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CRIM--A Computer Program to Compute Brine
Migration Adjacent to a Nuclear Waste
Canister in a Salt Repository

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June 10, 1980

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This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy.

FOREWORD

This report describes the mathematical model and computer program used in the analysis of brine migration in proximity to a bedded salt nuclear waste repository. The work was performed as part of the Nuclear Regulatory Commission Waste Management Program at Lawrence Livermore Laboratory.

DISCLAIMER

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VARIABLE DEFINITIONS

C_l	Concentration of solute in liquid, g/cm ³
C_s	Concentration of solid, g/cm ³
D	Diffusion coefficient, cm ² /sec
G_l	Thermal gradient in liquid, °C/cm
G_s	Thermal gradient in solid, °C/cm
k	Boltzman's constant, Joule/°K
r	Radius of diffusing particles, cm $\frac{r_{Na+} + r_{Cl-}}{2}$
t	Time, years
T_c	Temperature, °C
T_k	Temperature, °K
v	Brine velocity, cm/year
η	Viscosity, poises

I. INTRODUCTION

The BRINE program computes brine migration near a nuclear waste canister in a bedded salt repository. The mathematical model for BRINE was proposed by M. E. Fuller⁽¹⁾. The site for a nuclear waste repository is likely to be in a bedded salt region. Such areas offer a favorable environment for disposal of radioactive waste because of the following characteristics:

- High Plasticity
- Self Sealing
- Very Low Permeability
- Relatively Dry
- Stable for Geological Times

There are, however, some unfavorable properties associated with salt beds. Heat generated by the radioactive waste material will cause the temperature to rise in the repository. Brine inclusions tend to migrate up a thermal gradient, in this case toward the waste canister. This may cause thermal stress and corrosion problems with the radwaste container. The BRINE program was written to provide a tool for assessing the importance of brine migration in a bedded salt nuclear waste repository.

The mathematical model is a simplified version of the Anthony and Cline (A-C) complete model.⁽²⁾ It incorporates diffusion coefficient, density factor and thermal gradient. Brine velocity is computed as a one-dimensional function of distance from the center of a cylindrical canister. The calculations are performed for various times after canister insertion. From

these data the volume of brine arriving at the canister surface as a function of time is computed.

This report will briefly summarize the mathematical model used in BRINE. It presents the equations used and integration technique for computing brine volume in Section II. A general description of the program is given in Section III. The principle functions performed by each of the subroutines are indicated. Input requirements and output options are discussed in Section IV. A sample of the input and output is attached as an Appendix.

II. MATHEMATICAL MODEL

Brine migration in a bedded salt region depends primarily on the following:

- Temperature and Temperature Gradient
- Chemical Composition
- Size of Inclusions

In the development of this mathematical model, an attempt was made to include the significant effects and also parameters which would be readily evaluated. Fuller studied four existing models identified as Nernst, HOWS, Wilcox and Anthony-Cline; sample calculations using these models were in agreement within a factor of two. Based on computational ease and data which are currently available, a simplified version of the Anthony-Cline model

appears to offer the best approach. As new information becomes available, the model can be easily modified and refined.

In the simplified A-C model the velocity of brine migration is given by

$$v = 2 \frac{D}{C_s} \frac{\partial C_l}{\partial T} G_1 \quad (1)$$

The diffusion coefficient (D) in terms of temperature and viscosity has the form (Stokes-Einstein equation)⁽³⁾

$$D = kT_K / (6\pi r\eta) \quad (2)$$

Viscosity is a function of temperature and the concentration of salt in the brine solution. It will be approximated by applying a scaling factor to the viscosity of water, given as a function of temperature in Table 1.⁽⁴⁾ The scaling factor is applied in an attempt to account for brine salinity.

$$\eta_{NaCl} = FAC \cdot \eta_{H_2O} \quad (3)$$

Scaling factor (FAC) as a function of per cent salinity⁽⁵⁾ is given in Table 2. The concentration of salt in a saturated brine solution is a function of temperature. Per cent salinity is approximated with the polynomial⁽⁶⁾

$$C_s = 26.218 + 7.2 \times 10^{-3} T_C + 1.06 \times 10^{-4} T_C^2 \quad (4)$$

which assumes sodium chloride is the only solute in solution.

Table 1 Viscosity of Water as a Function of Temperature*

<u>Temperature,</u> <u>°C</u>	<u>Viscosity, η</u> <u>Centipoise</u>
0	1.77
8.24	1.40
16.47	1.13
24.71	.937
32.94	.800
41.18	.691
49.41	.616
57.65	.554
65.88	.501
74.12	.457
82.35	.425
90.59	.388
98.82	.367
115.29	.326
131.76	.297
148.24	.273
164.71	.251
197.65	.219
230.59	.202
263.53	.193
296.45	.189
329.41	.173

*From: GAMBILL, W. R., CHEMICAL ENG., April 6, 1959, p. 139

Table 2 Viscosity Scaling Factor for Salt Solutions*

<u>Salinity, %</u>	<u>Factor (FAC)</u>
0	1.0
2.5	1.054
5	1.114
7.5	1.179
10	1.251
12.5	1.328
15	1.414
17.5	1.506
20	1.61
22.5	1.72
25	1.85
27.5	1.99
30	2.13
32.5	2.28

* From: UNTERBERG, W., BRIT. CHEM. ENG., 11, 494 (June) (1966)

This can also be used to determine the $\frac{\partial C_l}{\partial T}$ term, remembering to convert from per cent to fraction.

