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The Elution of Radionuclides Through Columns of Crushed Rock From the Nevada Test Site

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This report was prepared by the Los Alamos National Laboratory as part of the Nevada Nuclear Waste Storage Investigations managed by the Nevada Operations Office of the US Department of Energy. Based upon their applicability to the investigations, some results from the Radionuclide Migration Project, managed by the Nevada Operations Office of the US Department of Energy, are included in this report.

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THE ELUTION OF RADIONUCLIDES THROUGH COLUMNS OF CRUSHED ROCK FROM THE NEVADA TEST SITE

by

E. N. Treher and N. A. Raybold

ABSTRACT

Results from the elution of radionuclides through columns of crushed tuff, granite, and argillite are presented. Good agreement between column and batch measurements on washed samples is generally observed for all three rock types. This is encouraging, since the results of batch measurements are often of value to show relative sorption under a variety of conditions, and their relevance to the migration of radionuclides under flowing conditions has been questioned.

Column elution behavior depended upon sample mineralogy. For example, ^{85}Sr gave fairly sharp, symmetric peaks on granite, argillite, and devitrified tuffs; however, on a vitrophyre, the peak was 10 to 100 times broader. For ^{137}Cs, the most unusual behavior was found on granites, where for columns run at ~20 m/year, most of the cesium was retained at the load point. For all the radionuclides studied, except ^{95m}Tc, zeolite-containing tuffs had to be run at flow rates of 10^3 to 10^4 m/year to obtain elutions, while samples composed primarily of alkali feldspar and SiO_2 gave elutions of ^{85}Sr, ^{137}Cs, and ^{133}Ba at flow rates of 10 to 100 m/year. Knowledge of the mineralogic compositions of tuffs and their ability to retard the migration of radionuclides is important--not only to identify the optimum horizon for a nuclear waste repository in Yucca Mountain, but also to estimate how well the repository will perform.

I. INTRODUCTION

The migration of radionuclides through columns of crushed tuff, granite, and argillite has been under investigation at the Los Alamos National Laboratory for several years. The purpose was to develop a simple means of studying the migration of radionuclides under flowing conditions. Before these experiments the potential for migration was estimated from sorption ratios obtained from batch-type tests.[1,2,3] For the batch measurements, geologic media was crushed and mixed with a fixed volume of groundwater containing the radionuclides. After a known contact time, the solution and solid phases were separated and counted to determine the concentration of radionuclide in each phase and the ratio of the concentrations, the sorption ratio, R_d.* In column studies the retardation factor, R_f, is determined; the velocity of a radionuclide is measured directly and then compared with respect to the groundwater velocity measured with nonreacting tracers such as HTO or ^{131}I. The R_f is related to the sorption ratio by the expression $R_f = 1 + (\rho/\varepsilon)R_d$, where ρ is the density of the rock column and ε is the porosity. Thus, both the retardation factor and sorption ratio indicate the extent to which the migration rate of a radionuclide is lowered by the geologic media compared to the movement of water.

Because a number of processes, such as ion exchange, sorption, precipitation, and mineral dissolution can be responsible for retardation, studies using columns have several advantages over those using batch measurements. Particulate transport can be studied; if more than one oxidation state or chemical species is present, each can be observed and its behavior studied. Also, migration rates can be directly observed by comparing the elution of a radionuclide with that of the groundwater itself (monitored with a nonreacting tracer). Column experiments, however, are time consuming and are generally much longer in duration, particularly when flow rates of 10 to 20 m/year are used. The disadvantage of both the batch-type measurements and the crushed-rock columns is, of course, that sample alteration that may influence the rock chemistry can occur because of crushing. For that reason larger columns of intact cores and even larger blocks of material are now being used.[4,5]

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*R_d is used in this report because K_d implies reversible equilibrium, and batch studies have shown that equilibrium is not attained in a few weeks or even a few months in many cases.

This report is primarily intended to tabulate the data thus far obtained, since it has not been published previously. As the work has progressed, the results and interpretation of those results have been reported;[6-10] they are summarized here.

II. MEASUREMENTS

A. Equipment

The first few columns were 0.5-cm diam and 2- to 4-cm long Bio-Rad Econo columns that were run by gravity flow. Syringe pumps (Sage Instruments, Model 352) were used to control the delivery rate to the top of the column. Flow rates through these columns tended to change with time, so a simple upflow column was developed to maintain a known, steady flow rate. The columns either were modified from glass Bio-Rad Econo columns by shortening them (and, for a few columns, lining with Teflon) or they were constructed of Teflon or acrylic tubing machined to fit the Bio-Rad polypropylene Luer fittings and polyethylene bed supports.

B. Materials

The waters used for the tuff columns were rock-pretreated water from well J-13 at the Nevada Test Site (NTS). Each water was prepared by contacting J-13 water for at least two weeks at ambient temperature with ground material of the appropriate tuff. The solution to solid ratio was 20 mℓ/g. The phases were separated by centrifugation at 7000 rpm (21 000 g) and then by filtration through either a 0.45-μm Nuclepore or a 0.40-μm Millipore filter. The waters for the granite and argillite columns were prepared by contacting synthetic waters[2,3] with the appropriate rock and then separated, following the procedures described above. Analyses were made of the tuff, granite, and argillite waters before their use in the columns.[1-3,6,7]

The tuff samples were obtained from the NTS, primarily from drill holes UE25a-1 and USW-G1, Yucca Mountain, Nevada. The samples from UE25a-1 are labelled with the prefix YM. Those from USW-G1 are labelled G1-, with the number following the G1 designation indicating the depth in feet from which the sample was taken. Additional samples labelled JA and GT-U12G came from drill hole J-13 located in Jackass Flats and from G tunnel, respectively.

The granite and argillite samples were also obtained from the NTS. Two samples of Climax Stock granite, labelled CS5 and CS7, were obtained from the

mine dump areas of the Piledriver tunnel. Eleana argillite samples were obtained from drill hole UE17e. They are labelled CN1, CN2, and CN3. A summary of the mineralogy of the tuff, granite, and argillite samples used is given in Table I.

Petrographic analysis of crushed rock from YM38-1 and JA32-1 was done both before and after elution. No change in YM38 tuff was observed, but there was a slight alteration of feldspar in the JA32 tuff.* Because x-ray diffraction might not be sensitive enough and making adequate thin sections of the powdered rock before and after elution for microscopic observations is difficult, there were no further attempts to assess changes in mineralogy because of the elutions.

C. Procedures

The columns were prepared by slurrying the sieved, washed, pretreated rock with groundwater and pouring it through funnels attached to the tops of the columns. Groundwater was eluted through the columns for several days to further pack and pretreat the columns. Each column was then mounted above a fraction collector, and groundwater containing $^{131}I^-$, HTO, or both was added to the funnel. The solution eluted was collected in individual drops and counted to determine the free column volume, which averaged ~0.2 to 0.4 mℓ. Typically, the flow rates used to measure the free column volumes were quite fast--on the order of 10^2 to 10^3 m/year. (See Table III, footnote d for comments on the consequences of these flow rates.)

After measuring the free column volume (FCV), a column was generally loaded with a 5- to 15-μℓ volume or "spike" containing one or more of the following radionuclides at concentrations of $\lesssim 10^{-6}$ M: ^{85}Sr, ^{137}Cs, ^{133}Ba, ^{95m}Tc, ^{152}Eu, and ^{141}Ce. The spikes for all radionuclides except ^{95m}Tc were prepared by evaporating a chloride solution of the carrier-free tracer, adding concentrated HCl and reevaporating, and finally adding groundwater to the dried tracer. Solutions with technetium were prepared by adding ^{95m}Tc as NH_4TcO_4 directly to the groundwater. Before use the solutions were filtered, either through Nuclepore 0.45-μm filters or through Amicon Centriflo membrane cones. The pH of the spike solutions and the waters was typically 7.5 to 8. There was little or no change in pH of the waters because of flow through the columns. For five columns--YM54-2, JA32-2, CN2-2, CN3, and G1-1436--radioisotopes were added to the groundwater at concentrations ~10^{-9} M, rather than using a spike of tracer.

*From information provided by M. L. Sykes, Los Alamos National Laboratory, May 1980.

After loading the spike, a frit and end cap were added, and the column was attached to a three-way stopcock which was mounted directly onto a syringe controlled by a Sage Pump. Flow rates were 11 to ~60 m/year, except in a few cases where much faster rates were used. Eluate fractions from each column were collected in pretared vials and weighed immediately after removal to determine the eluate volume. Each sample was then diluted to a known volume, sealed, and counted. Counting was done on a Ge(Li) detector when more than one isotope had been loaded on the column and on a NaI(Tl) detector when only one radionuclide had been used.

D. Summary of Columns Studied

Several parameters for each column studied are given in Table II. In addition to the free column volume discussed above, the column dimensions and the volume calculated from those dimensions, rock particle size, porosity,* column density of the dry rock, and flow rate are given. The radioisotopes used are indicated in the last column of Table II. Unless otherwise noted in the table, the columns were spike-loaded and run by upward flow.

III. DATA

A. Free Column Volume Determinations

The FCVs summarized in Table II were measured by elutions with $^{131}I^-$, or they are averages of the values obtained with $^{131}I^-$ and HTO, if both tracers were used. In Table III both HTO and $^{131}I^-$ results are given. The results have been corrected for the void volumes of the column fittings (frits, end caps, tubing, etc.). The peak volumes are also given in Table III. The peak volume is the volume eluted where the concentration of the eluate was between 0.001 and 0.999 of the initial solution. If the flow rates used for the $^{131}I^-$ and HTO elutions were measured, they are included in Table III.

B. Elution of Radioisotopes

The data obtained from the column elutions are given in Tables A-I to A-XXXI in App. A; these data are plotted in Figs. 1 to 31. The elution curves are plotted as C/C_I or C/C_o and A/A_T at the average total volume where

*The porosity was determined by dividing the FCV by the column volume calculated from column dimensions.

TABLE I

MINERALOGY OF SAMPLES USED FOR CRUSHED-ROCK COLUMNS

Sample	Glass (%)	Clay[a] (%)	Zeolite[b] (%)	Alkali Feldspar[c] (%)	SiO_2[d] (%)
YM5	70	~10 mnt	0	5-10 San 5-10 Plag	<5 Qz <5 Cr
YM22	0	5-10 mnt	0	40-60	40-60 Qz
YM38	0	2-5 mnt	50-70 Cpt	5-10	5-10 Qz 10-20 Cr
YM45	0	2-5 mnt	0	30-50	40-60 Qz tr Cr
YM54	0	tr mnt tr i/m	0	~30	~60 Qz
JA18	50	~5 mnt 5 i/m	10-20 Cpt	15-25	15-25 Cr
JA32	0	5-10 i/m	0	30-40	40-50 Qz
JA37	0	20-40 mnt ~5 i/m	~5 Cpt	15-30	30-60 Qz
G1-1292	80-90	tr mnt	0	10-20	5-10 Cr
G1-1436	0	tr i/m	65-85 Cpt	5-10	10-20 Qz 2-5 Cr
G1-1883	0	<10 mnt <5 m	0	50-70	30-50 Qz
G1-1982	0	tr mnt	0	30-50	40-60 Cr
G1-2233	0	<5 mnt 10-15 m	<5 Mrd 15-30 Cpt	40-60	5-10 Qz <5-10 Cr
G1-2289	0	tr i/m	30-50 Cpt 30-50 Mrd	10-20	tr Qz 2-5 Cr

TABLE I (cont)

Sample	Glass (%)	Clay[a] (%)	Zeolite[b] (%)	Alkali Feldspar[c] (%)	SiO_2[d] (%)
G1-2363	0	10-20 mnt 5-10 m	0	30-50	30-50 Qz
G1-2476	0	2-5 i/m	0	30-60	25-40 Qz 5-20 Cr
G1-2901	0	tr mnt 2-5 i/m	0	30-60	20-40 Qz 5-10 Cr
G1-3116	0	5-10 mnt 5-10 m	5-15 Cpt 10-30 Alc	20-40	20-40 Qz
G1-3658	0	40-80 mnt	0	40-60	tr Qz 2-5 Cr
GT-U12G	0	tr i/m	60-80	20-40	0
CS7	0	~5 bio/chl	0	~50	~30 Qz
CS5	0	~10 bio/chl	0	~50	~30 Qz
CN2	0	10-20 m 5-10 pyrp 20-40 sm 15-30 chl	0	0	30-50 Qz

[a]mnt = montmorillonite; i/m = illite/mica; m = mica; tr = trace; chl = chlorite; pyrp = pyrophyllite; sm = smectite; and bio = biotite.

[b]Cpt = clinoptilolite; Mrd = mordenite; and Alc = analcime.

[c]San = sanidine and Plag = plagioclase.

[d]Qz = quartz; Cr = cristobalite; and tr = trace.

TABLE II

CRUSHED ROCK COLUMNS

Sample	FCV (cm^3)	Column Size: Length x Width, (cm)	Column Size: Volume (cm^3)	Particle Size (μm)	Porosity	Density (g/cm^3)	Flow Rate[d] (ml/hour)	Flow Rate[d] (cm/second)	Flow Rate[d] (m/year)	Activity Added
Tuff										
YM54-1[a]	0.190	1.50 x 0.50	0.295	35-106	0.644	0.98	0.037	8.11×10^{-5}	26	^{85}Sr, ^{137}Cs, ^{127}Ba
YM54-2[a,b]	0.207	1.49 x 0.50	0.293	35-106	0.706	0.98	0.067	1.34×10^{-4}	42	^{137}Cs
YM54-3[a]	0.333	2.60 x 0.50	0.511	35-106	0.652	0.98	0.033	7.16×10^{-5}	23	^{85}Sr, ^{137}Cs, ^{133}Ba
YM45[c]	0.096	2.10 x 0.40	0.264	106-500	0.364	1.08	0.040	2.43×10^{-4}	77	^{141}Ce
YM38-1[a,c]	0.314	4.00 x 0.50	0.785	35-106	0.400	0.90	0.060	2.12×10^{-4}	67	^{85}Sr
YM38-2[c]	0.096	2.12 x 0.40	0.266	106-500	0.361	0.90	0.038	2.33×10^{-4}	74	^{141}Ce
YM38-3	0.147	2.45 x 0.45	0.390	106-500	0.377	0.90	5.30	2.45×10^{-2}	7740	^{137}Cs
YM22	0.202	1.90 x 0.50	0.373	35-106	0.542	1.16	0.077	2.01×10^{-4}	63	^{85}Sr, ^{137}Cs, ^{133}Ba
YM5[e]	0.481	4.90 x 0.50	0.962	75-500	0.500	1.05	0.058	1.64×10^{-4}	52	^{85}Sr, ^{137}Cs, ^{133}Ba
JA37	0.152	2.15 x 0.45	0.342	106-500	0.444	0.95	0.041	1.61×10^{-4}	51	^{85}Sr, ^{137}Cs
JA32-1[a]	0.470	4.40 x 0.49	0.830	35-106	0.566	0.89	0.131	3.41×10^{-4}	107	^{85}Sr
JA32-2[a,b]	0.328	2.20 x 0.50	0.432	35-106	0.759	0.89	18	3.35×10^{-2}	10 600	^{85}Sr
JA32-3	0.217	1.85 x 0.50	0.363	35-106	0.598	0.89	0.082	1.94×10^{-4}	61	^{85}Sr
JA18-1	0.136	2.00 x 0.40	0.251	106-150	0.542	0.98	0.044	1.80×10^{-4}	57	^{85}Sr, ^{137}Cs
JA18-2	0.116	1.80 x 0.40	0.226	106-150	0.513	0.98	0.048	2.07×10^{-4}	65	^{152}Eu
JA18-3	0.576	3.55 x 0.60	1.004	180-250	0.574	0.98	0.039	6.68×10^{-5}	21	^{85}Sr, ^{137}Cs, ^{133}Ba
G1-3658	0.293	3.05 x 0.50	0.599	38-106	0.489	1.40	~6.262	1.84×10^{-2}	5710	^{85}Sr, ^{137}Cs, ^{133}Ba
G1-3116	0.384	3.00 x 0.50	0.589	38-106	0.652	1.24	~6.654	1.44×10^{-2}	4550	^{85}Sr, ^{137}Cs, ^{133}Ba
G1-2901	0.419	2.90 x 0.49	0.547	38-106	0.766	1.31	0.044	8.46×10^{-5}	27	^{85}Sr, ^{137}Cs, ^{133}Ba
G1-2476	0.639	4.88 x 0.48	0.883	38-75	0.724	1.16	0.110	2.33×10^{-4}	74	^{85}Sr, ^{137}Cs, ^{133}Ba
G1-2363	0.508	4.85 x 0.48	0.878	38-106	0.579	1.21	0.068	1.80×10^{-4}	57	^{85}Sr, ^{137}Cs, ^{133}Ba
G1-2289	0.546	4.95 x 0.48	0.896	38-106	0.609	1.05	0.098	2.47×10^{-4}	77	^{152}Eu
G1-2233	0.369	2.96 x 0.50	0.589	38-106	0.635	1.00	~1.275	2.84×10^{-3}	896	^{85}Sr, ^{137}Cs, ^{133}Ba
G1-1982	0.364	3.10 x 0.42	0.429	38-106	0.848	1.30	0.040	9.33×10^{-5}	29	^{85}Sr, ^{137}Cs, ^{133}Ba
G1-1883-1	0.182	2.14 x 0.40	0.269	38-106	0.677	1.22	0.039	1.27×10^{-4}	40	^{85}Sr, ^{137}Cs, ^{133}Ba
G1-1883-2	0.859	4.95 x 0.60	1.40	38-106	0.614	1.22	0.042	6.72×10^{-5}	21	^{85}Sr, ^{137}Cs, ^{133}Ba
G1-1436[b]	1.099	8.00 x 0.50	1.571	38-106	0.700	0.94	0.017	3.44×10^{-5}	11	^{131}I, HTO
G1-1292	0.445	2.95 x 0.50	0.579	38-106	0.769	1.32	0.042	7.73×10^{-5}	24	^{85}Sr, ^{137}Cs, ^{133}Ba
GT-U12G	0.694	5.00 x 0.50	0.982	38-500	0.707	0.91	0.015	3.00×10^{-5}	9.5	^{95m}Tc, ^{85}Sr, ^{133}Ba, ^{137}Cs, ^{152}Eu

TABLE II (cont)

Granite										
CS7	0.229	2.10 x 0.50	0.412	35-106	0.556	1.26	0.045	1.15×10^{-4}	36	^{85}Sr, ^{137}Cs, ^{133}Ba
CS5-1	0.239	2.15 x 0.50	0.422	35-106	0.566	1.25	0.041	1.02×10^{-4}	32	^{85}Sr, ^{137}Cs, ^{133}Ba
CS5-2	0.601	3.63 x 0.60	1.026	35-106	0.586	1.25	4.98	8.35×10^{-3}	2630	^{85}Sr, ^{137}Cs, ^{133}Ba
CS5-3	0.222	1.90 x 0.50	0.373	38-106	0.630	1.25	0.297	7.06×10^{-4}	223	^{85}Sr, ^{137}Cs, ^{133}Ba
CS5-4	0.142	2.15 x 0.40	0.270	38-106	0.524	1.26	0.019	7.99×10^{-5}	25	^{95m}Tc, ^{152}Eu
Argillite										
CN1	0.283	2.40 x 0.45	0.382	180-250	0.741	1.11	0.041	9.66×10^{-5}	30	^{85}Sr, ^{137}Cs
CN2-1	0.274	2.43 x 0.45	0.386	180-250	0.710	1.16	0.054	1.33×10^{-4}	42	^{85}Sr, ^{137}Cs
CN2-2[b]	0.324	4.80 x 0.40	0.603	180-250	0.537	1.16	~ 2	8.23×10^{-3}	~2600	^{95m}Tc, $^{131}I^-$
CN2-3	0.183[f]	2.20 x 0.40	0.276	180-250	0.662[f]	1.16	0.019	6.34×10^{-5}	20	^{95m}Tc, ^{152}Eu
CN3[b,g]	0.483	4.60 x 0.45	0.732	180-250	0.660	1.18	~ 2	5.29×10^{-3}	1800	^{95m}Tc, $^{131}I^-$

[a]The column was run by gravity flow; therefore, the flow rates indicated are the delivery rates to the columns. The actual flow rate through the column was unknown.

[b]The column was run by adding the radioisotopes to the groundwater rather than using a "spike" of tracer.

[c]The activity decayed before elution, so no elution results were obtained.

[d]The flow rates of columns G1-3658, G1-3116, and G1-2233 varied considerably during the experiments.

[e]This column is still in progress.

[f]The porosity listed for CN2-3 is an average value of the other four argillite columns. This average porosity was used to estimate the FCV because its value measured with I^- was 0.256 mℓ, indicating either retardation of I^- or an error in the measurement.

[g]The column was run in a controlled nitrogen atmosphere containing ≤0.2 ppm oxygen and ≤20 ppm carbon dioxide.

TABLE III

COLUMN ELUTIONS WITH NONREACTING TRACERS[a]

Column	FCV (mℓ)[b]		Peak Volume (mℓ)[c]		Flow Rate[d]		
	$^{131}I^-$	HTO	$^{131}I^-$	HTO	(mℓ/hour)	(cm/second)	(m/year)
Tuff							
YM54-1	0.177	0.202	0.404	0.404	6.61(HTO)	1.36×10^{-2}	4300
YM54-2		0.207		0.555			
YM54-3		0.333		0.455			
YM45	0.096		0.505				
YM38-1	0.314						
YM38-2	0.096		0.379				
YM38-3	0.147		0.606				
YM22	0.202	0.202	0.455	0.455			
YM5	0.481		0.918				
JA37	0.152		0.480				
JA32-1	0.470		0.379				
JA32-2	0.328		0.455				
JA32-3	0.217		0.505				
JA18-1	0.136		0.480				
JA18-2	0.116		0.379				
JA18-3	0.576		0.732				
G1-3658	0.293		0.707				
G1-3116	0.384		0.909		3.03	6.57×10^{-3}	2070
G1-2901	0.419		0.732		60.0	1.15×10^{-1}	36 400
G1-2476	0.639		1.21				
G1-2363	0.508		0.631				
G1-2333	0.369		0.480		0.22	4.90×10^{-4}	155
G1-2289	0.546		0.455				
G1-2233	0.369		0.934		0.22		
G1-1982	0.369		0.909		6.28	1.47×10^{-2}	4620
G1-1883-1	0.182		0.379		0.57	1.90×10^{-3}	587
G1-1883-2	0.859		1.77				
G1-1436	0.869	1.099	2.57	0.237	0.017	3.44×10^{-5}	11
G1-1292	0.445		0.833		2.70	4.97×10^{-3}	1570
GT-U12G	0.699	0.689	1.9	2.0			

TABLE III (cont)

Column	FCV (mℓ)[b] $^{131}I^-$	FCV (mℓ)[b] HTO	Peak Volume (mℓ)[c] $^{131}I^-$	Peak Volume (mℓ)[c] HTO	Flow Rate[d] (mℓ/hour)	Flow Rate[d] (cm/second)	Flow Rate[d] (m/year)
Granite							
CS7	0.229		0.657				
CS5-1	0.239		0.657				
CS5-2	0.601		0.909				
CS5-3	0.222		0.556		0.962	2.29×10^{-3}	721
CS5-4	0.142		0.859		2.74	1.15×10^{-2}	3630
Argillite							
CN1	0.283		0.960		>2	$>4.71 \times 10^{-3}$	>1490
CN2-1	0.274		0.758		>2	$>4.93 \times 10^{-3}$	>1550
CN2-2	0.318	0.330	1.04		~2	$\sim 9 \times 10^{-3}$	~2800
CN2-3[e]	0.256		1.061		0.564	1.35×10^{-3}	425
CN3[f]	0.448	0.448	0.391		1.263	3.60×10^{-3}	1140

[a]Blank space indicates that no measurement was made.

[b]Total volume eluted before the eluate concentration reached 50% of the initial solution concentration, corrected for frit and end cap volumes of 0.111 mℓ.

[c]Total volume where the concentration of the eluate was between 0.001 and 0.999 of the initial solution concentration.

[d]Although the FCVs determined by fast-flow elutions may be slighly low, they will not significantly effect the R_d values except in cases where there is little retardation, as for technetium.

$$R_d = (R_f - 1)\varepsilon/\rho = \left(m\ell/FCV - \frac{FCV}{FCV}\right)\left(\frac{FCV/V}{\rho}\right)$$

$$= (m\ell - FCV)(1/\rho V) \text{ and generally } m\ell \gg FCV.$$

[e]The data used are plotted in Fig. 28.

[f]The data used are plotted in Fig. 30.

$$C/C_I = \frac{\text{concentration of sample from "continuous-feed" column}}{\text{concentration of feed solution}}$$

$$C/C_o = \frac{\text{concentration of sample from "spike-loaded" column}}{\text{concentration of most concentrated sample}}$$

$$A/A_T = \frac{\text{sum of the activities of the samples taken}}{\text{total activity of spike loaded on the column}}$$

The average total volume is the total volume which was eluted before a given sample plus one-half of the sample volume. For clarity, the average total volume is plotted against C/C_o and A/A_T in separate figures when more than one isotope was eluted from a single column.

C. Sectioning and Counting of Columns

Many of the columns were sectioned and counted to determine the distribution and amount of activity remaining on the column after elution. In some cases the activity remaining on the column represented a significant fraction (>50%) of the activity loaded. For these columns an effective retardation factor was calculated by measuring the distribution of activity along the column and knowing the total volume of solution eluted from the column. The data obtained from sectioning and counting the columns are given in Tables B-I to B-XXIV in App. B. The retardation factors and sorption ratios estimated from the sectioned column data are included in Table IV. A range of values is given because plots of the sum of an isotope on the column sections from load point to exit and from exit to load point vs column location are not identical. The difference between the two methods (in the location along the column of 50% of the activity) increases with increasing interval size. In some cases this difference is substantial; see, for example, Table B-III for column JA18-1 and Table B-XIX for column CS5-1.

TABLE IV

COLUMN SORPTION RATIOS OF STRONTIUM, CESIUM, AND BARIUM

Column	R_d (mℓ/g)		
	^{85}Sr	^{137}Cs	^{133}Ba
Tuff			
YM54-1	42	130	141
YM54-2		76	
YM54-3	44	122	149
YM38-3		24 100	
YM22	22	363	137
JA37	123	1390	
JA32-1	55		
JA32-2	39		
JA32-3	46		
JA18-1		[6560-13 800][a]	[22 200-95 000]
JA18-3		[11 500-24 700]	
G1-3658	984 [1705-4059]	4150 [1853-3806]	4720 [2755-8702]
G1-3116	449	4260	[38 300-54 200]
G1-2901	29	[728-810]	386
G1-2476	22	[369-393]	276
G1-2363	60	273	199
G1-2233	[24 000-38 200]	[84 000-129 000]	[168 000-672 000]
G1-1982	53	[1350-1720]	483
G1-1883-1	14	129	85
G1-1883-2	28	[281-285]	162
G1-1292	113	[903-1142]	[709-799]
GT-U12G	[>1550]	[>1550]	[>1550]
Granite			
CS7	12	[5620-7400]	56
CS5-1	7.2	[6630-18 900]	36
CS5-2	26	931	190
CS5-3	6.5	213	158
Argillite			
CN1	44	[2710-6770]	
CN2-1	57	[4333-7950]	

[a]Values in brackets are from data obtained from sectioned columns.

