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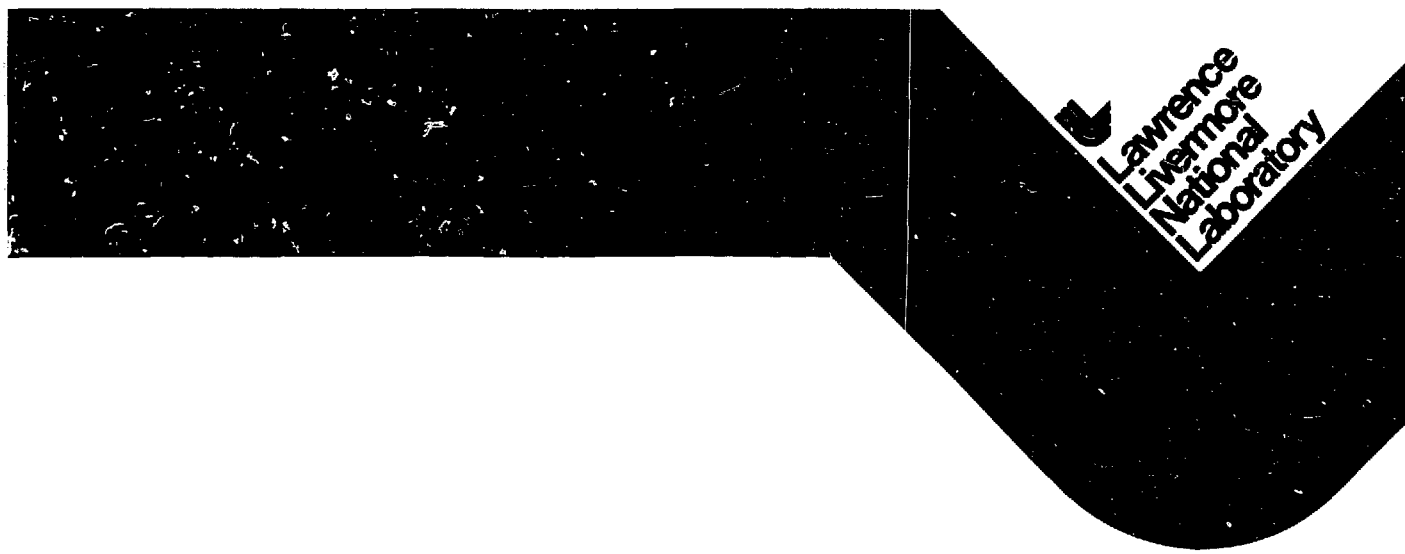

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*Whiteshell Nuclear Research Establishment, Pinawa, Manitoba, Canada

LAWRENCE LIVERMORE LABORATORY
University of California • Livermore, California • 94550

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LABORATORY STUDIES OF RADIONUCLIDE TRANSPORT IN FRACTURED CLIMAX GRANITE

ABSTRACT

This report documents our laboratory studies of radionuclide transport in fractured granite cores. To simulate natural conditions, our laboratory studies used naturally fractured cores and natural ground water from the Climax Granite Stock at the Nevada Test Site. For comparison, additional tests used artificially fractured granite cores or distilled water.

Relative to the flow of tritiated water, ^{85}Sr and ^{95m}Tc showed little or no retardation, whereas ^{137}Cs was retarded. After the transport runs the cores retained varying amounts of the injected radionuclides along the fracture. Autoradiography revealed some correlation between sorption and the fracture fill material. Strontium and cesium retention increased when the change was made from natural ground water to distilled water. Artificial fractures retained less ^{137}Cs than most natural fractures. Estimated fracture apertures from 18 to 60 μm and hydraulic conductivities from 1.7 to 26×10^{-3} m/s were calculated from the core measurements.

INTRODUCTION

Transport of radionuclides in ground water through crystalline rock will take place primarily along fractured surfaces. Retardation and sorption characteristics of the fracture surfaces differ from the characteristics of the crushed bulk rock samples described in previous studies (Coles et al., 1980; Los Alamos National Laboratory, 1980; MacLean et al., 1978). In the past, theoretical models describing radionuclide transport through fractured rock relied heavily on experimental results from static sorption or column tests on crushed rock for empirical values and model validation. Little laboratory or field data exist for radionuclide transport along fractures.

In our experiments, transport solutions spiked with radionuclides were pumped through fractured granite cores to simulate natural conditions. Our laboratory experiments were designed to study the effects of fracture fill material and transport solution on radionuclide transport and sorption by

using natural ground water and distilled water in both natural and artificial fractures. The core sorption apparatus and techniques, initially developed by Weed at LLNL (Weed et al., 1981a,b), were designed to simulate natural flow rates and lithostatic pressures. The granite for our experiments was obtained from the Climax Stock at the Nevada Test Site. Our interest in nuclear waste disposal prompted our choice of the radionuclides ^{3}H, ^{85}Sr, ^{95m}Tc, and ^{137}Cs for this study.

This report discusses the equipment used, the preparation of the core, the experimental procedure, the data reduction, and the experimental results from eleven cores. The results include estimates of the average fracture aperture values, retardation values of ^{85}Sr, ^{95m}Tc, and ^{137}Cs relative to ^{3}H, and the percentage of each radionuclide retained in the core after each run.

The core sorption study is a logical step in determining the scaling factor from laboratory to field studies. We need field data to determine whether laboratory studies accurately reflect in situ conditions. The studies described in this report were originally part of the Waste Rock Interaction (WRIT) Program administered by Pacific Northwest Laboratory (PNL). They were later included in the geochemical support studies for the Field Radionuclide Migration in Climax Granite Project funded by the Office of Nuclear Waste Isolation (ONWI) as described in Isherwood et al. (1982a). The objective of this project was to provide field-measured retardation factors for comparison with the laboratory measured values. Both the field and laboratory studies were designed to provide input to mass transport models to improve our ability to make dependable pretest predictions of radionuclide migration in fractured rock. The planned core sorption studies were not completed due to project cancellation; however, the results obtained provide information useful for understanding the processes influencing radionuclide migration.

EXPERIMENTAL METHODS

EQUIPMENT

Weed et al. (1981a,b) developed the core sorption apparatus and techniques to simulate the flow of radionuclides through porous rock. Our

program modified the equipment and procedure to study fracture flow in crystalline rock (see Appendix A). The apparatus approximates naturally occurring conditions by applying confining pressure to simulate the rock's overburden pressure. The transport solution passes through the core at a slow (approximately 0.002 ml/min) flow rate.

A schematic of the experimental setup (Fig. 1) shows the flow path as the solution flows from the reservoir, is pumped through the spike loop containing the radionuclide mixture, through the tubing and the core and into the sample tubes in the fraction collector. The volume of the tubing and the end fitting is called the system dead volume. A more complete description of the experimental concept, equipment, and procedure is found in previous reports (Weed et al., 1981a; Coles et al., 1980).

Appendix A details the equipment changes we made to convert from a study of porous rock cores (Weed et al., 1981a) to fractured rock cores. Briefly, we:

- Reduced the flow rate by a factor of 10 (lowest rate = 0.001 ml/min), by replacing the pump motor.
- Modified the inlet fitting to reduce the dead volume and eliminate a weak connection.
- Improved the solution pressure measurements with more sensitive pressure transducers.
- Installed a new fraction collector which improved the effluent collection.
- Removed the outlet throttle valve which simplified the flow path.

CORE PREPARATION

The overall procedure for the fractured core sorption runs differed very little from the porous core runs (Weed et al., 1981a). The major difference was in the core preparation.

The Piledriver Drift tunnels into the Climax Stock granite 400 m below the surface. NX (76 mm) boreholes were drilled horizontally into the face of the tunnel wall to intersect sets of high angle fractures. These holes were later used to study the hydrologic flow characteristics of the Climax Stock fractures (Isherwood et al., 1982a). Approximately 54 m of core (48 mm in diameter) containing a variety of natural fractures are now available. Before

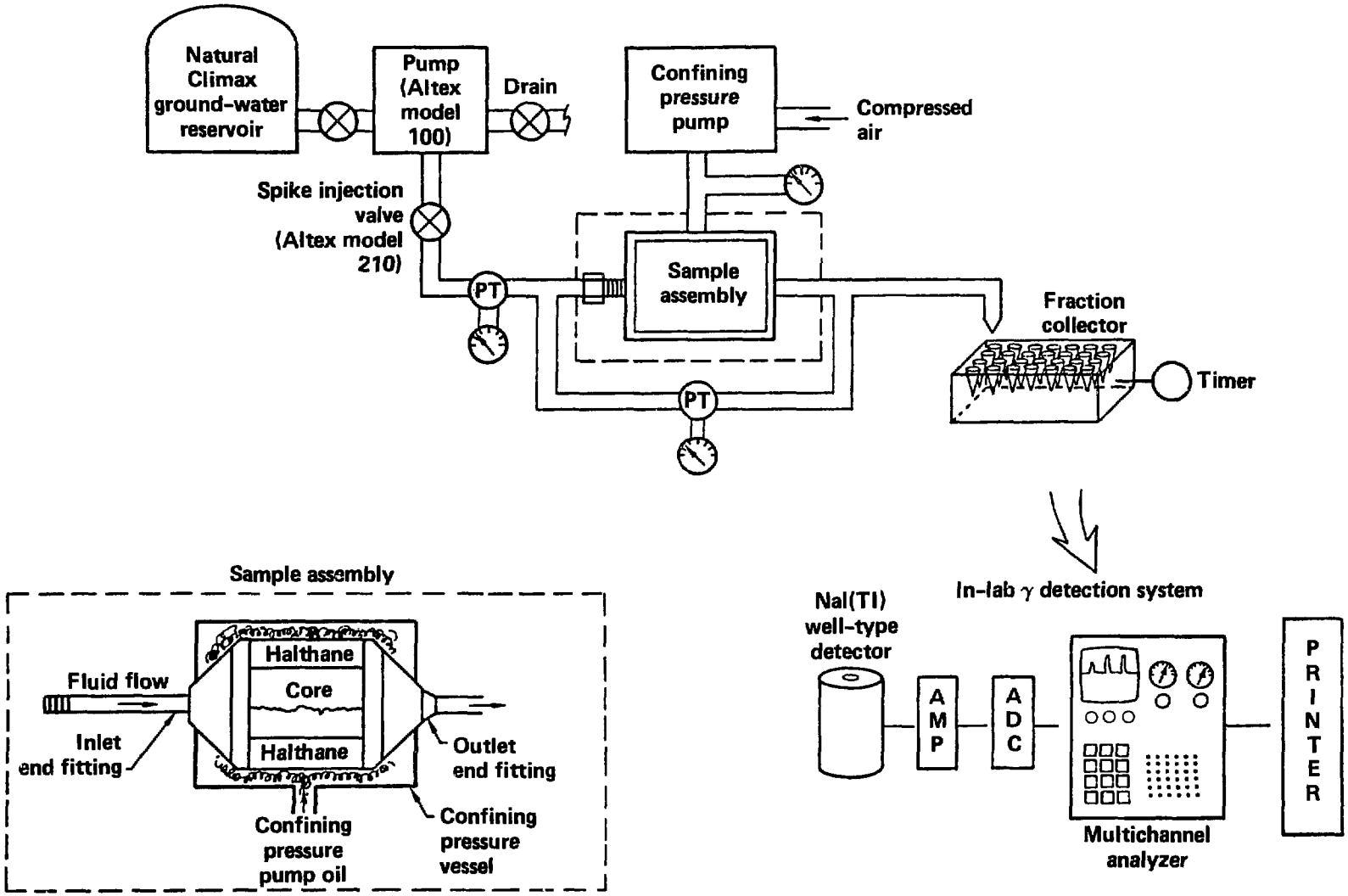
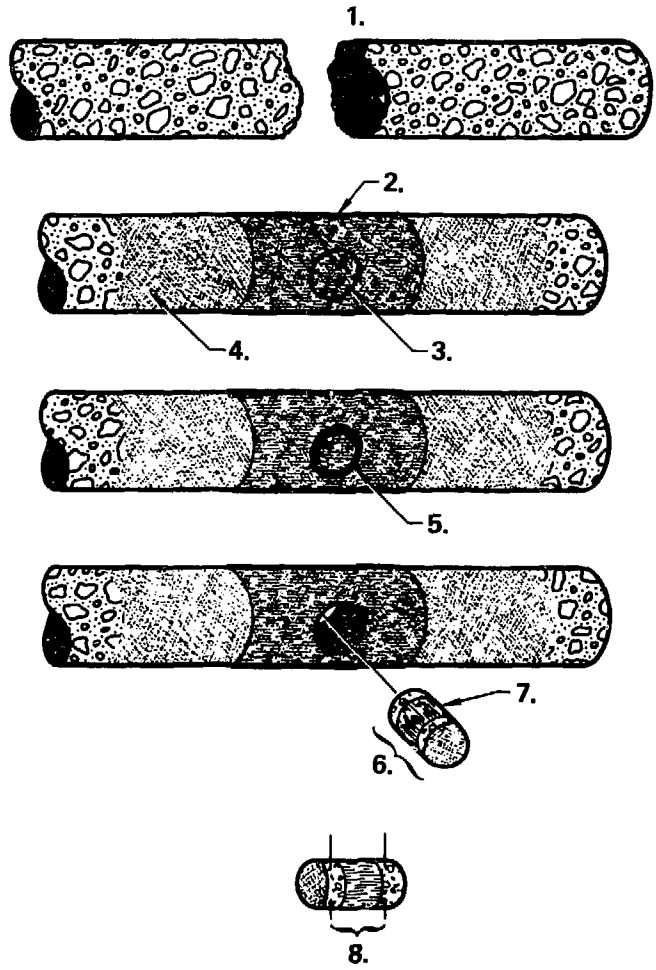


Figure 1. Schematic of core sorption experimental setup.

selecting the core sections, a visual check of the cores was made to differentiate between natural fractures and mechanical breaks.

The method of preparing the 25-mm cores for use in the radionuclide transport runs is illustrated in Fig. 2 (Steps 1-8). Often the NX cores broke apart along the natural fractures (Step 1) during the drilling process. In these cases the core was carefully reassembled and kept intact with 12-mm



Step 1: The fracture is carefully reassembled.
Step 2: Duct tape holds the fracture intact.
Step 3: The angle of drilling is marked on the tape.
Step 4: Fiberglass cloth is wrapped around the core and saturated with epoxy.
Step 5: Core is drilled with a diamond bit and drill press.
Step 6: A 1- X 2 1/2-in. core with epoxy caps results from drilling.
Step 7: Duct tape holds and marks the core.
Step 8: The core is sawed to the desired length.

Figure 2. Preparation of 25 mm cores from NX cores.

heavy duct tape (Step 2). Intact undisturbed fractures were also taped to avoid epoxy penetration of the fracture. The tape was marked establishing the best drilling angle such that the 25-mm core contained a fracture running along the entire length of the core (Step 3).

The NX core was wrapped twice in fiberglass cloth, saturated with Shell 828 epoxy, and allowed to dry (Step 4). Using a water-lubricated diamond bit and press, a 25-mm core was drilled from the NX core (Step 5). The resulting 25-mm core was 48 mm in length. Epoxy caps at either end held the core together (Step 6). The sides of the core were wrapped in duct tape (Step 7), and the core was cut to the desired length with a Buehler ISO-MET saw with a diamond blade (Step 8). The resulting 25-mm-diameter core contained a natural fracture running the full length of the core.

Studying natural vs artificial fractures indicated the effects of fracture fill material on the sorption of the radionuclides. To obtain

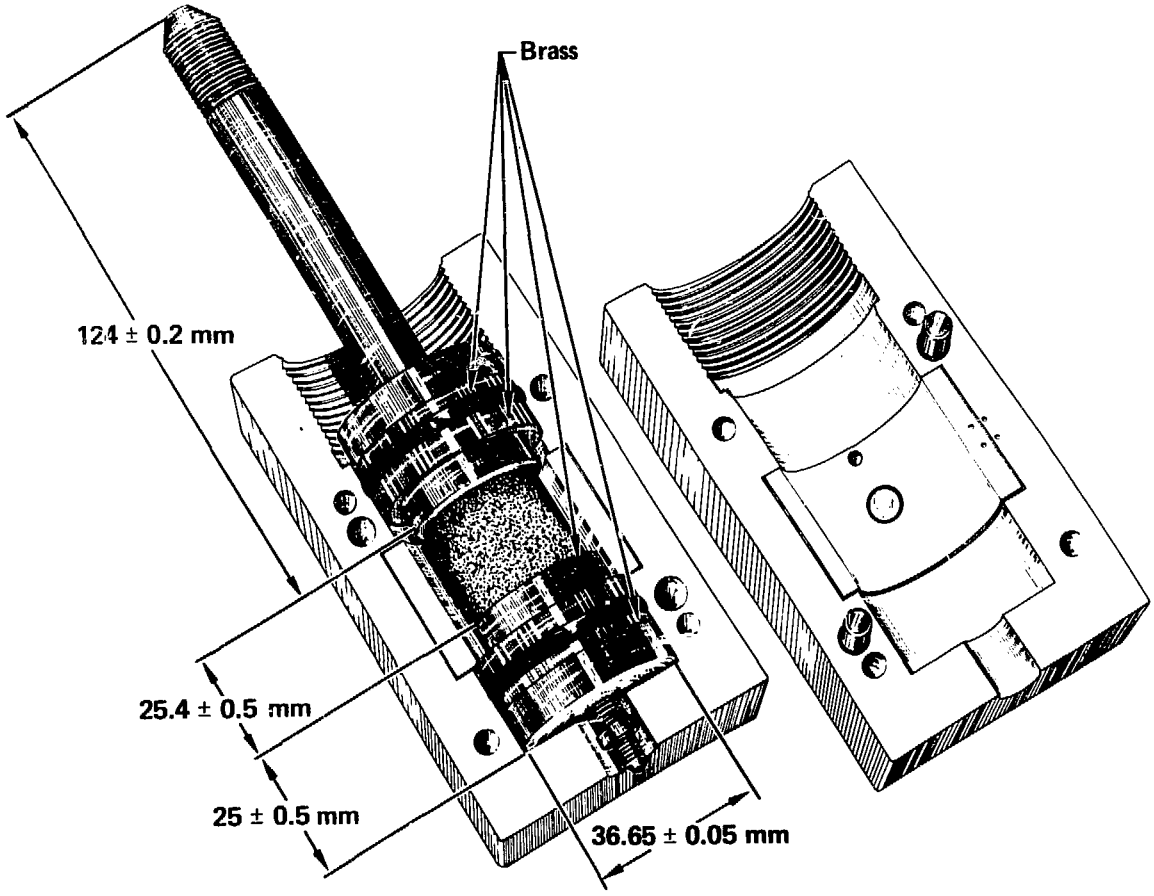


Figure 3. Teflon mold; sample and end fittings before injection of Halthane 73-18.

artificially fractured cores a 25-mm-diameter core was drilled from NX core containing no fractures (Steps 1-8). The edges of the 25-mm core were chiseled until the core fractured along an induced cleavage plane. These cores were treated in the same way as naturally fractured cores.

The 25-mm cores were prepared for the radionuclide transport run by jacketing them in the polyurethane adhesive Halthane 73-18 (Hammon and Althouse, 1977). The core was placed into the stainless steel end fittings and the edges of the fracture and interface between the core and end fittings were sealed with very viscous Halthane and left to cure overnight. This step was a precaution taken to avoid filling the fracture with the unpolymerized Halthane mixture when the jacket was molded around the core. The core and end fittings were then put into the Teflon jacketing mold (Fig. 3). The prepolymer and curing agent components of the Halthane were mixed, degassed, and injected into the bottom of the mold. After filling the mold with Halthane 73-18, it was left to cure overnight. The jacketed sample was carefully removed from the mold (Fig. 4) (Weed et al., 1981a).

It was very important that the Halthane jacket prevent the transport solution from flowing between the core edges and the jacket. To verify the seal between the core and the jacket, Rhodamine B, a dye which permanently

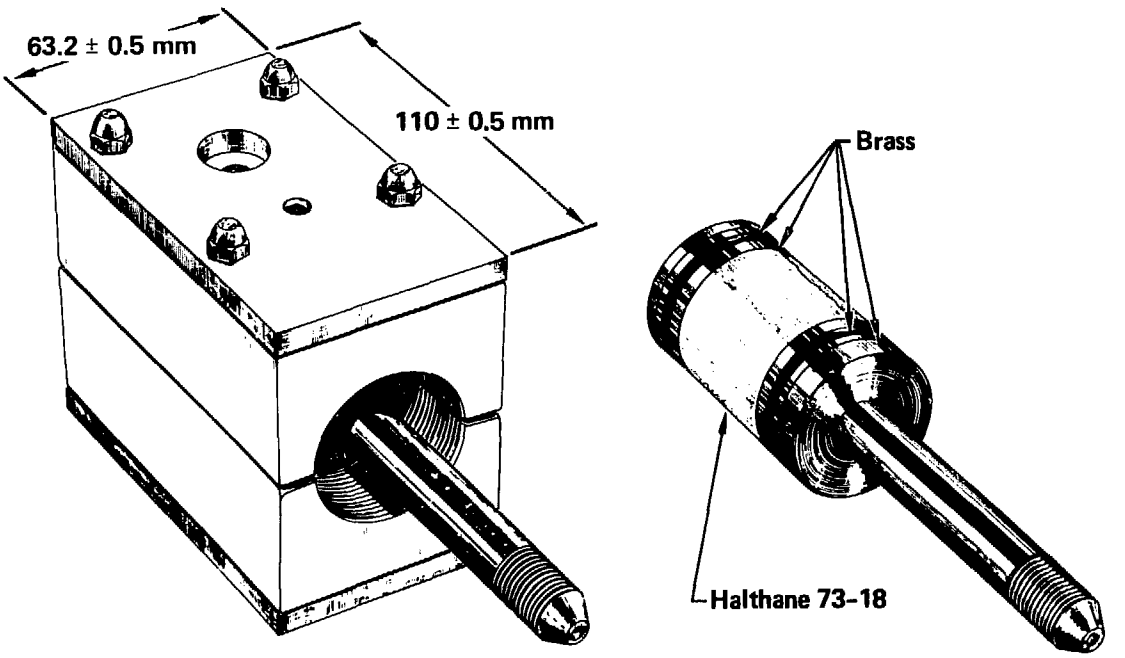


Figure 4. Assembled mold, sample and end fittings jacketed in Halthane 73-18.

stains Halthane, was pumped through two cores to check the flow paths. Dye was not found on the jacket or core except at the ends and where the fracture touches the jacket.