Assuming temperature profiles around the canister are known, thermal gradients can be computed using differencing techniques. The relationship between thermal gradient in a liquid and a solid is expressed by (7),

$$G_l = \frac{K_s}{(1-F) K_s + F K_l} \cdot G_s \quad (5)$$

where K_s and K_l are the thermal conductivities of the solid and liquid, respectively. F depends only on the aspect ratio of the droplet, and its value is 0.333 at $X/L = 1$ (cube and sphere) and increases to a value of 1 at $X/L \gg 1$. Intermediate values of F are 0.53, 0.64 and 0.70 at $X/L = 2.0, 3.0$ and 4.0, respectively. Normally, $X/L = 1$ is assumed, i.e., the droplet is cube shaped. K_s is a function of temperature and is expressed by

$$\log K_s = 0.7618 - 1.37 \times 10^{-3} T_c \quad (5a)$$

K_l is also a function of temperature and it is expressed by:

$$K = 0.5402 + 1.711 \times 10^{-3} T_c - 5.866 \times 10^{-6} T_c^2 \quad (5b)$$

Typical values for the remaining terms, r and C_s , are 1.38×10^{-8} cm and 2.13 g/cm^3 , respectively.

Equations (1) - (5) provide a means for computing brine velocity as a function of position around a canister. If temperature profiles are known as a function of time after waste canister insertion, velocity distribution can be computed as a function of time. From this it is possible to compute the volume of brine arriving at a canister surface as a function of time.

The technique for computing brine accumulation is quite simple. Assuming a droplet arrives at the canister surface at time, t , we trace its path back to its starting point at time zero. Brine droplets starting at positions closer to the canister will have arrived at some earlier time. Having found the droplet starting position, and assuming the initial brine concentration is known, the volume of brine accumulating at the canister can be computed. End effects due to the finite height of the container are neglected, (and the temperature profile is assumed the same over the height of the canister). The height of the annular volume of brine is taken to be the same as the canister height.

A crude method for determining brine starting position is to assume droplet velocity is constant for some time interval, Δt . The droplet position at $t - \Delta t$ is found by

$$X_{i+1} = X_i + \Delta t v_i \quad (6)$$

Decrementing time by Δt and computing a new velocity at each new time and position determines an approximate starting position when time becomes zero. However, for any sort of reasonable accuracy, Δt must be quite small using this method. An obvious improvement would be to take an average velocity over the increment.

$$X_{i+1} = X_i + \frac{\Delta t}{2} (v_i + v_{i+1}) \quad (7)$$

A major improvement is made by using Runge-Kutta methods. A Fourth Order Runge-Kutta integration with Gill coefficients⁽⁸⁾ offers much better accuracy with fewer time steps.

$$X_{i+1} = X_i + \frac{\Delta t}{6} (v_1 + C_1 v_2 + C_2 v_3 + v_4) \quad (8)$$

where velocities are given by:

$$v_1 = v(t_i, x_i)$$

$$v_2 = v(t_i + 1/2 \Delta t, x_i + 1/2 \Delta t v_1)$$

$$v_3 = v(t_i + 1/2 \Delta t, x_i + C_3 \Delta t v_1 + C_4 \Delta t v_2)$$

$$v_4 = v(t + \Delta t, x_i + C_5 \Delta t v_2 + C_6 \Delta t v_3)$$

and the Gill Coefficients are: $C_1 = 2 \left(1 - \frac{1}{\sqrt{2}} \right)$

$$C_2 = 2 \left(1 + \frac{1}{\sqrt{2}} \right)$$

$$C_3 = -\frac{1}{2} + \frac{1}{\sqrt{2}}$$

$$C_4 = 1 - \frac{1}{\sqrt{2}}$$

$$C_5 = -\frac{1}{\sqrt{2}}$$

$$C_6 = 1 + \frac{1}{\sqrt{2}}$$

An estimate of error can also be found by comparing the results from the above calculations using a full Δt step and two half Δt steps.

III. PROGRAM DESCRIPTION

The BRINE program consists of a main program and several computational and I/O subroutines for evaluating brine migration according to the mathematical model described above. The program executes entirely in the batch mode, requires one or two input files, and generates one output file. It is currently running on the CDC 7600 under CHAT/ORDERLIB. Comments on the functions performed by the subroutines used in BRINE follow.

The main program defines input/output files and controls the calling of various subroutines. In this program the input file name is defined to be BRINCASE. The output file name and TRUMP input data file name can be arbitrarily chosen by the user. Main calls INPUT which reads the input file in the format described in Section IV. TRUMP temperatures profiles can be

optionally read from a second input file using subroutine TDAT. Main then calls BRMIG which controls the calling of all major computational routines.

BRMIG first calls DIFSUB to compute diffusion coefficients according to equations (2) - (4). Output options are checked to see if certain partial derivatives are requested. Subroutine DER computes numerical derivatives for parameters in a variable grid spacing. These parameters are not needed in the migration calculations but were made available primarily for checking the smoothness of the input data. VFUN is called to generate a table of droplet velocity versus position and time based on the input temperature profiles. Finally, BRMIG loops up to 100 times, reading final times (t_f) and time increments (Δt) to use in subroutine INTG in determining brine starting positions. Brine volume is then computed for a 0.50% initial brine concentration and a brine accumulation table is printed.