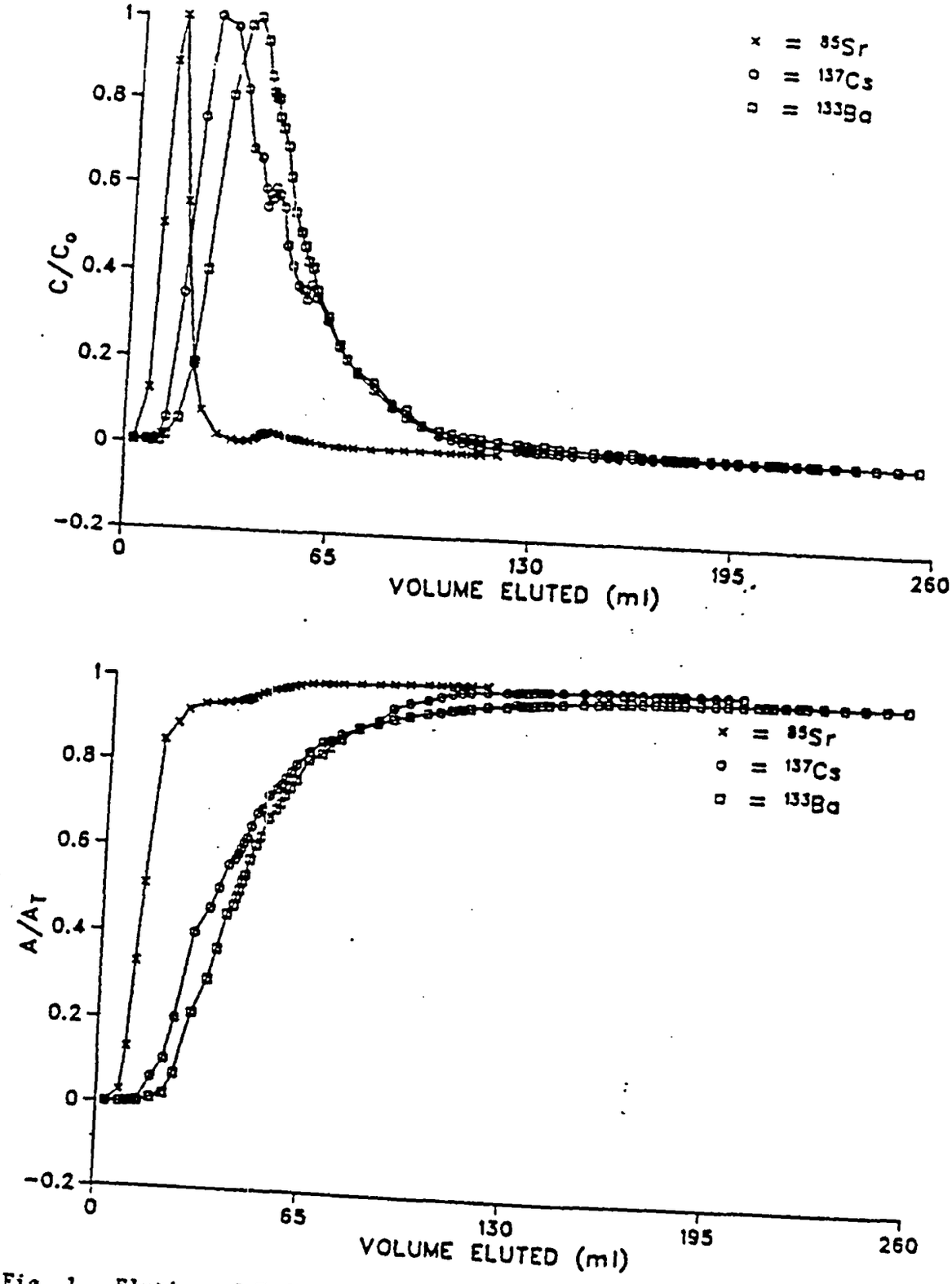


Fig. 1. Elution of Tuff YM54-1. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

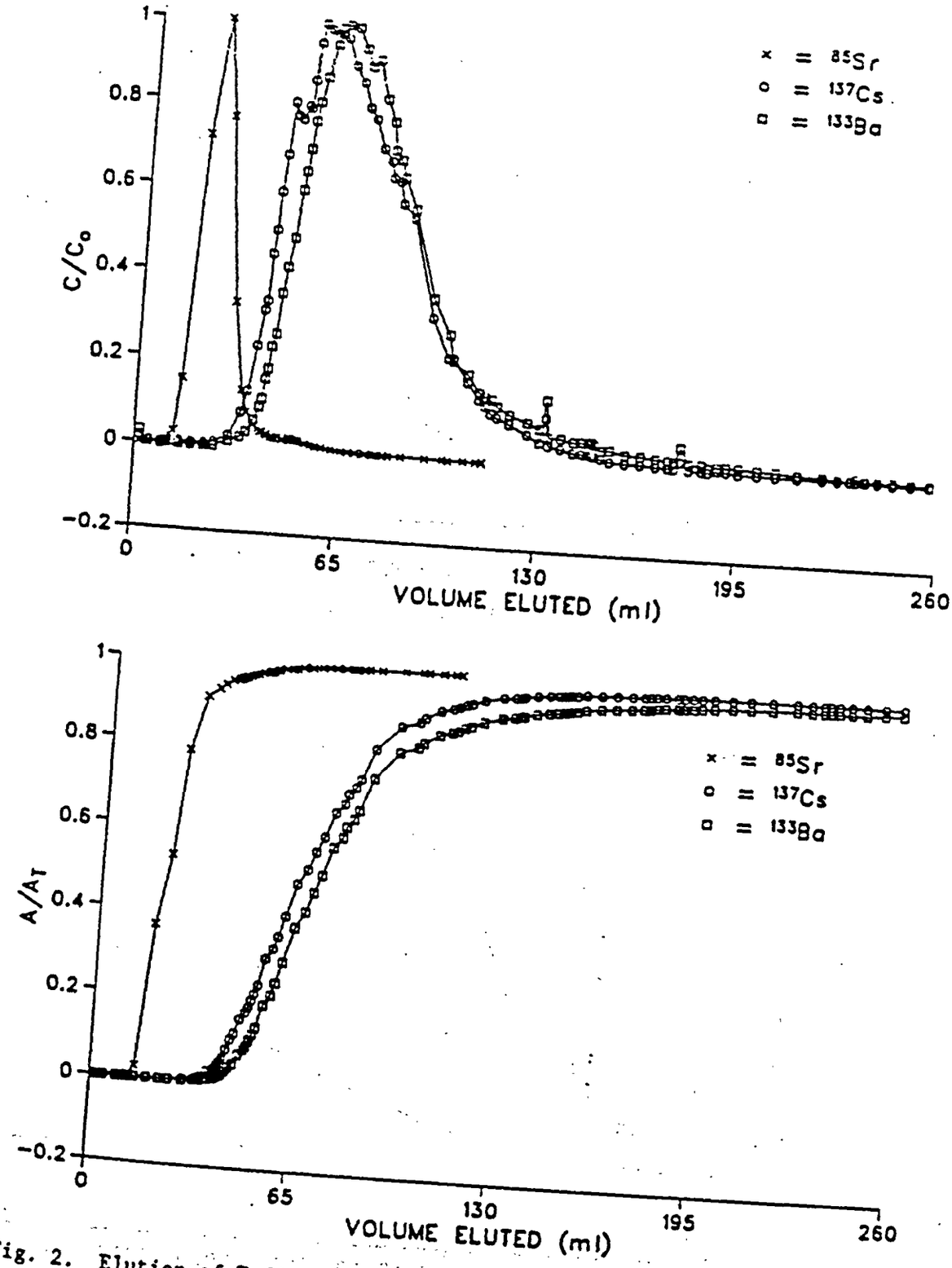


Fig. 2. Elution of Tuff YM54-3. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

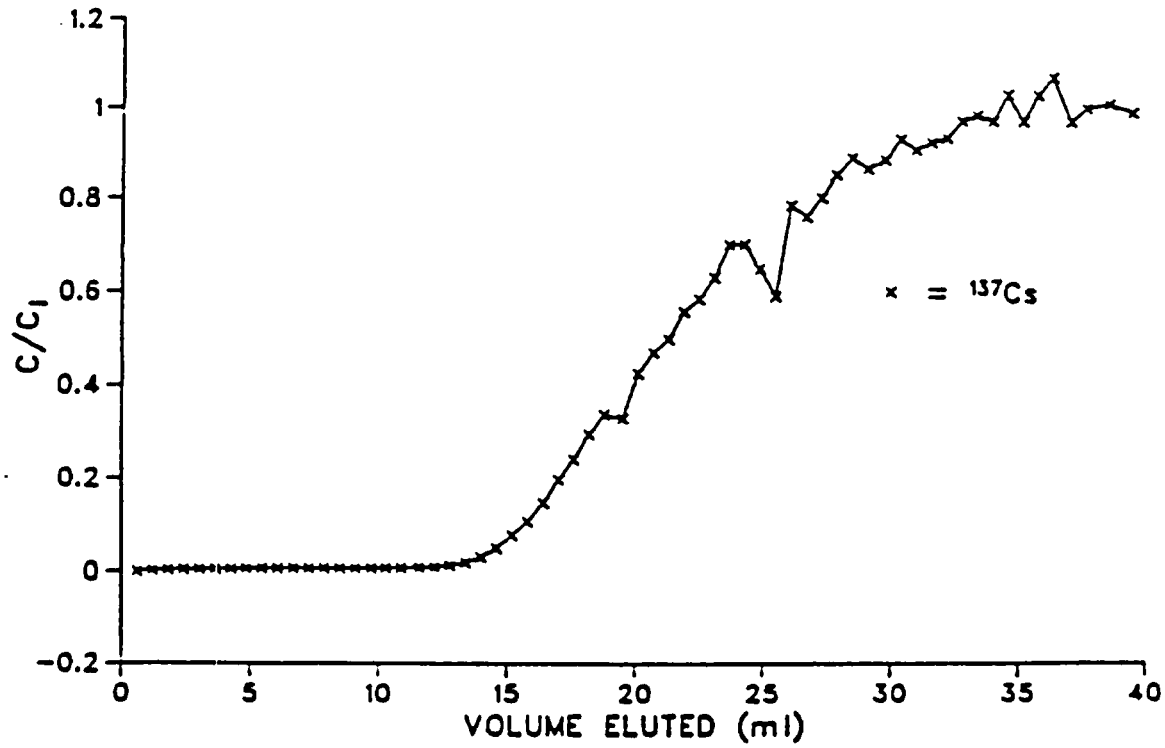


Fig. 3. Elution of Tuff YM54-2.

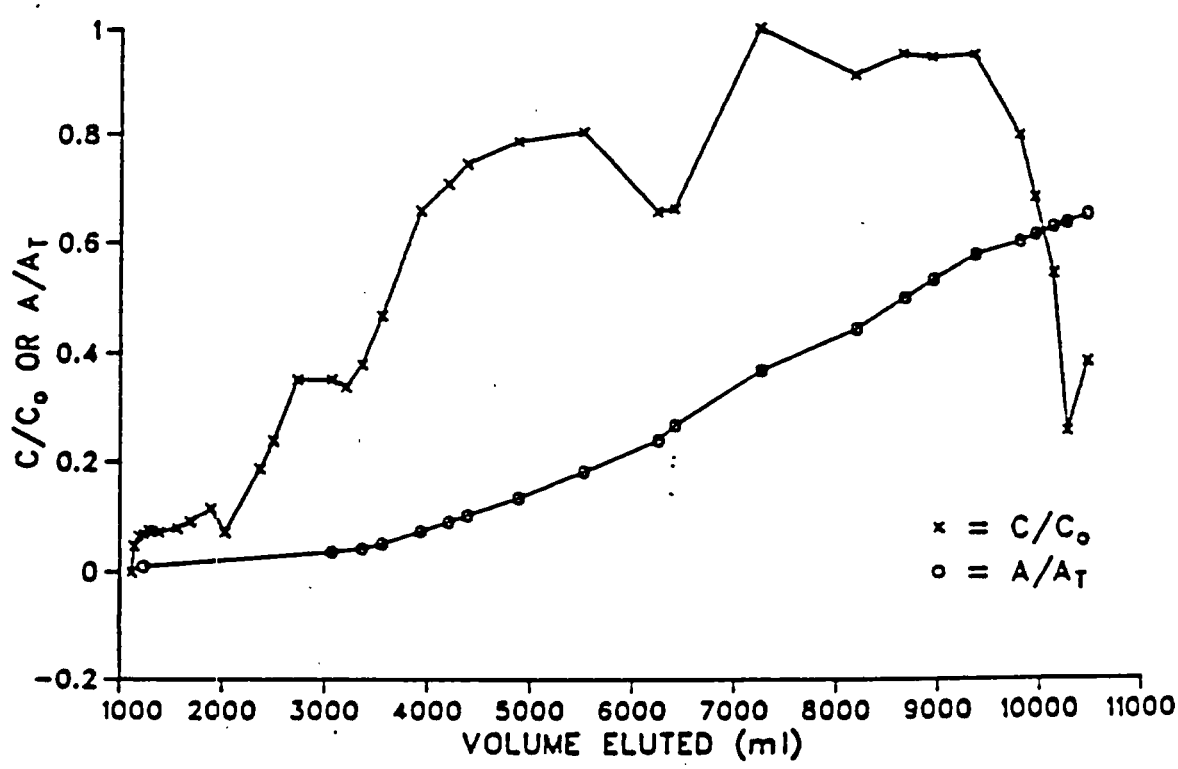
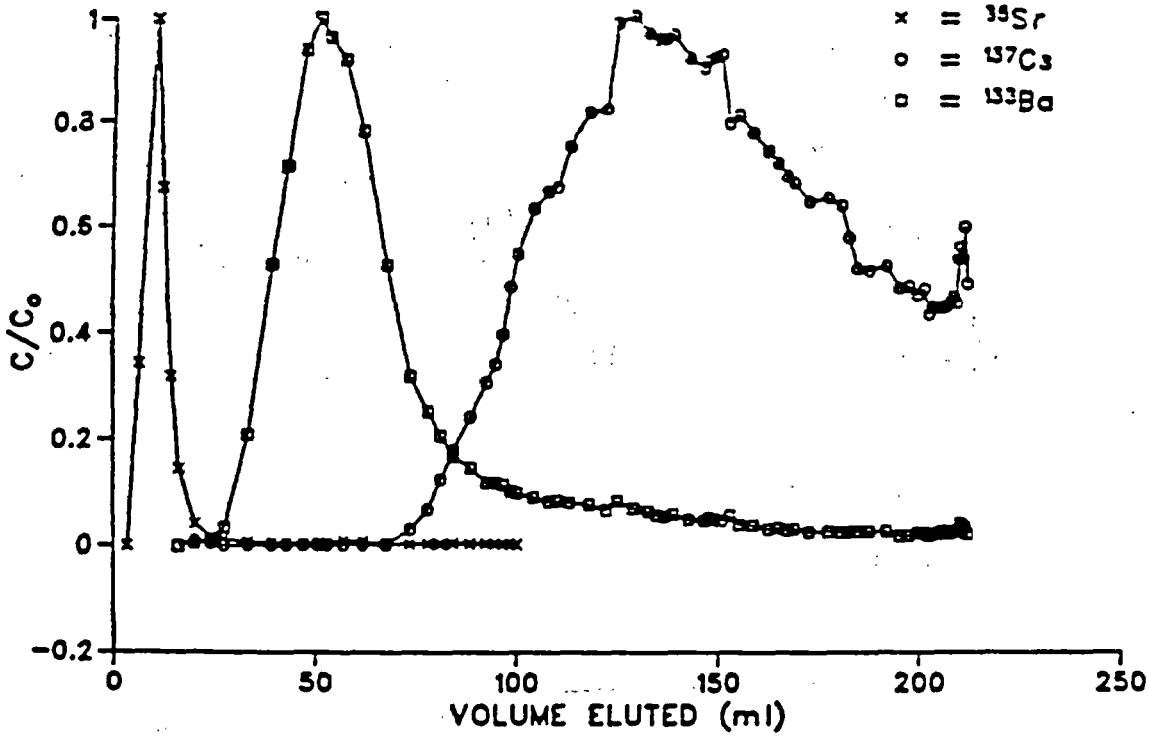


Fig. 4. Elution of Tuff YM38-3.



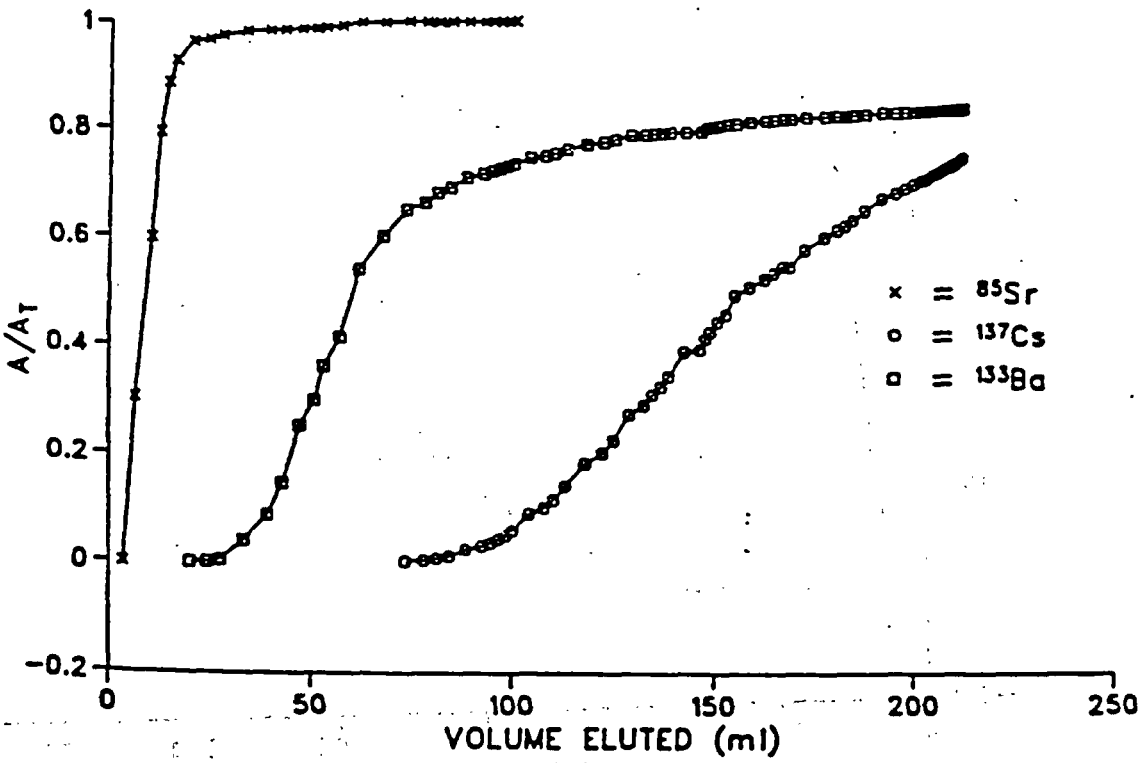


Fig. 5. Elution of Tuff YM22. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

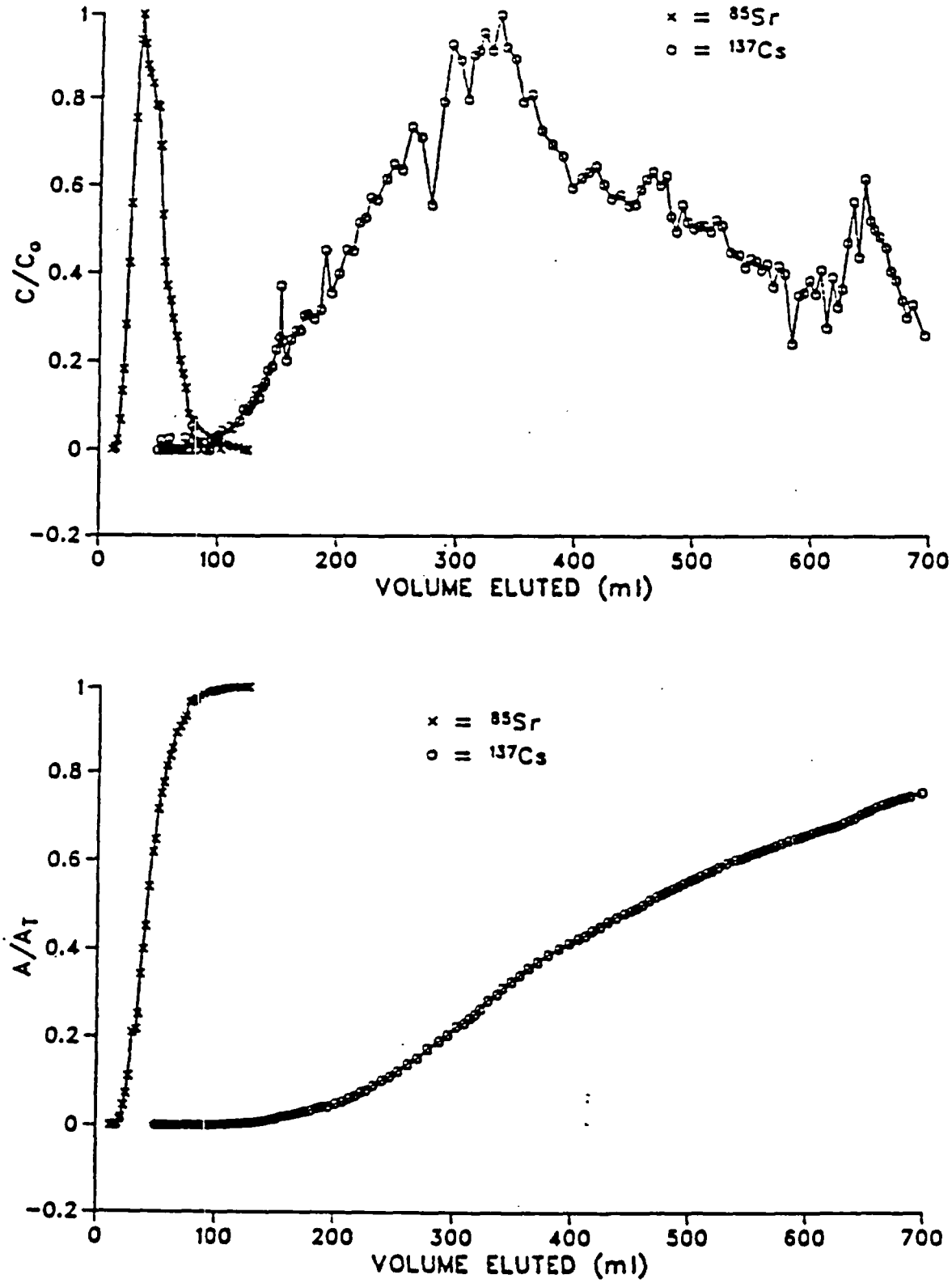


Fig. 6. Elution of Tuff JA37. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

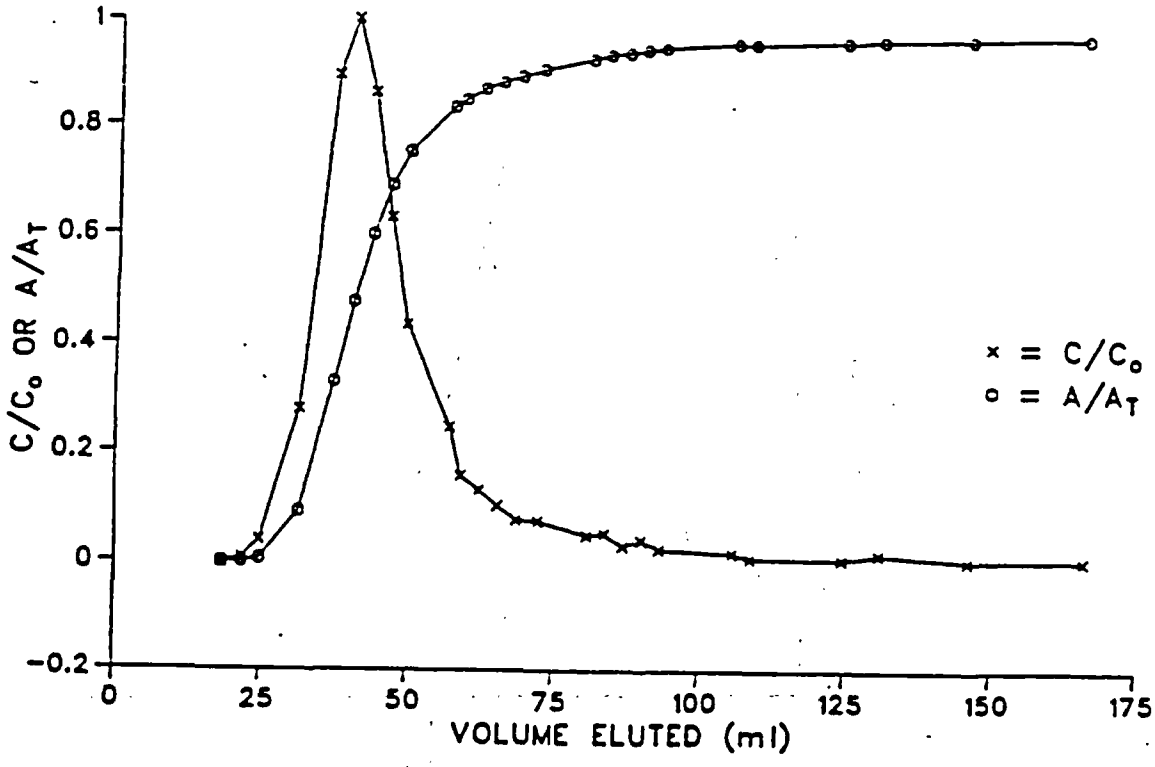


Fig. 7. Elution of Tuff JA32-1.

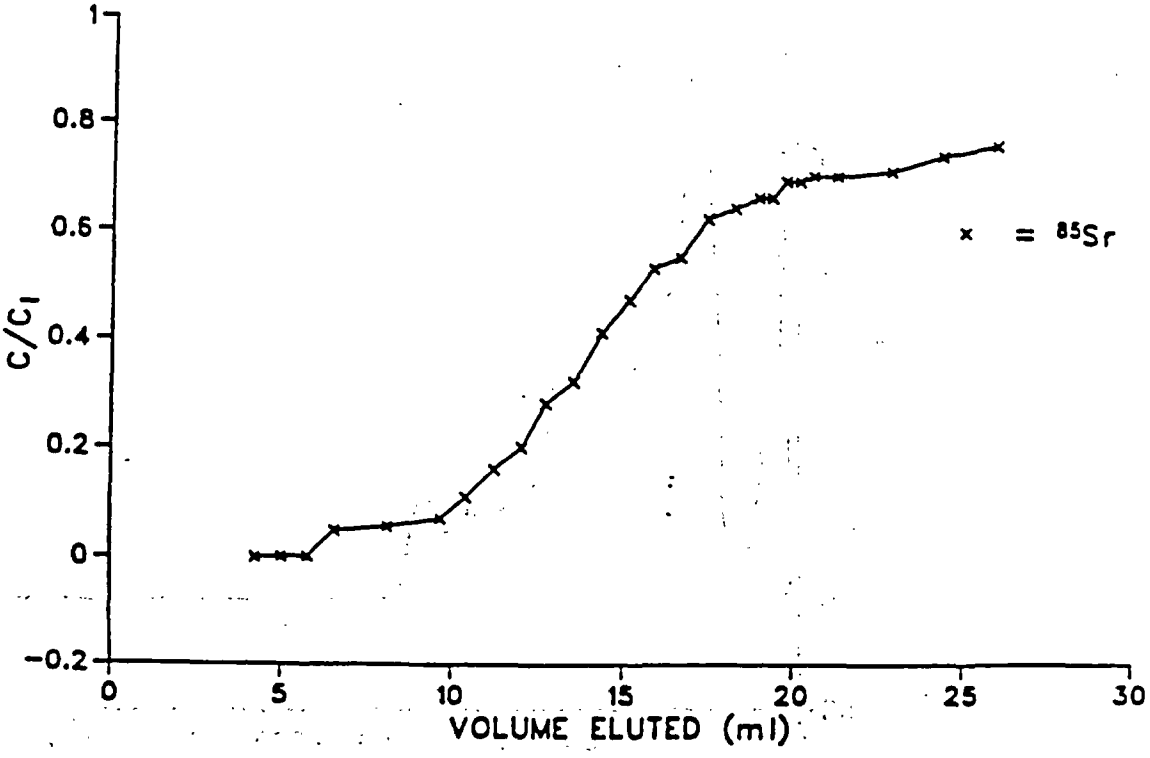


Fig. 8. Elution of Tuff JA32-2

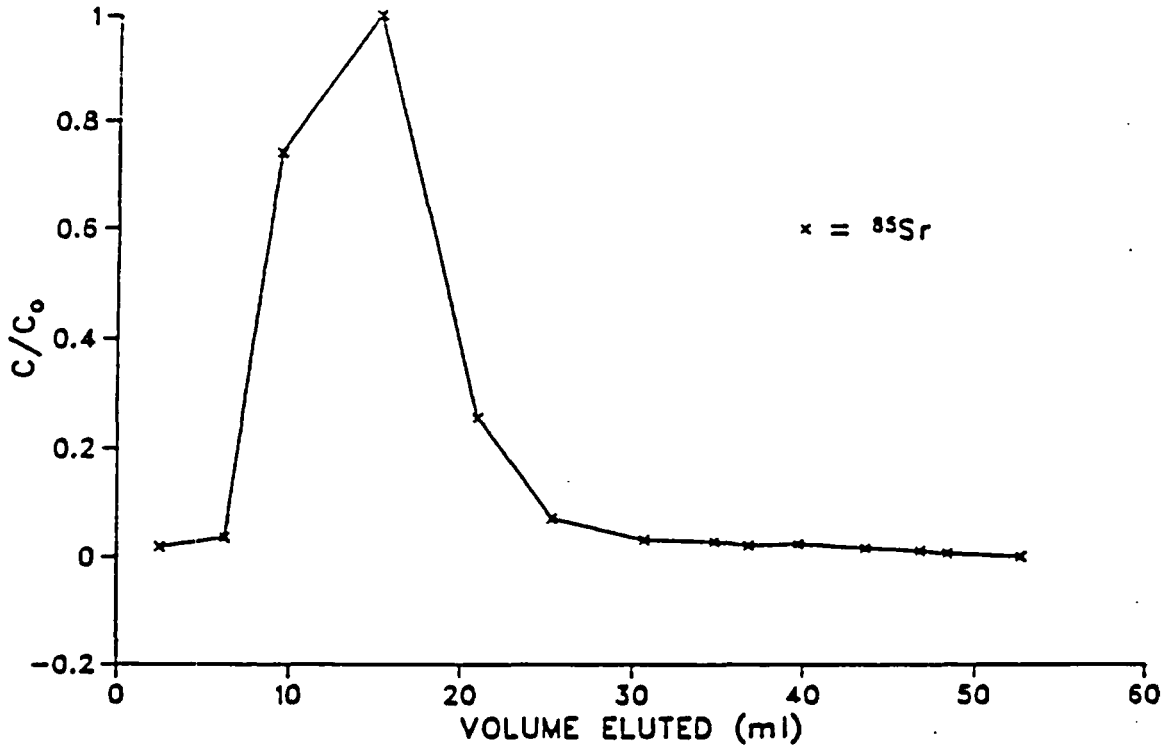


Fig. 9. Elution of Tuff JA32-3.

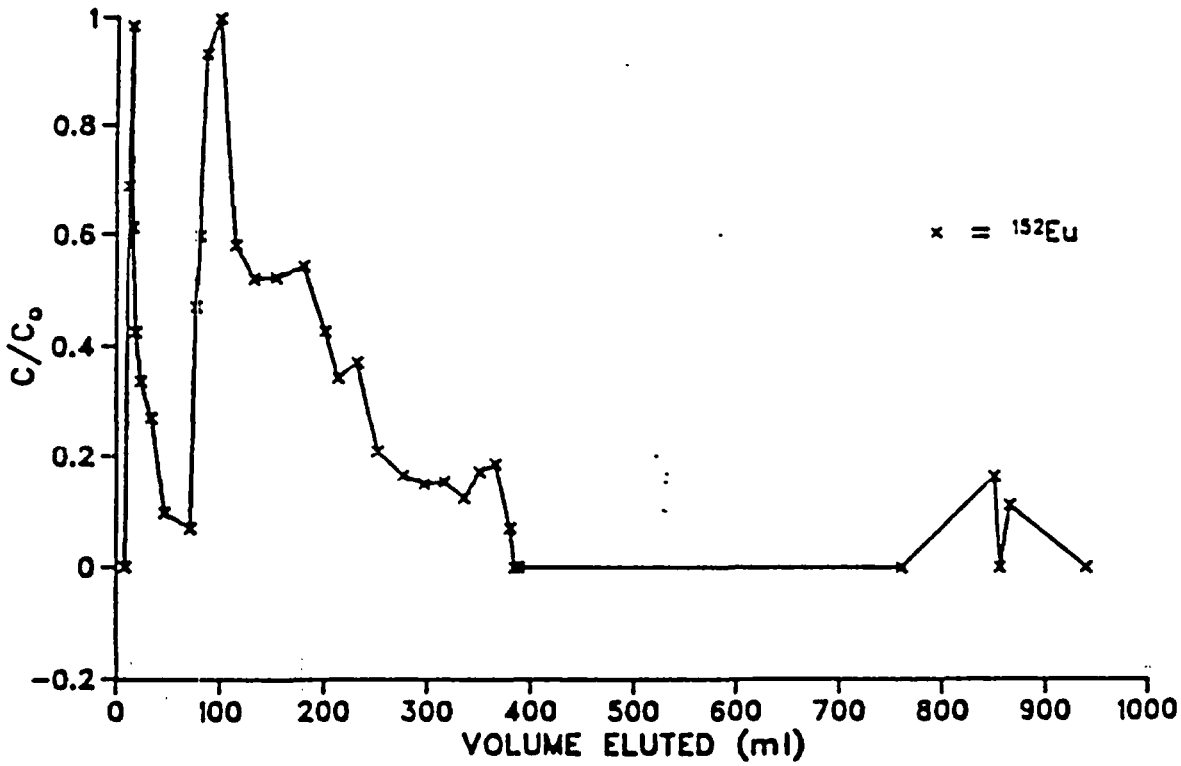


Fig. 10. Elution of Tuff JA18-2.