RUN PROCEDURES

After the core was jacketed, the sample assembly was placed into the experimental setup (Fig. 1). The radionuclide spike was loaded into the spike loop and held until the time of injection. While the transport solution was being run through the core, the confining pressure was incrementally increased until the fluid inlet and differential pressures plateaued. This confining pressure was between 10 and 22 MPa for all the cores studied. Higher confining pressures were avoided since asperities in the fracture surface could be crushed exposing fresh surface to the solution and possibly blocking the fracture flow. The confining pressure was held at the maximum value reached and not reduced throughout the run to avoid possible hysteresis effects.

Confining, inlet and differential pressures, pump flow settings, and sampling intervals were recorded throughout the run. After transport solution had been pumped through the fracture for at least 24 h the spike was injected. After the spike passed through the core and the gamma (γ) activity levels of the effluent dropped to a few percent above background, the run was ended.

After the run, the core was potted in epoxy and sliced normal to the fracture with a diamond saw. An organic lubricating solution was used to avoid washing away any sorbed activity. To determine the amount of the radionuclides retained in the core the slices (approximately 13) were γ-counted.

β^- ANALYSIS OF CONSERVATIVE TRACERS

Tritiated water (HTO) serves as a conservative (nonretarded) tracer for determination of the retardation factors for ^{85}Sr, ^{95m}Tc, and ^{137}Cs. To test the validity of tritiated water as a nonretarded tracer we included ^{36}Cl in some early runs as a second conservative tracer. Chloride ion is often used as a marker ion for water movement.

The radionuclide spikes which contained ^{36}Cl (for cores 7, 6A, and 6B) also contained ^{95m}Tc. Technetium-95m has a β^+ emission which interferes with quantitative detection of ^{3}H. When ^{95m}Tc was present, the samples for ^{3}H analysis were vacuum distilled prior to liquid scintillation counting. The distillation process did not, however, quantitatively recover the ^{36}Cl from the sample; hence, no data will be presented based on the ^{36}Cl analyses for cores 7, 6A, and 6B.

We verified the conservative nature of tritium in our experiments in core 8 where we injected a spike containing only ^{3}H and ^{36}Cl in natural ground water. Since ^{95m}Tc was not present in the spike, vacuum distillation was unnecessary and the β^- analysis for ^{3}H and ^{36}Cl used conventional liquid scintillation counting methods. Figure 5 displays the elution profiles from this run. The ^{3}H and ^{36}Cl plots coincide, supporting our use of ^{3}H

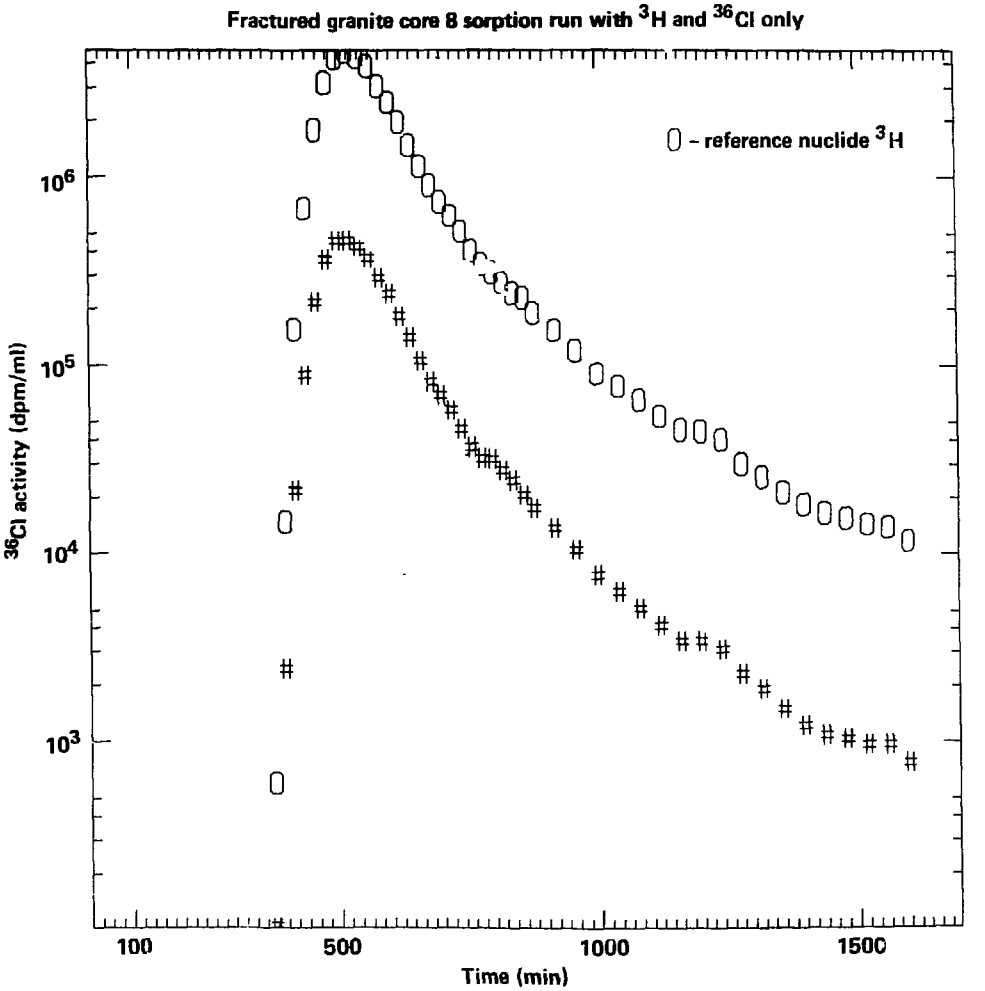


Figure 5. ^{3}H and ^{36}Cl overlap plot.

as the reference radionuclide. This does not prove that HTO is not retarded relative to the water flow in some situations. However, it did serve as a useful check on the HTO behavior in our experiment with respect to another accepted conservative tracer, ^{36}Cl.

PHYSICAL CHARACTERISTICS OF THE CORES

As previously stated we incrementally increased the confining pressure on the cores monitoring the differential and inlet pressures. Table 1 and Fig. 6 present the pressure data for an artificially fractured core (core 9). The differential fluid pressure remained below 1 psi with confining pressures of 10-21 MPa. The hydraulic conductivities for this 0.025-m core follow the size effect trends seen by Witherspoon et al. (1979). For small cores, such as ours, the laboratory fracture permeability may be lower than the actual field value. This must be considered if the fracture permeability is used in any flow models.

Table 1. Calculated aperture and conductivity at various confining pressures on an artificial fracture in a 0.025-m granite core.

P_c[a] (MPa)	Δh[b] (psi)	Δh[b] (cm, H_2O)	K_f[c] (m/s)	Fracture aperture (μm)
10	0.096	6.8	4.78×10^{-4}	25.6
13	0.17	12.3	3.24×10^{-4}	21.0
16	0.33	23.4	2.10×10^{-4}	17.0
18	0.47	33.3	1.67×10^{-4}	15.1
21	0.64	45.4	1.36×10^{-4}	13.6

[a] P_c = confining pressure.
[b] Δh = inlet pressure - outlet pressure (converted from psi to cm using 1 psi = 70.9 cm H_2O).
[c] Conductivity (K_f) and fracture aperture were calculated using Eqs. (2) and (4) from Witherspoon et al., 1979.

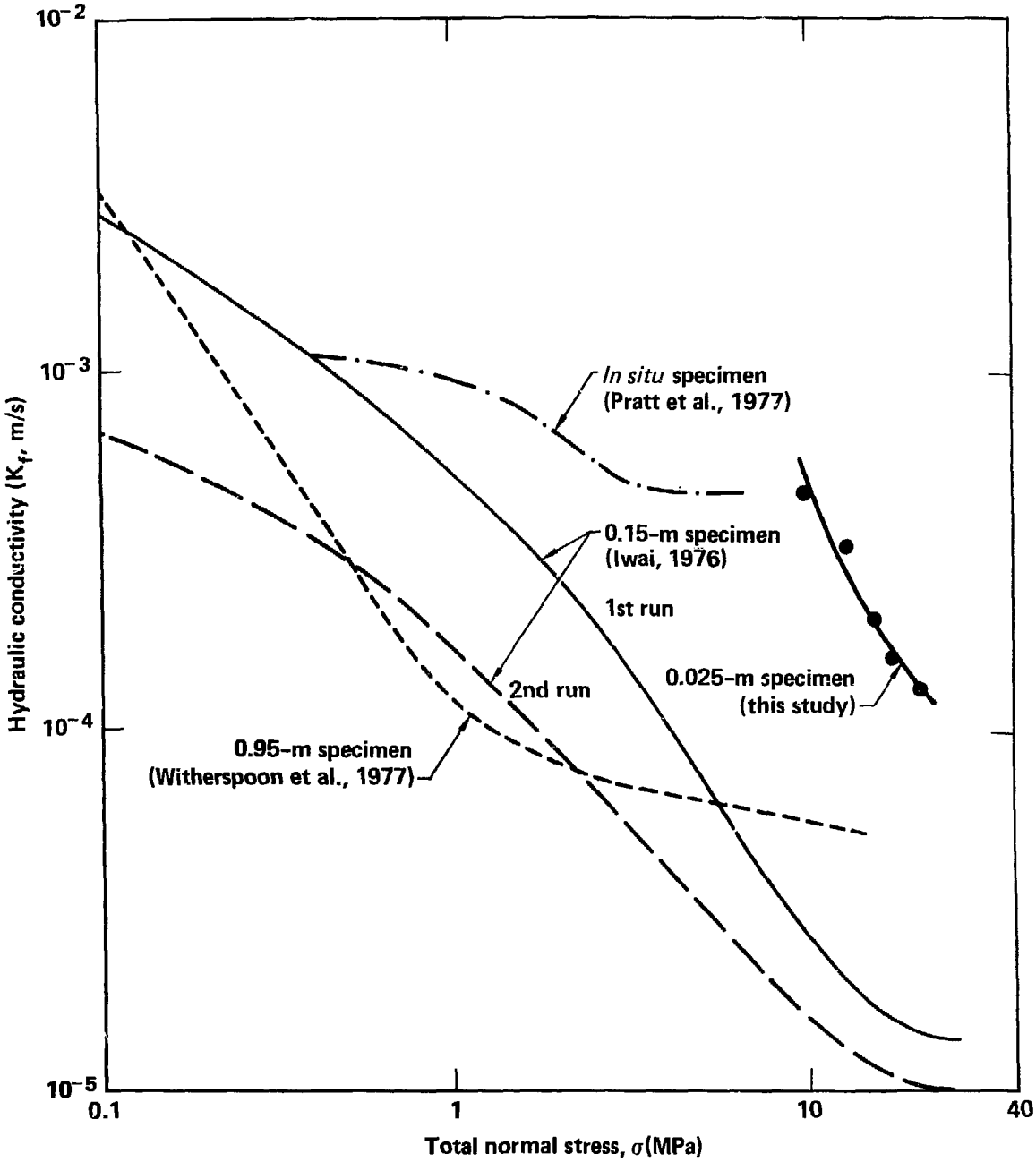


Figure 6. Variation of hydraulic conductivity in a fracture with increasing stress for four different size rock samples (results for 0.15-m and 0.95-m specimens are with radial divergent flow; results for in situ specimen and 0.025-m rock core are with linear flow). [Original from Witherspoon et al., 1979.]

Table 2 lists some of the run conditions for the eleven fractured granite cores. Table 3 gives the hydraulic conductivities and fracture apertures calculated from the pressure values in Table 2. Fill materials sealed the natural fractures in cores 8, 21, 22, 23, and 25 making them impervious to fluid flow. We stressed these cores along the natural fractures causing them to refracture. A fairly steady increase in the differential pressure in cores

Table 2. Pressures and flow rates for eleven fractured granite cores.

Core No.	Fracture type	Solution flow rate (ml/min)	Solution differential pressure (psid)	Confining pressure (MPa)
5	Natural	0.046 ± 0.004	0.014 ± 0.002	11.0 ± 0.2
6A	Natural	.0019 ± .0003	.02 ± .01	10.0 ± .5
6B	Natural	.0020 ± .0002	.010 ± .008	11.0 ± .5
7	Natural	.021 ± .003	.01 ± .01	22.0 ± .5
8	Natural Refractured	.0020 ± .0005	.00024[c]	9.0 ± .6
21	Natural Refractured	.0015 ± .0010	.0006[c]	12.0[a]
22	Natural Refractured	.0021 ± .0003	.0003[c]	14.0 ± .3
23	Natural Refractured	.0020 ± .0004	.00130 ± .00015	12.0 ± .7
25	Natural Refractured	.002 ± .0003[b] .01 ± .002[b]	.00150 ± .00015	13.0 ± .4
9	Artificial	.0021 ± .0007	.28 ± .03	15.0 ± .4
10	Artificial	0.0016 ± 0.0009	0.004 ± 0.001	15.0 ± 0.7

[a] Due to a drop in laboratory temperature P_c decreased to 5.45 MPa for a short time.

[b] Flow rate was increased at the end of the run. The higher flow rate (0.01 ml/min) is used in the aperture calculations.

[c] Because particles apparently blocked the outlet giving an artificially high differential pressure, lowest measured values are listed.

Table 3. Hydraulic conductivity and aperture values for eleven fractured granite cores.

Core No.	Flow rate, Q (ml/s) ×10-5	Confining pressure P_c (MPa)	Differential pressure Δh (cm, H_2O)	Hydraulic conductivity K_f (m/s) $\times 10^{-3}$	Fracture aperture (2b) (μm)
5	77. ± 7.	11.0 ± 0.2	0.99 ± 0.15	16 ± 3	47 ± 4
6A	3.2 ± 0.5	10.0 ± .5	1.4 ± .07	1.7 ± 0.9	15 ± 4
6B	3.33 ± 0.03	11.0 ± .5	0.7 ± 0.6	2.6 ± 1	19 ± 4
7	35.0 ± 0.5	22.0 ± .5	0.7 ± 0.7	12 ± 6	40 ± 10
8	3.33 ± 0.08	9.0 ± .6	0.03[a]	≤21	≤53[a]
21	2.5 ± 1.7	12.0	0.04[a]	≤14	≤44[a]
22	3.5 ± 0.5	14.0 ± .3	0.024[a]	≤25	≤58[a]
23	3.33 ± 0.07	12.0 ± .7	0.09 ± .01	10.6 ± 1	38 ± 2
25	3.5 ± 0.5	13.0 ± .4	0.11 ± .01	26.2 ± 1	60 ± 3
9	3.5 ± 1.2	15.0 ± .7	0.28 ± .07	2.5 ± 0.5	10 ± 1
10	2.7 ± 1.5	15.0 ± 0.7	0.28 ± 0.07	4.2 ± 0.7	24 ± 4

[a] Because particles apparently blocked the outlet giving an artificially high differential pressure, aperature values are upper limits only.

8, 21, and 22 led us to believe particles had broken loose during the refracturing and were moving to block the solution outlet, thereby increasing the differential pressure. Since the aperture is inversely proportional to the differential pressure, the apertures reported for cores 8, 21, and 22 are upper estimates.

The granite cores originated from boreholes in the Piledriver Drift of the Climax Stock at the Nevada Test Site. The Climax Stock is composed of two major phases, an equigranular biotite granodiorite and a porphyritic biotite quartz monzonite. Our cores originated in the quartz monzonite containing large potassium feldspar phenocrysts (Connolly, 1981). The report of J. A. Connolly contains a detailed description of the bulk minerals and alteration products found in the Climax granite.

In the eleven core sorption experiments we used nine naturally fractured and two artificially fractured granite cores. Using x-ray diffraction

Table 4. Fracture fill material.

Core No.	Borehole No., depth (m)	X-ray diffraction identification	Visual and chemical identification	Average fracture fill thickness (mm)	Notes
			Natural, open fractures		
5	TT4, 5.9	X-ray diffraction data not available	Calcite confirmed with HCl	1	
6A, 6B	TT4, 3.4	Quartz and calcite	Calcite confirmed with HCl	0.1 to 0.5	Both cores are from the same fracture
7	TT3, 4.6	Predominately calcite quartz present	Calcite confirmed with HCl	1	
			Natural, intact fractures		
8	TT3, 2.4	Predominately calcite quartz present	Calcite confirmed with HCl	1	Intact cores were refractured to allow water flow
21	TT5, 10.1	Quartz and calcite	Hematite, calcite confirmed with HCl	0.1 to 0.5	
22	TT5, 10.1	Predominately calcite quartz present	Calcite confirmed with HCl	1	
23	TT5, 8	Predominately quartz	Hematite and pyrite, absence of calcite confirmed	2 to 4	
25	TT6, 6.7	Predominately calcite quartz present	Hematite, calcite confirmed with HCl	1 to 2	
			Artificial fractures		
9	Bulk material	Not available	Bulk granite		
10	Bulk material	Not available	Bulk granite		

analysis, we identified calcite and quartz as the predominate fracture fill minerals of Climax granite. Visual examination identified hematite and pyrite not detected by the x-ray diffraction. As a check, we chemically tested for the presence of calcite in the fracture fill material. We dropped dilute HCl onto the fracture and monitored the effervescence. Of the natural fractures only core 23 contained no calcite. In the cores used in this study no clay minerals were identified in the fracture fill material. However, chlorite and montmorillinite were identified in other fractures in the Climax Stock granite (Isherwood et al., 1982b). Table 4 summarizes the information on the location of the cores and the composition of the fracture fill material. The bulk granite was composed of quartz, plagioclase, potassium feldspar, biotite, and some minor alteration products. Very little calcite was present in the bulk granite.

Allard et al. (1981) examined the differences in the fracture fill and the bulk material of the Finnsjön granite. As we found in the Climax granite the dominating fracture minerals were quartz and calcite. The composition of the bulk Finnsjön granite resembled the Climax granite.

CHEMICAL CHARACTERISTICS OF TRANSPORT SOLUTIONS

It is expected that the chemistry of the transport solution will affect the sorption of radionuclides on fracture surfaces. Simulated ground water may not accurately reflect the complex chemical composition of natural ground water. Isherwood et al. (1982b) collected and characterized water from seeps in the Climax drift. This natural ground water was used for eight of the radionuclide transport runs. The natural ground water was analyzed for elemental composition, oxygen content, pH, and Eh. The Eh and dissolved O_2 concentration represent *in situ* conditions (Table 5). The ground water used in our experiments was equilibrated with the atmosphere. The composition of the Climax Stock ground water was unusual for a granitic water (Table 5). The level of total dissolved solids, SO_4^{-2}, and U was elevated compared with other granitic waters (Allard et al., 1981; Johnston, 1980). The isotopic composition of the uranium identified it as natural, not originating from a nuclear device. Details of the ground-water collection and characterization are reported elsewhere (Isherwood et al., 1982b; Harrar and Raber, 1982).

Table 5. Climax ground water chemistry.[a]

pH	7.3	Alkalinity	163 ppm HCO_3^-
Eh	0.41 v	Conductivity	2160 mhos
Dissolved O_2	<0.02 ppm	Total dissolved solids	1900 mg/l

	ppm		ppm
Na	250	U	1.8
Ca	283	Mo	0.7
K	3.4	Sr	5.6
SiO_2	15.8	$SO_4^=$	1060
Al	0.03	$S^=$	<0.05
Cl	77	F	0.9
Mg	0.9	Fe	0.006
$PO_4^=$	<0.5	Cs	0.002

[Tritium = 157 pCi/ml.]

[a] Average composition of ground water collected at Climax site CGW-1 (Isherwood et al., 1982b).

Table 6. Conditions of granite core sorption experiments.

Core No.	Fracture type	Transport solution	Radionuclides
5	Natural	Distilled water	^{3}H, ^{85}Sr, ^{95m}Tc
6A	Natural	Natural ground water	^{3}H, ^{36}Cl, ^{85}Sr, ^{95m}Tc, ^{137}Cs
6B	Natural	Natural ground water	^{3}H, ^{36}Cl, ^{85}Sr, ^{95m}Tc, ^{137}Cs
7	Natural	Natural ground water	^{3}H, ^{36}Cl, ^{85}Sr, ^{95m}Tc
8	Natural[a]	Natural ground water	^{3}H and ^{36}Cl only
8	Natural[a]	Natural ground water	^{3}H, ^{85}Sr, ^{95m}Tc, ^{137}Cs
21	Natural[a]	Distilled water	^{3}H, ^{85}Sr, ^{95m}Tc, ^{137}Cs
22	Natural[a]	Natural ground water	^{3}H, ^{85}Sr, ^{95m}Tc, ^{137}Cs
23	Natural[a]	Distilled water	^{3}H, ^{85}Sr, ^{95m}Tc, ^{137}Cs
25	Natural[a]	Natural ground water	^{3}H, ^{85}Sr, ^{95m}Tc, ^{137}Cs
10	Artificial	Natural ground water	^{3}H, ^{85}Sr, ^{95m}Tc, ^{137}Cs
9	Artificial	Natural ground water	^{3}H, ^{85}Sr, ^{95m}Tc, ^{137}Cs

[a] Sealed fracture was refractured to allow water flow.