Subroutine INTG performs the integration from t_f to time zero starting at the canister surface. A Fourth-Order Runge-Kutta integration is done in RKINT using equation (8). Integration is performed using a full Δt step and two half Δt steps. Results are compared and the maximum difference in any one time step is retained for optional printout.

The Runge-Kutta routine must be able to compute velocity at any time or position. This is accomplished in subroutine VRT. It should be pointed out that times cannot extend beyond the range of input temperature profile times. VRT uses the velocity table and routine SEARCH to find the nearest velocity

curves. A simple linear interpolation is then done to provide velocity at the desired position time.

Other routines which are used for utility purposes are INTERP and PRSUB. INTERP is a three point interpolation routine used by DIFSUB in computing η . PRSUB is a routine used for printing a two dimensional parameter with variable dimensions.

IV. INPUT/OUTPUT

The BRINE program is written to operate entirely in the batch mode. Input is read from a file called BRINCASE. It may also read TRUMP temperature profile data from a user named file. Output is written to a user named file for subsequent disposal. Input requirements and options are discussed below. In general, alpha information is read with A10 format and a maximum of eight variables per line. The exception to this rule is the output option line which is read with 6A1. Integer variables (those whose names begin with I, J, K, L, M or N) are read with I5 format and a maximum of ten values per line. Floating point variables are read with E10.0 format and a maximum of eight entries per line. On the LLL computer system, I, E and F formatted input fields can be delimited with commas (see sample input in Appendix).

1. NOUT, NTRUMP (8A10)
NOUT = Output file name
NTRUMP = File name of temperature profile data from TRUMP.
If not coming from TRUMP enter "NONE".
2. TITI(I), I = 1, 8 (8A10)
TITI = Problem identification

3. IPRNT(I), I = 1, 10 (10A1)
- IPRNT = Output options ("Y" or "N") for printing various parameters vs. position and time
- 1 = Input temperature
- 2 = Brine velocity
- 3 = $\partial v / \partial r$
- 4 = $\partial v / \partial t$
- 5 = $\partial T / \partial r$
- 6 = Diffusion coefficient
4. II, JJ (10I5)
- II = Number of radial positions ≤ 20
- JJ = Number of time ≤ 170
- (When reading a TRUMP file, JJ is set by the program).
5. CS, R0, H0 (8E10.0)
- CS = Density of the solid, g/cm^3
- R0 = Repository canister radius, cm
- H0 = Repository canister height, cm
6. RR(I), I = 1, II (8E10.0)
- RR = Radial positions at which temperature will be supplied, cm (Maximum of eight items per line.)

- 7a. Optional input to be included when reading temperature profiles from a TRUMP file

NOD(I), I = 1, II (10I5)
NOD = TRUMP node numbers to be read corresponding to radial positions, RR. Subroutine TDAT stores information in TIME(J) and TEMP (I, J) (Maximum of ten items per line.)

- 7b. Optional input to be included when reading user supplied temperature profiles (NTRUMP = "NONE")

TIME (J), J = 1, JJ (8E10.0)
TIME = Time after waste product insertion, years

For I = 1, II

TEMP (I, J), J = 1, JJ (8E10.0)
TEMP = Temperatures (°F) for times 1, JJ and radial positions 1, II

8. TFINAL, DT (8E10.0)

TFINAL = Number of years for calculating volume of brine accumulation.

DT = Size of time steps to use for calculations. Note that (TFINAL/DT + 1) must be less than 1000 for that calculation.

Calculations can be repeated for up to 100 TFINAL values. A negative TFINAL is used to terminate the calculations.

A sample input data case along with some of the output generated by BRINE is included in Appendix. Note that all output options were turned on but only a page of each type of data is included. The final table of brine accumulation is the only output that would be printed if all print options were turned off.

Output from BRINE includes the input data specified by the user. Various output options are available as indicated under item 3 above to allow the user to control the amount of printed output. Temperature and velocity profiles can be printed as well as velocity and temperature gradients. One may also print a table of diffusion coefficients as a function of position and time. The program always prints a table of brine accumulation at the canister surface based on an initial 0.5% water content.

References

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Appendix. Sample Input/Output

LINE	INPUT DATA	DATA DESCRIPTION
1	OUTSAMPL TINPT	OUTPUT FILE NAME; INPUT TRUMP FILE NAME
2	BRINE SAMPLE RUN (USING TRUMP INPUT FILE)	PROBLEM IDENTIFICATION
3	YYYYYY	OUTPUT OPTIONS
4	15,0,	NUMBER OF NODES; NUMBER OF TIMES
5	2.126,15.24,597.68	DENSITY, G/CM3; R0, CM; H0, CM
6	0.0,15.24,19.05,26.67,45.72,76.2,105.7,137.2	NODE DISTANCES, CM
7	102.9,266.7,406.4,613.8,821.3,1032.9,1346.2	
8	601,602,603,605,607,609,611,613,615,617.	TRUMP NODE NUMBERS
9	619,620,621,622,623.	
10	1.0,0.02	NUMBER OF YEARS (T) FOR CALCULATING VOLUME OF
11	2.0,0.02	BRINE ACCUMULATION, AND SIZE OF TIME STEPS (DT)
12	5.0,0.05	TO USE IN CALCULATIONS.
13	10.0,0.05	NOTE THAT: T/DT + 1 GREATER THAN OR EQUAL TO 1000
14	20.0,0.1	
15	30.0,0.1	
16	40.0,0.1	
17	50.0,0.1	
18	-1.	ANY NEGATIVE NUMBER TERMINATES INPUT