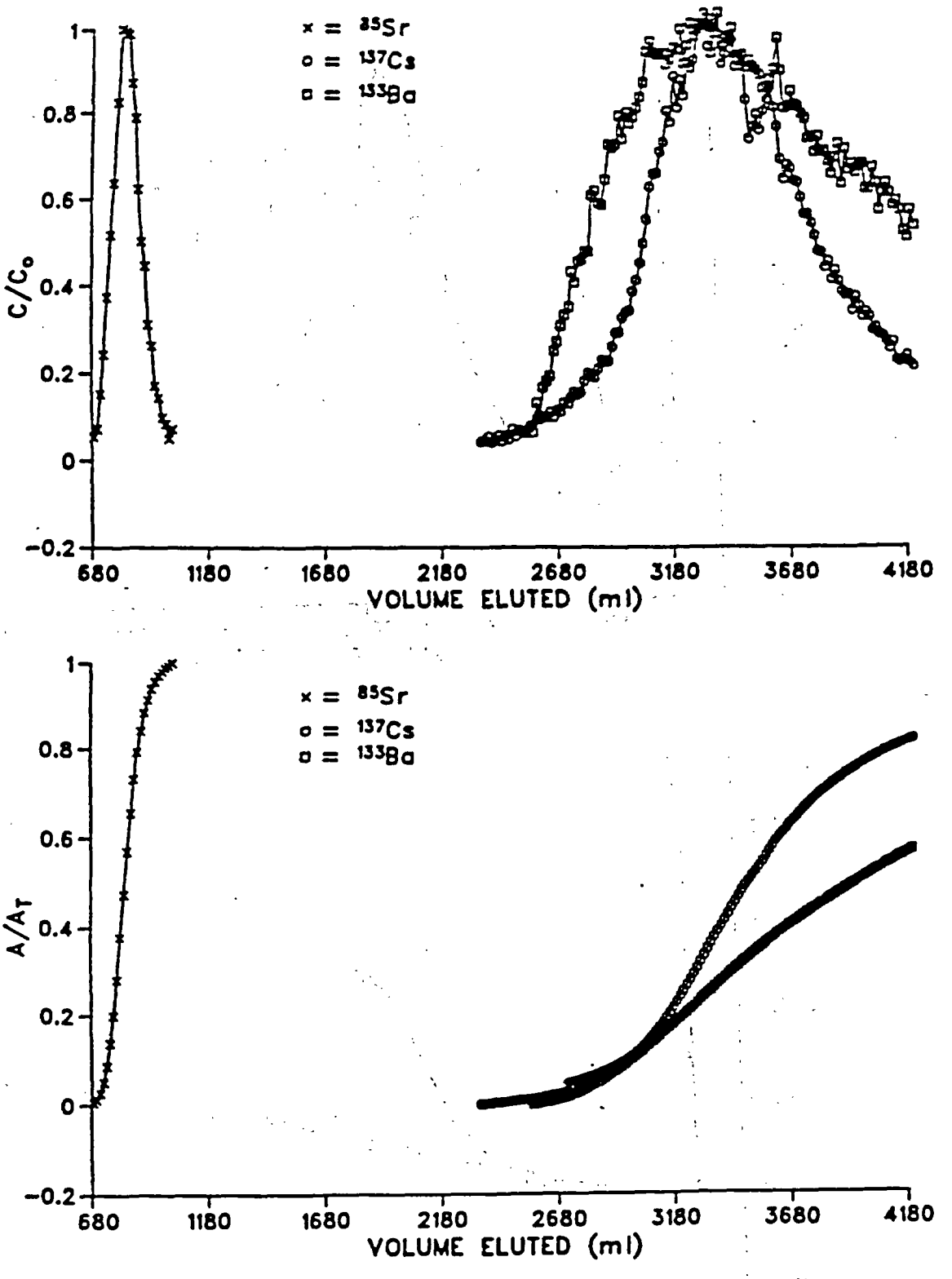
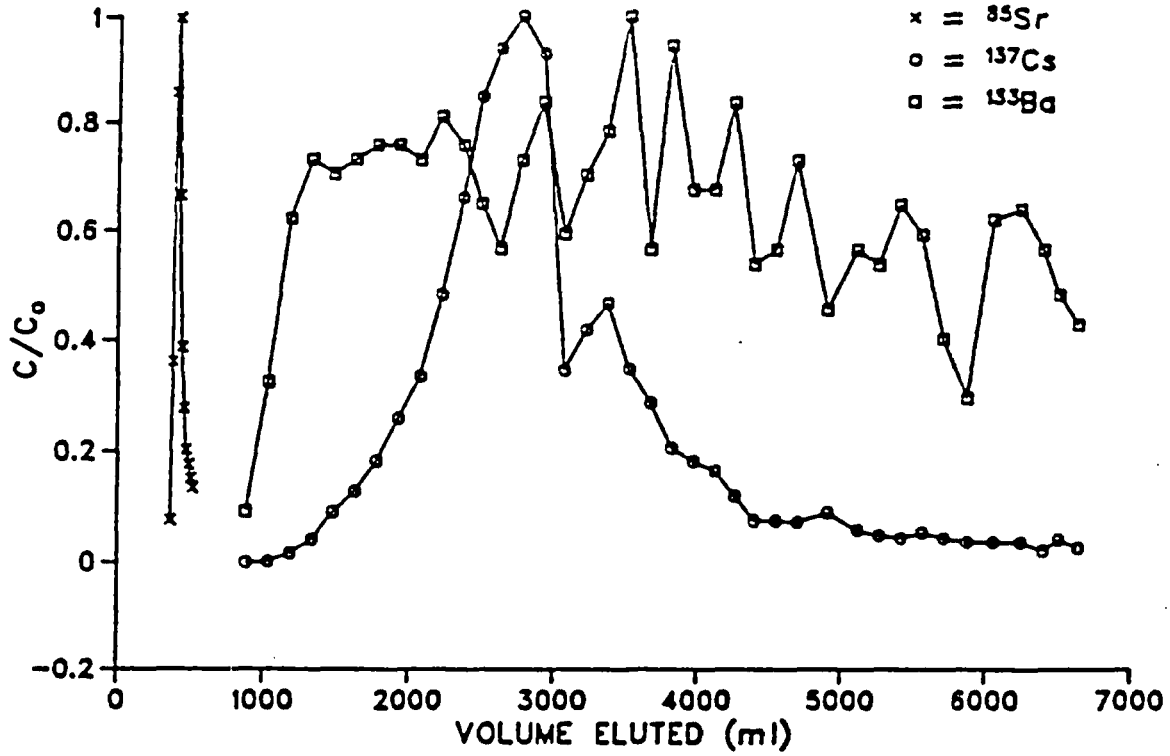


Fig. 11. Elution of Tuff G1-3658. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.



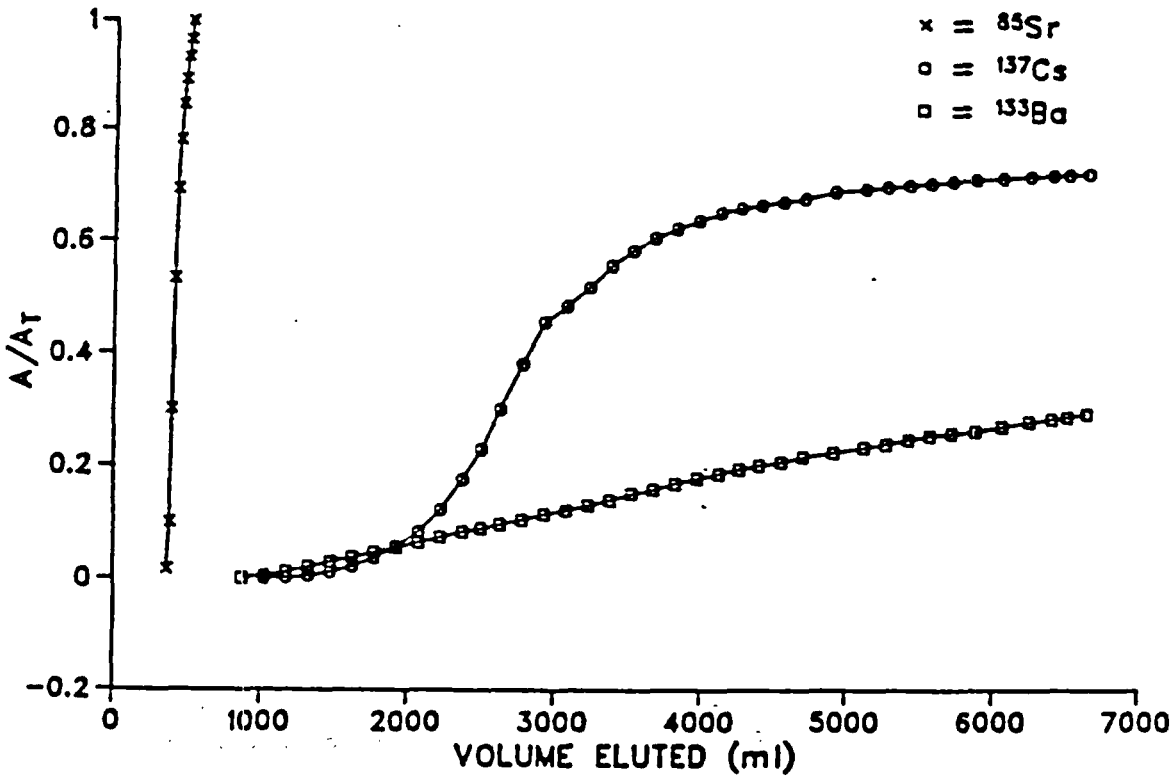


Fig. 12. Elution of Tuff G1-3116. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

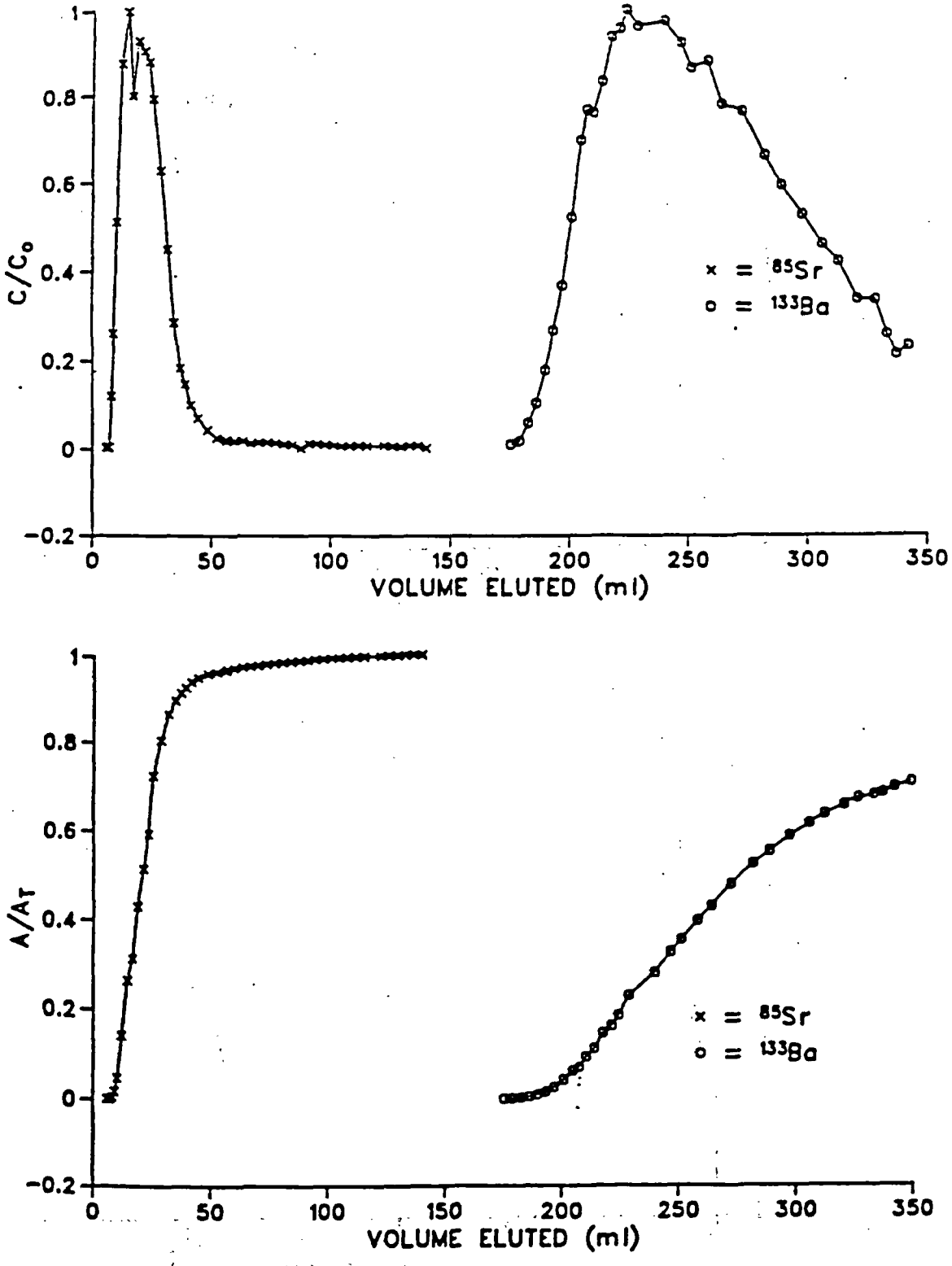


Fig. 13. Elution of Tuff G1-2901. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

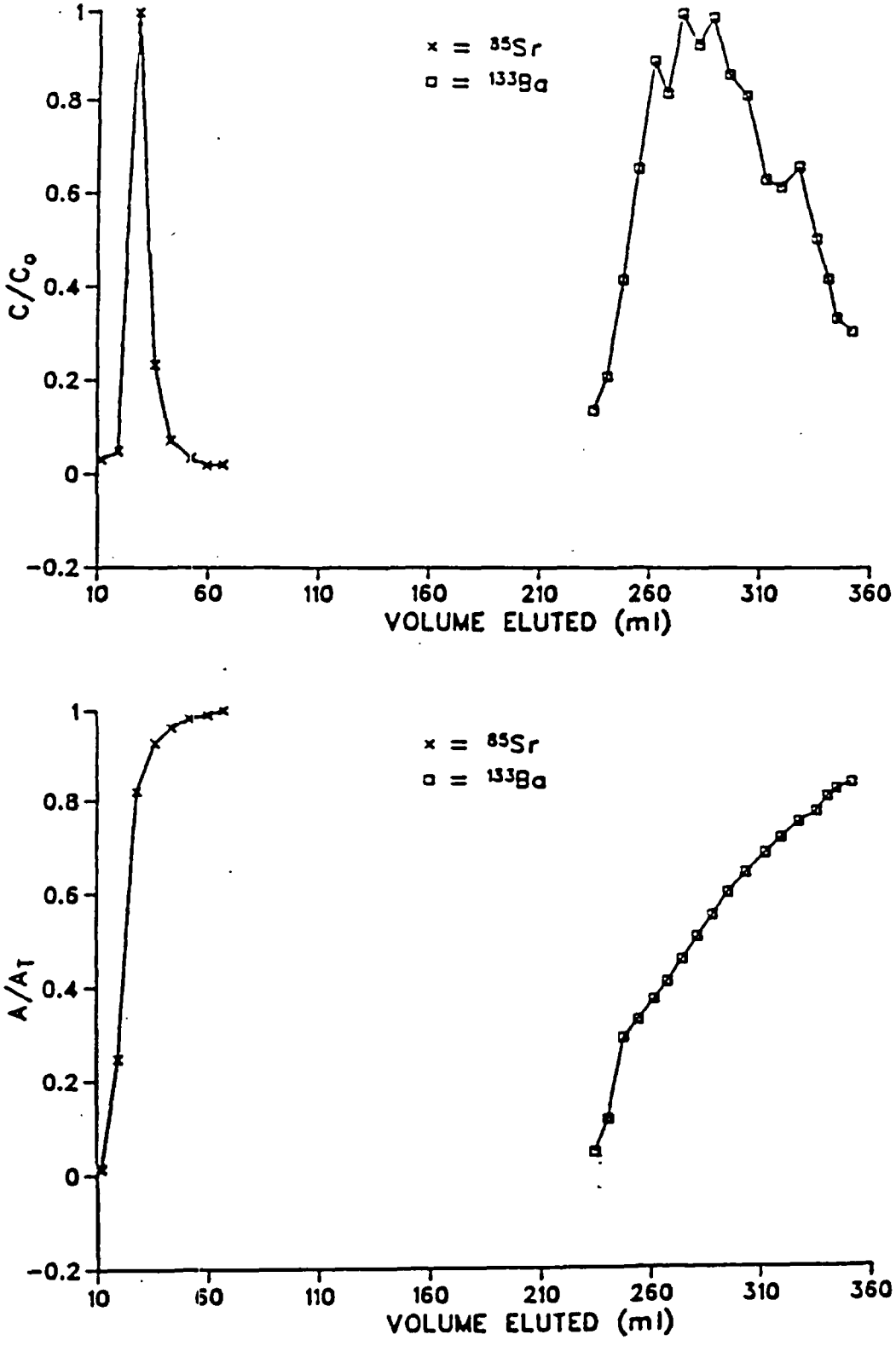


Fig. 14. Elution of Tuff G1-2476. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

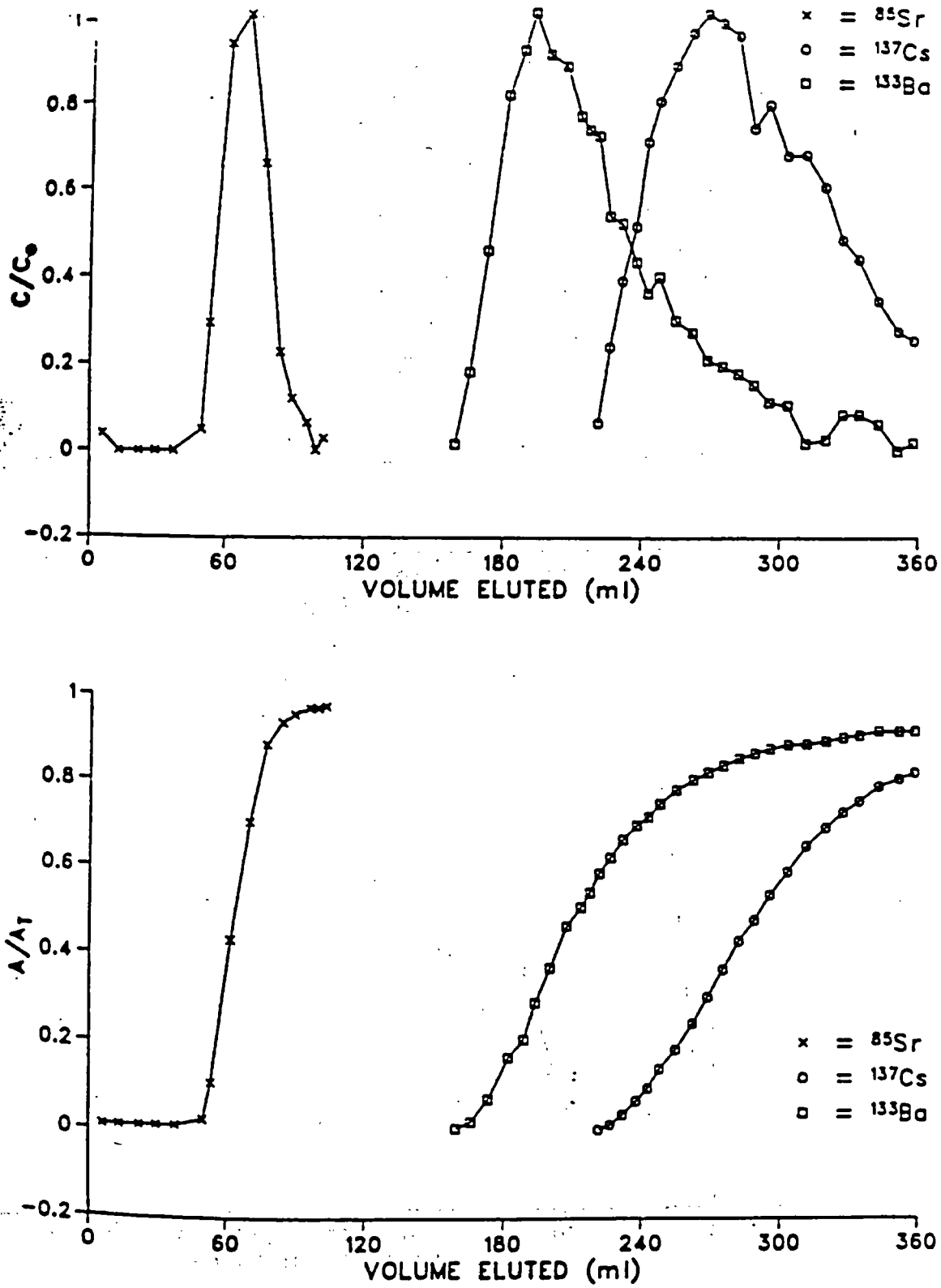


Fig. 15. Elution of Tuff G1-2363. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

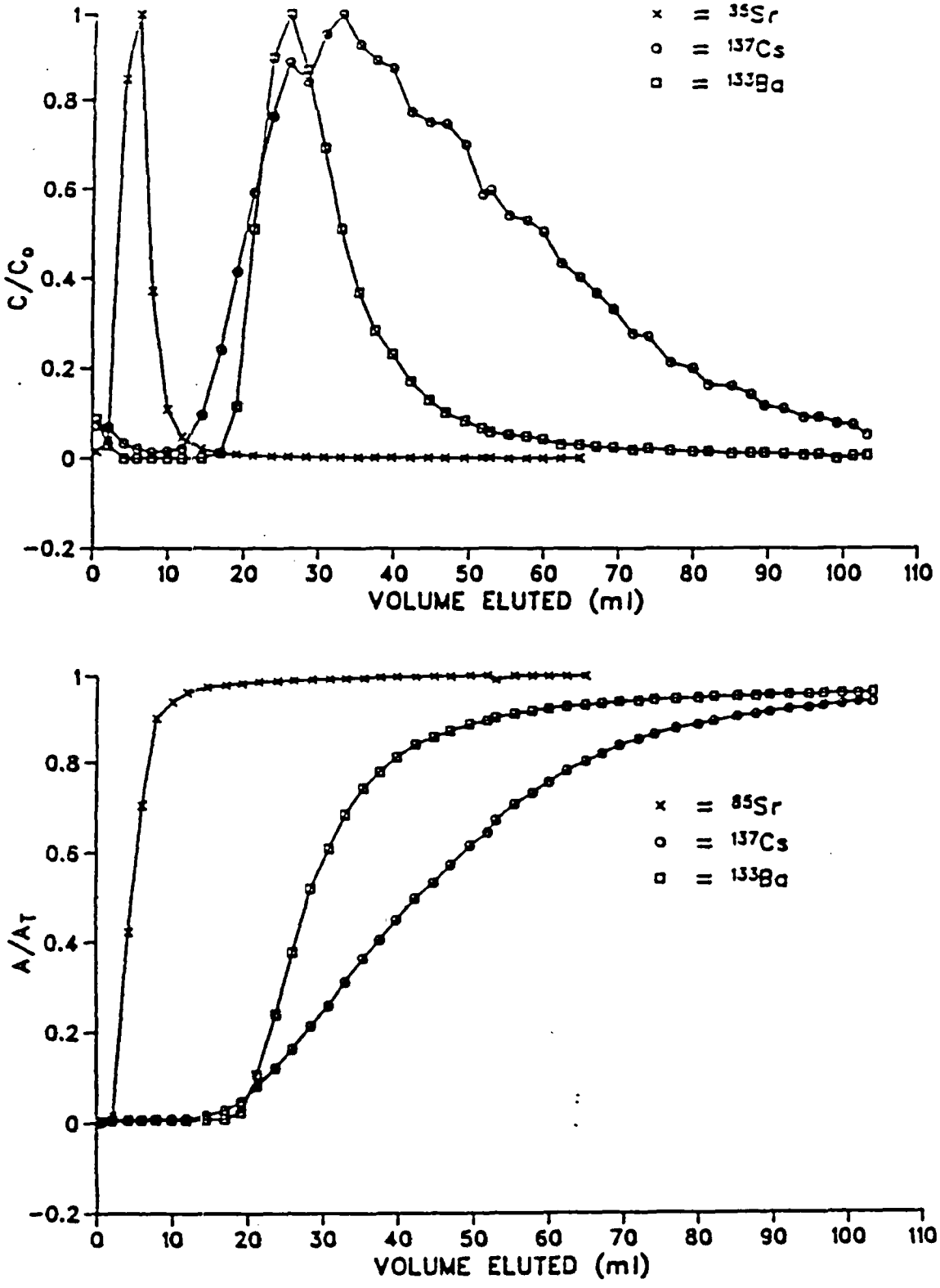


Fig. 16. Elution of Tuff G1-1883-1. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

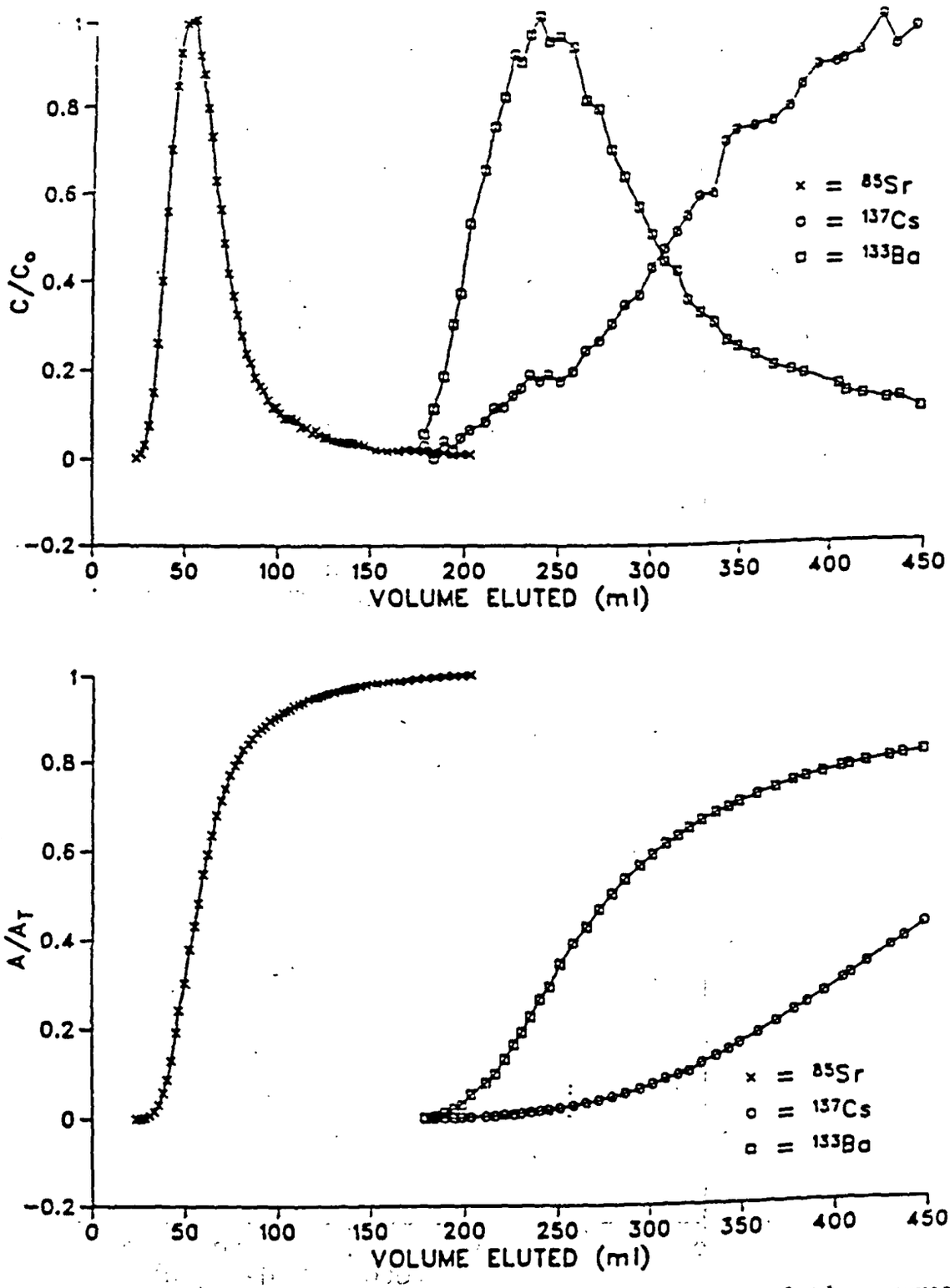


Fig. 17. Elution of Tuff G1-1883-2. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

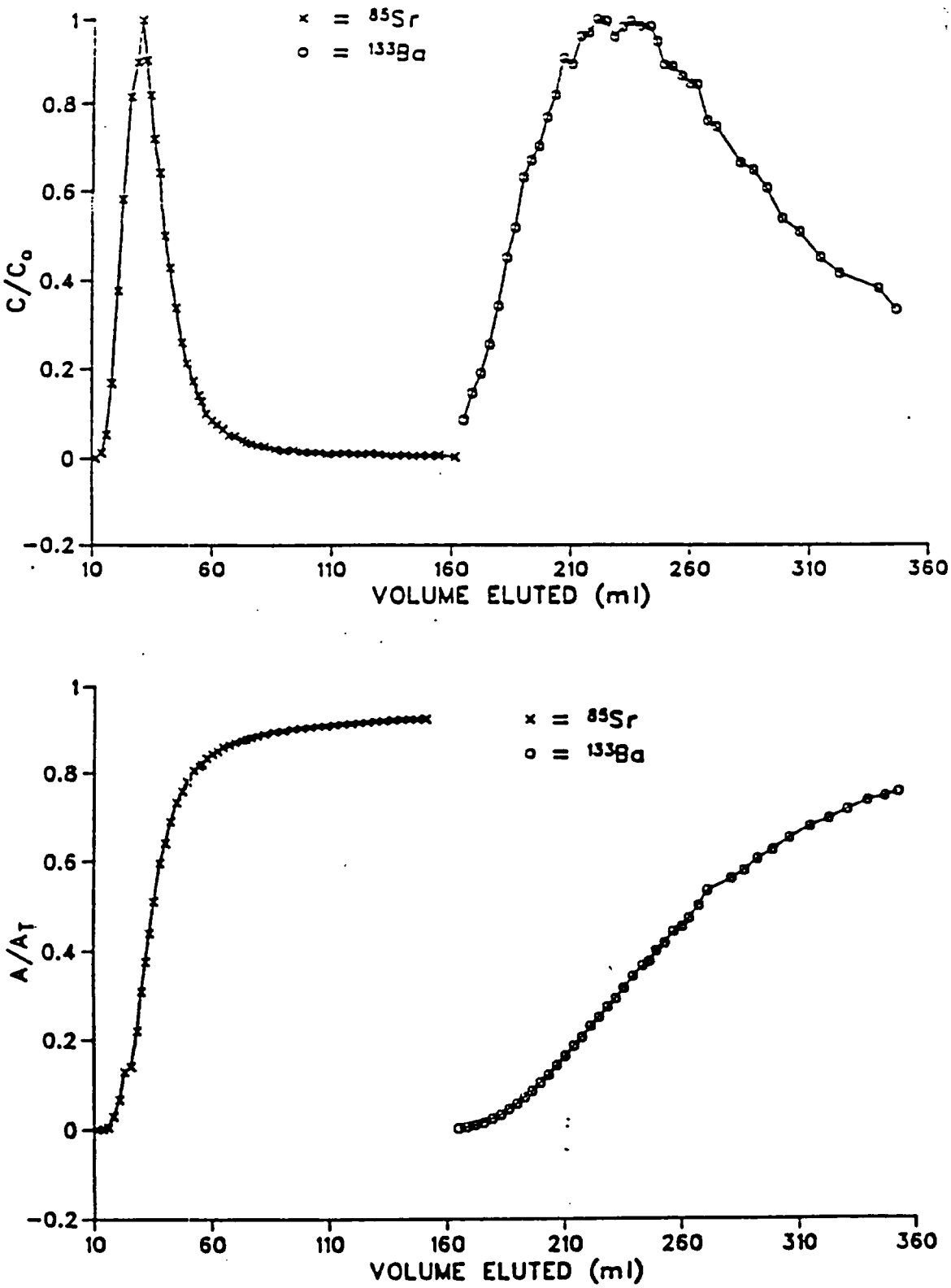


Fig. 18. Elution of Tuff G1-1982. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

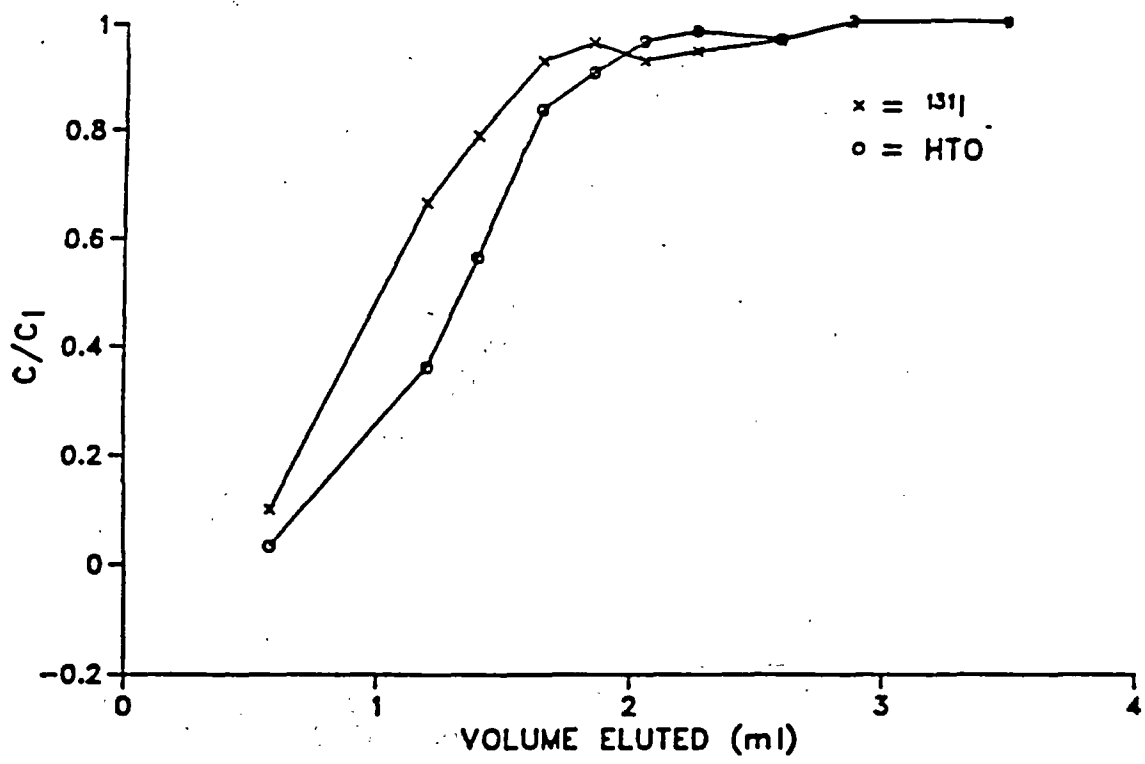


Fig. 19. Elution of Tuff G1-1436.