The natural levels of Ca, Sr, Cs, and ^{3}H in the Climax ground water are of interest for this study. The possibility of competition for sorption sites between Ca and Sr makes the 283 ppm Ca and 5.6 ppm Sr important. The effect of the Ca-Sr competition is evident in the lower Sr retention in runs with Climax ground water as compared to runs with distilled water. A cesium concentration of 2 ppb, while not unusual, is important when comparing distilled water with natural ground water as the transport solution due to competition between ^{137}Cs and natural Cs for sorption sites. Our tritium spike concentrations (approximately 1 μCi/ml) are not affected by the ambient 157 pCi/ml ^{3}H.

The fracture type, transport solution, and radionuclides for each core run are listed in Table 6. Cesium was not included in this study until after cores 5 and 7 were completed. As explained previously ^{36}Cl was included in cores 7, 6A, and 6B but not used in the data analysis.

DATA REDUCTION

Our data analysis computer program (ORB) performed three main functions:

- Volume and flow rate calculations
- Radionuclide activity calculations
- Graph plotting.

The volume and flow rate calculations were performed using gross and net tube weights and sample collection periods. The tritium activities were input as dpm/ml for each analyzed sample. The background and peak counts, counting period, count date, and half life were used to calculate the cpm/ml (or dpm/ml) of the γ-emitting radionuclides. The core slice data were calculated in dpm/mm and interpolated for slices which were not counted. The above calculations were output graphically and in tabular form.

The graphic output included average flow rate and the activity of each radionuclide plotted vs sample number, time, and cumulative volume. An overlap plot of the designated reference radionuclide with the remaining radionuclides may be requested on the time and cumulative volume plots.

The listing, and sample input and output files for ORB are given in Appendix B. The following are planned improvements to the code which were not carried out when the project was terminated:

- Bar graphing the core slice data.
- Calculating percent activity remaining in the core.
- Peak maxima calculating.
- Complete calculating of retardation factor.
- A curve fitting routine.

A sample of the elution profiles from core 25 is shown in Figs. 7a through 7c. Data used to generate these plots were used to determine the peak elution volume for the radionuclides. The retardation factor, R, for ^{85}Sr, ^{95m}Tc, and ^{137}Cs was determined by

$$R = \frac{\text{Elution peak volume of radionuclide X}}{\text{Elution peak volume of tritium}}$$

The elution peak volume is the cumulative volume of solution that passes through the core between the spike injection and the peak in activity of radionuclide X, minus the system dead volume (see Appendix A). The uncertainties reported arise mainly from the imprecision of the dead volume measurements and the peak locations (if there is scatter in the data points at the peak).

From the calculated dpm/mm for the γ-emitting radionuclides in the core slices we determined the percent of the injected activity retained in the core. We plotted the percentage of injected activity per millimeter of core vs the distance into the core (Fig. 8). These plots depict the sorption of radionuclides along the fracture.

RESULTS

The elution profiles for ^{95m}Tc and ^{85}Sr indicate little or no retardation of the eluted activity with respect to ^{3}H. In the runs of cores 6A and 6B, which contain the same natural fracture, strontium is slightly retarded. For cores 6A and 6B the calculated ^{85}Sr R values fall in the range of 2.5 ± 1.2. Technetium is slightly retarded in the core 6B run ($R = 1.8 \pm 0.4$). None of the other core runs indicate retardation of ^{95m}Tc or ^{85}Sr (Table 7).

The behavior of ^{137}Cs is more complex. We used distilled water and a naturally fractured core (core 21) and found less than 1% of the ^{137}Cs

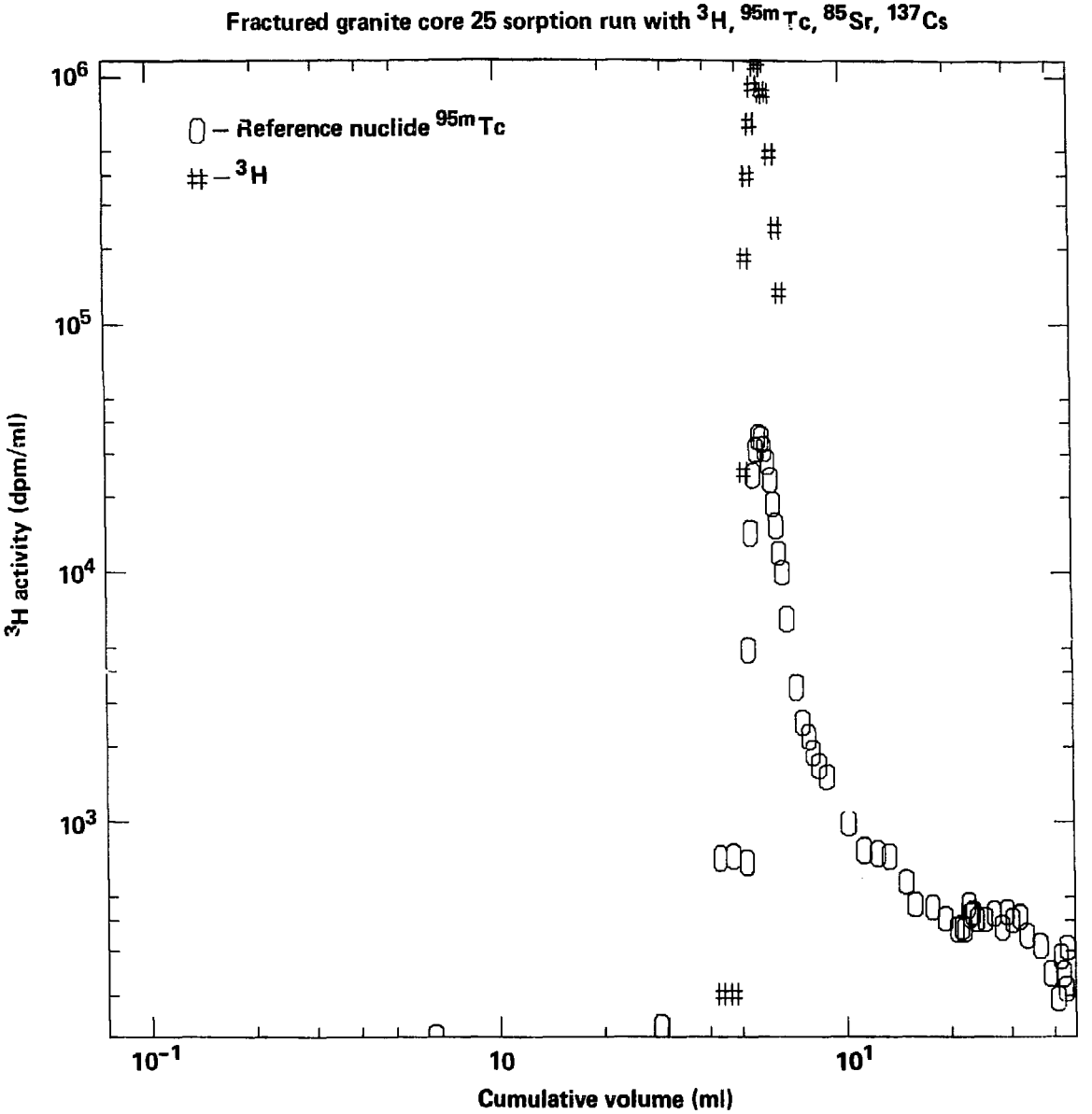


Figure 7a. ^{3}H and ^{95m}Tc overlap plot.

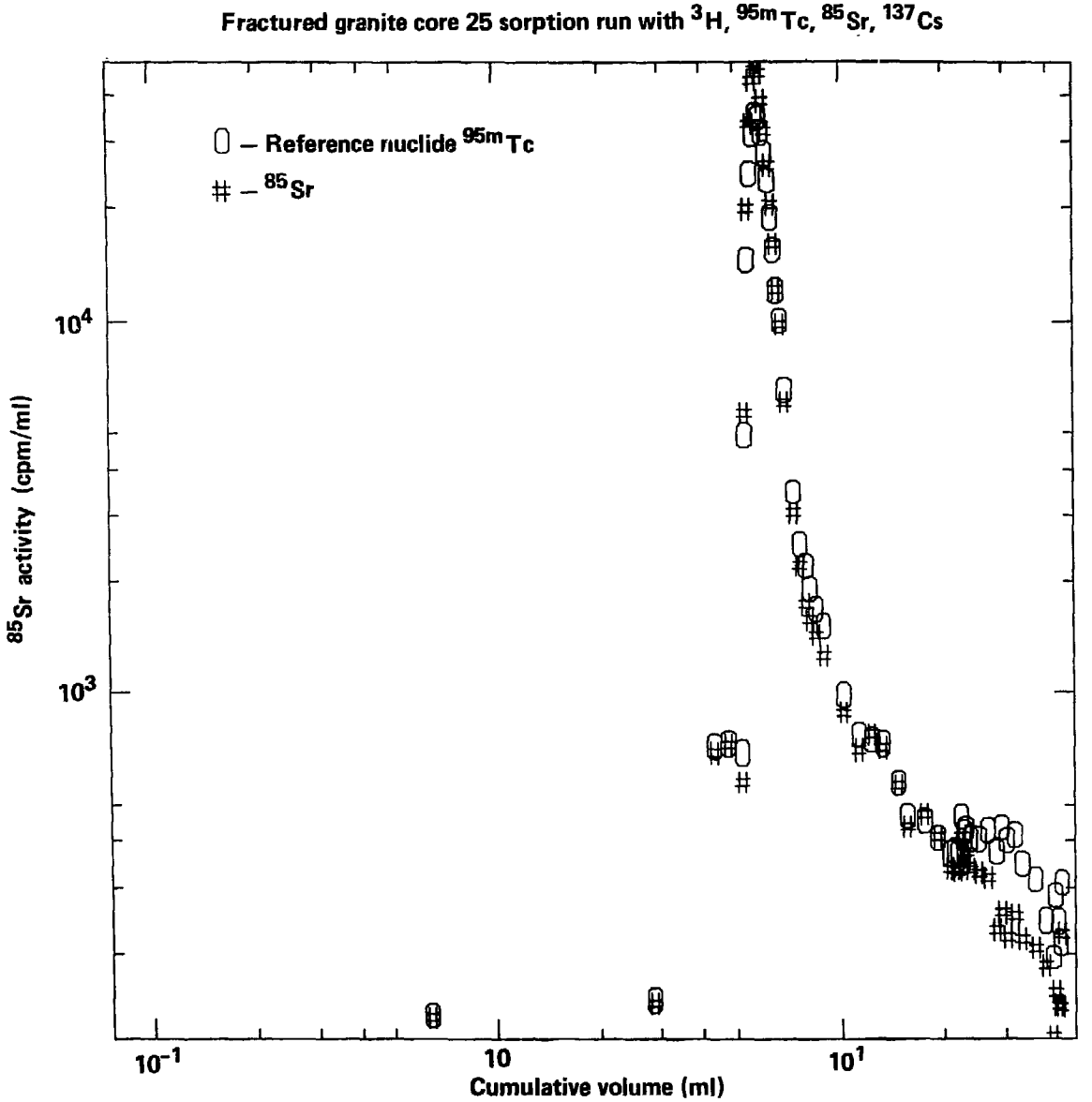


Figure 7b. ^{85}Sr and ^{95m}Tc overlap plot.

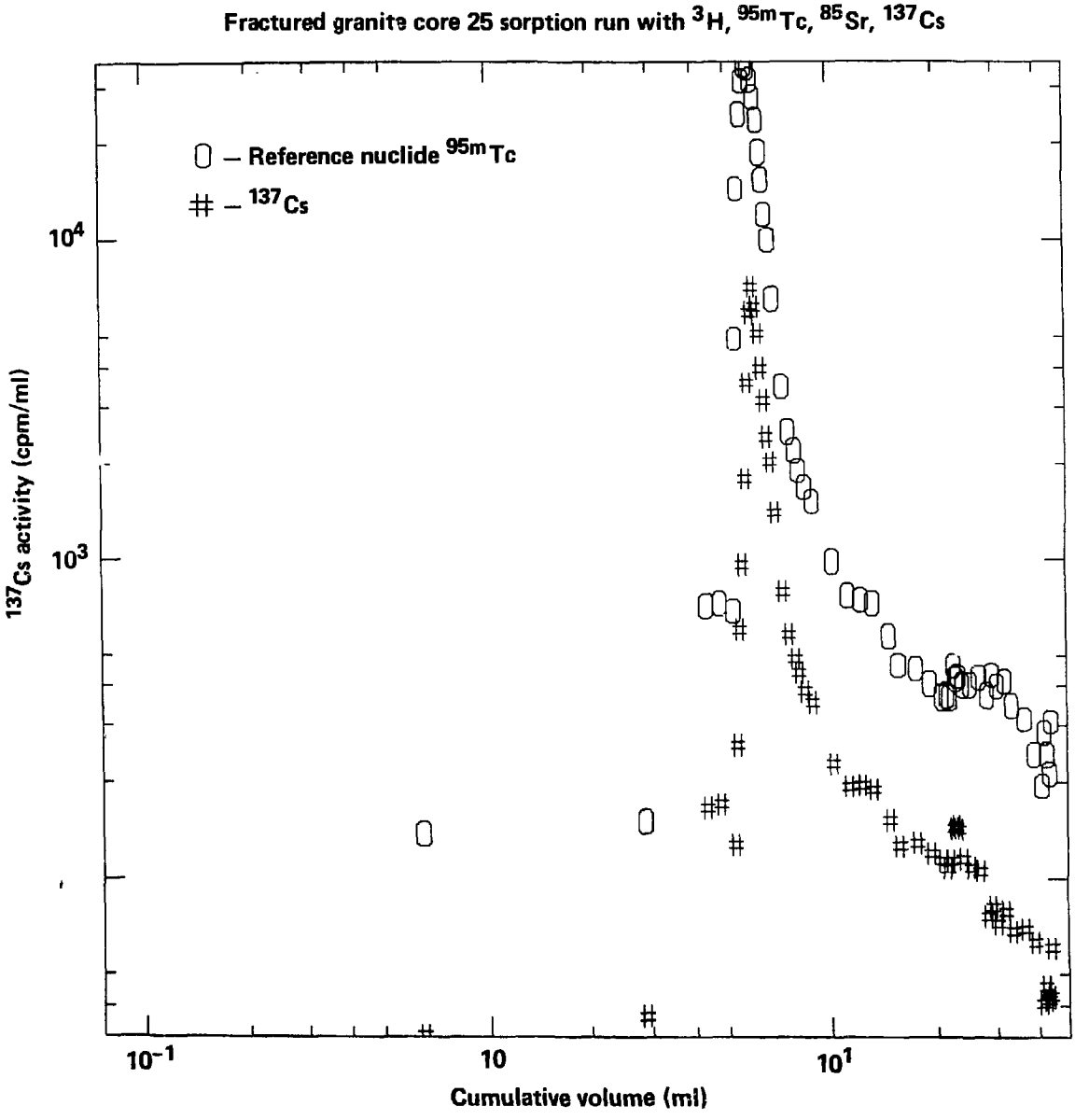


Figure 7c. ^{137}Cs and ^{95m}Tc overlap plot.

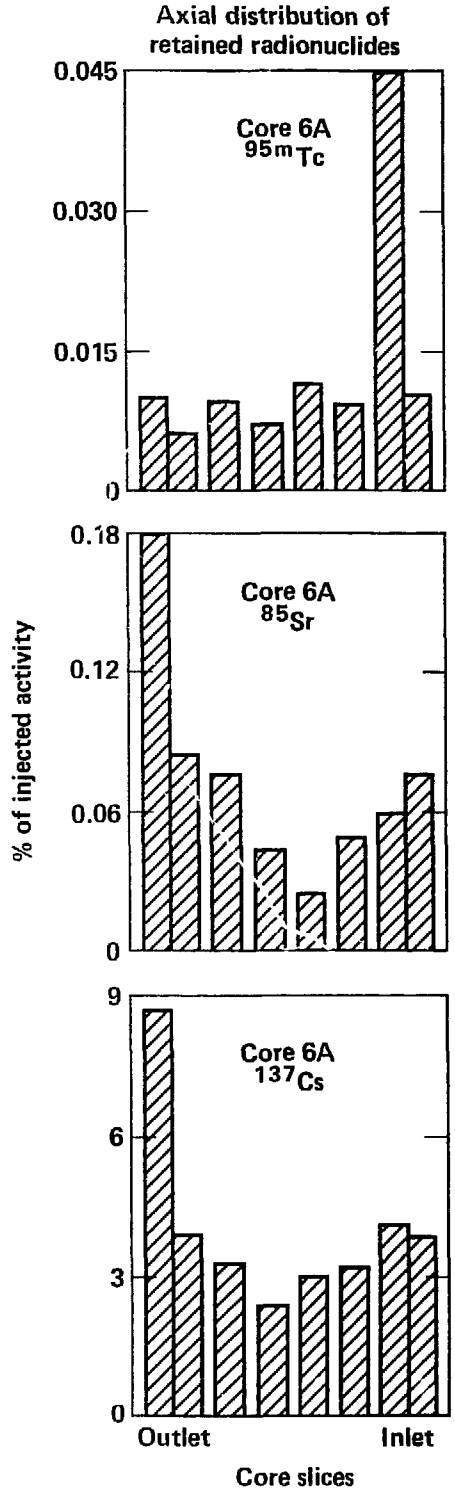


Figure 8. Core slice retention plots.

Table 7. Retardation values.

Core No.	Transport solution	Fracture type	Retardation (R) values Sr	Tc	Cs
5	Distilled water	Natural	1 ± 0.2	1 ± 0.2	Not included
21	Distilled water	Natural refractured	1 ± 0.2	1 ± 0.2	<1000
25	Distilled water	Natural refractured	1 ± 0.2	1 ± 0.2	90 ± 80
7	Natural ground water	Natural	1 ± 0.2	1 ± 0.2	not included
6A	Natural ground water	Natural same as 6B	2.5 ± 1.2	1.8 ± 0.4	120 ± 50
6B	Natural ground water	Natural same as 6A	2.9 ± 0.5	1.8 ± 0.4	43 ± 10
8	Natural ground water	Natural refractured	1 ± 0.2	1 ± 0.2	5 ± 25
22	Natural ground water	Natural refractured	1 ± 0.2	1 ± 0.2	1 ± 10
23	Natural ground water	Natural refractured	1 ± 0.2	1 ± 0.2	60 ± 50
9	Natural ground water	Artificial	1 ± 0.2	1 ± 0.2	1.5 ± 2
10	Natural ground water	Artificial	1 ± 0.2	1 ± 0.2	120 ± 120

eluted from the core. We estimated the maximum velocity the ^{137}Cs could have and still remain in the core throughout the run. Using this value, we calculated a minimum R value of 1000. However, in the second natural fracture run with distilled water (core 25) we found 12% of the injected ^{137}Cs eluted through the core. Though not obvious from the ^{95m}Tc and ^{137}Cs elution curves in Fig. 7c, the elution peak volume calculated from the data used to generate these curves produced a value of 90 ± 80 for the cesium retardation factor.

With artificial fractures and natural ground water (cores 9 and 10), approximately two-thirds of the injected ^{137}Cs was eluted through the core. The calculated R values are 1.5 ± 2 and 120 ± 120.

The five naturally fractured cores run with natural ground water also have a large range of Cs R values. The maximum R value, from core 6A, is 120 ± 50. In the core 22 run the first ^{137}Cs eluted unretarded (R = 1) from the core, however, the tailing of the peak was very broad. The R values fall in the range of 60 ± 60 for cores 6B, 8, and 23. The R values for these natural fractures do not correlate with the fracture fill mineral information or with the fraction of the injected ^{137}Cs retained in the core. For example, cores 6A and 6B (from the same natural fracture) both retained approximately 69% of the injected ^{137}Cs but showed a large difference in cesium retardation. The calculated retardation factors are listed in Table 7.

The large uncertainties in the R values result mainly from uncertainties in the system dead volume determinations. As designed the system has a dead volume (~1.7 ml) which is almost two orders of magnitude larger than the fracture volume. The elution volume used to calculate R is the cumulative volume (after spike injection) minus the dead volume. For unretarded flow this should equal the fracture volume. It is easy to see that even a 5% error in the dead volume causes a large percent error in the resultant elution volumes and hence in retardation value, especially when the errors in peak location and elution volume are compounded.

The percent of the injected activity which remains in the core reveals major differences in the behavior of ^{85}Sr, ^{95m}Tc, and ^{137}Cs. The retention varies from 99% of the injected ^{137}Cs retained in core 21 to less than 0.01% of the injected ^{85}Sr retained in core 7 (Table 8). The amount of injected activity retained in the core varies with the transport solution and fracture minerals.

For those cores run with natural ground water the retention was $\leq$2.4% of injected ^{85}Sr and $\leq$72% of injected ^{137}Cs. For cores run with distilled water the ^{85}Sr retention ranged from 7.7 to 37% and ^{137}Cs retention ranged from 88 to 99%.

The natural ground water contains 5.6 ppm Sr, 283 ppm Ca (a divalent ion which may affect Sr sorption), and 2 ppb Cs. The increased sorption in the runs using distilled water can be explained in terms of a nonlinear isotherm. This was shown to apply to cesium (Seitz et al., 1978) and may also apply to

Table 8. Radionuclide retention in cores.