BRINE SAMPLE RUN (USING TRUMP INPUT FILE)

INPUT DATA

OPTIONS = VVVVVV

II = 15 JJ = 0
 CS = 2.1260E+00
 RH = 1.5743E+01 H0 = 5.9768E+02

TRUMP FILE ID

* 3D SALT/NO VENT/10 YR SPENT FUEL/3 SURF CONV,RAD/50 YR SPAN/2DT

INPUT TEMP DATA

TIMES =		0.	0.05	0.05	0.10	0.11	0.15
NODE	R	TEMP	TEMP	TEMP	TEMP	TEMP	TEMP
1	0.	3.880E+02	3.795E+02	1.195E+02	1.222E+02	1.224E+02	1.239E+02
2	15.24	1.776E+02	1.779E+02	1.162E+02	1.180E+02	1.182E+02	1.197E+02
3	19.05	9.300E+01	9.352E+01	1.134E+02	1.162E+02	1.164E+02	1.178E+02
4	26.67	9.300E+01	9.300E+01	1.109E+02	1.137E+02	1.139E+02	1.153E+02
5	45.72	9.300E+01	9.300E+01	1.064E+02	1.092E+02	1.094E+02	1.108E+02
6	76.20	9.300E+01	9.300E+01	1.020E+02	1.056E+02	1.058E+02	1.072E+02
7	105.70	9.300E+01	9.300E+01	1.007E+02	1.035E+02	1.035E+02	1.049E+02
8	137.20	9.300E+01	9.300E+01	9.915E+01	1.017E+02	1.019E+02	1.032E+02
9	182.90	9.300E+01	9.300E+01	9.740E+01	9.903E+01	1.000E+02	1.013E+02
10	265.70	9.300E+01	9.300E+01	9.570E+01	9.794E+01	9.811E+01	9.932E+01
11	405.40	9.300E+01	9.300E+01	9.391E+01	9.534E+01	9.547E+01	9.643E+01
12	613.00	9.300E+01	9.300E+01	9.323E+01	9.590E+01	9.378E+01	9.457E+01
13	821.30	9.300E+01	9.300E+01	9.310E+01	9.339E+01	9.342E+01	9.375E+01
14	1032.90	9.300E+01	9.300E+01	9.300E+01	9.323E+01	9.325E+01	9.342E+01
15	1346.20	9.300E+01	9.300E+01	9.300E+01	9.310E+01	9.319E+01	9.320E+01

TIMES =		0.19	0.21	0.25	0.28	0.33	0.37
NODE	R	TEMP	TEMP	TEMP	TEMP	TEMP	TEMP
1	0.	1.245E+02	1.240E+02	1.256E+02	1.265E+02	1.265E+02	1.288E+02
2	15.24	1.204E+02	1.077E+02	1.214E+02	1.217E+02	1.223E+02	1.228E+02
3	19.05	1.184E+02	1.180E+02	1.195E+02	1.195E+02	1.204E+02	1.208E+02
4	26.67	1.160E+02	1.164E+02	1.170E+02	1.174E+02	1.180E+02	1.183E+02
5	45.72	1.114E+02	1.118E+02	1.125E+02	1.129E+02	1.134E+02	1.137E+02
6	76.20	1.079E+02	1.082E+02	1.089E+02	1.093E+02	1.098E+02	1.101E+02
7	105.70	1.055E+02	1.059E+02	1.066E+02	1.069E+02	1.075E+02	1.078E+02
8	137.20	1.039E+02	1.042E+02	1.049E+02	1.053E+02	1.058E+02	1.061E+02
9	182.90	1.020E+02	1.023E+02	1.029E+02	1.033E+02	1.038E+02	1.041E+02
10	265.70	9.993E+01	1.003E+02	1.009E+02	1.012E+02	1.018E+02	1.021E+02
11	405.40	9.694E+01	9.724E+01	9.776E+01	9.819E+01	9.857E+01	9.884E+01
12	613.00	9.493E+01	9.514E+01	9.554E+01	9.580E+01	9.610E+01	9.641E+01
13	821.30	9.396E+01	9.410E+01	9.437E+01	9.457E+01	9.486E+01	9.506E+01
14	1032.90	9.355E+01	9.365E+01	9.382E+01	9.396E+01	9.416E+01	9.433E+01
15	1346.20	9.335E+01	9.340E+01	9.352E+01	9.361E+01	9.370E+01	9.389E+01