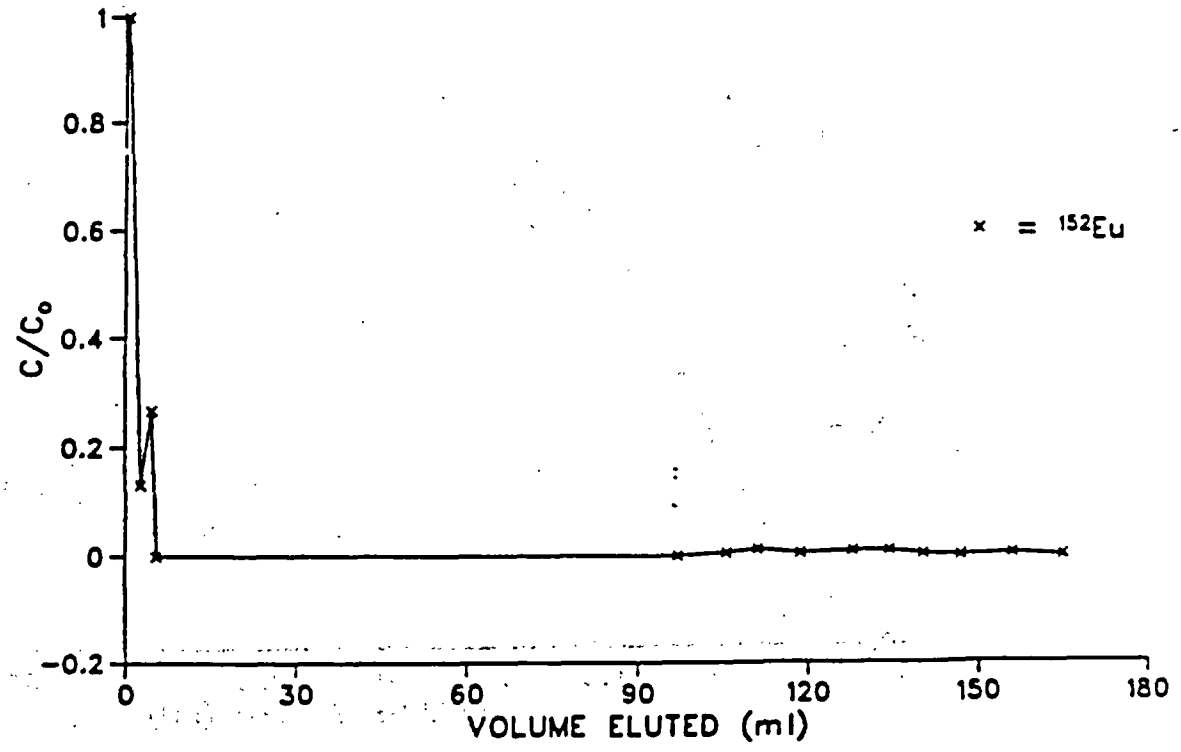
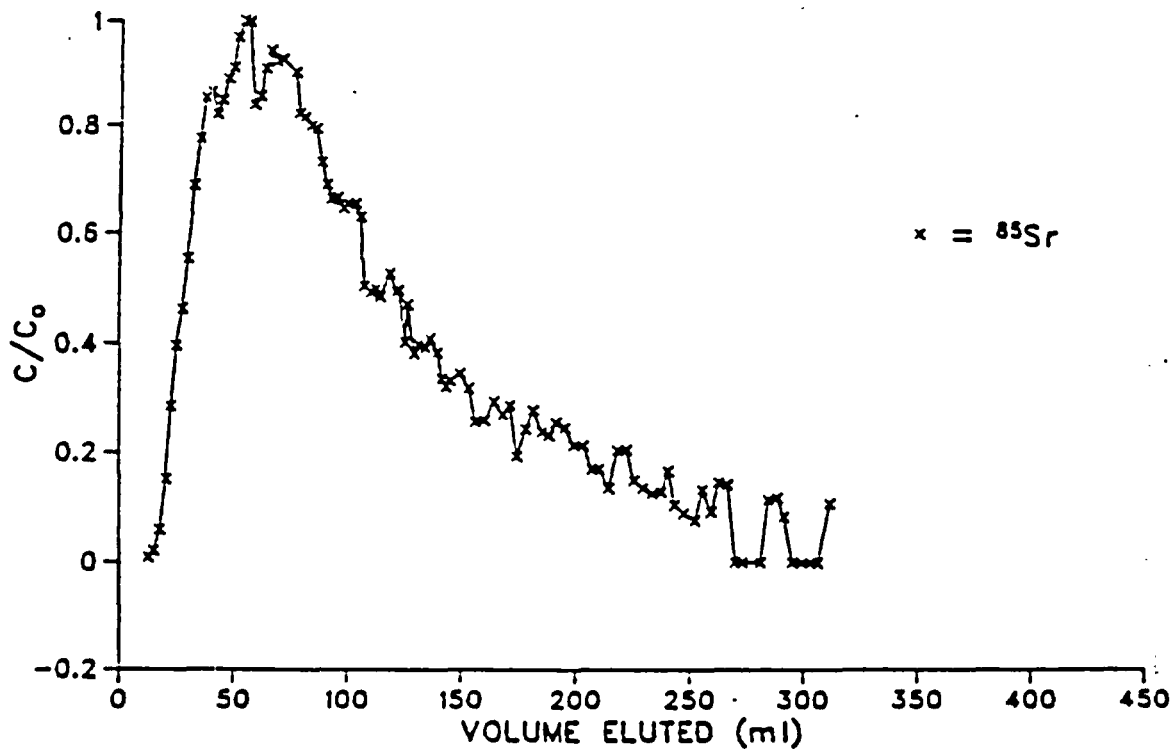


Fig. 20. Elution of Tuff G1-2289.



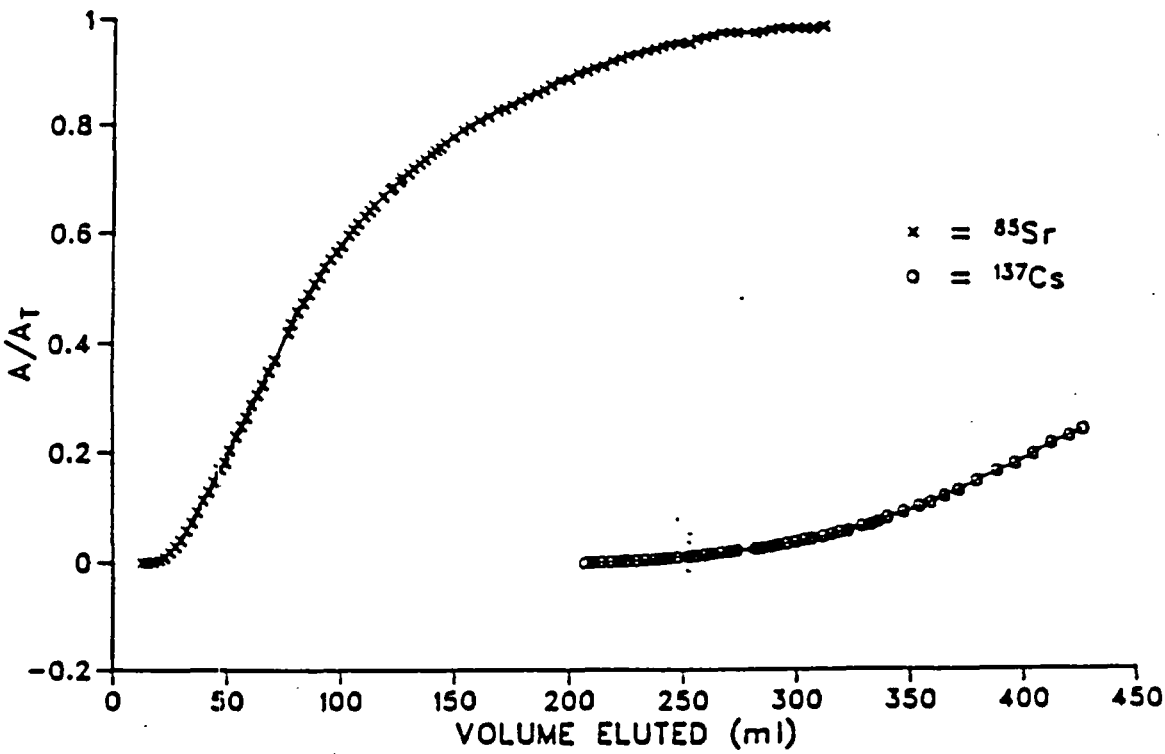
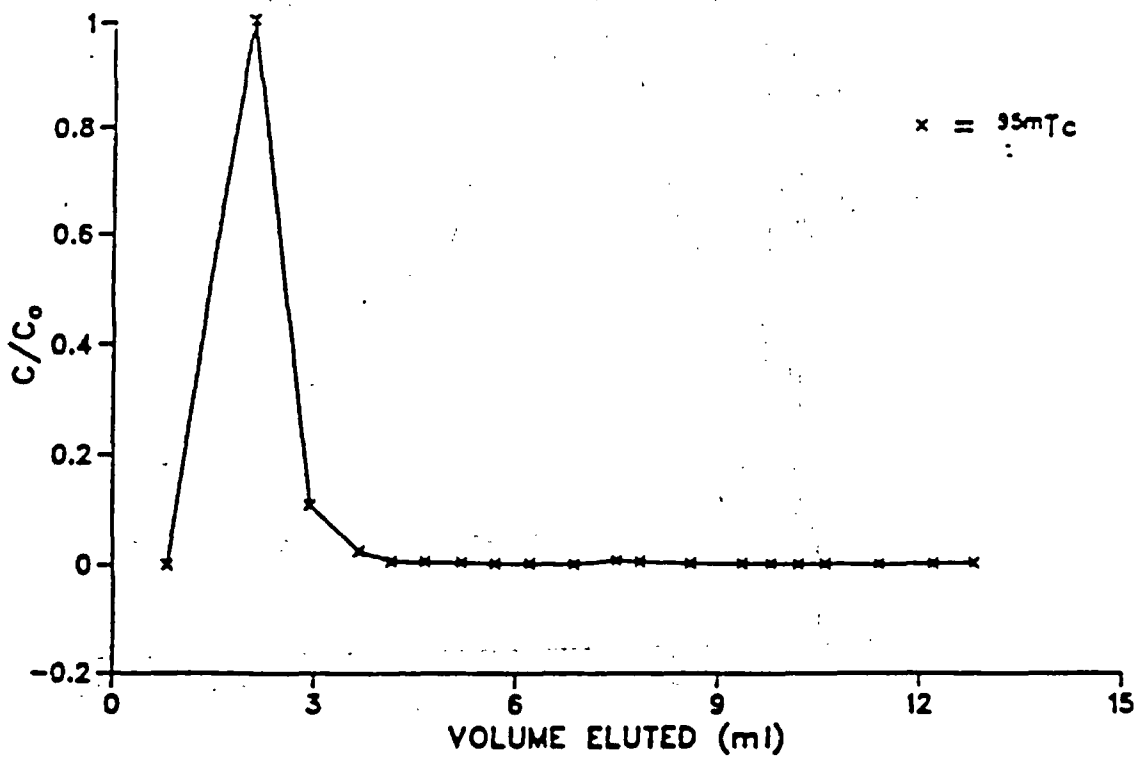


Fig. 21. Elution of Tuff G1-1292. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.



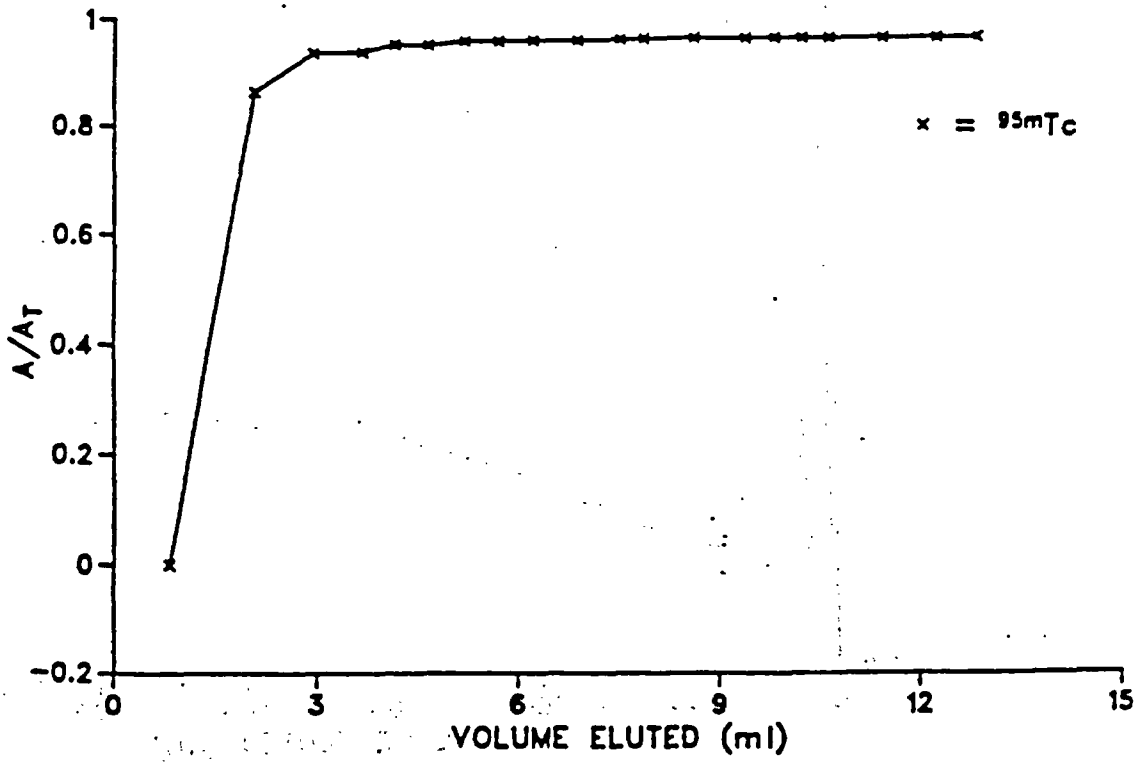
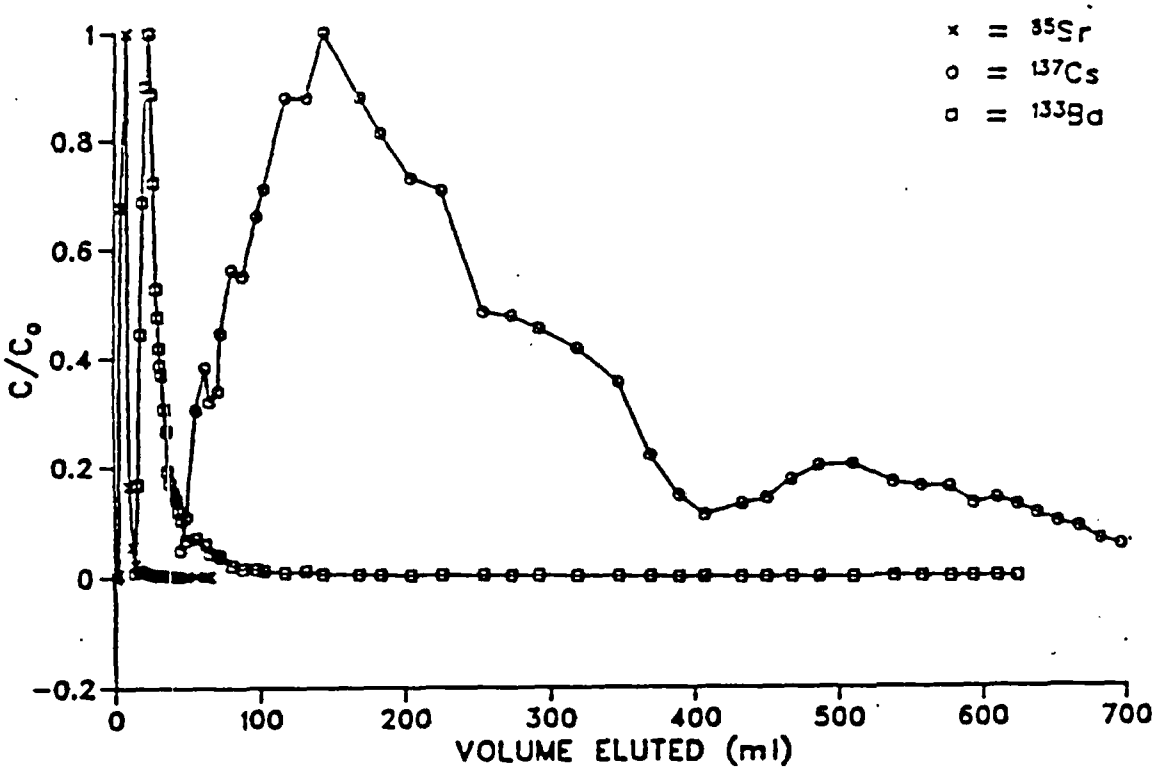


Fig. 22. Elution of Tuff GT-U12G. The top plot gives the elution curve, and the bottom plot gives the breakthrough curve.



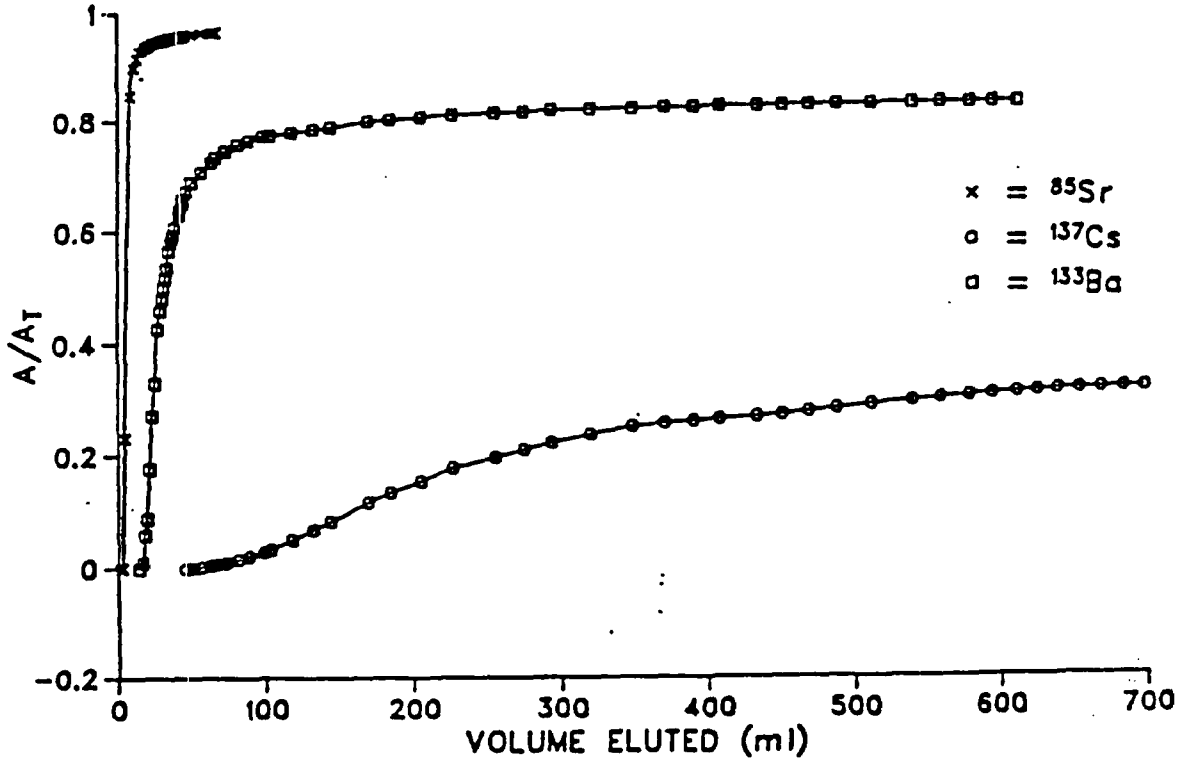


Fig. 23. Elution of Granite CS7. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

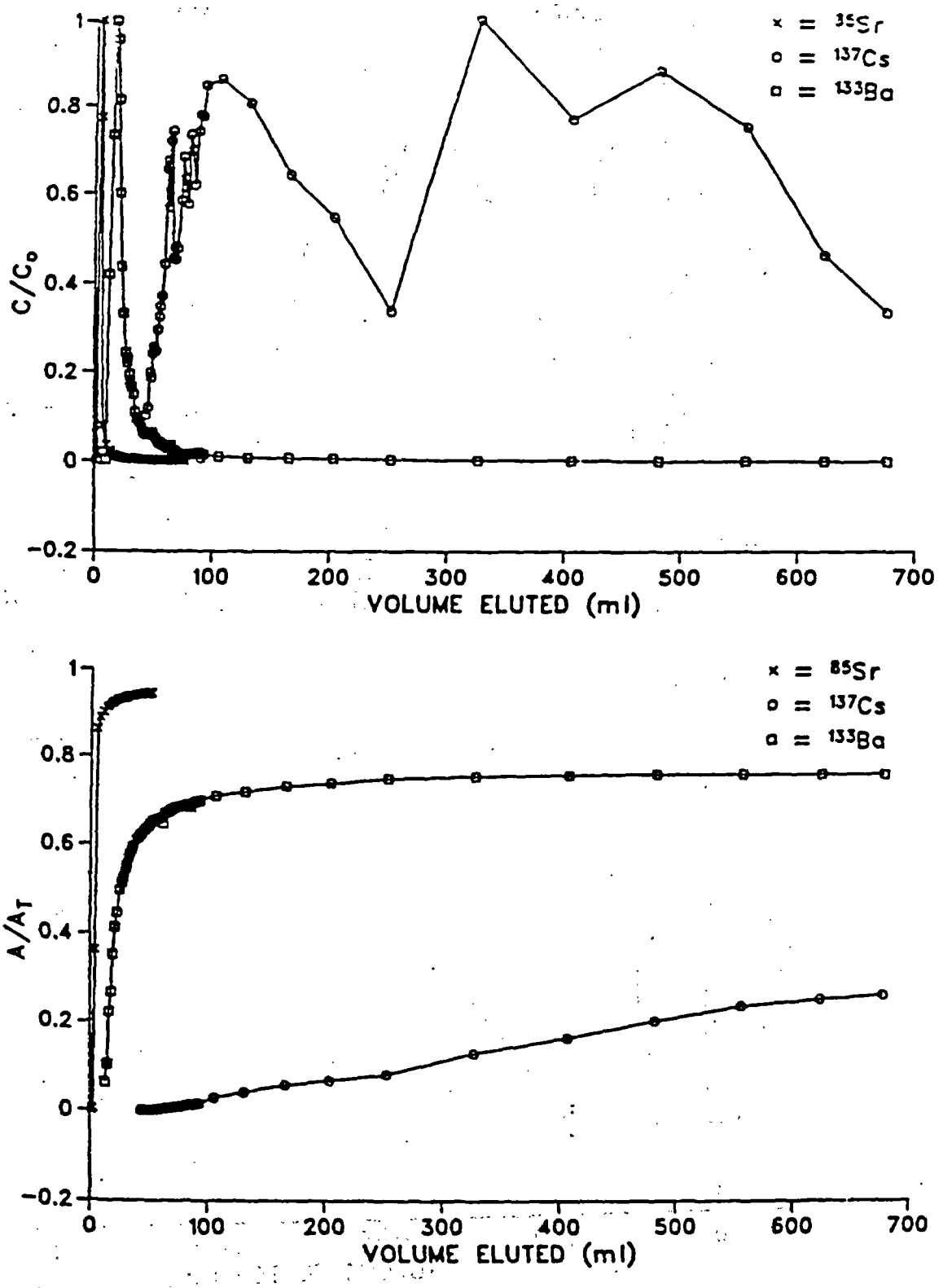


Fig. 24. Elution of Granite CS5-1. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

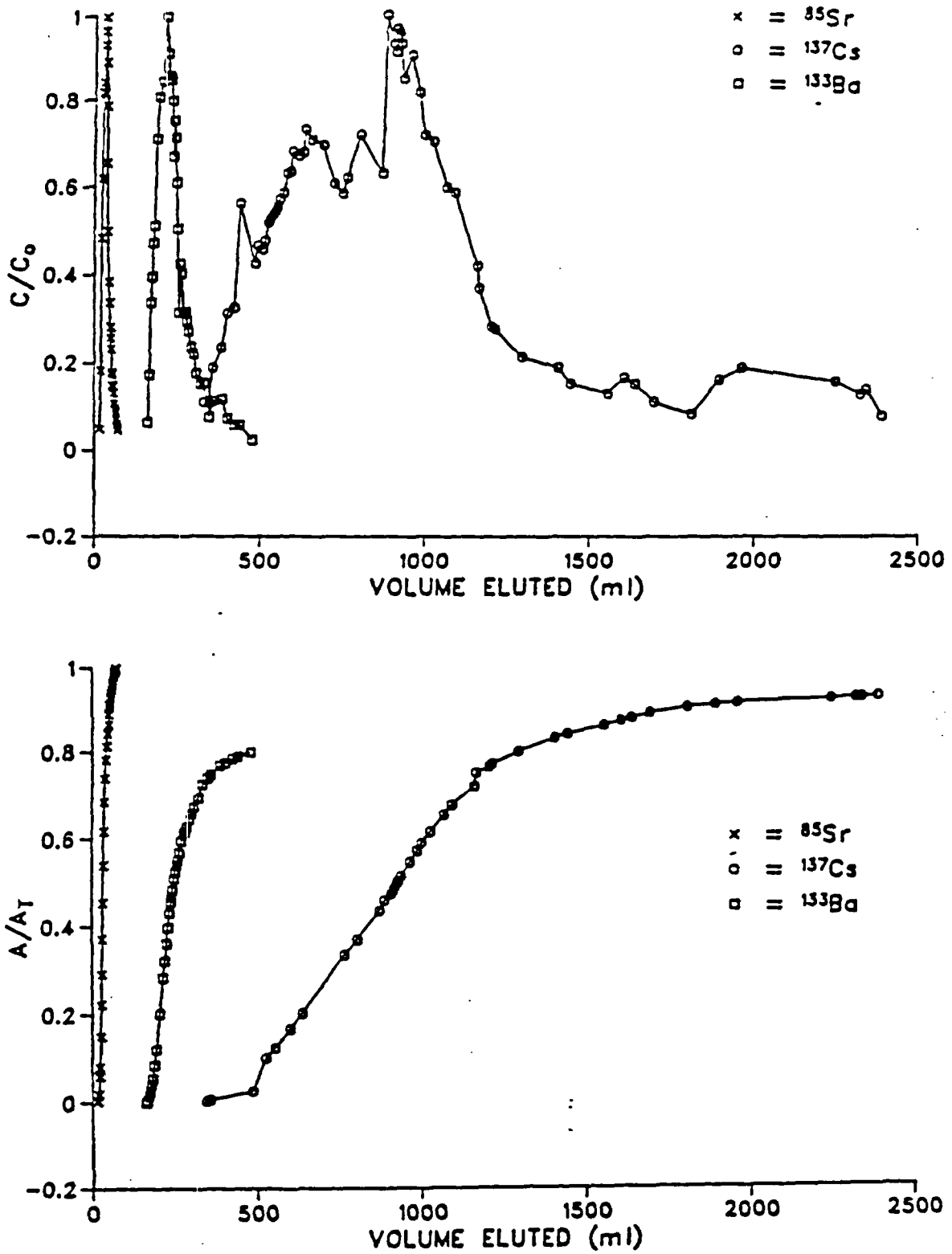


Fig. 25. Elution of Granite CS5-2. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

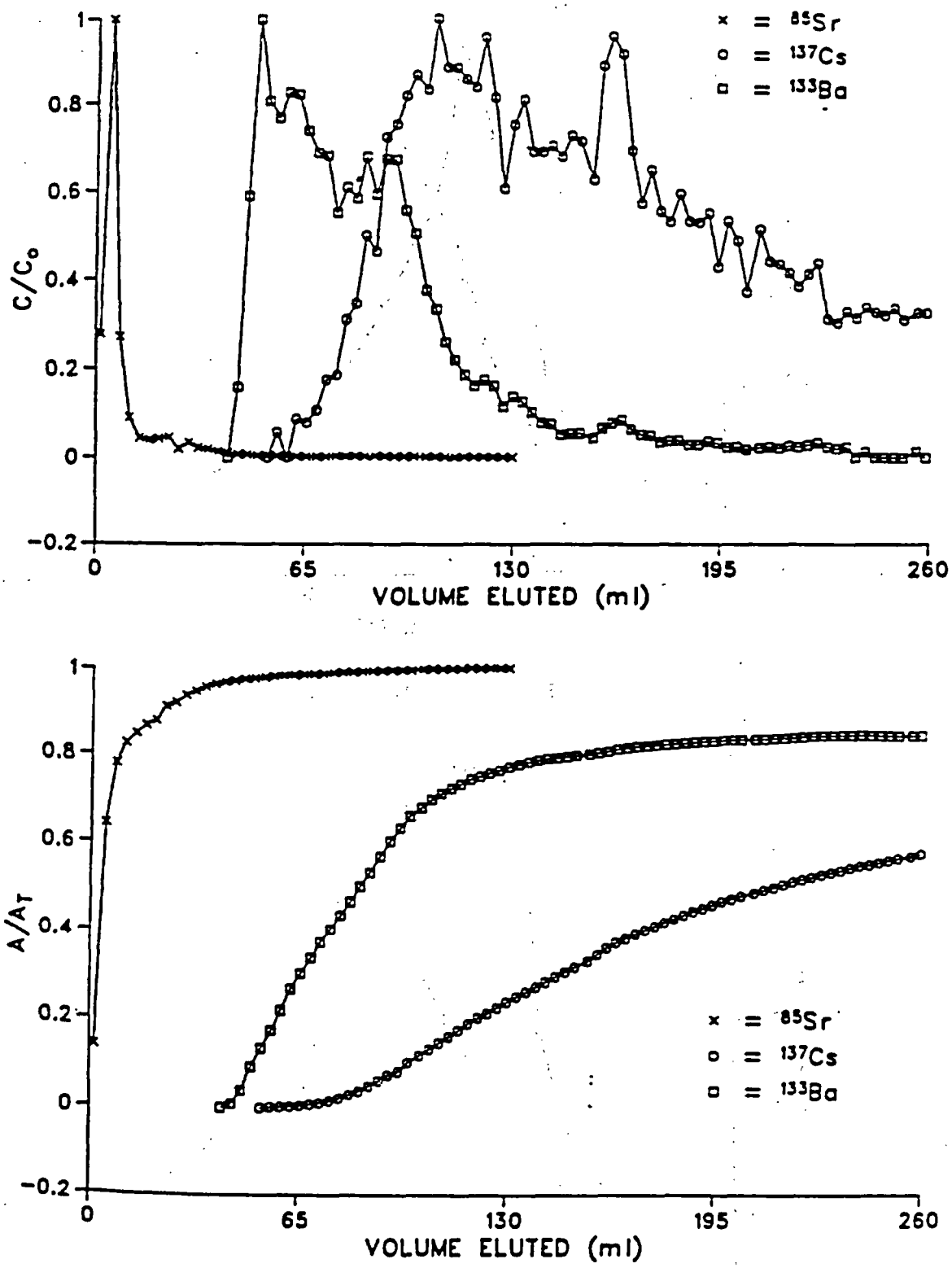


Fig. 26. Elution of Granite CS5-3. The top plot gives the elution curves, and the bottom plot gives the breakthrough curves.