Core No.	Transport solution	Fracture type	% Sr retained in core	% Tc retained in core	% Cs retained in core	Comments
5	Distilled water	Natural	7.7	0.1	Not included in spike	Spike inadvertently contained brine salts
21	Distilled water	Natural	37	9.2	99	5.0% of Tc and 39% of Cs injected retained on inlet slice
25	Distilled water	Natural	10	12	88	
6A	Natural ground water	Natural	1.3	0.3	68	
6B	Natural ground water	Natural	2.3	0.6	69	
7	Natural ground water	Natural	<0.01	30	Not included in spike	Tc activity found on particles blown out of core at end of run
8	Natural ground water	Natural	2.2	46	72	22% of Tc injected retained on inlet slice
22	Natural ground water	Natural	2.4	4.2	70	3.4% of Tc injected retained on inlet slice
23	Natural ground water	Natural	2.1	34	32	13% of T_c injected retained on inlet slice
9	Natural ground water	Artificial	0.6	12	38	
10	Natural ground water	Artificial	1.0	21	31	

NOTE: Less than 0.1% of total activity was retained on Halthane jackets.

strontium. The combined effect of calcium and strontium could account for the higher retention in distilled water compared to ground water runs.

The ^{137}Cs retention also varies with fracture type. For the naturally fractured cores run with natural ground water (6A, 6B, 8, and 22) the cores retained 68 to 72% of the ^{137}Cs injected. The fracture fill minerals in these cores contained calcite and quartz. One other naturally fractured core (core 23) contained no calcite in the fracture fill material, and retained only 32% of the ^{137}Cs when run with natural ground water.

The lower Cs sorption for the cores with no calcite along the fracture should not be directly attributed to the absence of calcite. Allard et al. (1982) reports a low sorption of Cs on calcite (11%) compared with an 88% sorption on granite or 91% on biotite (a major mineral component of granite). As explained in the next section, the autoradiographs actually show lower sorption in the regions of the fracture where calcite is present. Other minerals associated with calcite in the fracture fill material may contribute to the Cs sorption in cores 6A, 6B, 8, and 22.

A chemical stripping technique helped us to better understand the Cs sorption. As mentioned, dilute HCl was applied to the core slices to check for the presence of calcite. On core 25 the HCl was collected, the slices were rinsed, and the rinses were collected. The HCl and rinses were γ-counted. To dissolve the iron and manganese oxides the slices were broken along the fracture and contacted for 6 hr at 96°C with a solution of 0.04 mole/l hydroxylamine hydrochloride in 25 vol% acetic acid (Tessler et al., 1979). These solutions, rinses, and the rinsed slices were also γ-counted. Only ^{137}Cs was detected since the ^{85}Sr and ^{95m}Tc had decayed away. The results are presented in Fig. 9.

The HCl should remove all ^{137}Cs sorbed by ion exchange and associated with the calcite. The average of this ^{137}Cs was 8 ± 4% of the total ^{137}Cs retained by the core, while 62 ± 5% was removed along with the iron and manganese oxides and 31 ± 6% was not removed by these solutions. It is possible that this last fraction includes material sealed in place by the potting epoxy; however, it is striking that as much as one third of the ^{137}Cs has become immobilized after a relatively short contact time. In fact, most of the ^{137}Cs left in the core is evidently not available for desorption via ion exchange but can be removed by dissolution of the iron and manganese oxides.

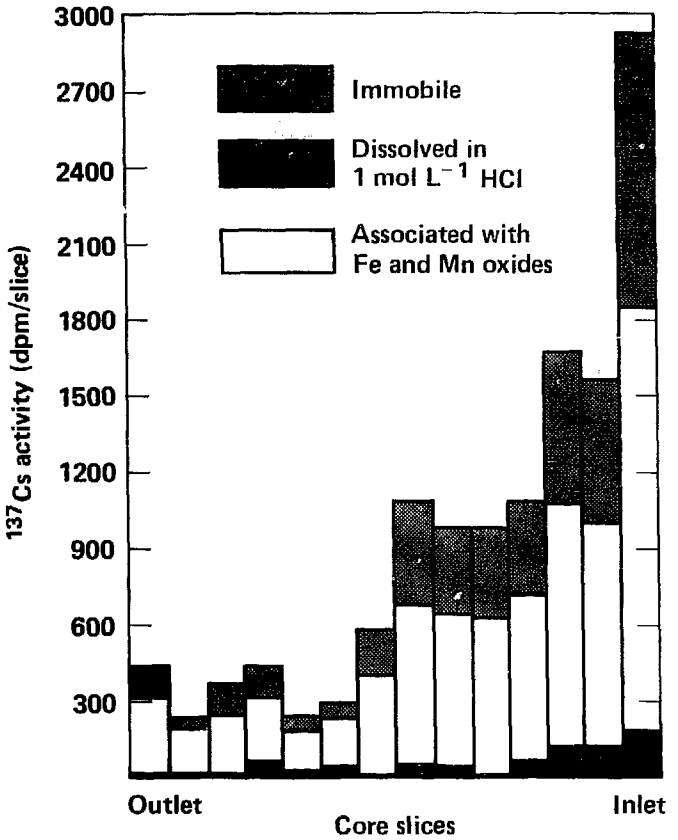


Figure 9. Chemical stripping profile of ^{137}Cs sorption.

The retention of ^{95m}Tc in the cores is not easily related to the transport solution or fracture fill material. Three of the natural fractures run with natural ground water (cores 7, 8, and 23) retained from 30 to 40% of the injected ^{95m}Tc. The other three natural fractures run with natural ground water (cores 6A, 6B, and 22) retained from 0.3 to 4.2% of the injected ^{95m}Tc. The natural fractures run with distilled water (cores 21 and 25) retained from 9 to 12% of the injected ^{95m}Tc. In core 5, also run with distilled water, only 0.1% of the ^{95m}Tc was retained; however this may have been the result of inadvertently using brine to make up the 0.5-ml spike.

The artificial fractures (cores 9 and 10) run with natural ground water retained from 12 to 21% of the injected ^{95m}Tc. On several cores (8, 21, 23, and 22) 40 to 80% of the ^{95m}Tc retained by the core was found on the inlet slice. Axial distribution plots show the spread of the retained activity through the core. Figure 8 displays a sample plot. The high sorption of

^{95m}Tc at the inlet end of the core is typical. Vandergraaf's review (1982a) suggests moderate sorption of Tc on granite (K_d = 28 ml/g) (LANL, 1979). Our results confirm technetium sorption on bulk granite.

AUTORADIOGRAPHY

Autoradiographs were made of the slices from core 25 (a natural fracture run with distilled water). The autoradiographs (Figs. 10-13) show that sorption of the radionuclides occurred only in the fracture except for the faces of the core where the radionuclides can contact the bulk granite.

The procedure for obtaining the autoradiographs is similar to that described by Vandergraaf and Abry (1982b). Slices of core 25 were contacted with glass slides coated with an Ilford K5 emulsion for 144 h. After exposure, the plates were developed in Kodak D19 developer for 10 min with constant agitation, followed by 5 min in a Kodak stop bath, 2^ min fixing in Kodak fixer, and 25 min washing in running distilled water.

The photographs and autoradiographs were photographed on Kodak Panatomic X film through a WILD macroscope using transmitted light, and printed to give a linear magnification of 4x. The autoradiographs are positive; i.e., the dark areas are the exposed areas and correspond to those containing the sorbed radionuclides. Since the core was sliced after the experiment, no autoradiographs could be made to check for natural radioactivity before contact with the radionuclide solutions. However, past experience has shown that exposure well in excess of four weeks is needed to register normal natural radioactivity levels on Ilford plates.

The autoradiographs (Figs. 10-13) clearly show that sorption occurred primarily along the fracture, and with the exception of the inlet slices (Fig. 10) and outlet slices (Fig. 11), did not spread beyond this fracture. The inlet face and oulet face sorb radionuclides before and after the spike enters the fracture. No sorption is evident on the outer surface of the core. This shows that the ground-water flow was restricted to the fracture, and no bypass occurred between the core and the Halthane jacket. This substantiates results obtained in earlier runs with Rhodamine B dye.

Sorption along the width of the fracture is not uniform. Near the inlet part of the core where gross inhomogeniety of the bulk rock can be seen from the optical photographs (Fig. 12), enhanced sorption in the fracture appears

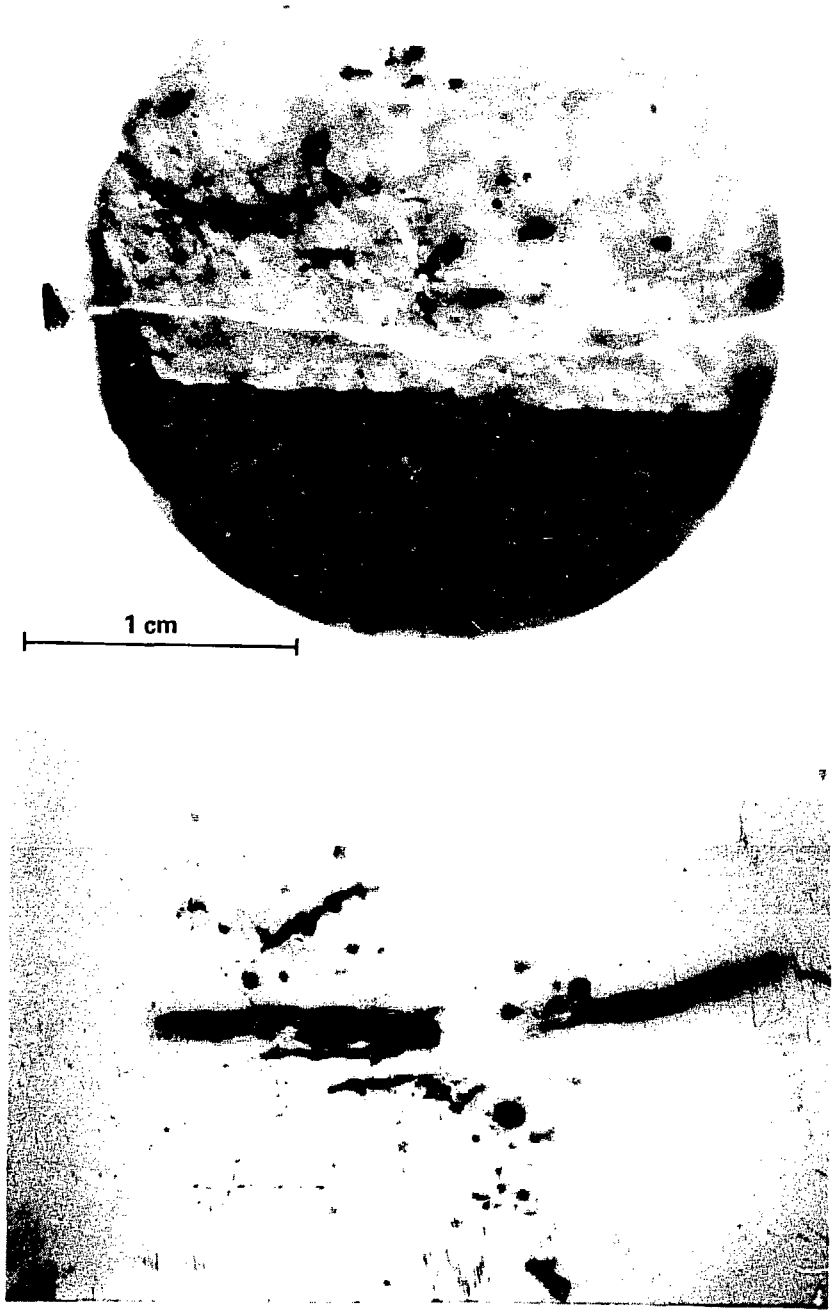


Figure 10. Photograph and autoradiograph of solution inlet slice of naturally fractured granite core--No. 25 (sorption occurred both in fracture and on bulk granite inlet face of core).

Figure 11. Photograph and autoradiograph of solution outlet slice of naturally fractured granite core--No. 25 (sorption occurred both in fracture and on bulk granite outlet face of core).

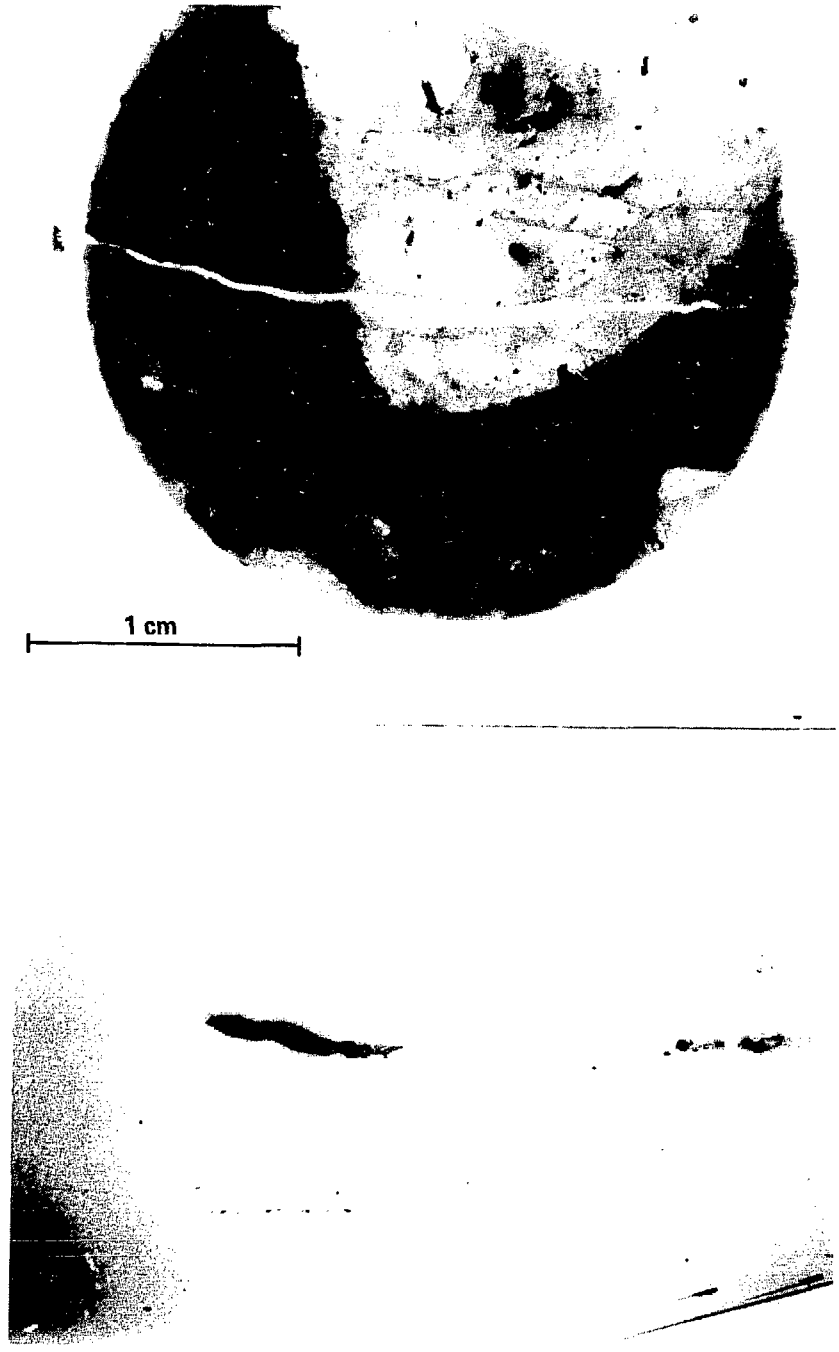


Figure 12. Photograph and autoradiograph of interior slice of naturally fractured granite core--No. 25 (sorption occurred only along fracture, mostly along ferromagnesium-rich mineral portion of core).

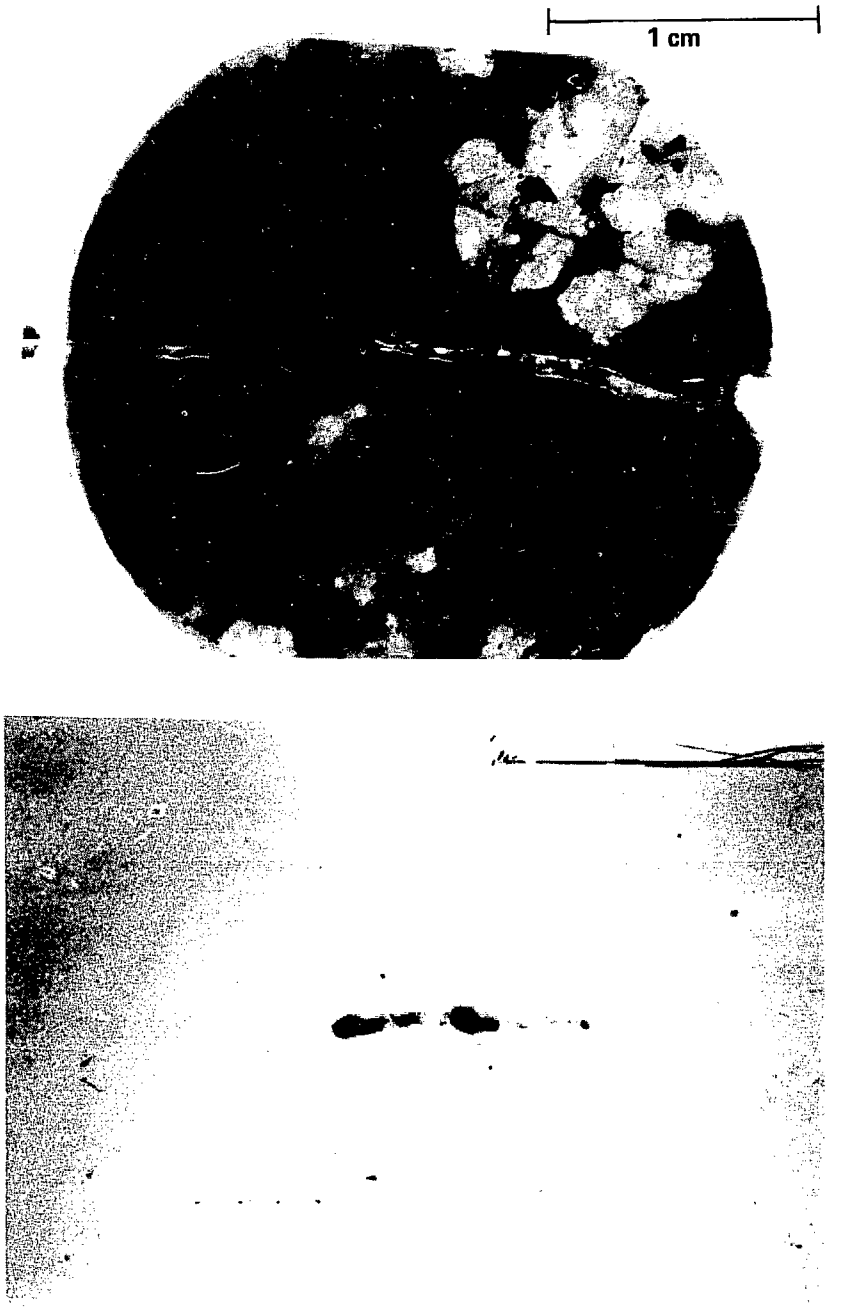


Figure 13. Photograph and autoradiograph of interior slice of naturally fractured granite core--No. 25 (sorption occurred only along fracture; specific sorption minerals are difficult to determine).

to correlate with the ferromagnesium rich mineral regions (the dark areas in the optical photographs) and is very low in the feldspar region. This agrees with other studies (Vandergraaf et al., 1982b,c). Closer to the outlet, sorption again occurs on specific sites in the fracture (Fig. 13).

It is difficult to determine which minerals are the prime sorption sites. To check for sorption by calcite, dilute HCl was dropped onto the fracture fill material of core 25 after the autoradiography was completed. The effervescence, an indication of the presence of calcite, was greatest in the regions with the lowest sorption.

At the time the radionuclide transport experiment was carried out, 88% of the ^{137}Cs was retained by the core, compared to 10% of the ^{85}Sr and 12% of the ^{95m}Tc injected. During the time between the core sorption run and the autoradiography most of the ^{85}Sr and ^{95m}Tc had decayed away. Therfore, the activity registered by the photographic emulsion is mostly ^{137}Cs, which is known to sorb on biotite.

SUGGESTED FUTURE STUDIES

The results of our experiments suggest some necessary improvements in equipment and alternate procedures. The major difficulty arises from the ratio of large dead volume to fracture volume.

To safely apply confining pressures up to 35 MPa to the cores, the end pieces and core are housed in a large brass vessel. These end pieces add to the dead volume. Also, the fittings for the pressure transducers add dead volume as do the lines from the spike loop and to the fraction collector. It is possible to add the spike directly into the fracture (Neretnieks et al., 1981) and remove the solution from the opposite end of the fracture as it accumulates. This reduces the dead volume significantly. However, Neretnieks does not apply confining pressure to the core.

In addition to improving the ratio of dead volume to fracture volume, increasing the area of the fractures will increase the residence times of the radionuclides in the fracture and provide a larger reaction surface. Neretnieks et al. (1981) has used cores 30 cm long by 20 cm in diameter. Future drilling procedures must be carefully planned to acquire satisfactory large samples of natural fractures.

The autoradiography results show sorption on the faces of the core (Figs. 10 and 11). The core slice counting indicated a large percent of the ^{95m}Tc sorbed on the faces (Table 8). We can minimize the sorption of the tracers on the face of the core by sealing the exposed bulk rock and leaving the fracture free. Halthane 73-18 (the polyurethane adhesive used to jacket the cores) has proven to be nonsorbing and forms a tight bond with the rock surface. A thin coat of Halthane 73-18 across the faces of the core, leaving the fracture free, would prevent loss of the tracer before it enters the fracture.