THE REMAINING PORTION OF THIS TABLE WAS DELETED
TO REDUCE THE VOLUME OF PRINTED OUTPUT

1 COMPUTE DT/DR

TIMES =		0.	0.03	0.05	0.10	0.11	0.15
NODE	R	DT/DR	DT/DR	DT/DR	DT/DR	DT/DR	DT/DR
1	0.	-7.379E+00	-7.352E+00	-1.541E-01	-1.540E-01	-1.539E-01	-1.538E-01
2	15.24	-1.134E+01	-1.131E+01	-2.455E-01	-2.467E-01	-2.466E-01	-2.473E-01
3	19.85	-0.221E+02	-8.211E+00	-2.382E-01	-2.396E-01	-2.395E-01	-2.403E-01
4	26.67	1.203E-13	-2.721E-02	-1.647E-01	-1.658E-01	-1.658E-01	-1.664E-01
5	45.72	0.	0.	-1.066E-01	-1.065E-01	-1.065E-01	-1.070E-01
6	76.20	4.203E-15	4.203E-15	-5.209E-02	-5.314E-02	-5.315E-02	-5.356E-02
7	106.70	-6.126E-15	-6.126E-15	-3.450E-02	-3.572E-02	-3.575E-02	-3.617E-02
8	137.20	1.754E-14	1.754E-14	-2.560E-02	-2.699E-02	-2.704E-02	-2.751E-02
9	182.90	-1.592E-14	-1.502E-14	-1.751E-02	-1.909E-02	-1.917E-02	-1.970E-02
10	266.70	-5.695E-15	-5.695E-15	-9.501E-03	-1.169E-02	-1.181E-02	-1.254E-02
11	406.40	-2.963E-15	-2.963E-15	-5.177E-03	-7.735E-03	-7.739E-03	-8.072E-03
12	613.80	1.999E-16	1.999E-16	-1.590E-03	-2.617E-03	-2.743E-03	-3.595E-03
13	821.30	-1.822E-15	-1.822E-15	-2.010E-04	-9.060E-04	-9.791E-04	-1.544E-03
14	1032.90	-1.713E-15	-1.713E-15	-3.005E-05	-2.836E-04	-3.168E-04	-6.126E-04
15	1346.20	0.	0.	-3.015E-06	-8.618E-05	-1.000E-04	-2.458E-04

TIMES =		0.19	0.21	0.25	0.28	0.33	0.37
NODE	R	DT/DR	DT/DR	DT/DR	DT/DR	DT/DR	DT/DR
1	0.	-1.537E-01	-1.537E-01	-1.535E-01	-1.534E-01	-1.533E-01	-1.532E-01
2	15.24	-2.473E-01	-2.474E-01	-2.476E-01	-2.475E-01	-2.475E-01	-2.475E-01
3	19.85	-2.403E-01	-2.404E-01	-2.407E-01	-2.406E-01	-2.407E-01	-2.407E-01
4	26.67	-1.662E-01	-1.664E-01	-1.667E-01	-1.665E-01	-1.666E-01	-1.667E-01
5	45.72	-1.069E-01	-1.070E-01	-1.072E-01	-1.071E-01	-1.071E-01	-1.072E-01
6	76.20	-3.565E-02	-3.566E-02	-3.567E-02	-3.565E-02	-3.566E-02	-3.567E-02
7	106.70	-3.626E-02	-3.624E-02	-3.651E-02	-3.650E-02	-3.656E-02	-3.661E-02
8	137.20	-2.762E-02	-2.771E-02	-2.709E-02	-2.709E-02	-2.797E-02	-2.802E-02
9	182.90	-1.985E-02	-1.996E-02	-2.015E-02	-2.018E-02	-2.027E-02	-2.031E-02
10	266.70	-1.282E-02	-1.295E-02	-1.310E-02	-1.320E-02	-1.340E-02	-1.347E-02
11	406.40	-9.276E-03	-9.475E-03	-9.790E-03	-9.953E-03	-1.015E-02	-1.025E-02
12	613.80	-3.994E-03	-4.203E-03	-4.537E-03	-4.727E-03	-4.961E-03	-5.077E-03
13	821.30	-1.816E-03	-2.015E-03	-2.293E-03	-2.459E-03	-2.672E-03	-2.780E-03
14	1032.90	-7.537E-04	-9.021E-04	-1.089E-03	-1.205E-03	-1.369E-03	-1.439E-03
15	1346.20	-3.495E-04	-4.155E-04	-5.355E-04	-6.127E-04	-7.107E-04	-7.749E-04

THE REMAINING PORTION OF THIS TABLE WAS DELETED
TO REDUCE THE VOLUME OF PRINTED OUTPUT

1 COMPUTED DIFFUSION COEFFICIENT

TIMES =		0.	0.05	0.10	0.11	0.15
NODE	R	D	D	D	D	D
1	0.	5.574E-05	5.566E-05	1.415E-05	1.450E-05	1.472E-05
2	15.24	2.237E-05	2.241E-05	1.363E-05	1.398E-05	1.418E-05
3	19.05	1.073E-05	1.080E-05	1.339E-05	1.374E-05	1.395E-05
4	26.67	1.073E-05	1.073E-05	1.309E-05	1.344E-05	1.364E-05
5	45.72	1.073E-05	1.073E-05	1.251E-05	1.285E-05	1.306E-05
6	76.20	1.073E-05	1.073E-05	1.205E-05	1.241E-05	1.261E-05
7	106.70	1.073E-05	1.073E-05	1.176E-05	1.210E-05	1.231E-05
8	137.20	1.073E-05	1.073E-05	1.154E-05	1.188E-05	1.208E-05
9	182.90	1.073E-05	1.073E-05	1.131E-05	1.166E-05	1.183E-05
10	266.70	1.073E-05	1.073E-05	1.109E-05	1.138E-05	1.156E-05
11	426.40	1.073E-05	1.073E-05	1.085E-05	1.104E-05	1.118E-05
12	613.80	1.073E-05	1.073E-05	1.176E-05	1.085E-05	1.094E-05
13	821.30	1.073E-05	1.073E-05	1.074E-05	1.078E-05	1.084E-05
14	1032.90	1.073E-05	1.073E-05	1.074E-05	1.076E-05	1.079E-05
15	1346.20	1.073E-05	1.073E-05	1.074E-05	1.075E-05	1.077E-05