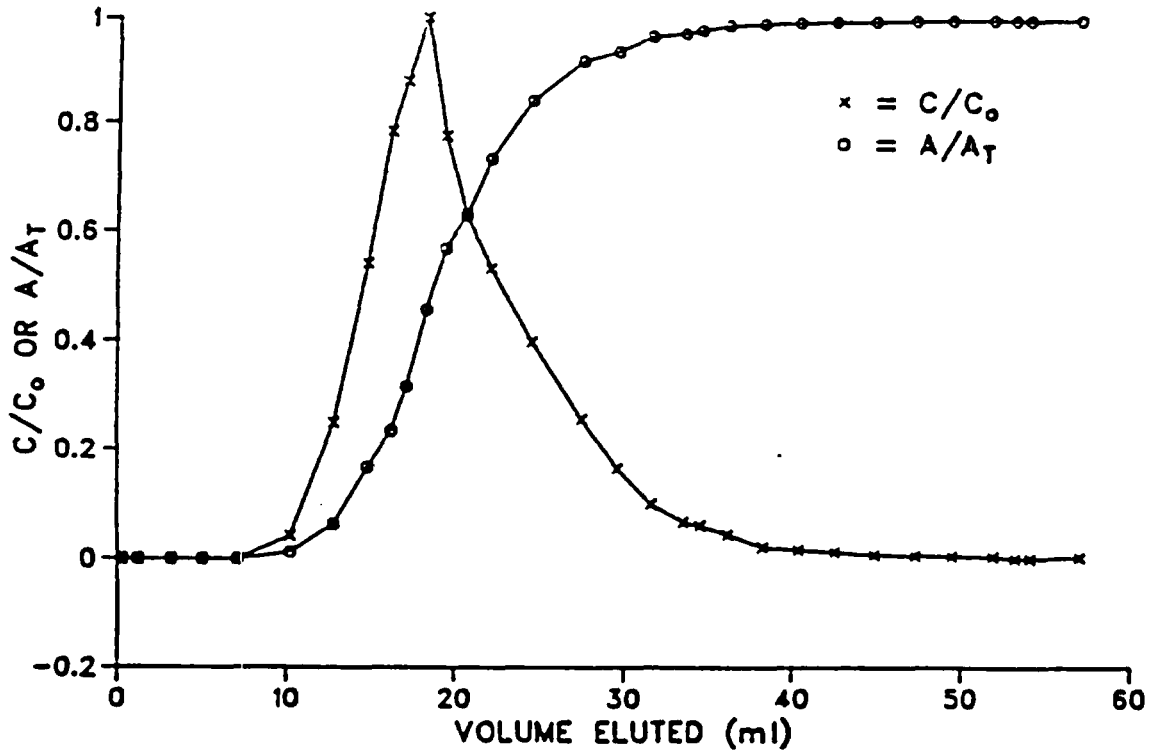


Fig. 27. Elution of Argillite CN1.

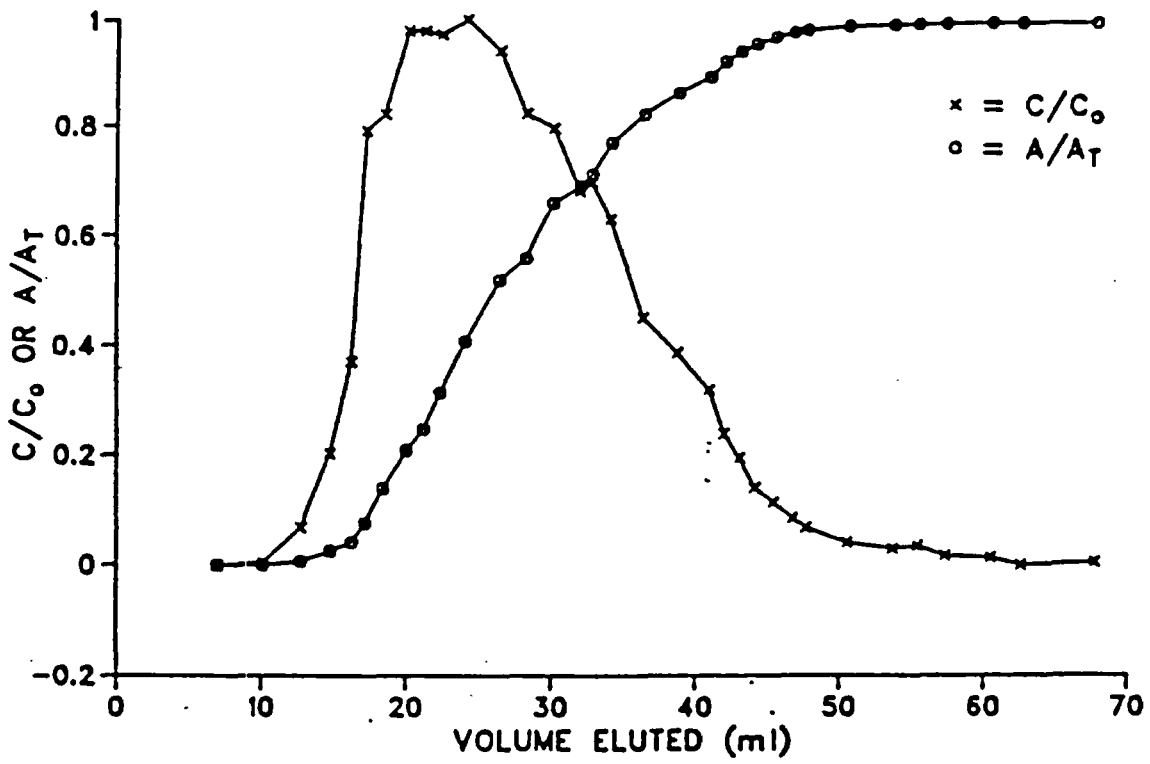


Fig. 28. Elution of Argillite CN2-1.

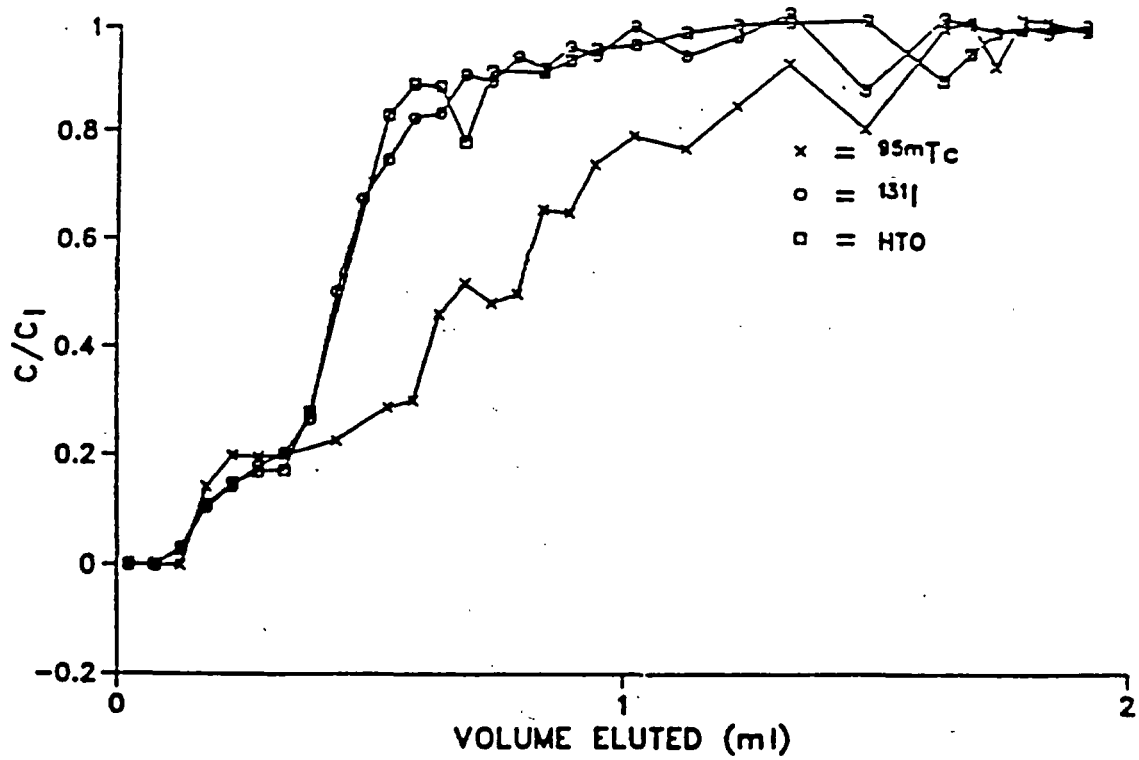


Fig. 29. Elution of Argillite CN2-2.

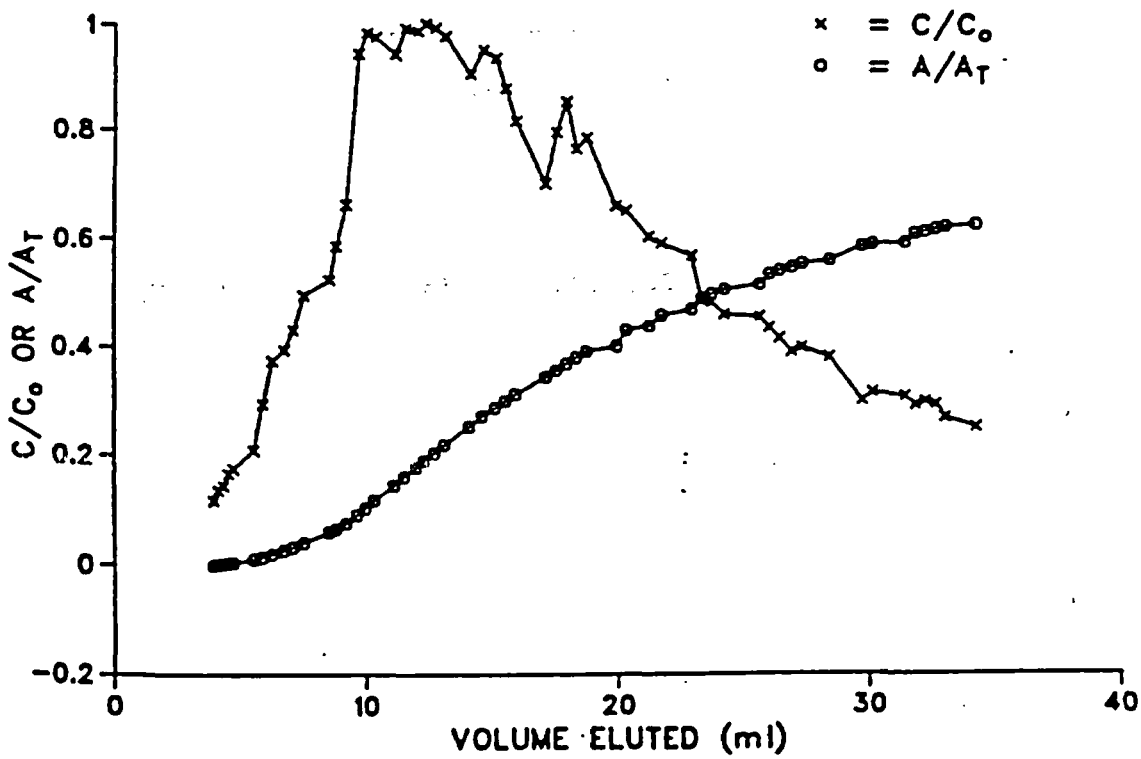


Fig. 30. Elution of ^{95m}Tc from Argillite CN2-3.

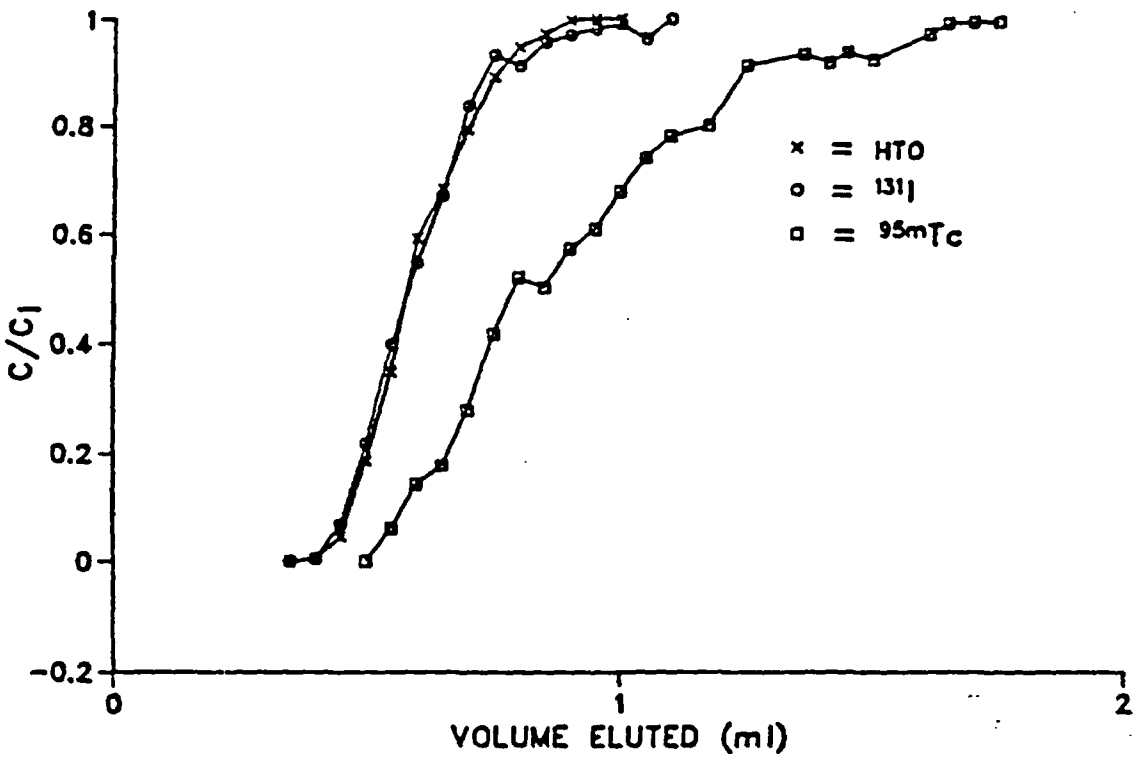


Fig. 31. Elution of Argillite CN3.

IV. RESULTS AND DISCUSSION

A. Iodide Elutions

As mentioned in the description of FCV measurements in Sec. II.C and shown in Table III, HTO and $^{131}I^-$ were both eluted from a number of columns. In one case only did the iodide and HTO data disagree: the iodide was eluted before the tritiated-water front. This was on an 8-cm long column of G1-1436 tuff that was run at a flow rate of 11 m/year. The elution data are plotted in Fig. 19. Anion exclusion of chloride has been observed previously.[11,12] On a soil with 40% clay content, Thomas and Swoboda[11] found that the rate of chloride movement was 1.37 times faster than D_2O. On column G1-1436 the $^{131}I^-$ breakthrough was at 1.016 mℓ and the HTO breakthrough was at 1.335 mℓ. Corrected for the frit, end cap, and tubing volumes, these are 0.779 and 1.099 mℓ. Thus, on G1-1436, which is predominantly clinoptilolite with a trace of clay, the relative rate of $^{131}I^-$ to HTO movement is 1.41. Whether the anion exclusion observed on column G1-1436 is reproducible and whether it is related to the cation exchange capacity, surface area, or other more complicated properties need to be determined.

B. Elutions of ^{85}Sr, ^{137}Cs, ^{133}Ba, ^{141}Ce, ^{152}Eu, and ^{95m}Tc

A summary of the retardation factors and corresponding sorption ratios for ^{85}Sr, ^{137}Cs, and ^{133}Ba on the columns studied is given in Table IV. The values were calculated using the volume at $A/A_T = 0.5$, where 50% of a given radionuclide was eluted, rather than the peak volume. The two volumes are not significantly different for the approximately symmetric elution peaks generally found for ^{85}Sr. However, barium and particularly cesium frequently gave asymmetric elutions with the peak containing <50% of the total activity. For these asymmetric peaks the volume to elute 50% of the activity could be significantly higher than the peak volume. For example, in the elution of ^{137}Cs from G1-1883-1 the peak occurred at ~32 mℓ, but 50% of the activity was not completely eluted until ~42 mℓ.

Because most radionuclide breakthrough curves are not symmetric, it has been said that such column breakthrough data cannot be used to accurately determine R_d values.[13] However, the sorption ratios obtained here on ~40 columns are generally in agreement with values measured by batch techniques.

Tables V through VIII give a comparison of batch and column R_d values, and the majority of column R_d values fall within the range of batch values measured on washed fractions.

Earlier reports[6,7] indicated that the column sorption ratios were usually ~1.2 to 3.2 times lower for ^{85}Sr and ^{137}Cs and 2 to 5 times lower for ^{133}Ba than the corresponding batch results. Since those reports were published, a number of batch measurements on tuffs have been repeated using washed, sieved fractions.[14,*] These measurements were made to see if fine material, <38 μm, present in many batch measurements, but not present in the crushed rock columns, was responsible for the difference between column and batch results. Preliminary results[14] on tuff G1-1982 supported this hypothesis. When fractions of G1-1982 were washed to remove the fine particles and then used in batch measurements, the range of sorption ratios for ^{85}Sr was 49 to 66 mℓ/g, compared to a column R_d value of 53 mℓ/g. The original ^{85}Sr batch measurements on a <500-μm fraction of G1-1982 gave 310 to 430 mℓ/g. Additional batch measurements on washed fractions of tuffs, such as YM54, G1-2363, and G1-1883, have also shown considerable differences in sorption ratios compared to measurements on the same tuffs containing fines.[10,*] There is evidence to suggest that the fines contain more clay, which could account for their higher sorption ratios.[15]

A summary of the differences in R_d values for ^{85}Sr, ^{137}Cs, and ^{133}Ba found by the batch and column methods is given in Table IX. Columns JA18 and GT-U12G are not included because the column data were insufficient to make comparisons. The sorption ratios for ^{85}Sr measured with crushed-rock columns fall within the range of measured batch values for 11 of 17 media. The apparent difference between column and batch R_d values for the other six materials may not be real. For four of the six materials, batch measurements have been made only on fractions that contained fines. It is, therefore, likely that the batch sorption ratios would agree much better with the measured column values if they were determined using fractions washed free of fines. Support for this hypothesis has been obtained with circulating batch-type measurements[8] where the rock is held fixed in a tube with frits on each end and the traced solution is recirculated through the rock. Better agreement has been obtained for the

*From information provided by S. Knight, Los Alamos National Laboratory, April 1982.

circulating batch-type system with the crushed-rock column data than with the batch measurements.[15,16] Except for ^{85}Sr on JA37, the crushed-rock column and circulating batch results agree--not only for ^{85}Sr but also for ^{137}Cs and ^{133}Ba. The agreement may be due to the lack of fines in the circulating batch measurements because once the fines were removed and the original (shaking) batch measurements were repeated on YM54, they, too, agreed with the R_d values from the column and circulating systems. Also, for YM22, there is agreement between the column and circulating-type batch measurements, while the batch measurements on unwashed fractions give R_d values ~2 times larger.

With 2 columns, G1-3658 and JA37, there is disagreement with ^{85}Sr batch R_d values obtained on washed fractions. However, JA37 was a lined column and leaking of activity around the liner may have occurred. Tuff G1-3658 is 40 to 80% montmorillonite. Although particles <38 μm were removed before the measurements, new fines may have been created by abrasion during the course of the batch experiments. Such abrasion would be unlikely in a packed column flowing at 30 to 50 m/year. This might also explain the factor of 2 difference between column and batch measurements on JA37, which is 20 to 40% clay. However, the agreement between the two types of batch measurements (because abrasion is unlikely in the circulating system) indicates that there is more likely to be an error in the column results (perhaps as a result of leaking, as mentioned).

Three columns gave broad, asymmetric strontium peaks: G1-3658, G1-3116, and G1-1292. For two, G1-3658 and G1-3116, this is not surprising, because the columns were run at flow rates 1 to 2 orders of magnitude faster than the other columns. The peaks of the three CS5 columns broadened with increasing flow rate, and such behavior is well known for ion exchange resins.[17] The only broad strontium peak from a column run at a slow flow rate was from tuff G1-1292. A comparison of this elution with those from columns YM22, YM54-3, and JA32-1 is given in Fig. 32. Sample G1-1292 is a vitrophyre containing 80 to 90% glass and is the only glassy tuff for which a strontium elution has been obtained. Elution of YM5 (70% glass) is in progress, and initial data indicates a similar broad elution. No strontium data were obtained from JA18, which contains 50% glass, because this tuff also contains a strongly sorbing zeolite, clinoptilolite, so that the ^{85}Sr was not eluted before decaying. Thus, preliminary evidence indicates that strontium behaves quite differently on glassy tuffs. Perhaps a gradual dissolution of the glass occurs, leading to a slow elution of

TABLE V

^{85}Sr: A COMPARISON OF BATCH AND COLUMN R_d VALUES

Column Material	R_d (mℓ/g) Batch[a]	R_d (mℓ/g) Column[b]
Tuff		
YM54	80-86[c] 37-57[d] (39-53)	42, 44
YM22	48-63[c] (21-29)	22
JA37	256-351[e] (365-420)	123
JA32	41-72[f]	39-55
G1-3658	11 600-13 500[d] 3500-17 000[g]	984
G1-3116	2200-2500 and 3100-58 000[g]	449
G1-2901	66-71[g]	29
G1-2476	40-41[h] 198-206	22
G1-2363	62-74[i]	60
G1-2233	40 000-50 000 and 13 000-190 000[g]	[24 000-38 200]
G1-1982	49-66[j]	53
G1-1883	22[i]	14, 28
G1-1292	110-220[g]	113
GT-U12G	470-2500[g]	[>1550]

TABLE V (cont)

Column Material	R_d (mℓ/g) Batch[a]	Column[b]
Granite		
CS7	14-30[k]	12
CS5	11-28[l]	7-26
Argillite		
CN1	48-80[m]	44
CN2-1	64-118[n]	57

[a]For batch data, the range of sorption and desorption values is given with the sorption values first and the desorption values second when the data are given in two lines (unless otherwise noted). Values in parentheses are from circulating-type batch measurements, Ref. 7, Table XVIII.

[b]Column R_d values given in brackets were calculated from data obtained by sectioning the column after elution.

[c]From Ref. 6, Table VII, unwashed fraction 106 to 500 μm, 20 to 40 days.

[d]From Ref. 11, washed fractions 38 to 106 μm and 106 to 500 μm, 3 weeks.

[e]From Ref. 1, Table XV, washed fraction 106 to 150 μm, 12 to 87 days.

[f]From Ref. 1, Table XIII, washed fraction 106 to 150 μm, 10 to 81 days.

[g]From Ref. 8, fraction <500 μm, 22 to 42 days. Note: G1-3658 values were wrong in Ref. 8 by a factor of 10. GT-U12G values are for sorption only, 1 to 6 weeks, fracture-fill material.

[h]From Ref. 9, unwashed fraction 75 to 500 μm, 21 to 42 days.

[i]From Ref. 10, washed fraction 38 to 106 μm, 21 days, sorption only.

[j]From Ref. 15, Table XIV, washed fractions 38 to 75 μm, 75 to 250 μm, and 250 to 500 μm; 2 to 3 weeks, sorption only.

[k]From Ref. 2, Table IX, 3 washed fractions >106 μm, 10 to 62 days.

[l]From Ref. 2, Table VIII, 3 washed fractions >106 μm, 10 to 62 days.

[m]From Ref. 3, Table VII, washed fraction 355 to 500 μm, 7 to 56 days.

[n]From Ref. 3, Table VIII, washed fraction 355 to 500 μm, 7 to 56 days.

TABLE VI

^{137}Cs: A COMPARISON OF BATCH AND COLUMN R_d VALUES

Column	R_d (mℓ/g) Batch[a]	Column[b]
Tuff		
YM54	205-393[c] 114-188[d] (99-158)	76-130
YM38	8220-13 100 and 14 000-16 600[c]	24 100
YM22	237-382[c] (405-616)	363
JA37	492-1022[e] (1480-1920)	1390
JA18	11 700-19 500[f]	[6 560-24 700]
G1-3658	4910-7080[d] 7700-18 000[g]	4150
G1-3116	5500-7600 and 6200-21 000[g]	4260
G1-2901	950-1400[g]	[728-810]
G1-2476	660-741 and 1520-1530[h]	[372-393]
G1-2363	520-553[i]	273
G1-2233	11 000-15 000 and 6500-31 000[g]	[84 000-129 000]
G1-1982	1410-2900[g] 960-1300[j]	[1350-1720]
G1-1883	183-198[i]	129, [283]
G1-1292	380-560[g]	[903-1142]
GT-U12G	2100-16 000[g]	[>1550]

TABLE VI (cont)

Column	R_d (mℓ/g) Batch[a]	Column[b]
Granite		
CS7	248-1030[k]	[5620-7400]
CS5	220-660[l]	[6630-18 900], 213, 931
Argillite		
CN1	823-2940[m]	[2710-6770]
CN2	671-4210[n]	[4333-7950]

[a]For batch data, the range of sorption and desorption values is given with the sorption values first and the desorption values second when the data are given in two lines (unless otherwise noted). Values in parentheses are from circulating-type batch measurements, Ref. 7, Table XVIII.

[b]Column R_d values given in brackets were calculated from data obtained by sectioning the column after elution.

[c]From Ref. 6, Table VII, unwashed fraction 106 to 500 μm, 20 to 40 days.

[d]From Ref. 14, washed fractions 38 to 106 μm and 106 to 500 μm, 3 weeks.

[e]From Ref. 1, Table XV, washed fraction 106 to 150 μm, 13 to 101 days.

[f]From Ref. 6, Table XI, washed fraction 106 to 150 μm, 20 to 40 days.

[g]From Ref. 8, fraction <500 μm, 22 to 42 days. Note: G1-3648 values were wrong in Ref. 8 by a factor of 10. GT-U12G values are for sorption only, 1 to 6 weeks, fracture-fill material.

[h]From Ref. 9, unwashed fraction 75 to 500 μm, 21 to 42 days.

[i]From Ref. 10, washed fraction 38 to 106 μm, 21 days, sorption only.

[j]From Ref. 15, Table XIV, washed fractions 38 to 75 μm, 75 to 250 μm, and 250 to 500 μm; 2 to 3 weeks, sorption only.

[k]From Ref. 2, Table IX, 3 washed fractions >106 μm, 10 to 62 days.

[l]From Ref. 2, Table VIII, 3 washed fractions >106 μm, 10 to 62 days.

[m]From Ref. 3, Table VII, washed fraction 355 to 500 μm, 7 to 56 days.

[n]From Ref. 3, Table VIII, washed fraction 355 to 500 μm, 7 to 56 days.