Our work is a first step in studying the effects of transport solution composition on the sorption of radionuclides. Much more work is necessary to understand the mechanisms involved. The idea of competition between strontium and calcium for sorption sites should be studied. The influence on migration by the high level of dissolved solids and high SO_4^{-2} in the Climax ground water has not been investigated. The effect of the transport solution composition on the radionuclide speciation (especially technetium) should be considered (Paquette et al., 1980).

In studying the effects of fracture fill material on radionuclide sorption, more details of the fracture fill composition are necessary. The reduction in ^{137}Cs retention in the cores with no calcite in the fractures points out one of many unanswered questions.

IN BRIEF

Following equipment modifications to adapt the core sorption apparatus to the study of fracture flow, radionuclide transport tests were performed on eleven fractured granite cores. To document the effects of fracture fill material and transport solution on radionuclide transport and sorption, our experiments used natural and artificial fractures, with natural ground water and distilled water labelled with the radionuclides ^{3}H, ^{85}Sr, ^{95m}Tc, and ^{137}Cs.

Strontium-85 shows little or no retardation relative to tritiated water under our experimental conditions. With natural ground water as the transport solution, less than 2.5% of the injected ^{85}Sr is retained in the core. With distilled water as the transport solution, 7.7 to 37% of the injected ^{85}Sr is retained in the core. We hypothesize a nonlinear isotherm combined with a competition for sorption sites between calcium and strontium to be the cause.

A correlation between ^{85}Sr retention in the cores and fracture fill material is not evident.

Technetium shows little or no retardation relative to tritiated water. The amount of ^{95m}Tc retained in the cores does not correlate with type of transport solution or fracture fill material. In agreement with other studies we detect technetium sorption on the bulk granite (Vandergraaf, 1982a).

Cesium shows a varied retardation from core to core relative to tritiated water. The amount of retardation does not correlate with the type of transport solution or fracture fill material in any clear way. With natural ground water as the transport solution, less than 73% of the injected ^{137}Cs is retained in the core. With distilled water as the transport solution, 88 to 99% of the injected ^{137}Cs is retained in the core. We hypothesize a nonlinear isotherm to be the cause of the increased cesium retention with distilled water.

With natural fractures containing calcite 68 to 72% of the injected ^{137}Cs is retained in the core. With artificial fractures and a natural fracture containing no calcite, 31 to 38% of the injected ^{137}Cs is retained in the core. The autoradiographs show lower sorption in the regions where calcite is present.

Hydraulic conductivity measurements follow the size effect trend predicted by Witherspoon (1979). Using Darcy's law, fracture apertures were calculated for each core and ranged from 18 to 60 μm. These apertures are typical of fractures in granite. Isherwood et al. (1982a) measured apertures of 20 and 30 μm in fractures in the Piledriver drift.

The vast majority of radionuclide sorption data comes from static tests on crushed rock. Whereas refined dynamic tests are needed to provide more reproducible experimental values, our test simulate natural conditions by using natural fracture surfaces with fracture fill and flowing transport solutions. Our results demonstrate the importance of transport solution compositions and fracture fill material, especially for Cs sorption. The lack of correlation between retardation and sorption from core to core indicates further studies are needed to determine whether there are different mechanisms occurring or whether the lack of correlation is simply due to the natural heterogeneity of the fractures.

A fundamental concern is whether laboratory fracture flow results accurately reflect the transport of radionuclides in the natural environment. Field test of radionuclide transport in fractures have been proposed by

several workers (Isherwood et al., 1982a; Neretnieks et al., 1982). The field results are vitally important to determine the validity of laboratory dynamic transport tests.

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APPENDIX A: EQUIPMENT AND PROCEDURES

A detailed description of the core sorption apparatus is available in Weed et al. (1981b). The following equipment changes converted the core sorption apparatus used to study radionuclide transport in brine through sandstone into the system used to study radionuclide transport in ground water through fractured Climax Stock granite. The first changes improved our ability to measure the hydraulic properties of the fracture flow. Previously a needle valve on the outlet side of the core (Fig. A1) throttled the flow of solution. The valve affected the fluid pressures in the core by acting as a second aperture. We removed the valve to allow for a more natural flow pattern through the fractured core.

The previous pressure transducers (Fig. A1) spanned a range of 0-15,000 psi and were placed on the inlet and outlet sides of the core. A Taber Model 2404 pressure transducer, spanning 0-300 psi at ±1% precision, now measures the inlet fluid pressure. A Validyne Model DP pressure transducer 15-50, spanning 0-100 psi at ±1% precision, now measures the differential fluid pressure. The hydraulic conductivities calculated using the new transducers pressure measurements allow us to determine the fracture apertures of the cores to two significant figures (Tables 3 and 4).

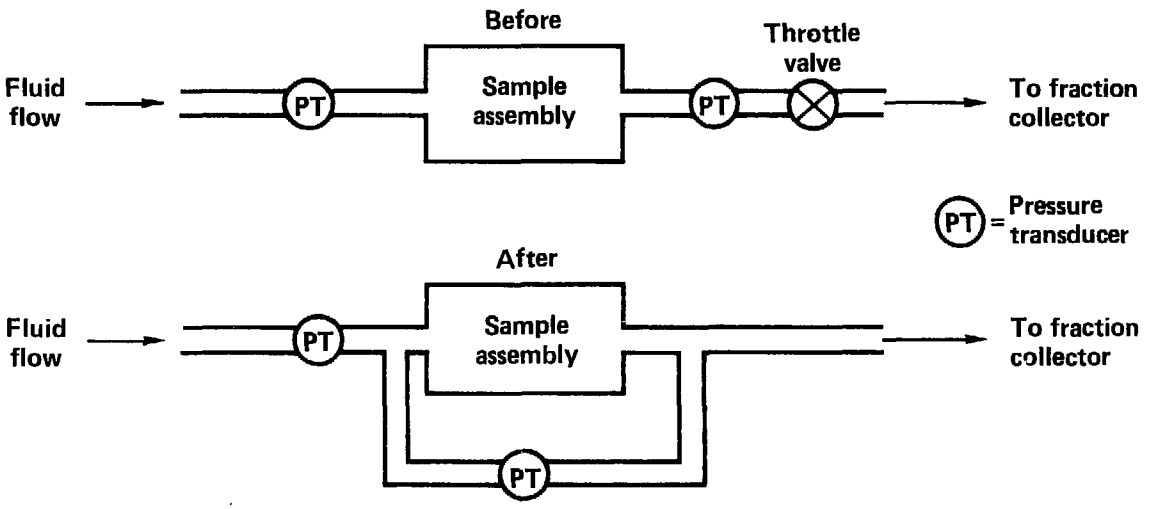

Figure A1. Schematic of changes made in pressure transducer arrangement and removal of throttle valve.

The lowest reliable flow rate obtained by the standard Altex Model 100 dual piston positive displacement pumps is approximately 0.03 ml/min. This is approximately 0.07 m/d for a fracture area of 6.45 cm^2. Reducing this flow rate more closely simulates the low flow expected for a repository site and increases the residence time of the radionuclides in the core. To obtain a slower flow rate we modified an Altex Model 100 pump by replacing the drive motor with a x10 slower motor. The modified pump can deliver a flow at 0.001 ml/min. However, this rate is not stable. This modified pump was used on all cores except 5 and 7 with an average flow rate of 0.002 ± 0.0005 ml/min.

We redesigned the inlet end fitting to improve the connection to the pressure transducers. The modification reduced the system dead volume and simplified the connection. The previous fraction collector was replaced with a Gilson Race Track Model. The new fraction collector holds more sample tubes, has a more precise timer, and is more reliable than the previous unit. We developed a simpler method of injecting the Halthane 73-18 unpolmerized mixture into the jacketing mold using syringes held in a caulking gun.

To prepare the spike solutions, aliquots of standard "carrier-free" radionuclide solutions of ^{85}Sr, ^{95m}Tc, and ^{137}Cs were heated to dryness in a volumetric flask using an infrared lamp. The radionuclides were added in μCi/ml levels. This low concentration will avoid swamping the fracture wtih Sr, Tc, or Cs far above natural levels. Known amounts of tritiated water and transport solution diluted the activity to the desired level. When distilled water was used as the transport solution, Sr and Cs carrier (5 ppm Sr and 1 ppm Cs) was added to the spike. The natural Cs and Sr levels in the Climax Stock ground water act as the carrier in the spikes made with natural ground water. No special carrier was added for Tc since decay corrected γ-counts did not show a loss of Tc from the spike solutions over time.

To determine the activity levels of the radionuclides in the spike 100 μl, 150 μl, and 200 μl aliquots of each spike were pipetted onto filter papers and counted on calibrated Ge(Li) detectors. A sample of the spike was also submitted for ^{3}H analysis.

The elution volume for a radionuclide includes the volume of the fracture plus the volume of the tubing and end fittings. The volume of the tubing and end fittings is called the system dead volume. The measured parameter from the experiments is the total elution volume for the radionuclides. We must know the system dead volume to determine the volume of the fracture only.

The procedure for a dead volume measurement run is very similar to the normal fractured granite core runs. A reference core made of dense alumina replaces the granite core in the experimental setup (Fig.1). A center bore hole with a volume of 5.8×10^{-3} cm^3 is drilled into the core. A radionuclide spike is loaded into the spike loop. The flow rate and sample collection rate are adjusted to get the best volume resolution. After the spike injection, the cumulative volume and activity are monitored until the activity level peaks and returns to the background level. The measured dead volume is the volume of solution collected between the spike injection and the peak of the eluted activity.

APPENDIX B: COMPUTER PROGRAM FOR DATA ANALYSIS

The ORB computer program was written to handle the large amount of data generated by a core sorption run. ORB performs three main functions:

- Volume and flow rate calculations.
- Radionuclide activity calculations.
- Graph plotting.

The input file is extensive and allows for a great deal of flexibility. The front end input information consists of:

- Titles.
- Radionuclide identification and half-life (days).
- Concentration in spike (dpm/ml) and calibration data for the activity calculation.
- Dead volume (ml).
- Spike volume (ml) and spike injection point [time (minutes) and sample number].
- Transport solution density (g/ml).
- Decay calculation zero time (Julian date).
- Time increments for sampling (minutes).

Following this for each sample the input information consists of:

- Sample number.
- Gross and tare sample tube weight (g).
- Number of β^- emitters analyzed for in that sample.
- Number of γ emitters analyzed for in that sample.

If β^- or γ analysis were performed on a given sample the input information consists of:

- Activity (dpm/ml) for β^- emitters.
- Count data necessary to calculate the activity (cpm/ml or dpm/ml) for γ emitters.

The core slice data input consists of:

- Number of slices.
- Saw blade thickness (mm).
- Radionuclide identification (for the γ emitters only).
- Slice thickness (mm).
- Radionuclide activity (dpm/slice).

ORB creates three output files, INECHO, OUTPUT, and a graph file. INECHO contains the input file information in tabular form with headings. OUTPUT is a tabulation of the calculated values. The first part of OUTPUT lists by sample number:

- Calculated volumes (ml), net for each sample and cumulative.
- Flow rates (ml/min), instantaneous and average.
- Time (minutes) since the sample collection started.

The second part of OUTPUT lists the core slice activities (dpm/mm) and slice thickness (mm) for each γ emitting radionuclide. Finally OUTPUT lists the decay-corrected radionuclide activities (dpm/ml or cpm/ml) for the analyzed samples.

ORB automatically prints the graphing file after each run of the program. The plots consist of:

- Average flow rate vs sample number, time, and cumulative volume (see for example, Fig. B1).
- Activity for each radionuclide vs sample number, time, and cumulative volume (see for example, Figs. B2 and B3).
- Overlap plots of the activity of the chosen reference radionuclide and each radionuclide vs time and cumulative volume (see, for example, Fig. B4).

ORB is an interactive program allowing the user the following options:

- Identifying the input file.
- Log-linear or log-log plots.
- Core slice analysis (yes or no).
- Overlap plotting routines (yes or no).

The program periodically updates the status of the run for the user. ORB identifies errors in the input file and informs the user of the problem and the result to the run. Following is an example of the ORB-user dialog for a a typical run with the listing and the input and output files. (Figures B1 through B4 are some of the graphs from the ^{3}H, ^{36}Cl run of core 8 used as short examples of the graphing output file.)

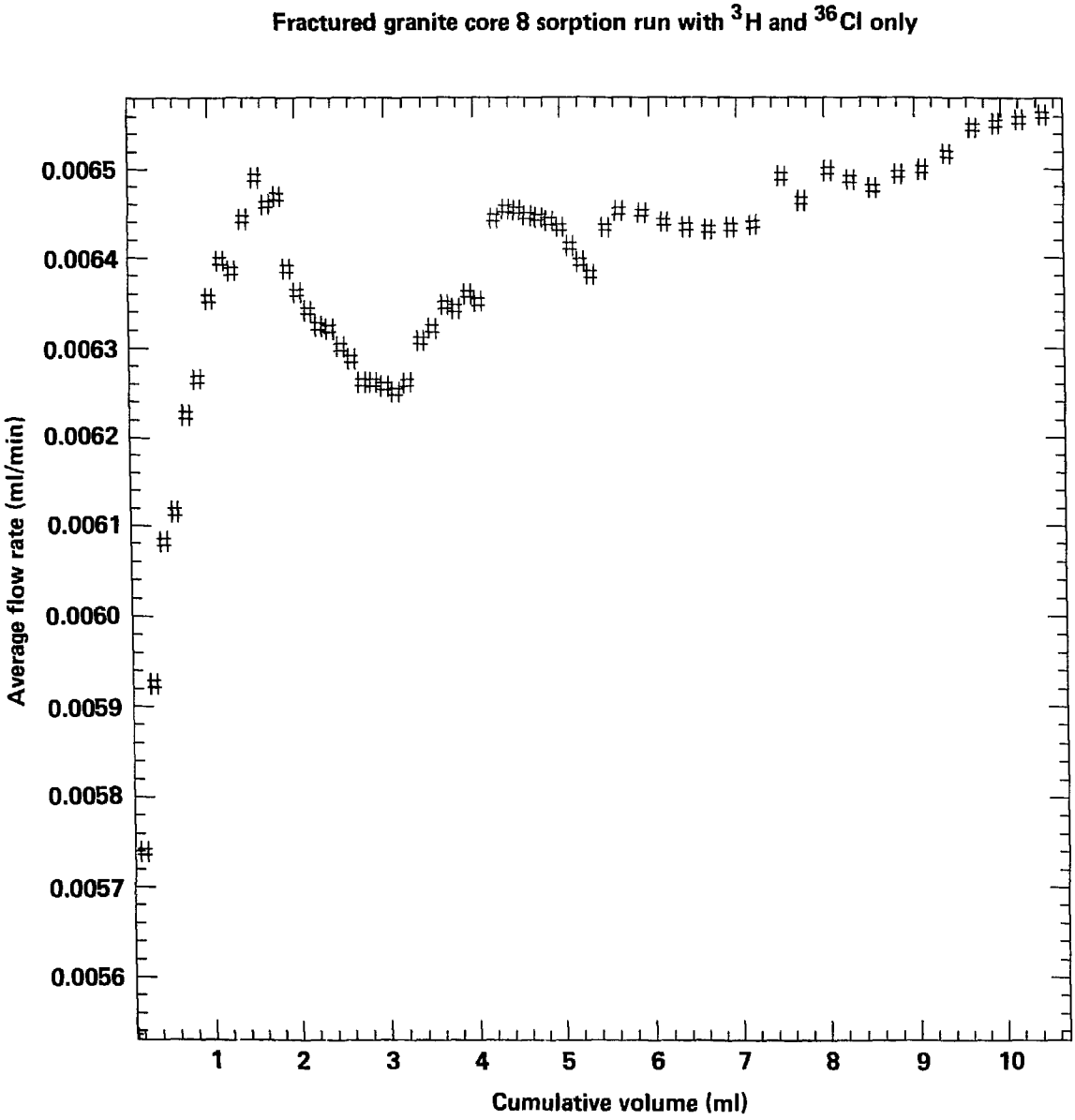

Figure B1. Average flow rate vs cumulative volume (a complete output file also includes plots of average flow rate vs sample number and time).

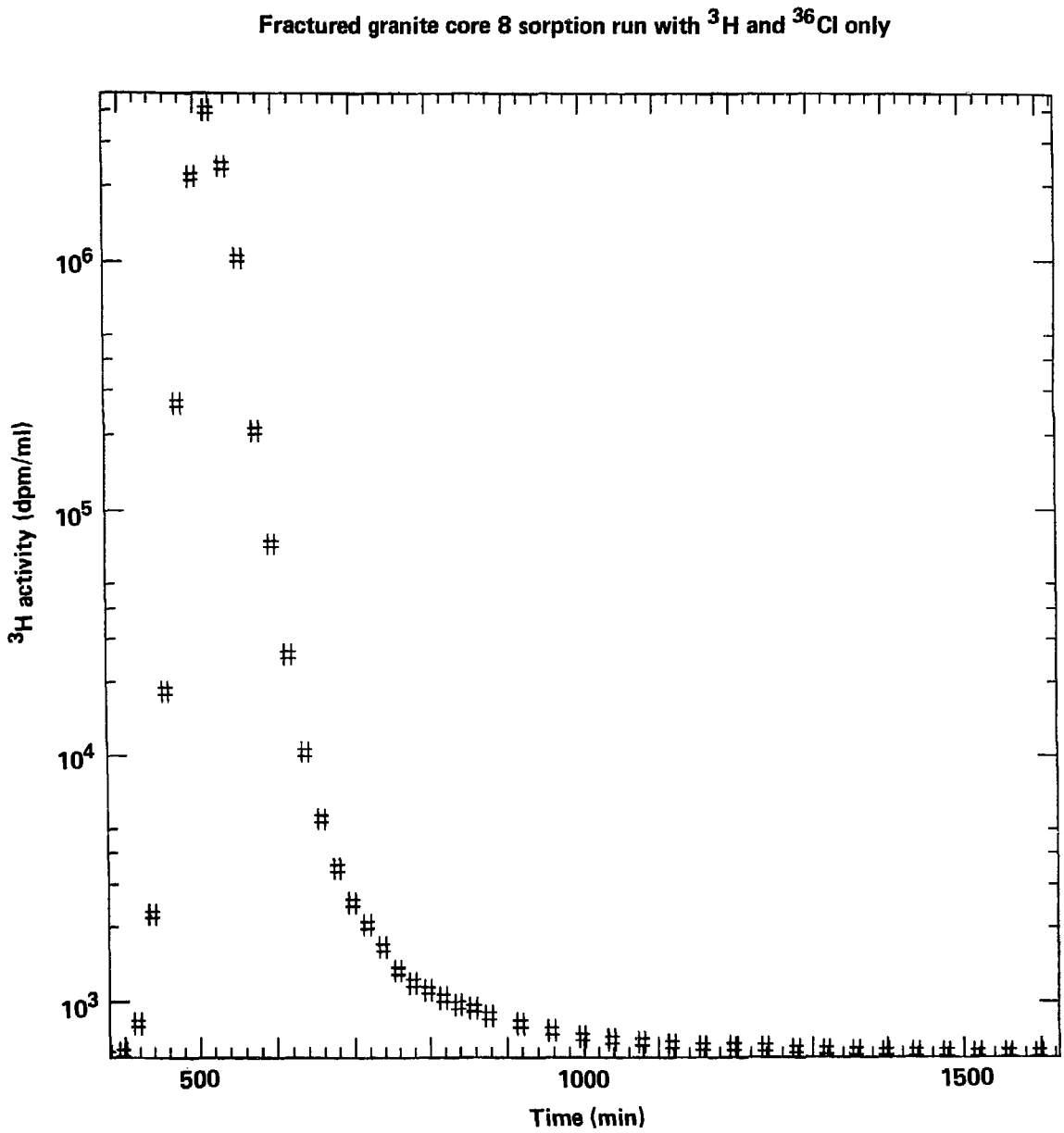

Figure B2. ^{3}H activity vs time (a complete output file includes plots of the activity of each radionuclide vs sample number, time, and cumulative volume).