TIMES =		0.19	0.21	0.25	0.28	0.33	0.37
NODE	R	D	D	D	D	D	D
1	0.	1.480E-05	1.485E-05	1.494E-05	1.499E-05	1.506E-05	1.511E-05
2	15.24	1.425E-05	1.431E-05	1.439E-05	1.444E-05	1.451E-05	1.455E-05
3	19.05	1.403E-05	1.408E-05	1.416E-05	1.421E-05	1.427E-05	1.431E-05
4	26.67	1.372E-05	1.377E-05	1.385E-05	1.390E-05	1.397E-05	1.401E-05
5	45.72	1.315E-05	1.319E-05	1.328E-05	1.333E-05	1.340E-05	1.344E-05
6	76.20	1.269E-05	1.274E-05	1.283E-05	1.287E-05	1.294E-05	1.298E-05
7	106.70	1.242E-05	1.245E-05	1.253E-05	1.256E-05	1.265E-05	1.269E-05
8	137.20	1.217E-05	1.222E-05	1.231E-05	1.236E-05	1.243E-05	1.247E-05
9	182.90	1.191E-05	1.196E-05	1.205E-05	1.210E-05	1.217E-05	1.221E-05
10	266.70	1.164E-05	1.169E-05	1.177E-05	1.182E-05	1.189E-05	1.193E-05
11	426.40	1.123E-05	1.129E-05	1.136E-05	1.140E-05	1.146E-05	1.150E-05
12	613.80	1.098E-05	1.101E-05	1.106E-05	1.110E-05	1.115E-05	1.118E-05
13	821.30	1.086E-05	1.087E-05	1.091E-05	1.093E-05	1.097E-05	1.100E-05
14	1032.90	1.080E-05	1.081E-05	1.084E-05	1.086E-05	1.088E-05	1.089E-05
15	1346.20	1.078E-05	1.078E-05	1.080E-05	1.081E-05	1.083E-05	1.085E-05

THE REMAINING PORTION OF THIS TABLE WAS DELETED
TO REDUCE THE VOLUME OF PRINTED OUTPUT

I VELOCITY CALCULATION

TIMES =		0.	0.05	0.05	0.10	0.11	0.15
NODE	R	VEL	VEL	VEL	VEL	VEL	VEL
1	0.	-7.989E-02	-7.939E-02	-1.699E-02	-1.668E-02	-1.672E-02	-1.728E-02
2	15.24	-2.564E-02	-2.564E-02	-2.385E-02	-2.505E-02	-2.511E-02	-2.574E-02
3	19.05	-5.341E-01	-5.391E-01	-2.246E-02	-2.363E-02	-2.369E-02	-2.431E-02
4	26.67	7.814E-15	-1.768E-03	-1.493E-02	-1.572E-02	-1.577E-02	-1.619E-02
5	45.72	0.	0.	-8.057E-03	-9.364E-03	-9.391E-03	-9.553E-03
6	76.20	-2.731E-16	-2.731E-16	-4.101E-03	-4.395E-03	-4.411E-03	-4.553E-03
7	106.70	-3.980E-16	-3.980E-16	-2.605E-03	-2.833E-03	-2.845E-03	-2.952E-03
8	137.20	1.139E-15	1.139E-15	-1.077E-03	-2.076E-03	-2.087E-03	-2.177E-03
9	182.90	-9.760E-16	-9.760E-16	-1.241E-03	-1.410E-03	-1.429E-03	-1.504E-03
10	266.70	-3.700E-16	-3.700E-16	-6.524E-04	-8.376E-04	-8.490E-04	-9.224E-04
11	406.40	-1.925E-16	-1.925E-16	-3.425E-04	-5.265E-04	-5.386E-04	-6.170E-04
12	613.00	1.252E-17	1.252E-17	-7.115E-05	-1.731E-04	-1.815E-04	-2.410E-04
13	821.30	-1.184E-16	-1.184E-16	-1.308E-05	-5.927E-05	-6.415E-05	-1.010E-04
14	1032.90	-1.113E-16	-1.113E-16	-1.956E-06	-1.051E-05	-2.068E-05	-4.013E-05
15	1346.20	0.	0.	-1.961E-07	-5.619E-06	-6.522E-06	-1.606E-05
TIMES =		0.19	0.21	0.25	0.28	0.32	0.37
NODE	R	VEL	VEL	VEL	VEL	VEL	VEL
1	0.	-1.724E-02	-1.734E-02	-1.750E-02	-1.759E-02	-1.772E-02	-1.779E-02
2	15.24	-2.560E-02	-2.616E-02	-2.646E-02	-2.661E-02	-2.683E-02	-2.695E-02
3	19.05	-2.455E-02	-2.472E-02	-2.501E-02	-2.514E-02	-2.536E-02	-2.548E-02
4	26.67	-1.634E-02	-1.646E-02	-1.667E-02	-1.674E-02	-1.690E-02	-1.699E-02
5	45.72	-9.759E-03	-9.832E-03	-9.906E-03	-1.001E-02	-1.011E-02	-1.017E-02
6	76.20	-4.607E-03	-4.644E-03	-4.712E-03	-4.738E-03	-4.780E-03	-4.817E-03
7	106.70	-2.995E-03	-3.022E-03	-3.071E-03	-3.090E-03	-3.124E-03	-3.145E-03
8	137.20	-2.213E-03	-2.235E-03	-2.276E-03	-2.293E-03	-2.321E-03	-2.337E-03
9	182.90	-1.536E-03	-1.553E-03	-1.586E-03	-1.600E-03	-1.623E-03	-1.635E-03
10	266.70	-9.538E-04	-9.702E-04	-9.981E-04	-1.013E-03	-1.032E-03	-1.043E-03
11	406.40	-6.516E-04	-6.695E-04	-6.987E-04	-7.149E-04	-7.356E-04	-7.466E-04
12	613.00	-2.696E-04	-2.851E-04	-3.100E-04	-3.247E-04	-3.434E-04	-3.529E-04
13	821.30	-1.222E-04	-1.339E-04	-1.531E-04	-1.648E-04	-1.802E-04	-1.881E-04
14	1032.90	-5.213E-05	-5.936E-05	-7.193E-05	-7.980E-05	-9.044E-05	-9.603E-05
15	1346.20	-2.286E-05	-2.721E-05	-3.515E-05	-4.029E-05	-4.742E-05	-5.125E-05