TABLE VII

^{133}Ba: A COMPARISON OF BATCH AND COLUMN R_d VALUES

Column	R_d (mℓ/g) Batch[a]	R_d (mℓ/g) Column[b]
Tuff		
YM54	586-719[c] (116-153) 476-471 and 124-148[d]	141-149
YM22	655-989[c] (102-133)	137
JA18	3120-40 000[e]	[22 200-95 000]
G1-3658	9020-10 200 and 12 700-14 200[d] 3100-19 000[f]	4720
G1-3116	116 000-130 000 and 23 000-7100 000[f]	[38 300-54 200]
G1-2901	1200-2000[f]	386
G1-2476	374-396 3640-3770[g]	276
G1-2363	243-255[h]	199
G1-2233	160 000-460 000[f]	[168 000-672 000]
G1-1982	2250-3100[f] 568-844[i]	483
G1-1883	199-208[h]	85-162
G1-1292	1400-2800[f]	[709-799]
GT-U12G	3 900-26 000[f]	[>1550]

TABLE VII (cont)

Column	R_d (mℓ/g) Batch[a]	Column[b]
Granite		
CS7	68-380[j]	56
CS5-1	73-415[k]	36-190

[a]For batch data, the range of sorption and desorption values is given with the sorption values first and the desorption values second when the data are given in two lines (unless otherwise noted). Values in parentheses are from circulating-type batch measurements, Ref. 7, Table XVIII.

[b]Column R_d values given in brackets were calculated from data obtained by sectioning the column after elution.

[c]From Ref. 6, Table VII, unwashed fraction 106 to 500 μm, 20 to 40 days.

[d]From Ref. 14, washed fractions 38 to 106 μm and 106 to 500 μm, respectively, 3 weeks.

[e]From Ref. 1, Table XI, washed fraction 106 to 150 μm, 13 to 101 days.

[f]From Ref. 8, fraction <500 μm, 22 to 42 days. Note: G1-3658 values are wrong for Ref. 8 by a factor of 10. GT-U12G values are for sorption only, 1 to 6 weeks, fracture-fill material.

[g]From Ref. 9, unwashed fraction 75 to 500 μm, 21 to 42 days.

[h]From Ref. 10, washed fraction 36 to 106 μm, 21 days, sorption only.

[i]From Ref. 15, Table XIV, washed fractions 38 to 75 μm, 75 to 250 μm, and 250 to 500 μm, 2-3 weeks, sorption only.

[j]From Ref. 2, Table IX, 3 washed fractions >106 μm, 10 to 62 days.

[k]From Ref. 2, Table VIII, 3 washed fractions >106 μm, 10 to 62 days.

TABLE VIII

^{141}Ce, ^{152}Eu, AND ^{95m}Tc: A COMPARISON OF BATCH AND COLUMN R_d VALUES

Column	Isotope	R_d (mℓ/g) Batch	R_d (mℓ/g) Column
Tuff			
YM45	^{141}Ce	711-7450[a]	>865[b]
YM38-2	^{141}Ce	624-2640[a]	>426[b]
JA18-2	^{152}Eu	1100-3000[c]	609 and [8420-10 900]
G1-2289	^{152}Eu	780[d]	~0 and [1390-1830]
GT-U12G	^{152}Eu	280-1000[e]	2.3 and [998-2560]
	^{95m}Tc	0.0047, 0.69, and 1.61[f]	0.84
Granite			
CS5-4	^{152}Eu	185-4550[g]	[6500-12 500]
CS5-4	^{95m}Tc	0-600[h]	[1300-3250]

TABLE VIII (cont)

Column	Isotope	R_d (mℓ/g) Batch	R_d (mℓ/g) Column
Argillite			
CN2-2	^{95m}Tc	18-222[i]	0.43 (Fast Flow)
CN2-3	^{95m}Tc	18-222[i]	72 or 50 and 651-823[j]
	^{152}Eu	2250-68 400 and 50 200-102 000[k]	[1570-2880]
CN-3	^{95m}Tc	Not Measured	0.29 (Fast Flow)

[a]From Ref. 6, Table VII, unwashed fraction 106 to 500 μm, 20 to 42 days, range of sorption and desorption values.

[b]Lower limit only determined because isotope decayed before elution.

[c]From Ref.7, Table I, washed fraction 180 to 250 μm, 21 to 84 days, range of sorption and desorption values.

[d]From Ref. 10, washed fraction 38 to 106 μm, 21 days, sorption only.

[e]From Ref. 8, <500 μm, 1 to 6 weeks, sorption only, fracture-fill material.

[f]From Ref. 8, unsieved, 1, 3, and 4 weeks, respectively, sorption only.

[g]From Ref. 2, Table VIII, 3 washed fractions >106 μm, 10 to 62 days, range of sorption and desorption values.

[h]From Ref. 2, Table XV, for CS7 (not CS5) washed fractions, 6.5 to 56 days. Only fraction 106 to 150 μm gave sorption and desorption values >0. This is probably due to contamination by iron during the grinding process. See discussion, Sec. IV.B.

[i]From Ref. 3, Table XXIII, fraction <75 μm, 7 to 59 days, sorption and desorption values increased with time.

[j]A value of 72 mℓ/g is obtained from A/A_T plot in Fig. 30. Since the ^{95m}Tc remaining on the column and the technetium eluted appear to be well separated, they were also treated separately, giving sorption ratios of 50 mℓ/g and 651 to 823 mℓ/g.

[k]From Ref. 3, Table VIII, fraction 106 to 150 μm, 6 to 56 days.

TABLE IX

SUMMARY OF DIFFERENCES IN SORPTION RATIOS BETWEEN CRUSHED-ROCK COLUMN AND BATCH MEASUREMENTS[a]

Column	^{85}Sr	^{137}Cs	^{133}Ba
YM54	0	0	0
YM38		C > B (1.45)	
YM22	C < B[b]	0	C < B[b]
JA37	C < B (2.08)	C > B (1.36)[b]	
JA-32	0		
G1-3658	C < B (11.8)	C < B (1.18)	C < B (1.91)
G1-3116	C < B	C < B	[0]
G1-2901	C < B	C < B	C < B
G1-2476	C < B	[C < B]	C < B
G1-2363	0	C < B	C < B
G1-2233	[0]	[C > B]	[0]
G1-1982	0	0	C < B (1.18)
G1-1883	0	0	C < B (1.23)
G1-1292	0	[C > B]	[C < B]
CS7	0	[C > B] (5.46)	C < B (1.21)
CS5	0	0, [C > B] (>10)	0
CN1	0	0	
CN2	0	0	

[a]"0" indicates the column R_d value fell within the range of measured batch values or that the ranges overlapped (if more than one column measurement was made). Brackets indicate the column R_d value(s) was obtained by sectioning the column. C < B or C > B indicates the column R_d value was less than or greater than the batch R_d value. If a number follows in parentheses, it is the factor by which column and batch values differ. Numbers are not given when only batch data on unwashed fractions are available for comparison. This is because the apparent difference between column and batch values may not be real. See discussion, Sec. IV.B.

[b]C = B when results from the "circulating" type of batch measurements are included. See discussion, Sec. IV.B.

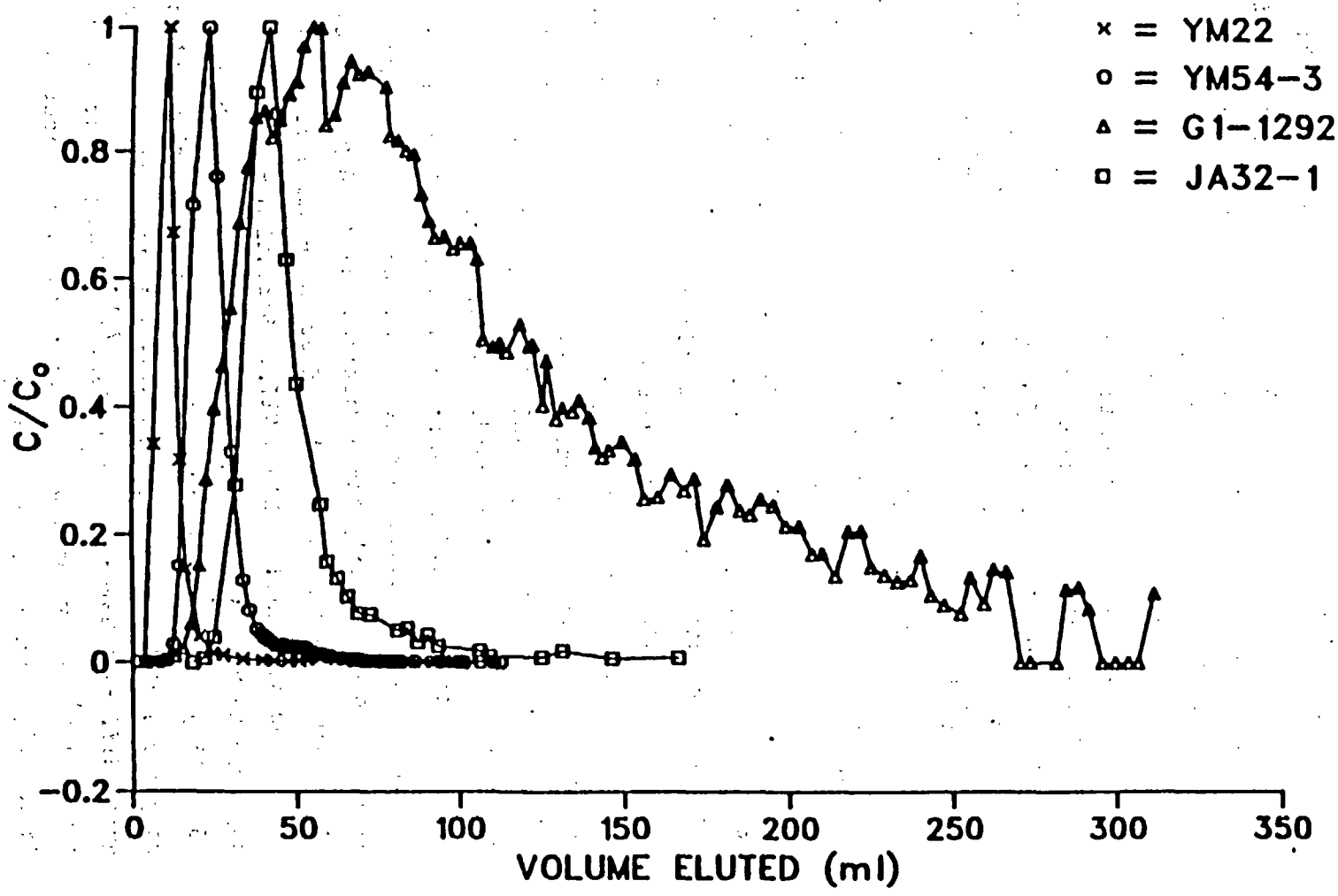


Fig. 32. Comparison of ^{85}Sr elutions from several crushed tuff columns.

^{85}Sr. Although the column and batch results on G1-1292 agree well, the comparison was made on batch data from unwashed fractions, which typically give erroneously high results on samples with low sorption ratios.

The elution of strontium from G1-1292 was similar to the elution of cesium on most of the columns studied, where, when elution began, a "slow leaking" of activity resulting in very broad peaks was observed. Many of the columns were sectioned after elution to see if fixation was occurring. In none of the tuff columns were significant amounts of ^{137}Cs, ^{85}Sr, or ^{133}Ba found at the loa end of the column. However, for the two granite columns CS7 and CS5-1 run at ~30 to 35 m/year for ~3 years, most of the ^{137}Cs remaining on the columns was at the load end. This may be due to irreversible sorption of cesium on biotite The gradual "leaking" behavior might then be explained by an exchange of ^{137}Cs on the rock with the cesium in the groundwater. The groundwater contained ~10^{-9} M cesium.[18] No apparent fixation of cesium, strontium, or barium occurrec in the montmorillonite-rich samples such as G1-3658. This is in agreement with observations by J. R. Eliason[19] that "ion fixation" did not occur with cesium or strontium on either of two montmorillonite samples.

Of the three isotopes studied most extensively, ^{85}Sr, ^{137}Cs, and ^{133}Ba, cesium was the only one to frequently give evidence of more than one peak. Although the data were treated as if a single peak were observed, in a number of the columns, for example YM38-3, JA37, and G1-3116, it appeared that cesium was eluted either in two broad, partially overlapping peaks or in one major peak with a distinct shoulder. This may be due to the presence of more than one exchange site available to cesium. On one column, G1-3116, ^{85}Sr also appeared to have two or possibly three distinct peaks. A peak containing ~24% of the strontium activity was eluted. After the elution of strontium stopped, the column was sectioned (Table B-VII). Strontium remained on the column in what appeared to be two bands. Sample G1-3116 contains the zeolites clinoptilolite (5 to 15%) and analcime (10 to 30%) and 5 to 10% clay and is the only such sample run with strontium. Analcime and clinoptilolite have been shown to have quite different sorptive properties.[7,10] The presence of 2 to 3 different sorption sites may explain why ^{85}Sr seems to be fractionating, although the degree of separation is surprising.

In general, the conclusions previously discussed regarding the relationship between strontium column and batch sorption ratios are also applicable to cesium

and barium. Column and batch data generally agree, except when the batch measurements were made on fractions containing fines. For cesium, however, column R_d values were significantly higher than batch results on CS7 and CS5-1, the two granite columns run at ~30 to 35 m/year for ~3 years. As mentioned earlier, the cesium on these two columns seemed to be fixed at the load end. A strong correlation of increased R_d values with time on granite has previously been observed[2] with batch measurements, so it is possible that the difference in column and batch results for cesium on the long-term column experiments is due to the comparison with short-term batch measurements lasting a maximum of 62 days. Granite columns run at faster flow rates gave cesium sorption ratios in agreement with batch measurements. As for ^{85}Sr on washed fractions of G1-3658, the column R_d value for ^{137}Cs is less than the batch sorption ratio. On JA37 the column R_d value falls between the range of values obtained by the two types of batch measurements.

On columns of YM38, G1-2233, and G1-1292, the cesium was retained better than would be expected from batch sorption ratios. The column to batch ratios were ~1.4, ~2.7, and ~1.6, respectively. Sample G1-1292 batch data were from unwashed fractions. However, in other cases, such batch data (on nonzeolitized samples) gave R_d values higher rather than lower than the column values. The elution of cesium was not completed, and the column R_d value was estimated by sectioning the column. Such data are much less sensitive for noting unusual behavior than is an elution curve. As pointed out earlier, the behavior of ^{85}Sr on column G1-1292 was also unusual because strontium was eluted in a broad, asymmetric peak, as shown in Fig. 32. Column G1-2233 was the only column run that became contaminated with algae. (Column G1-3658 also had algae, but only in the exit tubing and frit.) On sectioning column G1-2233, algae was observed throughout the entire column. Thus, the algae may be responsible for the increased retention of cesium on the column. Uptake of ^{137}Cs, ^{90}Sr, and other radioisotopes by algae has been reported, although no quantitative comparisons were given.[20]

The column to batch ratio of 1.4 on YM38 is probably not unreasonable agreement. Because of the high R_d value of $\lesssim$17 000 mℓ/g, the column was run at a fast flow rate, ~8000 m/year. Approximately 2760 samples of 3 to 4 mℓ each were collected. With the broad peak and poor counting statistics, the uncertainty in the column data is likely to be as large as the differences between the column and batch results.

Fewer measurements have been made on ^{133}Ba. There is agreement within 20% between column and batch data on 8 out of 13 columns. Column R_d values are ~20% less than the corresponding batch sorption ratios on 3 of the 8 samples (G1-1982, G1-1883, and CS7), which is probably within experimental uncertainty. Another granite column, CS5, gave results which agreed with the batch data. With column G1-3658 the R_d value of 4720 mℓ/g was less than most of the batch results, although it did fall within the range of measured batch sorption ratios (3100 to 19 000 mℓ/g). Of the remaining four columns run with barium, the difference between column and batch sorption ratios may be due to the fact that the batch measurements were made on fractions containing fines.

In addition to ^{85}Sr, ^{137}Cs, and ^{133}Ba, the radionuclides ^{95m}Tc, ^{152}Eu, and ^{141}Ce have been studied (Table VIII). Cerium was loaded on two columns but decayed before elution, and the columns were not sectioned. The $^{95m}TcO_4^-$ was strongly affected by kinetics. This is not surprising because the retardation mechanism of technetium is probably by reduction of TcO_4^- to Tc(IV), perhaps as TcO_2, rather than by ion exchange. At flow rates of ~2000 m/year, either in air or in a controlled atmosphere of nitrogen with $\leq$0.2 ppm O_2 and $\leq$20 ppm CO_2, argillite column sorption ratios were 0.29 to 0.43 mℓ/g. The corresponding batch sorption ratio in air was 18 to 222 mℓ/g. When the flow rate was slowed to 20 m/year (column CN2-3), allowing more time for reaction, the technetium R_d value increased to 72 mℓ/g. The ^{95m}Tc which was eluted and the ^{95m}Tc which remained on column CN2-3 seemed to be well separated. When treated as individual peaks, the sorption ratios were 50 and 823 mℓ/g. Additional columns would have to be run to determine whether fractionation really occurred and if it was due to precipitation of some of the reduced technetium, to the formation of more than one species, or to the presence of more than one sorption site. Europium was loaded on the same argillite column (CN2-3) but not eluted. Its sorption ratio was estimated, by sectioning the column, to be 1570 to 2880 mℓ/g, which falls within the very large range of measured batch values: 2250 to 102 000 mℓ/g for sorption and desorption.

Other columns loaded with europium were GT-U12G, CS5-4, JA18-2, and G1-2289. With all these columns, except CS5-4, which was contaminated with iron, a small peak of europium was observed while the majority of the activity remained on the column. With JA18-2, there were two peaks, totaling 5.7% of the ^{152}Eu loaded. The data for ^{152}Eu on G1-2289 are a bit strange; 2.4% was removed, most of it

immediately, the rest in a second peak. This column was run by loading the ^{152}Eu from 1/2 mℓ of solution, rather than from a 5- to 10-μℓ spike, and it appears that 1 to 2% of the ^{152}Eu moved essentially with the water front. On GT-U12G, ~4% of the ^{152}Eu was eluted with an R_d value of ~2.3 mℓ/g. The R_d values calculated from the sectioned column data gave europium sorption ratios which were 2 to 3 times larger than the batch values (see Table VIII) for column G1-2289, as well as for columns JA18-2 and GT-U12G.

Thus, on three tuffs the measured batch sorption ratios for europium fell between the R_d values corresponding to the small amounts of ^{152}Eu initially eluted and the majority of the ^{152}Eu remaining on the columns. Whether the europium removed initially from the columns was due to collodial species is unknown. The higher sorption ratios found by the column technique may be due to precipitation of ^{152}Eu, although the spikes were filtered before loading. Of the two other columns loaded with ^{152}Eu, one was contaminated with iron and the other gave a sorption ratio that overlapped with the large range of batch sorption ratios. Conclusions cannot be drawn for ^{152}Eu until additional measurements are made -- ideally using a continuous feed loading technique rather than a spike.

The results from column CS5-4, for technetium as well as for europium, are likely to be in error. It was found after the column was run that the granite contained iron from the grinding process. (Other materials, ground in an agate system, were free of iron.) Neither ^{95m}Tc nor ^{152}Eu were eluted from the column in 111 mℓ, and they gave sorption ratios (from the sectioned column data) well above the corresponding batch R_d values. Although the batch measurements were made on the same iron-contaminated rock, they were run for a maximum of ~60 days while the columns ran ~4.5 times longer at a flow rate of ~20 m/year. Thus, as for ^{95m}Tc on argillite where the sorption ratios increased when time was allowed for reduction of the technetium to occur, a higher column than batch R_d value for ^{95m}Tc is not surprising. The iron may also have caused the increase in sorption of ^{152}Eu on the column by reducing europium(III) to europium(II).

V. SUMMARY

The migration of ^{85}Sr, ^{137}Cs, ^{133}Ba, ^{141}Ce, ^{152}Eu, ^{95m}Tc, and ^{131}I through small columns of crushed tuff, granite, and argillite was investigated. In most cases, flow rates of ~10 to 80 m/year were used. The sorption ratios calculated from the elution data of strontium, cesium, and barium were found to be in agreement with batch measurements on washed fractions of the same materials. When comparisons were made with results from batch measurements which contained fine material (<38 μm), column results were consistently lower than batch results.

Since batch measurements are a convenient way to rapidly measure many parameters on a large number of samples and since their relevance to the migration of radionuclides has been questioned, these results are encouraging. Whether sample crushing is influencing the rock chemistry in both the batch and crushed-rock columns needs to be determined by studying radionuclide migration through larger columns of intact rock, through even larger blocks of intact rock, and in the field. Such research is in progress.[4,5,21]

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APPENDIX A
ELUTION DATA

The data from the elution of the radioactive tracers used on the crushed-rock columns are given in Tables A-I through A-XXXI. The data are reported as C/C_I or C/C_o and A/A_T at the average total volume, where

$$C/C_I = \frac{\text{concentration of sample from "continuous-feed" column}}{\text{concentration of feed solution}}$$

$$C/C_o = \frac{\text{concentration of sample from "spike-loaded" column}}{\text{concentration of most concentrated sample}}$$

$$A/A_T = \frac{\text{sum of the activities of the samples taken}}{\text{total activity of spike loaded on the column}}$$

The average total volume is the total volume that was eluted before a given sample plus one-half of the sample volume. As footnotes to each table, the values of C_o and A_T are given for each radionuclide loaded. The values are given as dpm (disintegrations/minute) or cpm (counts/minute). A_T was generally determined by adding the activity of a given radionuclide eluted from the column to the activity of the same radionuclide remaining on the column after elution was terminated. The latter was measured by sectioning the column and counting the samples obtained. If the column was not counted, A_T was determined by counting an aliquot or spike of the same size as that loaded on the column. Vertical single dots indicate that no activity was found in the samples taken.

TABLE A-I

ELUTION DATA FOR TUFF YM54-1[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
3.05	0.0038	0.0024	0.0059	0.0001	0.0073	0.0013
7.14	0.126	0.029	0.0061	0.0013	0.0069	0.0017
9.15	0.505	0.131	0.0084	0.0018	0.0033	0.0018
11.04	0.886	0.311	0.0171	0.0027	0.0044	0.0021
13.01	1.000	0.509	0.0575	0.0057	0.0180	0.0030
16.95	0.555	0.846	0.347	0.0617	0.0573	0.0125
20.95	0.183	0.886	0.753	0.106	0.188	0.0236
24.09	0.0769	0.919	1.000	0.202	0.401	0.0716
29.34	0.0228	0.934	0.975	0.399	0.807	0.215
33.96	0.0107	0.937	0.823	0.455	0.980	0.294
36.62	0.0087	0.939	0.682	0.501	1.000	0.363
39.34	0.0105	0.942	0.661	0.555	0.943	0.442
41.25	0.0156	0.944	0.590	0.569	0.858	0.462
42.08	0.0193	0.945	0.549	0.581	0.817	0.481
42.87	0.0242	0.947	0.577	0.593	0.807	0.498
43.72	0.0267	0.950	0.568	0.607	0.803	0.519
44.51	0.0284	0.952	0.592	0.618	0.758	0.532
45.73	0.0310	0.957	0.576	0.646	0.733	0.569
47.51	0.0294	0.963	0.548	0.677	0.691	0.603
48.96	0.0272	0.966	0.461	0.687	0.619	0.623
51.00	0.0224	0.973	0.415	0.720	0.538	0.667
53.23	0.0191	0.976	0.371	0.736	0.493	0.689
54.52	0.0188	0.978	0.363	0.746	0.461	0.702
55.84	0.0164	0.980	0.341	0.762	0.427	0.722
57.41	0.0138	0.983	0.375	0.777	0.412	0.739
59.10	0.0114	0.985	0.344	0.794	0.361	0.757
62.91	0.0067	0.989	0.292	0.824	0.302	0.806
66.97	0.0036	0.990	0.234	0.849	0.238	0.822
69.52	0.0029	0.990	0.205	0.854	0.206	0.838
72.90	0.0021	0.991	0.178	0.869	0.175	0.858
78.61	0.0012	0.992	0.155	0.885	0.139	0.886
84.64	0.0015	0.993	0.108	0.904	0.101	0.899
89.41	0.0022	0.994	0.0779	0.936	0.0960	0.910
94.40	0.0017	0.995	0.0598	0.950	0.0605	0.919
100.2	0.0013	0.996	0.0403	0.960	0.0499	0.928
104.3	0.0008	0.996	0.0317	0.969	0.0445	0.932
107.9	0.0004	0.996	0.0254	0.976	0.0375	0.936
111.0	0.0005	0.996	0.0224	0.979	0.0368	0.939
113.9	0.0007	0.997	0.0197	0.981	0.0343	0.942
119.1	0.0005	0.997	0.0147	0.983	0.0294	0.948
125.4			0.0116	0.984	0.0267	0.950
128.5			0.0112	0.984	0.0240	0.958
130.1			0.0131	0.986	0.0184	0.954
131.9			0.0088	0.986	0.0194	0.955

TABLE A-I (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
134.1			0.0113	0.987	0.0244	0.956
136.4			0.0097	0.988	0.0190	0.958
139.0			0.0084	0.988	0.0192	0.959
143.2			0.0073	0.989	0.0177	0.962
150.0			0.0064	0.991	0.0158	0.966
154.7			0.007	0.991	0.0144	0.966
158.0			0.005	0.992	0.0123	0.968
162.4			0.007	0.992	0.0164	0.970
165.4			0.005	0.993	0.0110	0.971
169.0			0.004	0.993	0.0090	0.972
173.0			0.005	0.993	0.0088	0.973
175.6			0.004	0.994	0.0086	0.973
177.6			0.006	0.994	0.0067	0.973
179.6			0.005	0.995	0.0080	0.974
182.6			0.005	0.995	0.0083	0.975
187.6			0.004	0.996	0.0085	0.976
192.4			0.004	0.996	0.0073	0.977
196.5			0.003	0.997	0.0079	0.978
201.5			0.003	0.997	0.0065	0.979
206.2			0.003		0.0059	0.979
209.2			0.004		0.0065	0.980
211.2			0.003		0.0057	0.980
215.1			0.003		0.0050	0.981
219.3			0.003		0.0050	0.982
221.9			0.003		0.0043	0.982
227.2			0.003		0.0045	0.983
234.0			0.002		0.0042	0.983
240.7					0.0031	0.984
247.7					0.0028	0.985
254.6					0.0030	0.985

[a] C_o = 2.393×10^5 dpm/mℓ for ^{85}Sr, 2.352×10^4 dpm/mℓ for ^{137}Cs, and 1.713×10^4 dpm/mℓ for ^{133}Ba.

A_T = 2.325×10^6 dpm for ^{85}Sr, 8.568×10^5 dpm for ^{137}Cs, and 6.112×10^5 dpm for ^{133}Ba.

TABLE A-II
ELUTION DATA FOR TUFF YM54-2[a]

Total Volume (mℓ)	C/C_I, ^{137}Cs
0.608	0.0011
1.22	0.0030
1.82	0.0038
2.43	0.0046
3.04	0.0048
3.65	0.0052
4.26	0.0056
4.86	0.0061
5.47	0.0064
6.08	0.0064
6.69	0.0068
7.30	0.0071
7.90	0.0070
8.51	0.0072
9.12	0.0072
9.73	0.0070
10.3	0.0073
10.9	0.0074
11.6	0.0081
12.2	0.0092
12.8	0.0125
13.4	0.0188
14.0	0.0306
14.6	0.0500
15.2	0.0770
15.8	0.106
16.4	0.146
17.0	0.195
17.6	0.239
18.2	0.293
18.8	0.335
19.5	0.327
20.1	0.423
20.7	0.467
21.3	0.496
21.9	0.555
22.5	0.582
23.1	0.628
23.7	0.698
24.3	0.699
24.9	0.647
25.5	0.589
26.1	0.783
26.7	0.759
27.3	0.800
27.9	0.851
28.5	0.887
29.1	0.864
29.8	0.883
30.4	0.929
31.0	0.905
31.6	0.922
32.2	0.932
32.8	0.970
33.4	0.983
34.0	0.970
34.6	1.03
35.2	0.975
35.8	1.03
36.4	1.07
37.1	0.976
37.7	1.00
38.6	1.01
39.5	0.991

[a] $C_I = 4.117 \times 10^4$ cpm.

TABLE A-III
ELUTION DATA FOR TUFF YM54-3[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
1.72	0.0014	0.0004	0.0155	0.0011	0.0278	0.0019
4.58	0.0007	0.001	0.0035	0.0015	0.0050	0.0025
8.44	0.0014	0.001	0.0038	0.0017	0.0000	0.0025
10.4	0.0038	0.001	0.0031	0.0018	0.0052	0.0027
12.4	0.0286	0.006	0.0042	0.0020	0.0143	0.0029
14.4	0.151	0.029	0.0060	0.0022	0.0000	0.0029
18.3	0.714	0.362	0.0055	0.0022	0.0000	0.0029
22.3	1.000	0.528	0.0050	0.0024	0.0000	0.0029
25.5	0.759	0.776	0.0075	0.0031	0.0000	0.0029
30.1	0.330	0.908	0.0246	0.0056	0.0128	0.0042
33.7	0.129	0.928	0.0793	0.0089	0.0229	0.0052
35.6	0.0822	0.940	0.130	0.0137	0.0358	0.0065
37.8	0.0527	0.950	0.234	0.0261	0.0635	0.0098
39.5	0.0436	0.953	0.316	0.0310	0.0948	0.011
40.2	0.0379	0.955	0.338	0.0363	0.114	0.013
40.9	0.0379	0.957	0.446	0.0425	0.160	0.015
41.7	0.0325	0.959	0.502	0.0515	0.183	0.018
42.4	0.0313	0.961	0.591	0.0587	0.234	0.021
43.5	0.0259	0.964	0.677	0.0792	0.263	0.029
44.7	0.0250	0.967	0.801	0.1024	0.357	0.039
45.9	0.0280	0.969	0.770	0.1173	0.418	0.047
47.5	0.0223	0.973	0.762	0.1513	0.486	0.069
49.1	0.0248	0.974	0.794	0.1678	0.597	0.081
49.9	0.0243	0.976	0.789	0.1793	0.641	0.090
50.7	0.0235	0.977	0.857	0.1955	0.693	0.103
51.6	0.0221	0.981	0.952	0.212	0.759	0.116
52.6	0.0223	0.981	1.00	0.233	0.805	0.133
54.6	0.0166	0.985	0.987	0.296	0.867	0.187
56.8	0.0137	0.986	0.977	0.320	0.950	0.211
58.1	0.0116	0.987	0.976	0.349	0.991	0.240
60.1	0.0099	0.991	0.967	0.398	1.00	0.290
63.3	0.0068	0.991	0.899	0.477	0.994	0.373
66.4	0.0043	0.993	0.859	0.512	0.943	0.411
68.7	0.0043	0.994	0.798	0.554	0.899	0.459
71.1	0.0034	0.994	0.772	0.590	0.917	0.501
74.2	0.0024	0.994	0.704	0.647	0.821	0.567
77.0	0.0020	0.994	0.676	0.669	0.768	0.591
78.0	0.0016	0.994	0.637	0.692	0.701	0.616
80.2	0.0015	0.994	0.629	0.709	0.680	0.635
81.7	0.0016	0.995	0.579	0.729	0.639	0.656
85.8	0.0015	0.995	0.546	0.803	0.568	0.733
93.6	0.0009	0.996	0.321	0.862	0.364	0.799
99.4	0.0005	0.996	0.232	0.875	0.285	0.814
101	0.0000	0.996	0.232	0.886	0.227	0.825
106	0.0005	0.996	0.180	0.906	0.198	0.847

TABLE A-III (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
110	0.0000	0.996	0.142	0.913	0.158	0.855
112	0.0000	0.996	0.128	0.918	0.150	0.860
114			0.112	0.924	0.144	0.868
116			0.104	0.928	0.129	0.873
120			0.091	0.938	0.112	0.885
126			0.070	0.947	0.097	0.897
130			0.053	0.949	0.085	0.901
132			0.110	0.951	0.151	0.904
133			0.047	0.953	0.067	0.906
137			0.042	0.957	0.066	0.913
141			0.034	0.960	0.059	0.917
144			0.033	0.961	0.060	0.920
146			0.033	0.962	0.059	0.922
147			0.030	0.963	0.062	0.923
148			0.030	0.964	0.056	0.925
150			0.025	0.964	0.044	0.926
153			0.019	0.967	0.045	0.931
158			0.017	0.968	0.037	0.935
163			0.017	0.970	0.036	0.938
168			0.015	0.971	0.032	0.941
172			0.014	0.972	0.030	0.943
174			0.013	0.973	0.029	0.944
176			0.029	0.974	0.062	0.947
179			0.012	0.975	0.025	0.949
183			0.011	0.976	0.025	0.950
185			0.009	0.976	0.019	0.951
188			0.014	0.977	0.022	0.952
191			0.013	0.978	0.023	0.954
195			0.009	0.979	0.022	0.956
201			0.009	0.980	0.019	0.959
207			0.008	0.981	0.018	0.961
214			0.007	0.982	0.014	0.963
222			0.007	0.983	0.013	0.965
227			0.007	0.983	0.010	0.965
231			0.007	0.983	0.009	0.965
233			0.007	0.984	0.014	0.966
236			0.007	0.984	0.010	0.967
240			0.006	0.985	0.010	0.967
245			0.004	0.985	0.010	0.967
251			0.004	0.985	0.008	0.970
257			0.004	0.986	0.007	0.971

[a] C_o = 1.800×10^5 dpm/mℓ for ^{85}Sr, 1.684×10^4 dpm/mℓ for ^{137}Cs, and 1.633×10^5 dpm/mℓ for ^{133}Ba.