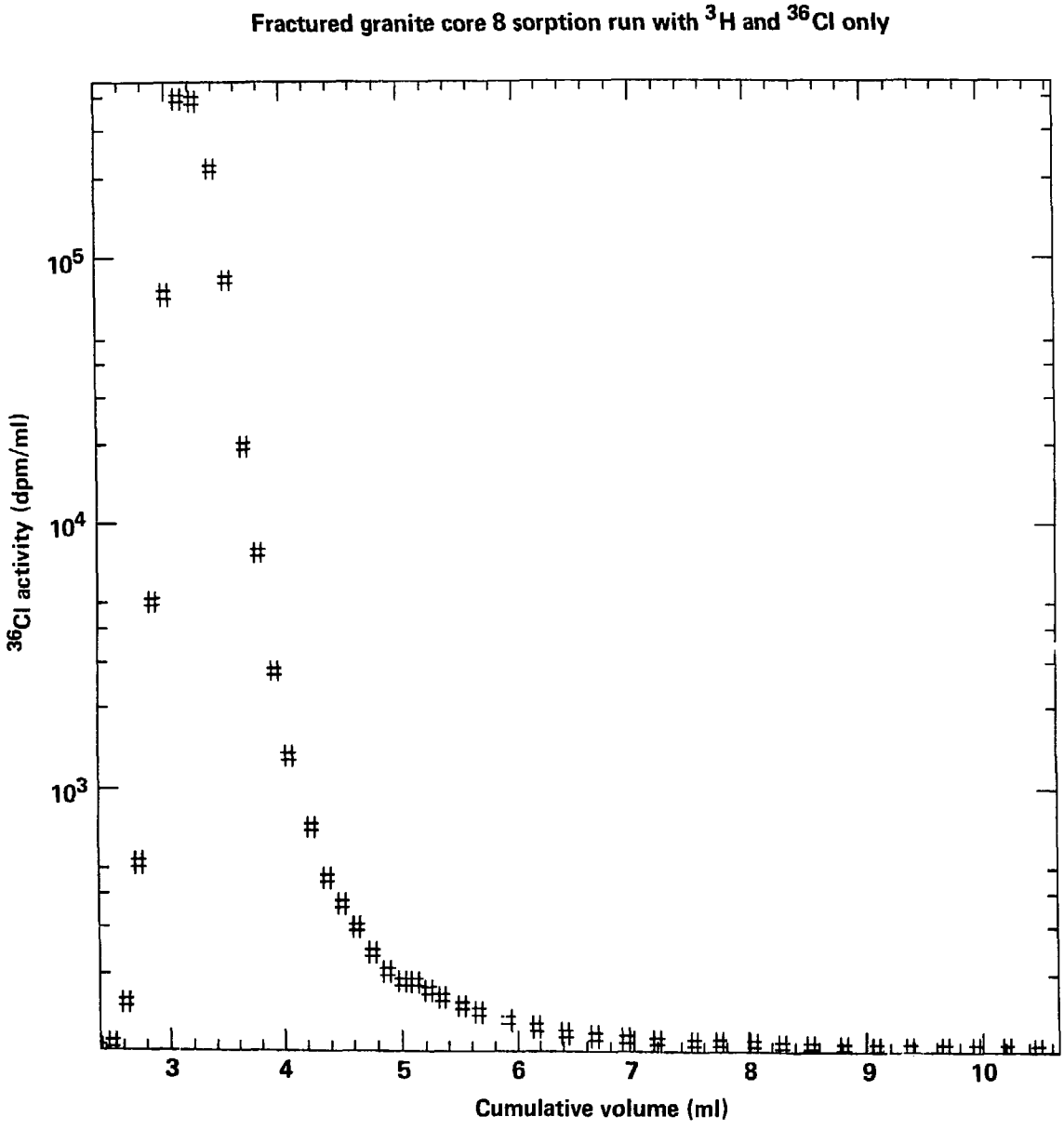

Figure B3. ^{36}Cl activity vs cumulative volume.

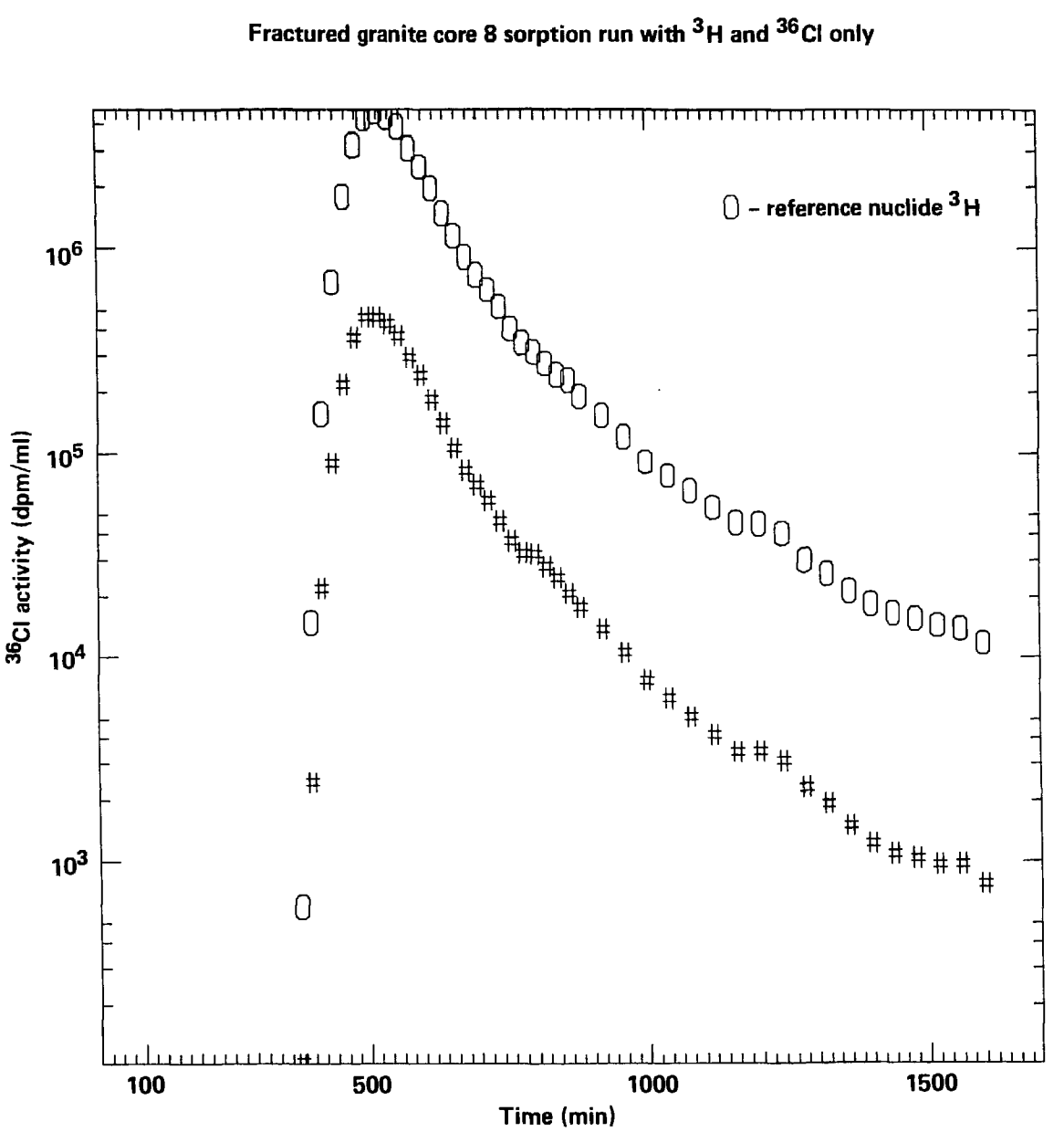

Figure B4. ^{3}H and ^{36}Cl overlap plot (a complete output file includes overlap plots of a chosen reference nuclide with the activity of all remaining radionuclides vs time and cumulative volume).