THE REMAINING PORTION OF THIS TABLE WAS DELETED
TO REDUCE THE VOLUME OF PRINTED OUTPUT

1 COMPUTE PARTIAL DV/DR

TIMES =		0.	0.05	0.05	0.10	0.11	0.15
MODE	R	DV/DR	DV/DR	DV/DR	DV/DR	DV/DR	DV/DR
1	0.	3.560E-01	3.526E-01	-5.155E-04	-5.492E-04	-5.502E-04	-5.681E-04
2	15.24	4.973E-01	4.958E-01	1.872E-04	1.876E-04	1.873E-04	1.854E-04
3	19.35	3.785E-01	3.779E-01	5.717E-04	5.940E-04	5.945E-04	6.052E-04
4	26.67	5.086E-02	5.039E-02	7.977E-04	8.370E-04	8.387E-04	8.591E-04
5	45.72	-2.490E-16	5.710E-05	2.560E-04	2.680E-04	2.680E-04	2.755E-04
6	76.20	-6.516E-18	-6.516E-18	1.025E-04	1.071E-04	1.074E-04	1.101E-04
7	106.70	1.420E-17	1.420E-17	3.647E-05	3.801E-05	3.809E-05	3.890E-05
8	137.20	1.170E-17	1.170E-17	1.989E-05	2.065E-05	2.068E-05	2.113E-05
9	182.50	-2.740E-17	-2.740E-17	1.148E-05	1.176E-05	1.177E-05	1.198E-05
10	266.70	4.996E-18	4.996E-18	5.223E-06	5.43E-06	5.157E-06	5.159E-06
11	406.40	1.158E-18	1.158E-18	1.052E-06	6E-06	2.020E-06	2.030E-06
12	613.80	1.791E-19	1.791E-19	7.942E-07	1.26E-06	1.144E-06	1.242E-06
13	821.30	-3.029E-19	-3.029E-19	1.673E-07	3.724E-07	3.873E-07	4.029E-07
14	1032.90	1.632E-19	1.632E-19	3.366E-08	1.310E-07	1.408E-07	2.050E-07
15	1346.20	3.552E-19	3.552E-19	5.615E-08	4.114E-08	4.519E-08	7.605E-08

TIMES =		0.19	0.21	0.25	0.28	0.33	0.37
MODE	R	DV/DR	DV/DR	DV/DR	DV/DR	DV/DR	DV/DR
1	0.	-5.745E-04	-5.791E-04	-5.877E-04	-5.919E-04	-5.981E-04	-6.016E-04
2	15.24	1.892E-04	1.871E-04	1.870E-04	1.894E-04	1.898E-04	1.902E-04
3	19.35	6.117E-04	6.136E-04	6.187E-04	6.238E-04	6.278E-04	6.302E-04
4	26.67	8.684E-04	8.734E-04	8.825E-04	8.882E-04	8.946E-04	8.982E-04
5	45.72	2.777E-04	2.797E-04	2.829E-04	2.841E-04	2.866E-04	2.880E-04
6	76.20	1.110E-04	1.117E-04	1.130E-04	1.135E-04	1.146E-04	1.152E-04
7	106.70	3.925E-05	3.949E-05	3.994E-05	4.008E-05	4.044E-05	4.065E-05
8	137.20	2.130E-05	2.144E-05	2.167E-05	2.175E-05	2.191E-05	2.203E-05
9	182.50	1.204E-05	1.211E-05	1.224E-05	1.228E-05	1.237E-05	1.244E-05
10	266.70	5.150E-06	5.155E-06	5.189E-06	5.179E-06	5.202E-06	5.213E-06
11	406.40	2.034E-06	2.032E-06	2.035E-06	2.031E-06	2.029E-06	2.031E-06
12	613.80	1.276E-06	1.291E-06	1.315E-06	1.326E-06	1.339E-06	1.346E-06
13	821.30	5.227E-07	5.424E-07	5.717E-07	5.870E-07	6.070E-07	6.165E-07
14	1032.90	2.764E-07	2.515E-07	2.764E-07	2.907E-07	3.005E-07	3.174E-07
15	1346.20	9.342E-08	1.026E-07	1.174E-07	1.261E-07	1.373E-07	1.429E-07

