s = number of sinks for subzone i

The radionuclide transfer coefficients associated with the physical movement of water and soil between subzones or between a subzone and a sink are calculated as follows:

$$B_{ij} = \frac{1}{M_{sj} + \frac{V_{Lj}}{K_{dj}}} \left(\frac{dM_s}{dt}\right)_{ij} + \frac{1}{M_{sj}K_{dj}+V_{Lj}} \left(\frac{dV_L}{dt}\right)_{ij}, \quad (4.2.3)$$

where

M_{sj} = mass solid in subzone j (kg)

V_{Lj} = volume of water in subzone j (L)

$\left(\frac{dM_s}{dt}\right)_{ij}$ = transfer rate for mass from subzone j to subzone i (kg/yr)

$\left(\frac{dV_L}{dt}\right)_{ij}$ = transfer rate for water from subzone j to subzone i (L/yr)

K_{dj} = distribution coefficient for subzone j (L/kg)

The solution method for Equation 4.2.1 in CELLTRANS requires determination of the eigenvalues and eigenvectors of the transfer matrix $\|B\|$ with elements B_{ij}. The matrix $\|P\|$, with the $\|B\|$ matrix eigenvectors as columns, can be used to generate a transformed subzone inventory vector $|y|$ as follows:

$$|A| = ||P||\ |y| \tag{4.2.4}$$

With this substitution, Equation 4.2.1 becomes

$$||P||\ \frac{d|y|}{dt} = ||B||\ ||P||\ |y| + |Q| \tag{4.2.5}$$

Multiplying both sides of Equation 4.2.5 from the left by the inverse of $||P||$ gives

$$\frac{d|y|}{dt} = ||P||^{-1}\ ||B||\ ||P||\ |y| + ||P||^{-1}\ |Q| \tag{4.2.6}$$

$$\frac{d|y|}{dt} = ||D||\ |y| + ||P||^{-1}|Q|, \tag{4.2.7}$$

where $||D||$ is the diagonal matrix of eigenvalues ($\lambda 1, \lambda 2 \ldots \lambda N$) of the matrix $||B||$. Equation 4.2.7 can be solved to yield the transformed inventory vector components:

$$y_i(t_m) = \left(\frac{\hat{Q}_{mi}}{\lambda_i} - \frac{K}{\lambda_i^2}\right)\left(1-e^{-\lambda_i(t_m-t_{m-1})}\right) + \frac{K}{\lambda_i}(t_m-t_{m-1}) + y(t_{m-1})\ e^{-\lambda_i(t_m-t_{m-1})}, \tag{4.2.8}$$

where

K = $\dfrac{\hat{Q}_{mi} - \hat{Q}_{m1-i}}{t_m - t_{m-1}}$

$\hat{Q}_{mi}$ = $(||P||^{-1}\ |Q_m|)_i$

t_m = time at the end of the mth time interval (yr)

$|Q_m|$ = vector of subzone radionuclide input rates at time t_m (atoms/yr)

The actual subzone concentrations can then be determined by use of Equation 4.2.4.

The solution given by Equation 4.2.8 is based upon an assumed linear variation of $|Q|$ within the time interval (t_{m-1}, t_m). Depending upon the length of the time interval, this is a reasonable approximation even for source terms associated with the decay of a parent radionuclide. When running CELLTRANS, the user should begin with logarithmically spaced time steps that subsequently can be refined until no significant change is observed in the calculated radionuclide concentrations within each subzone. This was the procedure used in the PATH1-CELLTRANS comparison.

CorSTAR

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