ORB-User Dialog for Typical Run

```
ORBRIT

 TYPE 1 TO PROCESS SLICE DATA ELSE RETURN

   TYPE THE INPUT FILE NAME
C8CLINPUT

 HEADER DATA READ. NO ERRORS DETECTED

 # OF SAMPLES TO READ =      62


 SAMPLES READ. CALCULATIONS COMPLETE

 GRAPH PLOTTING BEGINS

TYPE REFERENCE NUCLIDE FOR OVERLAP PLOTS OR RETURN
3H

TYPE REFERENCE NUCLIDE FOR OVERLAP PLOTS OR RETURN
   3H

 GRAPH PLOTTING ENDS. GRAPHS ON RJET 43

 FILE INECHO HAS INPUT DATA. FILE OUTPUT HAS TABLES

 ALL DONE
```

```
$CHAT (GRAFLIB,GRAFCORE,FORTLIB,MATHLIB,FRRJLIB,^) %ME,ORBR,$BIN,LST,U69,M,M
      CALL DROPFILE("+ORB")
      CALL LINK("UNIT59=TTY//")
C
C     DECLARATIONS FOLLOW
C
      COMMON /1/ GWT,TWT,DENS,ISCNT,SINC(30),SNUM,MAX,SRN(500)
      COMMON /1/ AFR(500),CVOL(500),STIME(500),ISBEG(30),ISEND(30)
      COMMON /2/ IXAXIS(8),IYAXIS(8),ITITLE(8),IUS
      COMMON /3/ DEADV,SPVOL,SPTIM,SPSAM,NN
      COMMON /4/ NNAME(6),NUCLN,ISNUM
      COMMON /5/ ICLBG,ICUBG,ICPEK,NLBG(6),NUBG(6),NPEK(6),HALFL(6)
      COMMON /5/ ACTIV,ZEROT,TJUL,CNTP,CONCS(6)
      COMMON /6/ KEYB,KEYG
      COMMON /7/ COEFF(4),WORSP(500),RSDU,FPEAK,IPEAK,PEAK
      DIMENSION ICHAR2(8),IBGC(6),IASNUM(6,100),SACTIV(6,100)
      DIMENSION C1(6),C2(6),C3(6)
      DIMENSION ZA(100),TA(100),VA(100)
      IC = 3
C
C     DETERMINE USER OPTIONS DESIRED
C
C     CORE SLICE DATA ?
C
      WRITE(59,FI14)
      READ(59,FRM2) IREFN
C
C     CREATE AND OPEN THE FILES
C
      WRITE(59,FRM0)
      READ(59,FRM1) IFINP
      CALL OPEN(3,IFINP,0,LEN)
      IFOUT = "OUTPUT"
      LEN = 10000
      CALL CREATE(7,IFOUT,1,LEN)
      IFOUT = "INECHO"
      CALL CREATE(8,IFOUT,1,LEN)
C
C     READ THE TITLES ,ISOTOPE DATA AND STATIC DATA
C     ECHO THE INPUT DATA TO THE FILE INECHO
C
      READ(IC,FRM1)ITITLE
      READ(IC,FRM1)ICHAR2
      READ(IC,FRM2)NN
      IF ((NN.LE.0).OR.(NN.GT.6)) ,10
      WRITE(59,ER1)
  ER1 FORMAT(" # OF NUCLIDES NOT IN RANGE 1 TO 6 - CHECK INPUT")
      CALL EXIT
   10 CONTINUE
      READ(IC,FRM3) (NNAME(I),HALFL(I),CONCS(I),C1(I),C2(I),C3(I),
     1NLBG(I),NUBG(I),NPEK(I),I=1,NN)
      READ(IC,FRM4) DEADV,SPVOL,SPTIM,SPSAM,DENS,ZEROT
      WRITE(8,FRM1) ITITLE
      WRITE(8,FRM1) ICHAR2
      WRITE(8,FI1)
      WRITE(8,FRM2) NN
      WRITE(8,FI2)
      WRITE(8,FRM3) (NNAME(I),HALFL(I),CONCS(I),C1(I),C2(I),C3(I),
     1NLBG(I),NUBG(I),NPEK(I),I=1,NN)
      WRITE(8,FI4)
```

```
      WRITE(8,FRM4) DEADV,SPVOL,SPTIM,SPSAM,DENS,ZEROT
C
CC    READ THE INCREMENT DATA
CC    ECHO THE INPUT DATA
C
      WRITE(8,FI3)
      DO 20 I=1,30
      READ(IC,FRM5) ISBEG(I),ISEND(I),SINC(I)
      IF (ISEND(I).EQ.0) GO TO 30
      WRITE(8,FRM5) ISBEG(I),ISEND(I),SINC(I)
   20 CONTINUE
   30 MAX = I-1
C
CC    CHECK FOR INPUT ERRORS
C
      IERR = 0
      CALL ERCHK1(IERR)
      IF (IERR.EQ.1) GO TO OUT
C
CC    FIND # OF SAMPLES AND WRITE STATUS MESSAGE TO USER
C
      NSAMP = ISEND(MAX) - ISBEG(1) + 1
      WRITE(59,FT1)
      WRITE(59,FT2) NSAMP
C
CC    CALCULATE THE TIMES FROM THE INCREMENT DATA
C
      TCUML = 0.0
      IJ = 0
      DO 60 I=1,MAX
      TINCR = SINC(I)
      DO 50 J=ISBEG(I),ISEND(I)
      IJ = IJ + 1
      TCUML = TCUML + TINCR
      STIME(IJ) = TCUML
   50 CONTINUE
   60 CONTINUE
      NSAMP = ISEND(MAX) - ISBEG(1) + 1
C
      WRITE(7,FRM6)
      WRITE(8,FI5)
      ISCNT = 0
C
CC    READ IN EACH SAMPLE. FROM KEYB AND KEYG DECIDE ON HOW MANY
CC    OF EACH NUCLIDE TO READ (IF ANY).
C
      DO 300 I=1,NSAMP
      READ(IC,FR10) ISNUM,TWT,GWT,KEYB,KEYG
      WRITE(8,FI6) ISNUM,TWT,GWT,KEYB,KEYG
      SRN(I) = FLOAT(ISNUM)
C
CC    CHECK FOR ERRORS
C
      IERR = 0
      CALL ERRCHK2(IERR,I)
      IF (IERR.EQ.1) GO TO 300
C
CC    CALCULATE FLOW RATES AND SET X AXIS PLOT WINDOW
C
      CALL VOLFLO
```

```
      SMIN = SRN(1)
      SMAX = SRN(NSAMP)
      TMIN = STIME(1)
      TMAX = STIME(NSAMP)
      VMIN = CVOL(1)
      VMAX = CVOL(NSAMP)
      IF (KEYB.EQ.0) GO TO 200
C
C     READ IN THE BETA NUCLIDES
C
      WRITE(8,FI10)
      DO 190 J=1,KEYB
      IERR = 0
      READ(IC,FRM7) NUCLN,ACTIV
      WRITE(8,FI7) NUCLN,ACTIV
C
C     LOCATE ARRAY INDEX FOR NUCLIDE
C
      IERR = 0
      CALL FINDN(IERR)
      IF (IERR.EQ.1) GO TO 190
      IBGC(NUCLN) = IBGC(NUCLN) + 1
      IASNUM(NUCLN,IBGC(NUCLN)) = ISNUM
      SACTIV(NUCLN,IBGC(NUCLN)) = ACTIV
  190 CONTINUE
  200 IF (KEYG.EQ.0) GO TO 300
C
C     READ IN THE GAMMA NUCLIDES
C
      WRITE(8,FI8)
      DO 290 J=1,KEYG
      IERR = 0
      READ(IC,FRM8) NUCLN,ICLBG,ICPEK,ICUBG,TJUL,CNTP
      WRITE(8,FI9) NUCLN,ICLBG,ICPEK,ICUBG,TJUL,CNTP
C
C     CALCULATE THE GAMMA ACTIVITY
C     LOCATE ARRAY INDEX FOR NUCLIDE
C
      IERR = 0
      CALL FINDN(IERR)
      IF (IERR.EQ.1) GO TO 290
      CALL GACTIVITY
      IBGC(NUCLN) = IBGC(NUCLN) + 1
      IASNUM(NUCLN,IBGC(NUCLN)) = ISNUM
      SACTIV(NUCLN,IBGC(NUCLN)) = ACTIV
  290 CONTINUE
  300 CONTINUE
C
C     PRINT STATUS TO USER
C
      WRITE(59,FR14)
C
C     READ AND PROCESS CORE SLICE DATA ( IF ANY )
C
      IF ( IREFN .EQ. 1 ) THEN
      CALL SLICE
      WRITE(59,FR19)
      ELSE
      CONTINUE
      ENDIF
```

```
      CALL CLOSE(8)
C
CC    PRINT STATUS TO USER
C
      WRITE(59,FR15)
C
CC    INITIALIZE THE FR80 PLOT FILE
C
      CALL GNPFMD
      CALL GSPRKP(1)
      CALL FR80ID("BOX Y46 BECKY$")
      CALL FREEUS(IUS)
      CALL GNTXFT(IUS)
      CALL JNFT01
      CALL JSTXFT(1)
C
CC    GENERATE THE FLOW RATE PLOTS
C
      IYAXIS(1) = "AVERAGE FL"
      IYAXIS(2) = "OW RATE (M"
      IYAXIS(3) = "L/MIN)     "
      IXAXIS(1) = "SAMPLE #   "
      IXAXIS(2) = "           "
      CALL PLOT(SRN,AFR,NSAMP,SMIN,SMAX)
      IXAXIS(1) = "   TIME (MI"
      IXAXIS(2) = "N)         "
      CALL PLOT(STIME,AFR,NSAMP,TMIN,TMAX)
      IXAXIS(1) = "CUMULATIVE"
      IXAXIS(2) = " VOLUME (M"
      IXAXIS(3) = "L)         "
      CALL PLOT(CVOL,AFR,NSAMP,VMIN,VMAX)
C
CC    OUTPUT A TABLE OF ACTIVITIES
C
      WRITE(7,FR11) NN,(NNAME(I),I=1,NN)
      NPEK(1) = NPEK(2) = NPEK(3) = NPEK(4) = NPEK(5) = NPEK(6) = 1
      NNSN = ISBEG(1) - 1
      DO 800 J=1,NSAMP
      NNSN = NNSN + 1
      IJ = 0
      DO 700 I=1,NN
      HALFL(I) = 0.0
      IF (IASNUM(I,NPEK(I)).EQ.NNSN) ,700
      HALFL(I) = SACTIV(I,NPEK(I))
      NPEK(I) = NPEK(I) + 1
      IJ = 1
  700 CONTINUE
      IF (IJ.EQ.1) WRITE(7,FR12) NNSN,NN,(HALFL(I),I=1,NN)
  800 CONTINUE
C
CC    OVERLAP PLOTS ?
C
  890 WRITE(59,FI11)
      READ(59,FRM1) IREFN
      NREF = 0
      IF ( IREFN .NE. "          ") THEN
      DO 900 IJ = 1,6
      IF ( IREFN .EQ. NNAME(IJ) ) GO TO 910
  900 CONTINUE
  910 NREF = IJ
```

```
      IF ( IJ .EQ. 7 ) GO TO 890
      DO 940 LL = 1,IBGC(NREF)
      ZA(LL) = SACTIV(NREF,LL)
      TA(LL) = STIME(IASNUM(NREF,LL) -ISBEG(1)+1)
  940 VA(LL) = CVOL(IASNUM(NREF,LL)-ISBEG(1)+1)
      ELSE
      CONTINUE
      ENDIF
C
C     LOAD ARRAYS FOR ACTIVITY PLOTS
C
      IYAXIS(2) = "  ACTIVITY"
      IYAXIS(3) = " (CPM/GM) "
      DO 2000 J=1,NN
      IYAXIS(1) = NNAME(J)
      IXAXIS(1) = "SAMPLE #"
      IXAXIS(2) = "          "
      IXAXIS(3) = "          "
      FPEAK = 0.0
      IPEAK = 0
      DO 1000 I=1,IBGC(J)
      AFR(I) = SACTIV(J,I)
      IF ( AFR(I) .GE. FPEAK ) THEN
      FPEAK = AFR(I)
      IPEAK = I
      ELSE
      CONTINUE
      ENDIF
 1000 SRN(I) = FLOAT(IASNUM(J,I))
      CALL PLOT(SRN,AFR,IBGC(J),SMIN,SMAX)
      IXAXIS(1) = "  TIME (MI"
      IXAXIS(2) = "N)"
      DO 1010 I=1,IBGC(J)
 1010 SRN(I) = STIME(IASNUM(J,I) - ISBEG(1) + 1)
      CALL PLOT(SRN,AFR,IBGC(J),TMIN,TMAX)
      IF(( NREF .NE. 0).AND.( IREFN.NE.NNAME(J))) THEN
      DO 1015 I = 1,IBGC(J)
 1015 SRN(I) = STIME(IASNUM(J,I)-ISBEG(1)+1)
      TMIN=1000.
      TMAX=4000.
      CALL OVERLP(SRN,AFR,IBGC(J),TA,ZA,IBGC(NREF),TMIN,TMAX,IREFN)
      ELSE
      CONTINUE
      ENDIF
      IXAXIS(1) = "CUMULATIVE"
      IXAXIS(2) = " VOLUME (M"
      IXAXIS(3) = "L)        "
      DO 1020 I=1,IBGC(J)
 1020 SRN(I) = CVOL(IASNUM(J,I) -ISBEG(1) + 1)
      CALL PLOT(SRN,AFR,IBGC(J),VMIN,VMAX)
      IF(( NREF .NE. 0 ).AND.( IREFN.NE.NNAME(J))) THEN
      DO 1025 I = 1,IBGC(J)
 1025 SRN(I) = CVOL(IASNUM(J,I)-ISBEG(1)+1)
      VMIN=2.5
      VMAX=7.00
      CALL OVERLP(SRN,AFR,IBGC(J),VA,ZA,IBGC(NREF),VMIN,VMAX,IREFN)
      ELSE
      CONTINUE
      ENDIF
 2000 CONTINUE
```

```
      CALL JEGCXX
C
CC    OUTPUT STATUS TO USER
C
      WRITE(59,FR16)
      WRITE(59,FR17)
      CALL FRTORJ(0,538,2,IERR)
      IF (IERR.NE.0) WRITE(59,FR13) IERR
  OUT CONTINUE
C
CC    THE FORMATS FOLLOW
C
 FRM0 FORMAT("   TYPE THE INPUT FILE NAME")
 FRM1 FORMAT(8A10)
 FRM2 FORMAT(I1)
 FRM3 FORMAT(1X,A5,2E15.6,3F10.4,3I3)
 FRM4 FORMAT(6F12.5)
 FRM5 FORMAT(2I5,F12.5)
 FRM6 FORMAT("  SAMPLE",5X,"NET VOL",5X,"  CUMULATIVE VOL",3X,
     1"INST FLOW RATE",3X,"AVER FLOW RATE",8X,"TIME",7X,"SAMPLE",
     1/)
 FRM7 FORMAT(A5,E15.6)
 FRM8 FORMAT(A5,3I7,2F6.2)
 FR10 FORMAT(I5,2F10.6,2I1)
 FR11 FORMAT(/,3X,"  SAMPLE #  ",*(4X,A5,9X),/)
 FR12 FORMAT(3X,I6,3X,*(3X,E15.6))
 FR13 FORMAT(" ERROR IN FRTORJ CALL .ERROR CODE = ",I4)
 FR14 FORMAT(/," SAMPLES READ. CALCULATIONS COMPLETE")
 FR15 FORMAT(/," GRAPH PLOTTING BEGINS")
 FR16 FORMAT(/," GRAPH PLOTTING ENDS. GRAPHS ON RJET 43")
 FR17 FORMAT(/," FILE INECHO HAS INPUT DATA. FILE OUTPUT HAS TABLES")
 FR19 FORMAT(/," CORE SLICE DATA PROCESSING COMPLETE")
  FI1 FORMAT(/," # OF ISOTOPES")
  FI2 FORMAT(/," NAME",3X,"HALF LIFE",7X,"CALIBRATION DATA")
  FI3 FORMAT(/," BEG"," END","  INCREMENT")
  FI4 FORMAT(/,"   DEAD VOL "," SPIKE VOL  ","SPIKE INJ T ",
     1"SPIKE INJ # "," DENSITY  "," ZERO TM  ")
  FI5 FORMAT(/," SAMP "," TARE WT "," GROSS WT "," # OF B ",
     1" # OF G")
  FI6 FORMAT(I5,2F10.6,2I6)
  FI7 FORMAT(4X,A5,5X,E15.6)
  FI8 FORMAT(/," NUCLIDE NAME "," LOWER BG "," PEAK  "," UPPER BG ",
     1" JULIAN TM "," COUNT PER ",/)
  FI9 FORMAT(4X,A5,6X,2(I7,2X),I7,5X,F6.2,6X,F6.2)
 FI10 FORMAT(/," NUCLIDE NAME "," ACTIVITY ",/)
 FI11 FORMAT(/,"TYPE REFERENCE NUCLIDE FOR OVERLAP PLOTS OR RETURN")
 FI14 FORMAT(/," TYPE 1 TO PROCESS SLICE DATA ELSE RETURN")
  FT1 FORMAT(/," HEADER DATA READ. NO ERRORS DETECTED",/)
  FT2 FORMAT(" # OF SAMPLES TO READ = ",I6,/)
      STOP
      END
C
CC    ************************************************************
C
CC    THIS SUBROUTINE CALCULATES VOLUMES AND FLOW RATES. THE RESULTS
CC    ARE WRITTEN TO AN OUTPUT FILE.
C
CC    ************************************************************
C
      SUBROUTINE VOLFLO
```

```
      COMMON /1/ GWT,TWT,DENS,ISCNT,SINC(30),SNUM,MAX,SRN(500)
      COMMON /1/ AFR(500),CVOL(500),STIME(500),ISBEG(30),ISEND(30)
      ISCNT = ISCNT + 1
      XNETW = GWT - TWT
C
CC    CALCULATE NET VOLUME
C
      VOL = XNETW / DENS
C
CC    CALCULATE CUMULATIVE VOLUME
C
      IF (ISCNT.EQ.1) THEN
      CVOL(ISCNT) = VOL
      ELSE
      CVOL(ISCNT) = CVOL(ISCNT-1) + VOL
      ENDIF
C
CC    CALCULATE INSTANTANEOUS FLOW RATE
C
      DO 11 I=1,30
      IF (SNUM.LE.ISEND(I)) GO TO 21
   11 CONTINUE
   21 XIFR = VOL / SINC(I)
C
CC    FIND AVERAGE FLOW RATE
C
      AFR(ISCNT) = CVOL(ISCNT) / STIME(ISCNT)
C
CC    CALCULATE THE SAMPLE NUMBER
C
      NSAMPL = ISBEG(1) + ISCNT - 1
C
CC    WRITE CALCULATED VALUES TO THE OUTPUT FILE
C
      WRITE(7,SRM1) NSAMPL,VOL,CVOL(ISCNT),XIFR,AFR(ISCNT),STIME(ISCNT),
     1NSAMPL
 SRM1 FORMAT(1X,I6,5(1X,E15.6,1X),I6)
      RETURN
      END
C
CC    ************************************************
C
C     THIS SUBROUTINE PLOTS THE CALCULATIONS
C
CC    ************************************************
C
      SUBROUTINE PLOT(X,Y,NUM,XMIN,XMAX)
      DIMENSION X(1),Y(1)
      COMMON /2/ IXAXIS(8),IYAXIS(8),ITITLE(8),IUS
      COMMON /7/ COEFF(4),WORSP(500),RSDU,FPEAK,IPEAK,PEAK
C
CC    FIND MAX AND MIN VALUES
C
      M1 = 0
      YMAX = AMAXAF(Y,1,NUM,M1)
      YMIN = AMINAF(Y,1,NUM,M1)
      DEL = (YMAX - YMIN) / 50.
      YMAX = YMAX + DEL
      DEL = (XMAX - XMIN) / 50.
      XMAX = XMAX + DEL
```

```
      IF (XMIN.LE.0.0) GO TO 69
      IF (YMIN.LE.0.0) GO TO 69
      CALL JSVTCL(0)
      CALL GSXFLG(0)
      CALL FSXF80(0.0,1.0,0.0,1.0,0.0,1.0,0.0,1.0)
C
CC    CREATE SEGMENT CONTAINING X-AXIS LABEL
C
      CALL JNSGDA("XAXIS")
      CALL GSTXNO(72.0)
      CALL GSCP2D(0.3,0.1)
      WRITE(IUS,F1) IXAXIS
   F1 FORMAT(8A10)
      CALL JESGDA("XAXIS")
C
CC    CREATE A SEGMENT CONTAINING Y-AXIS LABEL
C
      CALL JNSGDA("YAXIS")
      CALL GSTXNO(72.0)
      CALL GSCP2D(0.3,0.1)
      WRITE(IUS,F1) IYAXIS
      CALL JESGDA("YAXIS")
      CALL JSIT2R("YAXIS",-1.57)
      CALL JSIT2T("YAXIS",0.2,0.0)
C
CC    CREATE SEGMENT CONTAINING TITLE
C
      CALL JNSGDA("TITLE")
      CALL GSTXNO(72.0)
      CALL GSCP2D(0.1,0.9)
      WRITE(IUS,F1) ITITLE
      CALL JESGDA("TITLE")
C
CC    CREATE THE GRID AND PLOT THE DATA
C
      CALL GSCVMD(0)
      CALL JSVTCL(0)
      IF ((XMIN * 100..GT.XMAX).AND.(YMIN * 100..GT.YMAX)) THEN
      CALL GSXFLG(0)
      CALL FSXF80(XMIN,XMAX,YMIN,YMAX,.2,.8,.2,.8)
      IPL = 0
      ELSEIF (XMIN * 100..GT.XMAX) THEN
      CALL GSXFLG(2)
      CALL FSXF80(XMIN,XMAX,YMIN,YMAX,.2,.8,.2,.8)
      IPL = 2
      ELSEIF (YMIN * 100..GT.YMAX) THEN
      CALL GSXFLG(1)
      CALL FSXF80(XMIN,XMAX,YMIN,YMAX,.2,.8,.2,.8)
      IPL = 1
      ELSE
      CALL GSXFLG(3)
      CALL FSXF80(XMIN,XMAX,YMIN,YMAX,.2,.8,.2,.8)
      IPL = 3
      ENDIF
      CALL JNSGDA("PLOT")
      CALL GPGR80(IPL)
      CALL JSVTCL(1)
      CALL JSMKXX(35)
      CALL GSCVMD(1)
      CALL GPCV2D(X,Y,NUM)
```

```
      CALL JESGDA("PLOT")
      CALL JXGLFR
      CALL JESGXX("PLOT")
      CALL JESGXX("XAXIS")
      CALL JESGXX("YAXIS")
      CALL JESGXX("TITLE")
      RETURN
   69 WRITE(59,F2) IYAXIS(1),IYAXIS(2),IXAXIS(1),IXAXIS(2)
   F2 FORMAT(/,1X,2A10," <= 0.0 ",2A10," PLOT IGNORED")
   F3 FORMAT(6X,"PEAK NOT FOUND")
   F4 FORMAT(3X,"PEAK = ",E13.6," X COORD = ",E13.6)
      RETURN
      END
C
CC    ************************************************************
CC    SUBROUTINE FOR OVERLAP PLOTS
CC    ************************************************************
C
      SUBROUTINE OVERLP(XP,YP,NUM,XO,Z,NUMZ,XMIN,XMAX,IREFN)
      DIMENSION XP(1),YP(1),XO(1),Z(1)
      COMMON /2/ IXAXIS(8),IYAXIS(8),ITITLE(8),IUS
C
CC    DETERMINE YMIN AND YMAX FOR MAPPING
C
      M1 = 0
      YMAX = AMAXAF(YP,1,NUM,M1)
      YMIN = AMINAF(YP,1,NUM,M1)
      YMAX1 = AMAXAF(Z,1,NUMZ,M1)
      YMIN1 = AMINAF(Z,1,NUMZ,M1)
      IF ( YMAX1 .GT. YMAX ) YMAX = YMAX1
      IF ( YMIN1 .LT. YMIN ) YMIN = YMIN1
      DEL = ( YMAX - YMIN ) / 50.
      YMAX = YMAX + DEL
      IF ( YMIN .LE. 0 ) RETURN
      IF ( XMIN .LE. 0 ) RETURN
C
CC    CREATE A SEGMENT CONTAINING X-AXIS LABEL
C
      CALL JSVTCL(0)
      CALL GSXFLG(0)
      CALL FSXF80(0.0,1.0,0.0,1.0,0.0,1.0,0.0,1.0)
      CALL JNSGDA("XAXIS")
      CALL GSTXNO(72.0)
      CALL GSCP2D(0.3,0.1)
      WRITE(IUS,F1) IXAXIS
   F1 FORMAT(8A10)
      CALL JESGDA("XAXIS")
C
CC    CREATE A SEGMENT CONTAINING Y-AXIS LABEL
C
      CALL JNSGDA("YAXIS")
      CALL GSTXNO(72.0)
      CALL GSCP2D(0.3,0.1)
      WRITE(IUS,F1) IYAXIS
      CALL JESGDA("YAXIS")
      CALL JSIT2R("YAXIS",-1.57)
      CALL JSIT2T("YAXIS",0.2,0.0)
C
CC    CREATE A SEGMENT CONTAINING TITLE
C
```

```
      CALL JNSGDA("TITLE")
      CALL GSTXNO(72.0)
      CALL GSCP2D(0.1,0.9)
      WRITE(IUS,F1) ITITLE
      CALL JESGDA("TITLE")
C
CC    CREATE A SEGMENT TITLE DEFINING REFERENCE NUCLIDE
C
      CALL JNSGDA("REFTIT")
      CALL GSTXNO(72.0)
      CALL GSCP2D(.2,0.85)
      WRITE(IUS,F3) IREFN
      CALL JESGDA("REFTIT")
C
CC    MAP AND PLOT NUCLIDE
CC
CC    CALL GSCVMD(0)
CC    CALL JSVTCL(0)
CC    IF (( XMIN*100. .GT. XMAX) .AND. ( YMIN*100. .GT. YMAX )) THEN
CC    CALL GSXFLG(0)
CC    CALL FSXF80(XMIN,XMAX,YMIN,YMAX,.2,.8,.2,.8)
CC    IPL = 0
C     ELSEIF ( XMIN*100. .GT. XMAX ) THEN
      CALL GSXFLG(2)
      CALL FSXF80(XMIN,XMAX,YMIN,YMAX,.2,.8,.2,.8)
      IPL = 2
C     ELSEIF ( YMIN*100. .GT. YMAX ) THEN
CC    CALL GSXFLG(1)
CC    CALL FSXF80(XMIN,XMAX,YMIN,YMAX,.2,.8,.2,.8)
CC    IPL = 1
CC    ELSE
CC    CALL GSXFLG(3)
CC    CALL FSXF80(XMIN,XMAX,YMIN,YMAX,.2,.8,.2,.8)
CC    IPL = 3
C     ENDIF
      CALL JNSGDA("PLOT")
      CALL GPGR80(IPL)
      CALL JSVTCL(1)
      CALL JSMKXX(35)
      CALL GSCVMD(1)
      CALL GPCV2D(XP,YP,NUM)
C
CC    PLOT REFERENCE NUCLIDE
C
      CALL JSMKXX(79)
      CALL GSCVMD(1)
      CALL GPCV2D(X0,Z,NUMZ)
      CALL JESGDA("PLOT")
      CALL JXGLFR
      CALL JESGXX("REFTIT")
      CALL JESGXX("PLOT")
      CALL JESGXX("XAXIS")
      CALL JESGXX("YAXIS")
      CALL JESGXX("TITLE")
   F3 FORMAT(6X,"6 - REFERENCE NUCLIDE ",A10)
      RETURN
      END
C
CC    ***************************************************************
C
```

```
C      THIS ROUTINE CALCULATES THE ACTIVITY FOR THE GAMMA EMITTING
C      NUCLIDES.  CALIBRATIONS ARE USED HERE.
C
CC     ***************************************************************
C
       SUBROUTINE GACTIVITY
       COMMON /1/ GWT,TWT,DENS,ISCNT,SINC(30),SNUM,MAX,SRN(500)
       COMMON /1/ AFR(500),CVOL(500),STIME(500),ISBEG(30),ISEND(30)
       COMMON /4/ NNAME(6),NUCLN,IERR,ISNUM
       COMMON /5/ ICLBG,ICUBG,ICPEK,NLBG(6),NUBG(6),NPEK(6),HALFL(6)
       COMMON /5/ ACTIV,ZEROT,TJUL,CNTP,CONCS(6)
C
CC     BACKGROUND CALCULATION
C
       BACKG = .5 * (ICLBG / NLBG(NUCLN) + ICUBG / NUBG(NUCLN)) *
      1NPEK(NUCLN)
C
CC     COUNTS PER MINUTE
C
       CPM = (ICPEK - BACKG) / CNTP
C
CC     WILL INCLUDE CALIBRATION DATA LATER
C
       DPM = CPM
C
CC     CORRECT FOR DECAY
C
       DPM = DPM * EXP((.69314718 / HALFL(NUCLN)) * (TJUL - ZEROT))
C
CC     DIVIDE BY VOLUME
C
       VOL = (GWT - TWT) / DENS
       ACTIV = DPM / VOL
       RETURN
       END
C
CC     ***************************************************************
C
CC     SUBROUTINE FINDN FINDS THE ARRAY INDEX FOR THE GIVEN NUCLIDE
C
CC     ***************************************************************
C
       SUBROUTINE FINDN(IERR)
       COMMON /4/ NNAME(6),NUCLN,ISNUM
C
       DO 10 I=1,6
   10  IF( NNAME(I).EQ.NUCLN ) GO TO 30
       WRITE(59,F1) NUCLN,ISNUM
       IERR = 1
   F1  FORMAT(" NUCLIDE ",A5," IN SAMPLE ",I5," NOT VALID-IGNORED")
       RETURN
   30  NUCLN = I
       RETURN
       END
C
CC     ***************************************************************
C
CC     THIS ROUTINE CHECKS THE RANGES OF THE INPUT DATA UP TO
CC     THE SAMPLE DATA FOR ERRORS.  AN ERROR RESULTS IN AN ERROR
C      MESSAGE PRINTED AT THE USERS TERMINAL AND TERMINATION.
```

```
C
CC      ********************************************************
C
        SUBROUTINE ERCHK1(IERR)
        COMMON /1/ GWT,TWT,DENS,ISCNT,SINC(30),SNUM,MAX,SRN(500)
        COMMON /1/ AFR(500),CVOL(500),STIME(500),ISBEG(30),ISEND(30)
        COMMON /3/ DEADV,SPVOL,SPTIM,SPSAM,NN
        COMMON /5/ ICLBG,ICUBG,ICPEK,NLBG(6),NUBG(6),NPEK(6),HALFL(6)
        COMMON /5/ ACTIV,ZEROT,TJUL,CNTP,CONC(6)
        IF ((DEADV.LE.0.0).OR.(DEADV.GE.1.E+5)) GO TO DEAD
        IF ((SPVOL.LE.0.0).OR.(SPVOL.GE.1.E+5)) GO TO SPVO
        IF ((SPTIM.LE.0.0).OR.(SPTIM.GE.1.E+5)) GO TO SPTI
        IF ((SPSAM.LE.0.0).OR.(SPSAM.GE.1.E+5)) GO TO SPSA
        IF ((DENS.LE.0.0).OR.(DENS.GE.1.E+2)) GO TO DEN
        IF ((ZEROT.LE.0.0).OR.(ZEROT.GE.1.E+6)) GO TO ZERO
C
CC      CHECK HALF LIVES AND CONCENTRATIONS
C
        DO 700 I=1,NN
        IF ((HALFL(I).LE.0.0).OR.(HALFL(I).GT.1.E+10)) GO TO HALF
        IF ((CONC(I).LE.0.0).OR.(CONC(I).GT.1.E+10)) GO TO CON
    700 CONTINUE
C
CC      CHECK TIME INCREMENT DATA
C
        DO 800 I=1,MAX
        IF ((ISBEG(I).LE.0.0).OR.(ISBEG(I).GE.1.E+6)) GO TO ISBE
        IF ((ISEND(I).LE.0.0).OR.(ISEND(I).GE.1.E+6)) GO TO ISEN
        IF ((SINC(I).LE.0.0).OR.(SINC(I).GE.1.E+4)) GO TO SIN
        IF (I.EQ.1) GO TO 800
        IF (ISBEG(I).NE.ISEND(I-1) + 1) GO TO ISBN
    800 CONTINUE
C
CC      WRITE ERROR MESSAGES
C
        RETURN
   DEAD WRITE(59,FE1) DEADV
        GO TO EXX
   SPVO WRITE(59,FE2) SPVOL
        GO TO EXX
   SPTI WRITE(59,FE3) SPTIM
        GO TO EXX
   SPSA WRITE(59,FE4) SPSAM
        GO TO EXX
    DEN WRITE(59,FE5) DENS
        GO TO EXX
   ZERO WRITE(59,FE6) ZEROT
        GO TO EXX
   HALF WRITE(59,FE7) I,HALFL(I)
        GO TO EXX
    CON WRITE(59,FE8) I,CONC(I)
        GO TO EXX
   ISBE WRITE(59,FE9) ISBEG(I)
        GO TO EXX
   ISEN WRITE(59,FE9) ISEND(I)
        GO TO EXX
    SIN WRITE(59,FE10) SINC(I)
        GO TO EXX
   ISBN WRITE(59,FE11) ISBEG(I),ISEND(I-1)
C
```

```
C      FORMATS FOLLOW
C
  FE1 FORMAT(" DEAD VOLUME = ",E15.6," INPUT ERROR")
  FE2 FORMAT(" SPIKE VOLUME = ",E15.6," INPUT ERROR")
  FE3 FORMAT(" SPIKE TIME = ",E15.6," INPUT ERROR")
  FE4 FORMAT(" SPIKE SAMPLE # ",E15.6," INPUT ERROR")
  FE5 FORMAT(" SOLUTION DENSITY = ",E15.6," INPUT ERROR")
  FE6 FORMAT(" ZERO TIME = ",E15.6," INPUT ERROR")
  FE7 FORMAT(" HALF LIFE OF NUCLIDE ",I1," = ",E15.6," INPUT ERROR")
  FE8 FORMAT(" CONCENTRATION OF NUCL ",I1," = ",E15.6," INP ERROR")
  FE9 FORMAT(" SAMPLE NUMBER = ",I6," INPUT ERROR")
 FE10 FORMAT(" SAMPLE INCREMENT = ",E15.6," INPUT ERROR")
 FE11 FORMAT(" NUMBER SKIPPED BETWEEN ",E15.6," AND ",E15.6)
 FE12 FORMAT(" RUN TERMINATED. CORRECT ERROR IN INPUT FILE AND RERUN")
  EXX WRITE(59,FE12)
      CALL CLOSE(7)
      CALL CLOSE(8)
      IERR = 1
      RETURN
      END
C
CC    ************************************************************
CC
C     THIS ROUTINE CHECKS THE SAMPLE WEIGHT AND SAMPLE NUMBER
C     DATA FOR ERRORS.
C
CC    ************************************************************
C
      SUBROUTINE ERRCHK2(IERR,I)
      COMMON /1/ GWT,TWT,DENS,ISCNT,SINC(30),SNUM,MAX,SRN(500)
      COMMON /1/ AFR(500),CVOL(500),STIME(500),ISBEG(30),ISEND(30)
      COMMON /3/ DEADV,SPVOL,SPTIM,SPSAM,NN
      COMMON /6/ KEYB,KEYG
      IF ((KEYB.GT.NN).OR.(KEYG.GT.NN)) GO TO KEY
      IF (GWT - TWT.LE.0) GO TO WGT
      IF (I.GT.1) THEN
      IF (SRN(I) - 1.NE.SRN(I-1)) GO TO SRE
      ELSE
      IF (ISBEG(1).NE.SRN(I)) GO TO BEG
      ENDIF
      RETURN
  KEY WRITE(59,FE1) SRN(I)
      GO TO ISC
  WGT WRITE(59,FE2) SRN(I)
      GO TO ISC
  SRE WRITE(59,FE3) SRN(I)
      GO TO ISC
  BEG WRITE(59,FE4) SRN(I)
  ISC ISCNT = ISCNT + 1
      WRITE(59,FE5)
      IERR = 1
  FE1 FORMAT(" KEY IN SAMPLE ",I5," EXCEEDS NUMBER OF NUCLIDES")
  FE2 FORMAT(" GROSS - TARE WT <= 0 IN SAMPLE # ",I5)
  FE3 FORMAT(" SAMPLE # ",I5," NOT MONOTONIC INCREACING")
  FE4 FORMAT(" FIRST SAMPLE # , ",I5," ,NOT SAME AS INCREMENT CARD")
  FE5 FORMAT(" SAMPLE IGNORED. PROCESSING CONTINUES")
      RETURN
      END
C
C     ************************************************************
```

```
C
CCC     THIS ROUTINE IS OPTIONALLY CALLED TO PROCESS SLICE DATA
CCC     . OTHER THAN THIS ROUTINE, ALL READING AND WRITING TO DISK
C       FILES IS DONE IN THE MAIN.
CCC
CCC     ***********************************************************
C
        SUBROUTINE SLICE
        DIMENSION SGAMA(4,15),STHCK(15),WORK(15),IG(4),INUK(4)
C
CCC     READ THE SLICE DATA FROM THE INPUT FILE
C
        READ (3,1000) NSLIC,BTHCK,INUK(1),INUK(2),INUK(3),INUK(4)
        DO 10 I = 1,NSLIC
        READ(3,1010) STHCK(I),SGAMA(1,I),SGAMA(2,I),SGAMA(3,I),SGAMA(4,I)
        IF ( SGAMA(1,I) .NE. 0.0 ) IG(1) = 1
        IF ( SGAMA(2,I) .NE. 0.0 ) IG(2) = 1
        IF ( SGAMA(3,I) .NE. 0.0 ) IG(3) = 1
     10 IF ( SGAMA(4,1) .NE. 0.0 ) IG(4) = 1
C
CCC     ECHO THE INPUT TO THE FILE INECHO
C
        WRITE(8,2060)
        WRITE(8,2070) NSLIC,BTHCK
        WRITE(8,2080) (INUK(I),I=1,4)
        WRITE(8,2090)
        DO 15 I = 1,NSLIC
     15 WRITE(8,2100) STHCK(I),(SGAMA(J,I),J=1,4)
C
CCC     OUTER LOOP IS OVER EACH NUCLIDE
C
        DO 50 J = 1,4
        IF ( IG(J) .EQ. 0 ) GO TO 50
C
CCC     INNER LOOP IS OVER ALL SLICES
C
        ILAST = 0
        DO 30 I = 1,NSLIC
        IF ( SGAMA(J,I) .NE. 0.0 ) THEN
        IF ( STHCK(I) .EQ. 0.0 ) GO TO 60
        WORK(I) = SGAMA(J,I) / STHCK(I)
C
CCC     SEE IF WE NEED TO INTERPOLATE
C
        IF (( ILAST .NE. 0 ) .AND. ( ILAST+1 .NE. I )) THEN
C
CCC     INTERPOLATE
C
        INTP = I - ILAST
        DEL = ( WORK(I) - WORK(ILAST) ) / FLOAT(INTP)
        DO 20 M = 1,INTP-1
     20 WORK(ILAST+M) = DEL * FLOAT(M) + WORK(ILAST)
        ELSE
        CONTINUE
        ENDIF
        ILAST = I
        ELSE
        CONTINUE
        ENDIF
     30 CONTINUE
```

```
C
C       OUTPUT A TABLE OF SLICE ACTIVITIES
C
        WRITE(7,2000)
        WRITE(7,2010)
        WRITE(7,2020) INUK(J)
        WRITE(7,2030)
        DO 40 K = 1,NSLIC
   40   WRITE(7,2040) K,STHCK(K),WORK(K)
   50   CONTINUE
        RETURN
   60   WRITE(59,2050)
        RETURN
C
 1000   FORMAT(I5,1X,F12.5,4A5)
 1010   FORMAT(F12.5,1X,4E15.6)
 2000   FORMAT(/," RESIDUAL ACTIVITY FROM SLICE DATA")
 2010   FORMAT(" -------- -------- ---- ----- ----")
 2020   FORMAT(/,14X,"NUCLIDE ",A5)
 2030   FORMAT(/,1X,"SAMPLE #",3X,"THICKNESS(MM)",7X,"DPM/MM",/)
 2040   FORMAT(2X,I5,5X,F12.5,4X,E15.6)
 2050   FORMAT(/," **ERROR** IN CORE SLICE DATA ")
 2060   FORMAT(/,7X,"# OF SLICES",3X,"BLADE THICKNESS")
 2070   FORMAT(/,10X,I5,8X,F12.5)
 2080   FORMAT(/,4X,"THICKNESS (MM)",4(9X,A5,3X))
 2090   FORMAT(/,4X,"--------------",4(9X,"-----",3X),/)
 2100   FORMAT(4X,F12.5,2X,4(2X,E15.6))
        END
```

```
 FRACTURED GRANITE CORE 25 SORPTION RUN WITH 3H, 95MTC, 85SR, 137CS
NATURAL FRACTURE, DISTILLED WATER, NO TEFLON O-RINGS NEW INLET FITTING
4
   3H       4.490E+03          5.0E+07
 95MTC      6.120E+01      2. 638E+05        1.          1.          1.  5  5 73
  85SR      6.480E+01      3. 429E+05        1.          1.          1.  5  5119
 137CS      1.100E+04      4. 443E+05        1.          1.          1.  5  5144
        2.222          0.505          2022.0          10          1.0          294.0
     1    8          240.0
     9    9          102.0
    10   55           50.0
    56   83          100.0
    84  122          150.0
   123  145          240.0
   146  146          208.0
   147  147           90.0
   148  150           60.0
   151  151           35.0

     1   2.3555         2.430900
     2   2.2522         2.828103
 95MTC     69    1228       64   397.    50.
  85SR     40    1278       18   397.    50.
 137CS     34     917       26   397.    50.
     3   2.2859         2.877400
     4   2.3172         2.898800
     5   2.3411         2.921600
     6   2.3203         2.824103
 95MTC    130    2463      144   393.   100.
  85SR     87    2547       72   393.   100.
 137CS     74    1845       54   393.   100.
     7   2.2711         2.868100
     8   2.2754         2.826600
     9   2.2991         2.520900
    10   2.3131         2.415413
    3H       2.00E+02
 95MTC     96    1148       61   397.    50.
  85SR     33    1167       36   397.    50.
 137CS     26     839       23   397.    50.
    11   2.3151         2.421000
    12   2.3461         2.450200
    13   2.2597         2.367300
    14   2.2379         2.342813
    3H       2.00E+02
 95MTC     74    1187       79   397.    50.
  85SR     35    1244       33   397.    50.
 137CS     35     875       21   397.    50.
    15   2.2856         2.399900
    16   2.3600         2.467600
    17   2.2746         2.382800
    18   2.3145         2.448813
    3H       2.49E+04
 95MTC     77    1506       71   393.    50.
  85SR     36    1325       29   393.    50.
 137CS     34     837       24   393.    50.
    19   2.2708         2.387913
    3H       1.82E+05
 95MTC    517   18881      338   393.   100.
  85SR    240   22681      223   393.   100.
 137CS    122    2997       86   393.   100.
```