A_T = 2.299×10^6 dpm for ^{85}Sr, 8.190×10^5 dpm for ^{137}Cs, and 5.630×10^5 dpm for ^{133}Ba.

TABLE A-IV

ELUTION OF TUFF YM38-3

Total Volume (mℓ)	^{137}Cs[a] C/C_o	A/A_T
1116	0.000	
1141	0.047	
1188	0.065	
1234	0.068	
1277	0.075	0.010
1322	0.074	
1384	0.072	
1557	0.079	
1682	0.091	
1888	0.114	
2024	0.072	
2369	0.187	
2498	0.238	
2732	0.268	
3066	0.350	0.037
3203	0.336	
3361	0.377	0.043
3555	0.466	0.052
3932	0.655	0.074
4201	0.704	0.091
4387	0.741	0.103
4881	0.783	0.134
5521	0.800	0.182
6247	0.653	0.239
6411	0.658	0.266
7261	1.00	0.367
8192	0.912	0.443
8665	0.953	0.500
8949	0.947	0.533
9360	0.953	0.578
9798	0.799	0.603
9955	0.683	0.616
10 133	0.546	0.630
10 265	0.257	0.638
10 467	0.385	0.653

[a] C_o = 57.1 cpm/average sample of 3 to 4 mℓ. To analyze the data, all samples were counted, the activities for x number of samples were summed and divided by x and not by the total volume of the samples. Initially all samples were of the same volume but as the experiment progressed sample volume began to fluctuate. Since sample volumes did vary, dividing the total activity by the number of samples is not as accurate as determining the cpm/mℓ. However, since count rates were low and counting statistics poor, it was not felt that using cpm/mℓ would make a significant difference. Approximately 2760 samples were taken.

$A_T = 1.360 \times 10^5$ cpm.

TABLE A-V
ELUTION OF TUFF YM22[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
3.60	0.001	0.00047				
6.56	0.342	0.303				
10.51	1.00	0.597				
12.45	0.671	0.792				
14.5	0.317	0.885				
16.4	0.145	0.927	0.000		0.000	
20.4	0.041	0.963	0.009		0.005	0.0007
24.4	0.015	0.967	0.004		0.011	0.0012
27.6	0.012	0.975	0.000		0.033	0.0045
33.5	0.006	0.982	0.000		0.207	0.0407
39.3	0.004	0.984	0.000		0.524	0.0875
43.0	0.003	0.985	0.000		0.710	0.146
47.2	0.002	0.986	0.000		0.937	0.251
50.7	0.003	0.987	0.000		1.000	0.297
53.1	0.004	0.989	0.000		0.962	0.359
57.0	0.008	0.992	0.000		0.917	0.413
61.8	0.006	0.998	0.000		0.777	0.538
67.7	0.002	0.998	0.000		0.522	0.598
73.6	0.001	0.999	0.028	0.0024	0.315	0.646
78.1	0.002	0.999	0.066	0.0039	0.250	0.660
81.2	0.001	0.999	0.122	0.0079	0.205	0.678
84.4	0.002	0.999	0.177	0.0119	0.166	0.688
88.5	0.001	0.999	0.239	0.0236	0.144	0.706
92.5	0.002	0.999	0.303	0.0303	0.116	0.713
94.7	0.001	1.000	0.337	0.0359	0.116	0.718
96.6	0.001	1.000	0.392	0.0429	0.112	0.723
98.5	0.000	1.000	0.481	0.0502	0.100	0.727
100.1	0.000	1.000	0.543	0.0596	0.096	0.731
104.1			0.629	0.0900	0.088	0.743
107.8			0.661	0.101	0.080	0.746
110.0			0.669	0.115	0.081	0.751
113.1			0.747	0.141	0.078	0.758
117.9			0.813	0.182	0.075	0.768
122.1			0.819	0.201	0.065	0.772
124.9			0.986	0.225	0.081	0.777
128.9			1.000	0.271	0.068	0.785
132.4			0.966	0.288	0.062	0.786
134.5			0.955	0.307	0.055	0.788
136.6			0.954	0.322	0.052	0.789
138.6			0.963	0.341	0.056	0.790
142.5			0.919	0.386	0.046	0.791
146.2			0.900	0.390	0.044	0.792
147.5			0.916	0.410	0.050	0.799
148.8			0.920	0.423	0.047	0.801
150.6			0.926	0.442	0.044	0.803
152.7			0.793	0.455	0.054	0.805

TABLE A-V (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
155.0			0.809	0.491	0.037	0.807
158.5			0.775	0.506	0.036	0.811
162.3			0.739	0.521	0.029	0.813
164.6			0.716	0.532	0.031	0.815
166.8			0.692	0.544	0.027	0.816
168.7			0.679	0.544	0.029	0.817
172.4			0.644	0.575	0.023	0.820
177.2			0.650	0.598	0.024	0.822
180.4			0.637	0.611	0.023	0.823
182.4			0.577	0.620	0.024	0.823
184.4			0.519	0.630	0.024	0.825
187.4			0.514	0.648	0.025	0.827
191.6			0.523	0.670	0.025	0.830
195.0			0.481	0.680	0.017	0.830
197.3			0.485	0.689	0.017	0.831
199.4			0.468	0.697	0.022	0.832
201.1			0.480	0.704	0.022	0.833
202.2			0.433	0.706	0.017	0.833
202.9			0.445	0.709	0.021	0.834
204.2			0.445	0.716	0.020	0.834
205.3			0.445	0.718	0.025	0.835
206.3			0.447	0.723	0.021	0.835
207.3			0.457	0.727	0.021	0.836
208.3			0.466	0.731	0.024	0.836
208.9			0.455	0.732	0.025	0.837
209.4			0.538	0.735	0.028	0.837
209.8			0.559	0.736	0.039	0.837
210.3			0.539	0.739	0.025	0.838
210.9			0.598	0.743	0.033	0.838
211.5			0.491	0.746	0.020	0.839

[a] C_o = 2.172×10^5 dpm/mℓ for ^{85}Sr, 7.207×10^3 dpm/mℓ for ^{137}Cs, and 1.084×10^4 dpm/mℓ for ^{133}Ba.

A_T = 1.469×10^6 dpm for ^{85}Sr, 8.194×10^5 dpm for ^{137}Cs, and 4.704×10^5 dpm for ^{133}Ba.

TABLE A-VI
ELUTION OF TUFF JA37[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs	
	C/C_o	A/A_T	C/C_o	A/A_T
11.47	0.0008	0.0001	0.040	0.0002
13.66	0.0055	0.0003	0.046	0.0003
15.45	0.0232	0.0023	0.018	0.0005
17.32	0.0689	0.0047	0.045	0.0006
18.87	0.134	0.0138	0.019	0.0007
20.39	0.183	0.0198	0.043	0.0008
22.29	0.283	0.0463	0.017	0.0009
24.65	0.423	0.0729	0.024	0.0010
26.64	0.558	0.1121	0.000	0.0010
29.65	0.752	0.2102	.	.
32.55	0.938	0.2161	.	.
34.03	1.000	0.2514	.	.
36.02	0.928	0.3416		
38.45	0.877	0.3982		
40.32	0.856	0.4498		
42.84	0.834	0.5393		
45.95	0.783	0.6175		
48.00	0.779	0.6463		
50.04	0.689	0.7144	0.000	0.0010
52.54	0.532	0.7504	0.022	0.0011
54.44	0.425	0.7752	0.000	0.0011
56.83	0.371	0.8135	0.000	0.0011
59.41	0.337	0.8370	0.025	0.0012
61.44	0.296	0.8563	0.000	0.0012
64.49	0.255	0.8915	0.000	0.0012
67.62	0.201	0.9056	0.000	0.0012
70.05	0.171	0.9214	0.000	0.0012
72.41	0.139	0.9303	0.026	0.0014
75.49	0.081	0.9642	0.000	0.0014
77.96	0.068	0.9659	0.054	0.0015
79.46	0.065	0.9707	0.020	0.0016
81.53	0.058	0.9744	0.000	0.0016
84.04	0.049	0.9795	0.015	0.0017
87.08	0.043	0.9838	0.016	0.0018
90.56	0.034	0.9884	0.000	0.0018
93.30	0.031	0.9900	0.000	0.0018
95.24	0.022	0.992	0.022	0.0019
97.76	0.020	0.9932	0.022	0.0021
100.3	0.015	0.9943	0.033	0.0023
102.2	0.001	0.9951	0.042	0.0024
105.7	0.011	0.9969	0.032	0.0029
109.3	0.010	0.9976	0.052	0.0031
112.8	0.008	0.9989	0.049	0.0038
117.9	0.006	1.00	0.065	0.0046
121.5	0.000	1.00	0.091	0.0051

TABLE A-VI (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs	
	C/C_o	A/A_T	C/C_o	A/A_T
124.7	0.000	1.00	0.089	0.0065
127.4			0.101	0.0063
129.9			0.111	0.0069
132.0			0.135	0.0076
134.5			0.116	0.0085
137.0			0.142	0.0091
139.0			0.152	0.0099
141.6			0.178	0.0112
145.1			0.188	0.0121
148.6			0.226	0.0138
151.2			0.252	0.0152
152.4			0.369	0.0166
154.0			0.244	0.0190
157.0			0.201	0.0208
160.9			0.249	0.0223
164.9			0.268	0.0252
168.6			0.268	0.0274
172.1			0.302	0.0301
175.1			0.305	0.0324
180.5			0.295	0.0346
185.7			0.316	0.0400
189.5			0.451	0.0425
194.7			0.354	0.0431
201.1			0.398	0.0503
207.2			0.452	0.0557
212.7			0.449	0.0626
217.8			0.514	0.0677
222.9			0.525	0.0757
227.6			0.571	0.0803
232.9			0.565	0.0908
240.6			0.613	0.103
247.2			0.646	0.112
253.6			0.634	0.123
261.8			0.732	0.139
269.7			0.708	0.152
278.8			0.553	0.174
288.4			0.791	0.190
295.3			0.928	0.204
302.7			0.890	0.223
309.2			0.796	0.231
313.6			0.902	0.242
318.0			0.913	0.251
322.6			0.956	0.263
329.2			0.914	0.282
336.7			1.00	0.296
341.2			0.921	0.310

TABLE A-VI (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs	
	C/C_o	A/A_T	C/C_o	A/A_T
348.7			0.893	0.325
355.6			0.791	0.339
362.9			0.809	0.355
370.8			0.726	0.369
379.8			0.693	0.386
389.0			0.666	0.400
397.3			0.594	0.412
405.0			0.618	0.423
410.9			0.631	0.430
416.8			0.643	0.442
423.6			0.602	0.451
430.4			0.570	0.462
437.8			0.579	0.472
444.6			0.555	0.481
450.3			0.558	0.488
455.0			0.591	0.494
459.7			0.615	0.502
465.3			0.632	0.512
471.3			0.602	0.521
476.3			0.623	0.527
480.5			0.531	0.533
485.3			0.497	0.539
490.1			0.557	0.545
494.7			0.518	0.552
499.9			0.504	0.558
504.4			0.510	0.563
508.9			0.510	0.569
514.2			0.498	0.576
518.9			0.524	0.581
523.8			0.510	0.589
531.1			0.450	0.598
538.3			0.444	0.605
543.6			0.416	0.609
548.1			0.436	0.614
553.0			0.430	0.620
557.6			0.410	0.624
562.2			0.423	0.629
567.3			0.372	0.634
571.9			0.419	0.638
577.0			0.402	0.644
583.3			0.242	0.650
588.9			0.353	0.655
593.5			0.360	0.659
598.2			0.386	0.663
603.1			0.355	0.668
607.7			0.410	0.672

TABLE A-VI (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs	
	C/C_o	A/A_T	C/C_o	A/A_T
612.5			0.278	0.676
617.4			0.394	0.680
621.6			0.326	0.683
625.5			0.368	0.687
629.9			0.474	0.693
634.8			0.566	0.699
639.3			0.440	0.704
644.1			0.620	0.712
648.9			0.524	0.718
652.4			0.505	0.722
657.0			0.489	0.729
662.5			0.465	0.735
667.0			0.410	0.739
671.6			0.389	0.744
677.0			0.343	0.748
681.0			0.304	0.751
686.0			0.334	0.755
696.0			0.264	0.763

[a] $C_o = 7.420 \times 10^4$ dpm/mℓ for ^{85}Sr and 1.760×10^3 dpm/mℓ for ^{137}Cs.
$A_T = 2.229 \times 10^6$ dpm for ^{85}Sr and 7.087×10^5 dpm for ^{137}Cs.

TABLE A-VII
ELUTION OF TUFF JA32-1

Total Volume (mℓ)	^{85}Sr[a]	
	C/C_o	A/A_T
18.4	0.000	0.0000
21.8	0.007	0.0012
24.8	0.040	0.0066
31.5	0.278	0.0916
37.3	0.894	0.329
40.5	1.000	0.475
43.6	0.859	0.597
46.7	0.628	0.686
49.8	0.434	0.748
57.3	0.246	0.832
59.2	0.157	0.846
62.4	0.131	0.867
65.5	0.103	0.880
68.7	0.077	0.891
72.4	0.075	0.904
80.8	0.050	0.923
83.8	0.053	0.931
87.0	0.031	0.935
90.1	0.042	0.941
93.2	0.025	0.945
105.8	0.018	0.955
108.9	0.010	0.956
124.6	0.008	0.962
130.9	0.018	0.967
146.1	0.006	0.971
166.1	0.007	0.978

[a] $C_o = 2.630 \times 10^3$ cpm/mℓ and $A_T = 5.741 \times 10^4$ cpm.

TABLE A-VIII
ELUTION OF TUFF JA32-2

Total Volume (mℓ)	C/C_I, ^{85}Sr[a]
0.39	
1.16	
1.93	
2.70	
3.48	
4.25	0.000
5.02	0.001
5.79	0.002
6.57	0.049
8.11	0.056
9.66	0.071
10.4	0.11
11.2	0.16
12.0	0.20
12.7	0.28
13.5	0.32
14.3	0.41
15.1	0.47
15.8	0.53
16.6	0.55
17.4	0.62
18.2	0.64
18.9	0.66
19.3	0.66
19.7	0.69
20.1	0.69
20.5	0.70
21.2	0.70
22.8	0.71
24.3	0.74
25.9	0.76

[a] $C_I = 1.336 \times 10^3$ cpm/mℓ.

TABLE A-IX
ELUTION OF TUFF JA32-3

Total Volume (mℓ)	C/C_o, ^{85}Sr[a]
2.48	0.020
6.26	0.037
9.48	0.740
15.2	1.00
21.0	0.254
25.3	0.071
30.7	0.032
34.8	0.028
36.8	0.021
39.7	0.024
43.6	0.017
46.8	0.012
48.4	0.007
52.7	0.002

[a] C_o = 880 cpm/mℓ and A_T was not measured.

TABLE A-X
ELUTION OF TUFF JA18-2[a]

Total Volume (mℓ)	^{152}Eu	
	C/C_o	A/A_T
8.38	0.000	0.0000
11.92	0.687	0.0159
14.11	0.985	0.0025
15.68	0.612	0.0032
18.27	0.425	0.0038
23.3	0.336	0.0049
33.2	0.269	0.0066
46.3	0.097	0.0071
71.3	0.069	0.0076
76.5	0.470	0.0092
80.5	0.597	0.0100
85.6	0.933	0.0121
98.1	1.000	0.0145
114.9	0.580	0.0195
132.8	0.520	0.0228
154.1	0.522	0.0268
180.4	0.542	0.0327
201.3	0.426	0.0376
214.6	0.343	0.0404
232.8	0.371	0.0434
252.7	0.209	0.0451
277.8	0.165	0.0473
298.2	0.150	0.0494
317.3	0.154	0.0507
336.7	0.125	0.0529
351.5	0.172	0.0546
366.8	0.186	0.0563
380.7	0.070	0.0563
385.1	0.000	0.0567
389.7	0.000	0.0567
.	.	.
.	.	.
.	.	.
941.1	0.000	0.0567

[a] C_o = 134 dpm/mℓ and $A_T = 2.906 \times 10^5$ dpm.

TABLE A-XI
ELUTION OF TUFF G1-3658[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
688	0.055	0.005				
703	0.073	0.012				
718	0.153	0.027				
732	0.243	0.051				
747	0.373	0.087				
761	0.517	0.138				
776	0.636	0.200				
791	0.823	0.280				
806	1.000	0.377				
821	0.994	0.474				
835	0.988	0.570				
850	0.869	0.655				
865	0.786	0.731				
880	0.622	0.792				
894	0.501	0.841				
909	0.445	0.884				
924	0.311	0.914				
938	0.263	0.940				
953	0.171	0.956				
968	0.144	0.971				
983	0.098	0.980				
997	0.083	0.988				
1012	0.050	0.993				
1026	0.072	1.000				
.						
.						
2351			0.042	0.0006		
2366			0.044	0.0012		
2380			0.053	0.0019		
2396			0.039	0.0025		
2410			0.045	0.0037		
2425			0.056	0.0039		
2440			0.042	0.0045		
2455			0.054	0.0052		
2469			0.047	0.0059		
2484			0.070	0.0069		
2499			0.054	0.0076		
2513			0.068	0.0086		
2528			0.062	0.0094		
2543			0.062	0.0103		
2558			0.078	0.0114		
2572			0.080	0.0125	0.063	0.0004
2587			0.095	0.0138	0.130	0.0014
2602			0.092	0.0151	0.098	0.0020

TABLE A-XI (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
2616	0.096	0.0164	0.165	0.0032		
2631	0.097	0.0178	0.179	0.0045		
2646			0.109	0.0193	0.191	0.0058
2661			0.098	0.0210	0.248	0.0076
2675			0.113	0.022	0.269	0.0095
2690			0.109	0.024	0.305	0.0116
2705			0.130	0.026	0.329	0.0139
2725			0.128	0.045	0.348	0.0164
2734			0.142	0.047	0.429	0.0194
2749			0.154	0.049	0.404	0.0222
2764			0.149	0.051	0.452	0.0254
2778			0.154	0.054	0.457	0.0286
2793			0.178	0.056	0.474	0.0320
2808			0.196	0.059	0.475	0.0361
2823			0.192	0.062	0.605	0.0403
2837			0.187	0.064	0.615	0.0447
2852			0.206	0.067	0.587	0.0488
2867			0.226	0.070	0.583	0.0529
2881			0.222	0.073	0.641	0.0574
2896			0.224	0.076	0.722	0.0625
2911			0.257	0.080	0.715	0.0675
2926			0.288	0.084	0.723	0.0727
2940			0.290	0.088	0.790	0.0782
2955			0.323	0.093	0.735	0.0834
2970			0.336	0.097	0.798	0.0890
2984			0.339	0.102	0.772	0.0945
2999			0.383	0.107	0.787	0.100
3014			0.408	0.113	0.809	0.106
3029			0.448	0.119	0.834	0.112
3043			0.493	0.126	0.870	0.118
3058			0.549	0.134	0.944	0.124
3073			0.625	0.142	0.968	0.131
3088			0.654	0.152	0.942	0.138
3102			0.657	0.161	0.937	0.144
3117			0.707	0.171	0.938	0.151
3132			0.729	0.181	0.941	0.158
3146			0.803	0.192	0.914	0.164
3161			0.776	0.203	0.925	0.171
3176			0.885	0.215	0.953	0.177
3191			0.810	0.227	0.948	0.184
3205			0.877	0.239	0.998	0.191
3220			0.838	0.251	0.916	0.197
3235			0.917	0.263	0.958	0.204
3249			0.904	0.276	1.011	0.211
3264			0.924	0.289	0.981	0.218

TABLE A-XI (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
3279			1.000	0.303	0.998	0.225
3294			1.006	0.317	1.011	0.233
3308			1.036	0.331	1.014	0.240
3323			0.957	0.345	1.023	0.247
3338			1.002	0.359	0.940	0.253
3352			1.011	0.373	0.987	0.260
3367			0.987	0.387	1.036	0.268
3382			0.915	0.399	0.961	0.274
3397			0.937	0.413	0.980	0.281
3411			0.965	0.426	0.977	0.288
3426			0.971	0.440	1.000	0.295
3441			0.933	0.453	0.908	0.302
3456			0.921	0.466	0.930	0.308
3470			0.937	0.479	0.935	0.315
3485			0.828	0.490	0.905	0.321
3500			0.737	0.501	0.923	0.328
3514			0.765	0.511	0.908	0.334
3529			0.794	0.522	0.899	0.340
3544			0.757	0.533	0.888	0.347
3559			0.802	0.544	0.856	0.353
3573			0.860	0.556	0.828	0.359
3588			0.856	0.568	0.877	0.365
3603			0.811	0.579	0.902	0.371
3617			0.766	0.590	0.975	0.378
3632			0.690	0.600	0.899	0.384
3647			0.664	0.609	0.809	0.390
3662			0.677	0.618	0.814	0.396
3676			0.669	0.628	0.850	0.402
3691			0.640	0.637	0.819	0.408
3706			0.637	0.645	0.814	0.413
3720			0.603	0.654	0.797	0.419
3735			0.564	0.662	0.786	0.424
3750			0.564	0.670	0.740	0.430
3765			0.543	0.677	0.743	0.435
3779			0.514	0.684	0.708	0.440
3794			0.478	0.691	0.744	0.445
3808			0.476	0.698	0.709	0.450
3824			0.442	0.704	0.712	0.455
3838			0.456	0.710	0.687	0.460
3853			0.414	0.716	0.659	0.465
3868			0.435	0.722	0.696	0.469
3882			0.410	0.728	0.728	0.475
3897			0.388	0.733	0.637	0.479
3912			0.379	0.739	0.717	0.484
3927			0.380	0.744	0.669	0.489

TABLE A-XI (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
3941			0.343	0.749	0.683	0.494
3956			0.374	0.754	0.662	0.498
3971			0.352	0.759	0.677	0.503
3985			0.329	0.763	0.683	0.508
4000			0.339	0.768	0.626	0.512
4015			0.329	0.773	0.625	0.517
4030			0.298	0.777	0.674	0.521
4044			0.303	0.781	0.639	0.526
4059			0.287	0.785	0.576	0.530
4074			0.284	0.789	0.616	0.534
4088			0.273	0.793	0.639	0.539
4103			0.255	0.796	0.617	0.543
4118			0.270	0.800	0.588	0.547
4133			0.229	0.803	0.598	0.552
4147			0.224	0.807	0.576	0.556
4162			0.227	0.810	0.528	0.559
4177			0.238	0.813	0.513	0.563
4192			0.221	0.816	0.576	0.567
4206			0.213	0.819	0.540	0.571

[a] C_o = 1.391×10^4 dpm/mℓ for ^{85}Sr, 729 dpm/mℓ for ^{137}Cs, and 291 dpm/mℓ for ^{133}Ba.

A_T = 2.103×10^6 dpm for ^{85}Sr, 7.259×10^5 dpm for ^{137}Cs, and 5.303×10^5 dpm for ^{133}Ba.

TABLE A-XII

ELUTION OF TUFF G1-3116[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
365	0.076	0.0167				
380	0.361	0.100				
394	0.857	0.300				
409	1.000	0.533				
424	0.664	0.691				
439	0.387	0.779				
454	0.277	0.845				
469	0.202	0.892				
484	0.176	0.933				
499	0.151	0.966				
514	0.134	1.000				
.						
.						
.						
880			0.000		0.092	0.001
1029			0.002	0.000	0.324	0.005
1178			0.017	0.002	0.622	0.012
1328			0.042	0.005	0.730	0.021
1478			0.091	0.012	0.703	0.030
1627			0.128	0.022	0.730	0.038
1776			0.182	0.037	0.757	0.047
1926			0.258	0.058	0.757	0.056
2075			0.334	0.084	0.730	0.065
2225			0.484	0.123	0.811	0.075
2374			0.661	0.176	0.757	0.084
2501			0.848	0.229	0.649	0.090
2628			0.939	0.299	0.568	0.097
2777			1.00	0.379	0.730	0.105
2927			0.929	0.454	0.838	0.115
3076			0.346	0.483	0.595	0.122
3226			0.420	0.517	0.703	0.131
3375			0.469	0.555	0.784	0.140
3523			0.349	0.582	1.00	0.152
3672			0.287	0.605	0.568	0.159
3821			0.206	0.622	0.946	0.170
3971			0.182	0.636	0.676	0.179
4120			0.165	0.650	0.676	0.187
4260			0.120	0.658	0.838	0.195
4399			0.076	0.664	0.541	0.202
4548			0.076	0.670	0.568	0.208
4697			0.074	0.676	0.730	0.217
4905			0.091	0.689	0.459	0.225
5113			0.059	0.694	0.568	0.234
5263			0.049	0.698	0.541	0.240
5412			0.044	0.701	0.649	0.248
5558			0.054	0.705	0.595	0.255

TABLE A-XII (cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
5705			0.044	0.709	0.405	0.260
5868			0.037	0.713	0.297	0.264
6051			0.037	0.716	0.622	0.273
6240			0.037	0.720	0.641	0.282
6397			0.022	0.722	0.568	0.287
6505			0.042	0.724	0.486	0.291
6639			0.027	0.726	0.432	0.297

[a] $C_o = 3.386 \times 10^3$ dpm/mℓ for ^{85}Sr, 407 dpm/mℓ for ^{137}Cs, and 37 dpm/mℓ for ^{133}Ba.

$A_T = 9.039 \times 10^5$ dpm for ^{85}Sr, 7.580×10^5 dpm for ^{137}Cs, and 4.611×10^5 for ^{133}Ba.

TABLE A-XIII
ELUTION OF TUFF G1-2901[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs[b]		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
5.91	0.0046	0.0002				
7.11	0.0042	0.0005				
8.16	0.121	0.0051				
9.10	0.261	0.0168				
10.3	0.511	0.0463				
12.1	0.875	0.141				
14.7	1.000	0.263				
16.8	0.799	0.311				
18.9	0.929	0.429				
21.4	0.904	0.514				
23.5	0.879	0.591				
25.4	0.792	0.722				
28.7	0.627	0.803				
31.7	0.448	0.864				
34.5	0.285	0.896				
36.9	0.183	0.914				
39.0	0.147	0.927				
41.4	0.100	0.940				
44.4	0.0699	0.949				
48.4	0.0435	0.959				
52.3	0.0251	0.962				
56.0	0.0199	0.966				
56.7	0.0189	0.968				
59.7	0.0174	0.972				
63.3	0.0175	0.973				
66.6	0.0115	0.975				
69.8	0.0142	0.977				
73.4	0.0146	0.980				
76.9	0.0131	0.982				
80.4	0.0104	0.984				
84.0	0.0096	0.985				
87.6	0.0012	0.987				
91.1	0.0105	0.988				
94.1	0.0107	0.990				
97.7	0.0089	0.991				
101.4	0.0076	0.992				
104.5	0.0058	0.993				
108.0	0.0062	0.994				
111.7	0.0064	0.995				
115.4	0.0059	0.996				
122.3	0.0056	0.997				
125.9	0.0045	0.998				
129.5	0.0030	0.998				
133.0	0.0051	0.999				
136.5	0.0052	1.00				

TABLE A-XIII (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs [b]		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
140.1	0.000	1.00				
143.7						
147.3						
171.8						
175.4					0.0089	0.00025
178.9					0.0163	0.00064
182.5					0.0579	0.00232
186.1					0.103	0.00483
189.6					0.177	0.00963
193.1					0.266	0.0159
196.6					0.367	0.0261
200.6					0.519	0.0425
204.7					0.694	0.0627
207.3					0.764	0.0701
210.0					0.757	0.0927
213.7					0.831	0.112
217.7					0.936	0.146
221.3					0.956	0.162
224.1					1.00	0.185
228.7				0.00034	0.962	0.229
239.8				0.00034	0.974	0.280
246.6				0.00068	0.923	0.326
251.0				0.00106	0.864	0.354
257.9				0.00177	0.880	0.398
263.7				0.00230	0.779	0.431
272.3				0.00345	0.761	0.480
281.5				0.00511	0.661	0.525
288.4				0.00658	0.594	0.554
297.0				0.00895	0.528	0.588
305.4				0.0117	0.462	0.617
312.0				0.0142	0.424	0.638
320.2				0.0176	0.340	0.658
327.7				0.0211	0.338	0.675
333.1				0.0231	0.260	0.682
336.8				0.0247	0.215	0.687
341.8				0.0286	0.233	0.700
348.8				0.0335	0.221	0.711

[a] $C_o = 7.721 \times 10^4$ dpm/mℓ for ^{85}Sr and 4.044×10^3 dpm/mℓ for ^{133}Ba.
$A_T = 1.750 \times 10^6$ dpm for ^{85}Sr, 5.494×10^5 dpm for ^{137}Cs, and 5.754×10^5 dpm for ^{133}Ba.

[b] C/C_o is not reported for ^{137}Cs because the column was terminated before the concentration of ^{137}Cs reached the maximum "C_o".