THE REMAINING PORTION OF THIS TABLE WAS DELETED
TO REDUCE THE VOLUME OF PRINTED OUTPUT

1 COMPUTE PARTIAL DV/DT

TIMES =		0.	0.05	0.10	0.11	0.15
NODE	R	DV/DT	DV/DT	DV/DT	DV/DT	DV/DT
1	0.	1.774E+05	1.774E+05	9.516E+01	-8.369E-03	-7.882E-03
2	15.24	-3.187E+03	-3.187E+03	3.051E+01	-1.192E-02	-1.111E-02
3	19.05	-1.776E+04	-1.776E+04	6.196E+00	-1.196E-02	-1.118E-02
4	26.67	-6.292E+03	-6.292E+03	-1.647E-01	-8.961E-03	-8.434E-03
5	45.72	0.	-1.265E-05	-1.105E-01	-5.285E-03	-4.949E-03
6	76.20	0.	-5.580E-07	-5.171E-02	-3.101E-03	-2.876E-03
7	106.70	0.	-3.544E-07	-3.319E-02	-2.367E-03	-2.184E-03
8	137.20	0.	-2.653E-07	-2.420E-02	-2.153E-03	-1.985E-03
9	182.90	0.	-1.689E-07	-1.638E-02	-2.045E-03	-1.886E-03
10	266.70	0.	-8.875E-08	-9.376E-03	-2.170E-03	-1.991E-03
11	406.40	0.	-4.660E-08	-5.644E-03	-2.283E-03	-2.115E-03
12	613.80	0.	-9.680E-09	-1.782E-03	-1.545E-03	-1.483E-03
13	821.30	0.	-1.780E-09	-5.419E-04	-8.590E-04	-8.514E-04
14	1032.90	0.	-2.660E-10	-1.611E-04	-3.824E-04	-3.915E-04
15	1346.20	P.	-2.669E-11	-4.744E-05	-1.566E-04	-1.659E-04

TIMES =		0.19	0.21	0.25	0.28	0.33	0.37
NODE	R	DV/DT	DV/DT	DV/DT	DV/DT	DV/DT	DV/DT
1	0.	-4.625E-03	-4.256E-03	-3.215E-03	-2.620E-03	-2.351E-03	-2.122E-03
2	15.24	-7.829E-03	-7.496E-03	-5.694E-03	-4.680E-03	-4.044E-03	-3.651E-03
3	19.05	-7.673E-03	-7.458E-03	-5.331E-03	-4.238E-03	-3.890E-03	-3.521E-03
4	26.67	-5.258E-03	-5.357E-03	-3.448E-03	-2.690E-03	-2.838E-03	-2.549E-03
5	45.72	-3.267E-03	-3.306E-03	-2.210E-03	-1.726E-03	-1.793E-03	-1.590E-03
6	76.20	-1.711E-03	-1.609E-03	-1.150E-03	-8.758E-04	-9.063E-04	-8.179E-04
7	106.70	-1.292E-03	-1.233E-03	-8.484E-04	-6.343E-04	-6.375E-04	-5.845E-04
8	137.20	-1.068E-03	-1.013E-03	-7.195E-04	-5.453E-04	-5.146E-04	-4.612E-04
9	182.90	-8.872E-04	-8.098E-04	-5.837E-04	-4.425E-04	-3.974E-04	-3.546E-04
10	266.70	-8.546E-04	-7.331E-04	-5.464E-04	-4.306E-04	-3.425E-04	-2.830E-04
11	406.40	-9.343E-04	-7.892E-04	-5.902E-04	-4.735E-04	-3.564E-04	-3.036E-04
12	613.80	-7.938E-04	-6.806E-04	-5.180E-04	-4.297E-04	-3.154E-04	-2.629E-04
13	821.30	-5.817E-04	-5.152E-04	-4.070E-04	-3.453E-04	-2.603E-04	-2.176E-04
14	1032.90	-3.533E-04	-3.250E-04	-2.703E-04	-2.345E-04	-1.821E-04	-1.538E-04
15	1346.20	-2.074E-04	-1.984E-04	-1.738E-04	-1.545E-04	-1.235E-04	-1.054E-04

THE REMAINING PORTION OF THIS TABLE WAS DELETED
TO REDUCE THE VOLUME OF PRINTED OUTPUT

1 TRUMP FILE ID

* 3D SALT/NO VENT/18 YR SPENT FUEL/3 SURF CONV.RAD/58 YR SPAN/2DT
 CANISTER RADIUS = 15.24 CM
 CANISTER HEIGHT = 597.68 MC

BRINE ACCUMULATION CALCULATION -- MODEL

YEARS	RADIUS DEPLETED CM	VOLUME DEPLETED LITERS	LITERS BRINE ACCUMULATED AT 8.6%
1.8	15.32	4.8184E+08	8.82
2.8	15.35	6.4279E+08	8.83
5.8	15.44	1.1428E+09	8.86
18.8	15.58	1.9564E+09	8.18
28.8	15.82	3.3789E+09	8.17
38.8	16.82	4.5721E+09	8.23
48.8	16.28	5.6838E+09	8.28
48.5	16.34	6.5466E+09	8.33

LL:1980/6