Continues for all samples

.
.
.

```
137CS      93    3895      60   404.   100.
  131   2.3085       2.830900
  132   2.3795       2.883500
  133   2.3889       2.928603
95MTC     219    5520     169   402.   100.
 85SR      90    3695      78   402.   100.
137CS      85    3629      56   402.   100.
  134   2.2951       2.781600
  135   2.3803       2.904200
  136   2.3641       2.886400
  137   2.2775       2.794300
  138   2.2959       2.841000
  139   2.2814       2.780603
95MTC     193    4582     158   403.   100.
 85SR     103    3189      78   403.   100.
137CS      86    3410      53   403.   100.
  140   2.2822       2.800000
  141   2.2958       2.818200
  142   2.2968       2.799200
  143   2.2881       2.801400
  144   2.3793       2.914503
95MTC      98    1885      67   404.    50.
 85SR      43    1510      29   404.    50.
137CS      42    1662      37   404.    50.
  145   2.3031       2.818900
  146   2.3180       2.774800
  147   2.3275       3.357603
95MTC     220    5772     178   404.   100.
 85SR     116    3754      89   404.   100.
137CS     112    4132      64   404.   100.
  148   2.3810       3.126003
95MTC     105    3024      76   405.    50.
 85SR      51    1770      49   405.    50.
137CS      53    1672      32   405.    50.
  149   2.2899       3.035903
95MTC     115    2586      84   405.    50.
 85SR      52    1639      32   405.    50.
137CS      55    1530      39   405.    50.
  150   2.2888       3.018503
95MTC     220    4473     173   404.   100.
 85SR     110    3210      66   404.   100.
137CS      72    3054      60   404.   100.
  151   2.3090       2.733203
95MTC     101    1867     100   405.    50.
 85SR      44    1449      38   405.    50.
137CS      45    1266      27   405.    50.
   14          .381 85SR95MTC137CS
         1.65       2.330E+03       6.348E+02       7.063E+03
         1.70       1.120E+03       1.224E+02       3.770E+03
         1.65
         1.65       5.188E+02       8.197E+01       7.085E+03
         1.60
         1.55       4.574E+02       1.124E+02       5.109E+03
         1.50
         1.70       1.127E+03       2.161E+02       1.701E+04
         1.55
         1.60       7.654E+02       2.993E+02       1.298E+04
         1.60
         1.60       1.090E+03       1.877E+03       2.678E+04
         1.00       9.297E+02       2.746E+03       2.175E+04
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Sample INECHO File from ORB Program

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 FRACTURED GRANITE CORE 25 SORPTION RUN WITH 3H, 95MTC, 85SR, 137CS
NATURAL FRACTURE, DISTILLED WATER, NO TEFLON O-RINGS NEW INLET FITTING

 # OF ISOTOPES
4

 NAME    HALF LIFE        CALIBRATION DATA
    3H    4.490000E+03    5.000000E+07     0.          0.          0.          0  0  0
 95MTC    6.120000E+01    2.063800E+05     1.0000      1.0000      1.0000500507300
  85SR    6.480000E+01    3.042900E+05     1.0000      1.0000      1.0000500511900
 137CS    1.100000E+04    4.044300E+05     1.0000      1.0000      1.0000500514400

   DEAD VOL    SPIKE VOL   SPIKE INJ T SPIKE INJ #     DENSITY      ZERO TM
    2.22200      0.50500   2022.00000      0.00010     1.00000    294.00000

 BEG   END   INCREMENT
   1     8    240.00000
   9     9    102.00000
  10    55     50.00000
  56    83    100.00000
  84   122    150.00000
 123   145    240.00000
 146   146    208.00000
 147   147     90.00000
 148   150     60.00000
 151   151     35.00000

 SAMP    TARE WT   GROSS WT   # OF B   # OF G
    1   2.355500   2.430900        0        0
    2   2.252200   2.828100        0        3

 NUCLIDE NAME   LOWER BG    PEAK    UPPER BG   JULIAN TM   COUNT PER

    95MTC            69      1228          64      397.00       50.00
     85SR            40      1278          18      397.00       50.00
    137CS            34       917          26      397.00       50.00
    3   2.285900   2.877400        0        0
    4   2.317200   2.898800        0        0
    5   2.341100   2.921600        0        0
    6   2.320300   2.824100        0        3

 NUCLIDE NAME   LOWER BG    PEAK    UPPER BG   JULIAN TM   COUNT PER

    95MTC           130      2463         144      393.00      100.00
     85SR            87      2547          72      393.00      100.00
    137CS            74      1845          54      393.00      100.00
    7   2.271100   2.868100        0        0
    8   2.275400   2.826600        0        0
    9   2.299100   2.520900        0        0
   10   2.313100   2.416400        1        3

 NUCLIDE NAME      ACTIVITY

       3H         2.000000E+02

 NUCLIDE NAME   LOWER BG    PEAK    UPPER BG   JULIAN TM   COUNT PER

    95MTC            96      1148          61      397.00       50.00
     85SR            33      1167          36      397.00       50.00
    137CS            26       839          23      397.00       50.00


 Continues for all samples
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NUCLIDE NAME	LOWER BG	PEAK	UPPER BG	JULIAN TM	COUNT PER
95MTC	115	2586	84	405.00	50.00
85SR	52	1639	32	405.00	50.00
137CS	55	1530	39	405.00	50.00
150 2.288800	3.018500	0	3		

NUCLIDE NAME	LOWER BG	PEAK	UPPER BG	JULIAN TM	COUNT PER
95MTC	220	4473	173	404.00	100.00
85SR	110	3210	66	404.00	100.00
137CS	72	3054	60	404.00	100.00
151 2.309000	2.733200	0	3		

NUCLIDE NAME	LOWER BG	PEAK	UPPER BG	JULIAN TM	COUNT PER
95MTC	101	1867	100	405.00	50.00
85SR	44	1449	38	405.00	50.00
137CS	45	1266	27	405.00	50.00

# OF SLICES	BLADE THICKNESS
14	0.38100

THICKNESS (MM)	85SR	95MTC	137CS	
1.65000	2.330000E+03	6.348000E+02	7.063000E+03	0.
1.70000	1.120000E+03	1.224000E+02	3.770000E+03	0.
1.65000	0.	0.	0.	0.
1.65000	5.188000E+02	8.197000E+01	7.085000E+03	0.
1.60000	0.	0.	0.	0.
1.55000	4.574000E+02	1.124000E+02	5.109000E+03	0.
1.50000	0.	0.	0.	0.
1.70000	1.127000E+03	2.161000E+02	1.701000E+04	0.
1.55000	0.	0.	0.	0.
1.60000	7.654000E+02	2.993000E+02	1.298000E+04	0.
1.60000	0.	0.	0.	0.
1.60000	1.090000E+03	1.877000E+03	2.678000E+04	0.
1.00000	9.297000E+02	2.746000E+03	2.175000E+04	0.
1.40000	1.533000E+03	1.337000E+04	3.956000E+04	0.

Sample Output File from ORB Program

SAMPLE	NET VOL	CUMULATIVE VOL	INST FLOW RATE	AVER FLOW RATE	TIME	SAMPLE
1	7.540000E-02	7.540000E-02	3.141667E-04	3.141667E-04	2.400000E+02	1
2	5.759000E-01	6.513000E-01	2.399583E-03	1.356875E-03	4.800000E+02	2
3	5.915000E-01	1.242800E+00	2.464583E-03	1.726111E-03	7.200000E+02	3
4	5.816000E-01	1.824400E+00	2.423333E-03	1.900417E-03	9.600000E+02	4
5	5.805000E-01	2.404900E+00	2.418750E-03	2.004083E-03	1.200000E+03	5
6	5.038000E-01	2.908700E+00	2.099167E-03	2.019931E-03	1.440000E+03	6
7	5.970000E-01	3.505700E+00	2.487500E-03	2.086726E-03	1.680000E+03	7
8	5.512000E-01	4.056900E+00	2.296667E-03	2.112969E-03	1.920000E+03	8
9	2.218000E-01	4.278700E+00	9.241667E-04	2.116073E-03	2.022000E+03	9
10	1.033000E-01	4.382000E+00	4.304167E-04	2.114865E-03	2.072000E+03	10
11	1.059000E-01	4.487900E+00	4.412500E-04	2.114939E-03	2.122000E+03	11
12	1.041000E-01	4.592000E+00	4.337500E-04	2.114180E-03	2.172000E+03	12
13	1.076000E-01	4.699600E+00	4.483333E-04	2.115032E-03	2.222000E+03	13
14	1.049000E-01	4.804500E+00	4.370833E-04	2.114657E-03	2.272000E+03	14
15	1.143000E-01	4.918800E+00	4.762500E-04	2.118346E-03	2.322000E+03	15
16	1.076000E-01	5.026400E+00	4.483333E-04	2.119056E-03	2.372000E+03	16

Continues for all sample

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137	5.168000E-01	3.589690E+01	2.153333E-03	2.166118E-03	1.657200E+04	137
138	5.451000E-01	3.644200E+01	2.271250E-03	2.167618E-03	1.681200E+04	138
139	4.992000E-01	3.694120E+01	2.080000E-03	2.166385E-03	1.705200E+04	139
140	5.178000E-01	3.745900E+01	2.157500E-03	2.166262E-03	1.729200E+04	140
141	5.224000E-01	3.798140E+01	2.176667E-03	2.166404E-03	1.753200E+04	141
142	5.024000E-01	3.848380E+01	2.093333E-03	2.165418E-03	1.777200E+04	142
143	5.133000E-01	3.899710E+01	2.138750E-03	2.165062E-03	1.801200E+04	143
144	5.352000E-01	3.953230E+01	2.230000E-03	2.165916E-03	1.825200E+04	144
145	5.158000E-01	4.004810E+01	2.149167E-03	2.165699E-03	1.849200E+04	145
146	4.568000E-01	4.050490E+01	1.903333E-03	2.166037E-03	1.870000E+04	146
147	1.030100E+00	4.153500E+01	4.292083E-03	2.210484E-03	1.879000E+04	147
148	7.450000E-01	4.228000E+01	3.104167E-03	2.242971E-03	1.885000E+04	148
149	7.460000E-01	4.302600E+01	3.108333E-03	2.275304E-03	1.891000E+04	149
150	7.297000E-01	4.375570E+01	3.040417E-03	2.306574E-03	1.897000E+04	150
151	4.242000E-01	4.417990E+01	1.767500E-03	2.324646E-03	1.900500E+04	151

RESIDUAL ACTIVITY FROM SLICE DATA

NUCLIDE 85SR

SAMPLE #	THICKNESS(MM)	DPM/MM
1	1.65000	1.412121E+03
2	1.70000	6.588235E+02
3	1.65000	4.866239E+02
4	1.65000	3.144242E+02
5	1.60000	3.047605E+02
6	1.55000	2.950968E+02
7	1.50000	4.790190E+02
8	1.70000	6.629412E+02
9	1.55000	5.706581E+02
10	1.60000	4.783750E+02
11	1.60000	5.798125E+02
12	1.60000	6.812500E+02
13	1.00000	9.297000E+02
14	1.40000	1.095000E+03

RESIDUAL ACTIVITY FROM SLICE DATA

NUCLIDE 95MTC

SAMPLE #	THICKNESS(MM)	DPM/MM
1	1.65000	3.847273E+02
2	1.70000	7.200000E+01
3	1.65000	6.083939E+01
4	1.65000	4.967879E+01
5	1.60000	6.109746E+01
6	1.55000	7.251613E+01
7	1.50000	9.981689E+01
8	1.70000	1.271176E+02
9	1.55000	1.570901E+02
10	1.60000	1.870625E+02
11	1.60000	6.800937E+02
12	1.60000	1.173125E+03
13	1.00000	2.746000E+03
14	1.40000	9.550000E+03

RESIDUAL ACTIVITY FROM SLICE DATA

NUCLIDE 137CS

SAMPLE #	THICKNESS(MM)	DPM/MM
1	1.65000	4.280606E+03
2	1.70000	2.217647E+03
3	1.65000	3.255793E+03
4	1.65000	4.293939E+03
5	1.60000	3.795034E+03
6	1.55000	3.296129E+03
7	1.50000	6.651006E+03
8	1.70000	1.000588E+04
9	1.55000	9.059191E+03
10	1.60000	8.112500E+03
11	1.60000	1.242500E+04
12	1.60000	1.673750E+04
13	1.00000	2.175000E+04
14	1.40000	2.825714E+04

SAMPLE #	3H	95MTC	85SR	137CS
2	0.	1.369357E+02	1.335681E+02	3.205317E+01
6	0.	1.500260E+02	1.457732E+02	3.685085E+01
10	2.000000E+02	7.136857E+02	6.799697E+02	1.634972E+02
14	2.000000E+02	7.266758E+02	7.137793E+02	1.679118E+02
18	2.490000E+04	6.882389E+02	5.689535E+02	1.254263E+02
19	1.820000E+05	4.908676E+03	5.584859E+03	2.575367E+02
20	3.910000E+05	1.446586E+04	1.954031E+04	5.950425E+02
21	6.370000E+05	2.454442E+04	3.298308E+04	9.498502E+02
22	8.970000E+05	3.127546E+04	4.309294E+04	1.768063E+03
23	1.090000E+06	3.510513E+04	4.783570E+04	3.520141E+03
24	1.130000E+06	3.446242E+04	4.492768E+04	5.843174E+03
25	8.520000E+05	3.150392E+04	3.791032E+04	7.025002E+03
26	8.420000E+05	2.775642E+04	3.143509E+04	6.082727E+03
27	0.	2.351620E+04	2.557797E+04	5.044757E+03
28	4.790000E+05	1.876308E+04	2.007272E+04	3.914485E+03
29	0.	1.541388E+04	1.580336E+04	3.104265E+03
30	2.400000E+05	1.198021E+04	1.191776E+04	2.385391E+03
32	1.320000E+05	9.980355E+03	9.683769E+03	2.004192E+03
34	0.	6.519416E+03	5.980589E+03	1.380908E+03
38	0.	3.476619E+03	3.019206E+03	7.827618E+02
41	0.	2.513782E+03	2.174333E+03	5.764207E+02
44	0.	2.196134E+03	1.711840E+03	4.809714E+02
46	0.	1.901443E+03	1.559071E+03	4.343187E+02
49	0.	1.680314E+03	1.416663E+03	3.799519E+02
53	0.	1.515365E+03	1.244711E+03	3.512695E+02
60	0.	9.840467E+02	8.726504E+02	2.261622E+02
65	0.	7.682730E+02	6.940859E+02	1.909417E+02
70	0.	7.457438E+02	7.615334E+02	1.930953E+02
75	0.	7.273983E+02	7.033850E+02	1.870049E+02
82	0.	5.747438E+02	5.602260E+02	1.493988E+02
85	0.	4.645287E+02	4.306595E+02	1.240282E+02
91	0.	4.522289E+02	4.646938E+02	1.266056E+02
96	0.	4.064931E+02	4.045286E+02	1.177319E+02
101	0.	3.688680E+02	3.336198E+02	1.117688E+02
103	0.	3.744791E+02	3.318834E+02	1.060070E+02
104	0.	3.678087E+02	3.285663E+02	1.118860E+02

Continues for all γ or β^- analyzed samples

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Technical Information Department · Lawrence Livermore National Laboratory
University of California · Livermore, California 94550

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