TABLE A-XIV
ELUTION OF TUFF G1-2476[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs[b]		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
12.1	0.031	0.014				
19.5	0.485	0.247				
27.7	1.00	0.820				
35.8	0.232	0.929				
43.1	0.071	0.963				
51.5	0.033	0.982				
59.6	0.018	0.990				
66.9	0.020	1.000				
.						
.						
.						
230						
235					0.135	0.0454
241					0.207	0.114
248					0.414	0.287
255					0.653	0.326
262				0.0024	0.891	0.369
268					0.817	0.407
275				0.0058	1.000	0.455
282				0.0131	0.928	0.503
289				0.0229	0.989	0.549
296				0.0411	0.859	0.597
304				0.0684	0.812	0.639
313				0.103	0.631	0.681
320				0.139	0.615	0.714
328				0.183	0.658	0.748
336				0.216	0.505	0.771
341				0.278	0.419	0.804
345				0.322	0.334	0.821
352				0.358	0.305	0.835

[a] $C_o = 2.804 \times 10^3$ dpm/mℓ for ^{85}Sr and 3.77×10^2 dpm/mℓ for ^{133}Ba.
$A_T = 4.382 \times 10^4$ dpm for ^{85}Sr, 1.346×10^5 dpm for ^{137}Cs, and 5.176×10^4 dpm for ^{133}Ba.

[b] C/C_o is not reported for ^{137}Cs because the column was terminated before the concentration of ^{137}Cs reached the maximum "C_o".

TABLE A-XV
ELUTION OF TUFF G1-2363[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
6.17	0.0383	0.0112				
13.38	0.0000	0.0112				
22.28	0.0000	0.0112				
29.63	0.0000	0.0112				
37.84	0.0000	0.0112				
49.94	0.0486	0.0246				
53.42	0.289	0.108				
61.80	0.931	0.430				
69.93	1.000	0.699				
77.16	0.648	0.879				
83.91	0.222	0.931				
89.13	0.117	0.950				
95.54	0.062	0.965				
99.32	0.000	0.965				
102.8	0.0268	0.969				
107.5						
112.7						
118.2						
125.4						
132.4						
138.8						
146.4						
153.4						
159.4					0.0140	0.0056
165.7					0.177	0.0209
173.2					0.451	0.0722
181.9					0.807	0.166
188.5					0.912	0.207
193.4					1.000	0.290
199.8					0.902	0.368
207.1					0.874	0.463
213.3					0.758	0.506
217.2					0.726	0.540
221.3			0.062	0.0027	0.712	0.583
226.1			0.233	0.0136	0.528	0.619
231.6			0.383	0.0365	0.512	0.660
237.5			0.505	0.0674	0.426	0.692
242.5			0.698	0.0961	0.356	0.712
247.5			0.792	0.140	0.393	0.742
254.6			0.876	0.184	0.295	0.774
261.9			0.954	0.243	0.267	0.798
268.4			1.000	0.303	0.205	0.815
274.9			0.978	0.365	0.191	0.831
281.8			0.949	0.429	0.174	0.848

TABLE A-XV (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
288.4			0.731	0.478	0.149	0.860
295.1			0.786	0.536	0.109	0.871
302.9			0.670	0.588	0.102	0.881
311.0			0.672	0.647	0.0163	0.883
319.3			0.599	0.689	0.0240	0.890
326.9			0.480	0.725	0.0810	0.899
334.0			0.437	0.751	0.0814	0.905
342.5			0.342	0.786	0.0605	0.915
351.3			0.273	0.804	0.0000	0.915
357.9			0.252	0.819	0.0186	0.916

[a] $C_o = 1.565 \times 10^3$ dpm/mℓ for ^{85}Sr, 1.165×10^3 dpm/mℓ for ^{137}Cs, and 4.30×10^2 dpm/mℓ for ^{133}Ba.

$A_T = 4.141 \times 10^4$ dpm for ^{85}Sr, 1.225×10^5 dpm for ^{137}Cs, and 3.245×10^4 dpm for ^{133}Ba.

TABLE A-XVI
ELUTION OF TUFF G1-2289

Total Volume (mℓ)	^{152}Eu[a]	
	C/C_o	A/A_T
0.53	1.000	0.0086
2.74	0.132	0.0169
4.65	0.267	0.0192
5.48	0.000	0.0192
.	.	.
.	.	.
.	.	.
96.9	0.000	0.0192
105.5	0.0049	0.0200
111.0	0.011	0.0212
118.5	0.0043	0.0218
127.7	0.0089	0.0226
134.1	0.0089	0.0226
140.1	0.0033	0.0237
146.7	0.0000	0.0237
155.8	0.0038	0.0244
164.8	0.0000	0.0244

[a] $C_o = 6.283 \times 10^3$ dpm/mℓ and $A_T = 3.262 \times 10^5$.

TABLE A-XVII
ELUTION OF TUFF G1-1982[a]

Total Volume (mℓ)	^{85}Sr		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T
11.50	0.0015	0.0002		
14.07	0.0134	0.0017		
15.93	0.0540	0.0056		
18.19	0.1685	0.0293		
20.73	0.3766	0.0666		
22.89	0.5820	0.128		
25.62	0.8155	0.140		
28.29	0.8978	0.220		
30.17	1.000	0.309		
31.90	0.9032	0.376		
33.50	0.8197	0.439		
35.37	0.7161	0.510		
37.83	0.6398	0.595		
40.16	0.4983	0.639		
42.29	0.4266	0.687		
44.89	0.3368	0.731		
47.34	0.2586	0.757		
49.44	0.2121	0.778		
52.17	0.1712	0.805		
54.5	0.1396	0.814		
55.6	0.1263	0.819		
57.6	0.0985	0.833		
60.1	0.0836	0.842		
62.2	0.0746	0.849		
64.7	0.0647	0.858		
67.2	0.0503	0.863		
69.5	0.0488	0.868		
72.9	0.0395	0.873		
74.3	0.0339	0.877		
76.5	0.0322	0.880		
79.0	0.0276	0.883		
82.1	0.0252	0.887		
86.2	0.0190	0.892		
90.2	0.0160	0.894		
94.1	0.0170	0.898		
97.9	0.0132	0.900		
101.6	0.0126	0.902		
104.9	0.0121	0.904		
108.1	0.0089	0.905		
111.8	0.0101	0.907		
115.4	0.0105	0.909		
119.1	0.0096	0.910		
122.5	0.0089	0.912		
125.8	0.0101	0.913		

TABLE A-XVII (cont)

Total Volume (mℓ)	^{85}Sr		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T
129.5	0.0085	0.915		
132.7	0.0066	0.916		
136.8	0.0058	0.917		
140.6	0.0062	0.918		
143.9	0.0041	0.919		
147.0	0.0050	0.919		
150.8	0.0048	0.920		
154.5				
154.8				
161.4				
165.0			0.085	0.00216
168.5			0.144	0.00491
172.1			0.188	0.00962
175.6			0.253	0.0144
179.2			0.340	0.0232
182.8			0.449	0.0318
186.3			0.517	0.0446
189.8			0.630	0.0565
193.0			0.669	0.0706
196.3			0.701	0.0848
199.8			0.768	0.103
203.3			0.820	0.120
206.8			0.907	0.141
210.4			0.893	0.162
214.1			0.959	0.185
217.5			0.968	0.204
221.1			1.00	0.229
224.7			0.996	0.249
228.3			0.959	0.272
231.8			0.982	0.291
235.2			0.996	0.314
239.2			0.984	0.341
243.3			0.984	0.365
246.1			0.948	0.375
249.0			0.893	0.398
252.6			0.888	0.415
256.4			0.866	0.441
260.1			0.847	0.453
263.0			0.846	0.471
267.1			0.760	0.500
270.8			0.746	0.533
281.0			0.664	0.560
286.4			0.648	0.578
292.1			0.608	0.604
298.5			0.540	0.624
305.7			0.510	0.651

TABLE A-XVII (cont)

Total Volume (mℓ)	^{85}Sr		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T
314.5			0.453	0.677
322.5			0.417	0.695
330.4			0.384	0.716
339.0			0.336	0.737
346.5				0.747
352.2				0.757

[a] C_o = 6.789 x 10^4 dpm/mℓ for ^{85}Sr and 2.748 x 10^3 dpm/mℓ for ^{133}Ba.
A_T = 1.440 x 10^6 dpm for ^{85}Sr, 4.897 x 10^5 dpm for ^{137}Cs, and 4.390 x 10^5 dpm for ^{133}Ba.

C/C_o is not reported for ^{137}Cs because the column was terminated before the concentration of ^{137}Cs reached the maximum "C_o".

TABLE A-XVIII
ELUTION OF TUFF G1-1883-1[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
0.54	0.016	0.0037	0.073	0.0018	0.088	0.0030
2.10	0.039	0.0164	0.069	0.0050	0.029	0.0069
4.23	0.848	0.423	0.033	0.0066	0.000	0.0069
6.00	1.00	0.703	0.021	0.0072	0.000	0.0069
7.91	0.371	0.902	0.013	0.0080	0.000	0.0069
9.99	0.108	0.940	0.016	0.0086	0.000	0.0069
11.9	0.047	0.962	0.022	0.0097	0.000	0.0069
14.5	0.020	0.974	0.095	0.0158	0.000	0.0069
17.0	0.011	0.979	0.241	0.0276	0.012	0.0086
19.1	0.0089	0.983	0.414	0.0460	0.115	0.023
21.3	0.0056	0.986	0.590	0.081	0.509	0.106
23.8	0.0046	0.988	0.762	0.121	0.898	0.239
26.0	0.0036	0.990	0.886	0.162	1.000	0.377
28.4	0.0027	0.991	0.840	0.214	0.869	0.519
30.8	0.0019	0.992	0.952	0.257	0.690	0.607
33.0	0.0021	0.993	1.000	0.310	0.510	0.682
35.4	0.0016	0.994	0.927	0.363	0.367	0.740
37.6	0.0012	0.995	0.890	0.403	0.281	0.776
39.8	0.0013	0.996	0.872	0.448	0.230	0.809
42.3	0.0015	0.996	0.771	0.497	0.170	0.839
44.7	0.0008	0.997	0.748	0.531	0.128	0.855
46.9	0.0009	0.997	0.745	0.570	0.101	0.870
49.5	0.0009	0.998	0.698	0.613	0.083	0.885
51.8	0.0008	0.998	0.587	0.641	0.066	0.893
52.9	0.0008	0.989	0.597	0.669	0.058	0.901
55.4	0.0000	0.999	0.541	0.704	0.053	0.910
57.8	0.0007	0.999	0.530	0.729	0.049	0.917
60.0	0.0000	0.999	0.505	0.754	0.043	0.923
62.4	0.0000	0.999	0.434	0.780	0.030	0.928
64.9	0.0009	1.00	0.403	0.801	0.030	0.932
67.1			0.366	0.818	0.025	0.935
69.4			0.331	0.838	0.024	0.940
72.0			0.277	0.853	0.019	0.942
74.1			0.270	0.864	0.022	0.945
77.0			0.214	0.879	0.018	0.948
80.0			0.202	0.888	0.016	0.950
82.1			0.164	0.896	0.016	0.953
85.2			0.162	0.907	0.012	0.955
87.7			0.143	0.913	0.013	0.956
89.5			0.117	0.918	0.012	0.958
92.1			0.111	0.926	0.011	0.960
94.7			0.092	0.930	0.009	0.961
96.7			0.092	0.934	0.010	0.962

TABLE A-XVIII (Cont)

Total Volume (mℓ)	^{85}Sr[a]		^{137}Cs[b]		^{133}Ba[c]	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
99.1			0.079	0.939	0.008	0.964
101.3			0.076	0.942	0.007	0.964
103.2			0.054	0.945	0.009	0.966

[a] C_o = 2.280×10^5 dpm/mℓ for ^{85}Sr, 7.487×10^3 dpm/mℓ for ^{137}Cs, and 1.173×10^4 dpm/mℓ for ^{133}Ba.

A_T = 1.066×10^6 dpm for ^{85}Sr, 3.317×10^5 dpm for ^{137}Cs, and 1.859×10^5 dpm for ^{133}Ba.

TABLE XIX
ELUTION OF TUFF G1-1883-2[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
23.87	0.003	0.0002				
26.41	0.011	0.001				
28.61	0.031	0.003				
31.05	0.075	0.008				
33.47	0.149	0.016				
35.68	0.258	0.032				
38.15	0.397	0.059				
40.45	0.554	0.088				
42.61	0.695	0.130				
45.18	0.842	0.192				
46.61	0.921	0.241				
49.80	0.991	0.302				
52.43	0.996	0.378				
54.93	1.000	0.432				
57.02	0.913	0.483				
59.51	0.869	0.548				
62.02	0.790	0.592				
64.22	0.723	0.634				
66.70	0.622	0.679				
69.24	0.557	0.713				
71.44	0.481	0.738				
73.86	0.413	0.769				
76.44	0.362	0.791				
78.56	0.320	0.807				
80.98	0.274	0.828				
83.50	0.234	0.840				
85.63	0.214	0.853				
88.28	0.180	0.867				
90.79	0.161	0.875				
92.69	0.152	0.883				
95.28	0.131	0.894				
97.91	0.113	0.900				
99.92	0.115	0.906				
102	0.102	0.914				
104	0.090	0.917				
106	0.091	0.922				
108	0.091	0.929				
111	0.086	0.934				
113	0.071	0.938				
116	0.069	0.944				
119	0.057	0.948				
121	0.063	0.950				
123	0.054	0.954				
125	0.047	0.957				

TABLE A-XIX (cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
127	0.048	0.959				
130	0.041	0.962				
132	0.039	0.965				
135	0.036	0.967				
137	0.035	0.969				
139	0.037	0.971				
141	0.035	0.973				
144	0.032	0.975				
147	0.028	0.978				
153	0.019	0.982				
159	0.016	0.984				
165	0.017	0.986				
169	0.019	0.988				
174	0.018	0.991				
179	0.015	0.993	0.029	0.00047	0.055	0.002
184	0.016	0.995	0.000	0.00047	0.111	0.006
189	0.013	0.997	0.038	0.00115	0.182	0.013
194	0.009	0.998	0.021	0.00141	0.299	0.022
198	0.010	0.999	0.046	0.00188	0.367	0.031
203	0.009	1.000	0.064	0.00309	0.524	0.054
211			0.082	0.00442	0.645	0.079
216			0.113	0.00544	0.743	0.099
221			0.115	0.00731	0.811	0.131
226			0.142	0.00906	0.908	0.164
230			0.157	0.0109	0.891	0.190
235			0.187	0.0133	0.956	0.225
240			0.173	0.0163	1.00	0.263
245			0.187	0.0185	0.941	0.291
251			0.173	0.0229	0.953	0.342
258			0.194	0.0282	0.928	0.390
265			0.241	0.0334	0.805	0.427
272			0.262	0.0400	0.784	0.467
279			0.300	0.0471	0.692	0.502
286			0.342	0.0552	0.631	0.535
294			0.365	0.0647	0.563	0.565
301			0.426	0.0749	0.502	0.590
308			0.469	0.0864	0.441	0.614
315			0.508	0.0953	0.419	0.630
321			0.542	0.101	0.353	0.648
328			0.587	0.120	0.325	0.665
336			0.593	0.134	0.302	0.681
343			0.709	0.148	0.262	0.693
349			0.735	0.162	0.248	0.704
359			0.743	0.184	0.229	0.720
369			0.755	0.207	0.204	0.735

TABLE A-XIX (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
379			0.785	0.231	0.192	0.749
386			0.834	0.247	0.184	0.757
395			0.881	0.271		0.768
405			0.887	0.300	0.158	0.779
409			0.894	0.311	0.141	0.783
418			0.915	0.336	0.135	0.791
431			1.00	0.374	0.125	0.802
438			0.931	0.394	0.129	0.808
449			0.974	0.427	0.105	0.816

[a] C_o = 3.956×10^4 dpm/mℓ for ^{85}Sr, 1.301×10^3 dpm/mℓ for ^{137}Cs and 1.706×10^3 dpm/mℓ for ^{133}Ba.

A_T = 1.516×10^6 dpm for ^{85}Sr, 4.309×10^5 dpm for ^{137}Cs, and 2.510×10^5 dpm for ^{133}Ba

TABLE A-XX
ELUTION OF TUFF G1-1436[a]

Total Volume (mℓ)	^{131}I C/C_I [a]	HTO C/C_I [b]
0.58	0.102	0.035
1.20	0.660	0.360
1.40	0.783	0.560
1.65	0.921	0.830
1.85	0.956	0.900
2.05	0.923	0.960
2.26	0.942	0.980
2.59	0.963	0.965
2.87	0.998	1.000
3.48	1.002	1.000

[a] $C_I = 6.865 \times 10^2$ dpm/mℓ for ^{131}I and 2.500×10^3 cpm/mℓ for HTO.

TABLE A-XXI
ELUTION OF TUFF G1-1292[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs	
	C/C_o	A/A_T	C/C_o[b]	A/A_T
12.9	0.010	0.00020		
15.2	0.022	0.00037		
17.8	0.060	0.0020		
20.4	0.152	0.0051		
22.6	0.286	0.0102		
24.9	0.396	0.0197		
27.5	0.462	0.0300		
29.8	0.553	0.0406		
32.3	0.686	0.0585		
34.8	0.774	0.0732		
37.1	0.853	0.0921		
39.7	0.864	0.113		
42.1	0.820	0.129		
44.3	0.848	0.147		
47.0	0.889	0.170		
49.2	0.910	0.182		
51.1	0.968	0.204		
53.8	1.000	0.229		
56.2	0.997	0.248		
58.3	0.839	0.264		
60.9	0.855	0.287		
63.4	0.908	0.305		
65.7	0.942	0.324		
68.2	0.921	0.348		
70.9	0.925	0.368		
76.6	0.900	0.419		
78.1	0.821	0.434		
80.6	0.814	0.456		
83.2	0.797	0.472		
85.5	0.791	0.488		
88.0	0.728	0.507		
90.4	0.686	0.519		
92.4	0.660	0.537		
95.1	0.662	0.551		
97.8	0.643	0.563		
99.9	0.651	0.575		
103	0.651	0.594		
105	0.627	0.604		
107	0.502	0.615		
110	0.491	0.628		
112	0.497	0.638		
114	0.483	0.647		
118	0.525	0.663		
121	0.492	0.676		

TABLE A-XXI (cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs	
	C/C_o	A/A_T	C/C_o^b	A/A_T
122	0.495	0.680		
125	0.400	0.691		
126	0.469	0.698		
129	0.379	0.706		
131	0.396	0.716		
134	0.390	0.724		
136	0.407	0.732		
139	0.381	0.741		
141	0.334	0.748		
143	0.319	0.754		
145	0.330	0.763		
149	0.343	0.773		
153	0.316	0.786		
156	0.254	0.793		
160	0.257	0.804		
164	0.292	0.812		
168	0.267	0.823		
171	0.285	0.827		
174	0.192	0.834		
178	0.242	0.842		
181	0.276	0.850		
185	0.236	0.857		
188	0.230	0.864		
191	0.253	0.872		
195	0.244	0.881		
199	0.212	0.885		
203	0.211	0.895		
207	0.168	0.899		0.00040
210	0.169	0.905		0.00092
214	0.134	0.909		0.0013
218	0.203	0.918		0.0020
222	0.204	0.923		0.0029
225	0.148	0.929		0.0037
229	0.135	0.933		0.0044
233	0.125	0.938		0.0056
237	0.128	0.942		0.0065
240	0.165	0.947		0.0078
243	0.104	0.950		0.0086
247	0.089	0.953		0.010
252	0.076	0.953		0.012
255	0.131	0.961		0.013
259	0.091	0.965		0.015
262	0.144	0.968		0.017
266	0.140	0.973		0.018
270	0.000	0.973		0.020

TABLE A-XXI (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs	
	C/C_o	A/A_T	C/C_o[b]	A/A_T
273	0.000	0.973		0.022
281	0.000	0.973		0.025
284	0.113	0.976		0.026
288	0.117	0.980		0.029
291	0.083	0.983		0.032
295	0.000	0.983		0.035
299	0.000	0.983		0.038
303	0.000	0.983		0.042
306	0.000	0.983		0.044
311	0.107	0.987		0.048
315				0.052
318				0.056
322				0.058
328				0.066
332				0.069
335				0.074
339				0.082
346				0.092
353				0.102
358				0.109
364				0.121
370				0.131
378				0.148
387				0.166
395				0.180
403				0.198
411				0.218
419				0.232
425				0.244

[a] $C_o = 9.559 \times 10^3$ dpm/mℓ for ^{85}Sr.
$A_T = 1.059 \times 10^6$ dpm for ^{85}Sr and 2.871×10^5 dpm for ^{137}Cs.

[b] No data is given for C/C_o because the column was terminated before the concentration of ^{137}Cs reached the maximum, "C_o".

TABLE A-XXII
ELUTION OF TUFF GT-U12G[a]

Total Volume (mℓ)	^{95m}Tc		^{152}Eu	
	C/C_o	A/A_T	C/C_o	A/A_T
0.825	0.000	0.000	0.424	0.0125
2.08	1.000	0.863	0.000	0.0125
2.94	0.107	0.936	0.697	0.0225
3.67	0.024	0.938	0.975	0.0354
4.15	0.0048	0.952	1.000	0.0405
4.65	0.0040	0.951	0.000	0.0405
5.19	0.0029	0.958		
5.69	0.0010	0.958		
6.20	0.0013	0.959		
6.86	0.0007	0.959		
7.49	0.0063	0.961		
7.84	0.0050	0.963		
8.59	0.0013	0.964		
9.36	0.0012	0.964		
9.79	0.0011	0.965		
10.2	0.0000	0.965		
10.6	0.0009	0.965		
11.4	0.0008	0.966		
12.2	0.0011	0.966		
12.8	0.0021	0.967		

[a] C_o = 8.530 x 10^5 dpm/mℓ for ^{95m}Tc and 4.877 x 10^3 dpm/mℓ for the small ^{152}Eu peak (~4% total ^{152}Eu).
A_T = 9.489 x 10^5 dpm for ^{95m}Tc, 1.204 x 10^5 dpm for ^{152}Eu.

The radionuclides ^{85}Sr, ^{137}Cs, and ^{133}Ba were also loaded on the column but were not eluted before stopping the column at 187 mℓ.

TABLE XXIII
ELUTION OF GRANITE CS-7[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
1.29	0.0005	0.0002				
3.12	0.0066	0.0013				
4.72	0.676	0.232				
7.70	1.000	0.848				
10.61	0.165	0.901				
12.62	0.056	0.919				
14.13	0.024	0.931			0.0101	0.00049
16.28	0.016	0.934			0.168	0.0115
18.04	0.012	0.938			0.445	0.0609
19.58	0.011	0.940			0.686	0.0889
21.00	0.010	0.943			0.901	0.0177
22.98	0.0085	0.946			1.000	0.271
24.63	0.0069	0.947			0.887	0.330
26.69	0.0053	0.949			0.721	0.427
28.72	0.0045	0.950			0.528	0.460
29.82	0.0042	0.951			0.476	0.481
30.76	0.0041	0.952			0.418	0.501
31.68	0.0041	0.952			0.386	0.518
32.60	0.0039	0.953			0.368	0.535
34.14	0.0040	0.954			0.305	0.566
35.73	0.0035	0.955			0.265	0.580
36.84	0.0029	0.955			0.192	0.591
38.38	0.0028	0.956			0.170	0.607
40.82	0.0025	0.957			0.152	0.629
41.48	0.0025	0.958			0.143	0.638
42.97	0.0020	0.958			0.139	0.649
43.80	0.0021	0.959			0.119	0.657
45.82	0.0019	0.960	0.0496	0.00018	0.104	0.671
49.42	0.0019	0.961	0.109	0.00082	0.067	0.687
56.23	0.0022	0.963	0.303	0.0025	0.071	0.705
62.93	0.0017	0.964	0.381	0.0060	0.060	0.724
65.68	0.0013	0.965	0.318	0.0074	0.043	0.732
71.53			0.338	0.0099	0.040	0.743
72.96			0.445	0.0106	0.036	0.745
80.82			0.562	0.0164	0.021	0.756
88.30			0.550	0.0227	0.015	0.763
97.90			0.659	0.0289	0.014	0.770
102.9			0.708	0.0344	0.011	0.772
117.4			0.877	0.0513	0.0075	0.777
131.9			0.877	0.0688	0.011	0.782
143.5			1.000	0.0832	0.0054	0.786
169.0			0.877	0.116	0.0047	0.796
183.7			0.810	0.133	0.0040	0.799
204.6			0.727	0.153	0.0033	0.803

TABLE A-XXIII (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
226.0			0.705	0.176	0.0033	0.807
254.6			0.484	0.194	0.0029	0.810
273.9			0.477	0.208	0.0026	0.812
292.7			0.454	0.220	0.0027	0.815
319.4			0.418	0.235	0.0022	0.817
347.9			0.355	0.249	0.0018	0.818
369.9			0.221	0.255	0.0016	0.820
389.8			0.148	0.259	0.0013	0.821
407.5			0.112	0.262	0.0013	0.823
433.3			0.133	0.267	0.0012	0.824
450.3			0.143	0.270	0.0013	0.825
468.3			0.176	0.275	0.0010	0.826
487.2			0.202	0.280	0.00080	0.827
510.7			0.205	0.287	0.00060	0.828
538.7			0.171	0.293	0.0014	0.839
557.9			0.164	0.298	0.0015	0.830
577.8			0.162	0.302	0.00063	0.830
593.4			0.132	0.305	0.00053	0.831
610.2			0.141	0.308	0.00053	0.831
624.2			0.129	0.311		
638.1			0.114	0.313		
653.0			0.098	0.314		
667.9			0.089	0.316		
683.4			0.067	0.317		
697.8			0.057	0.318		
713.5			0.049	0.319		
729.1			0.035	0.320		
743.0			0.039	0.321		
760.7			0.044	0.322		
775.2			0.038	0.323		
789.5			0.044	0.324		
804.3			0.043	0.325		
818.8			0.037	0.325		
833.2			0.025	0.326		
849.8			0.024	0.327		

[a] C_o = 3.528×10^5 dpm/mℓ for ^{85}Sr, 1.573×10^3 dpm/mℓ for ^{137}Cs, and 3.016×10^4 dpm/mℓ for ^{133}Ba.

A_T = 2.195×10^6 dpm for ^{85}Sr, 1.070×10^6 dpm for ^{137}Cs, and 6.201×10^5 dpm for ^{133}Ba.

TABLE A-XXIV
ELUTION OF GRANITE CS5-1[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
1.1	0.0009	0.00033				
2.7	0.0206	0.0040				
4.3	1.000	0.363				
5.4	0.771	0.862				
7.3	0.0781	0.889				
10.3	0.0351	0.901			0.0032	
12.7	0.0222	0.911			0.418	0.063
14.6	0.0205	0.915			0.731	0.104
16.2	0.0142	0.920			1.00	0.222
17.8	0.0116	0.922			0.956	0.266
19.2	0.0096	0.925			0.813	0.352
21.1	0.0077	0.928			0.600	0.413
22.8	0.0068	0.929			0.436	0.445
24.9	0.0057	0.932			0.331	0.496
27.0	0.0050	0.933			0.243	0.513
28.1	0.0047	0.934			0.220	0.523
29.0	0.0050	0.935			0.229	0.535
30.0	0.0047	0.935			0.194	0.544
30.9	0.0047	0.936			0.175	0.553
32.4	0.0044	0.938			0.165	0.569
33.8	0.0045	0.937			0.148	0.578
35.0	0.0039	0.937			0.108	0.585
36.5	0.0035	0.939			0.0939	0.594
38.9	0.0027	0.940			0.0862	0.608
41.0	0.0026	0.940			0.0736	0.613
42.5	0.0025	0.941			0.0632	0.619
44.1	0.0025	0.942	0.101	0.00008	0.0571	0.623
46.1	0.0023	0.943	0.118	0.0003	0.0569	0.631
47.9	0.0025	0.943	0.197	0.0004	0.0597	0.634
49.0	0.0022	0.944	0.186	0.0005	0.0599	0.638
50.0	0.0021	0.944	0.240	0.0006	0.0620	0.641
51.0	0.0024	0.944	0.254	0.0008	0.0543	0.644
52.8	0.0022	0.945	0.246	0.0012	0.0495	0.651
54.5	0.0021	0.946	0.293	0.0013	0.0414	0.653
55.6	0.0023	0.946	0.323	0.0015	0.0401	0.655
56.6	0.0022	0.946	0.346	0.0017	0.0401	0.657
57.7	0.0022	0.947	0.368	0.0020	0.0359	0.659
59.7	0.0020	0.948	0.440	0.0027	0.0312	0.664
61.6	0.0024	0.948	0.653	0.0031	0.0313	0.666
62.3	0.0025	0.948	0.672	0.0033	0.0265	0.667
63.2	0.0026	0.949	0.568	0.0037	0.0287	0.669
64.4	0.0023	0.949	0.717	0.0042	0.0302	0.670
65.6	0.0026	0.950	0.739	0.0047	0.0341	0.672
66.8	0.0016	0.950	0.454	0.0051	0.0239	0.674

TABLE A-XXIV (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
67.9	0.0018	0.951	0.477	0.0053	0.0223	0.675
68.9	0.0016	0.951	0.450	0.0056	0.0212	0.676
70.8	0.0014	0.951	0.474	0.0064	0.0186	0.679
73.2	0.0014	0.952	0.582	0.0071	0.0148	0.681
74.9	0.0018	0.952	0.680	0.0076	0.0138	0.682
76.1	0.0017	0.953	0.632	0.0080	0.0136	0.683
77.2	0.0017	0.953	0.611	0.0084	0.0126	0.683
79.1			0.574	0.0093	0.0116	0.684
80.8			0.731	0.0098	0.0124	0.685
82.6			0.696	0.0106	0.0145	0.687
85.1			0.616	0.0118	0.0153	0.681
87.6			0.739	0.0126	0.0155	0.691
89.1			0.776	0.0131	0.0174	0.692
90.9			0.774	0.0143	0.0058	0.694
93.4			0.846	0.0154	0.0132	0.696
106			0.861	0.0272	0.0091	0.706
131			0.803	0.0407	0.0062	0.716
166			0.638	0.0570	0.0054	0.728
204			0.542	0.0674	0.0041	0.735
253			0.336	0.0806	0.0025	0.745
327			1.00	0.128	0.0015	0.751
407			0.768	0.164	0.0009	0.755
482			0.883	0.202	0.0007	0.758
556			0.754	0.236	0.0004	0.760
623			0.466	0.252	0.0004	0.761
677			0.338	0.262	0.0004	0.762
726			0.202	0.268		
777			0.118	0.271		
827			0.141	0.275		

[a] C_o = 3.707×10^5 dpm/mℓ for ^{85}Sr, 6.25×10^2 dpm/mℓ for ^{137}Cs, and 5.822×10^4 dpm/mℓ for ^{133}Ba.

A_T = 2.195×10^6 dpm for ^{85}Sr, 1.054×10^6 dpm for ^{137}Cs, and 1.090×10^6 dpm for ^{133}Ba.

TABLE A-XXV
ELUTION OF GRANITE CS5-2[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
17.0	0.049	0.004				
19.4	0.182	0.020				
21.8	0.483	0.061				
23.1	0.618	0.081				
25.7	0.819	0.151				
27.1	0.843	0.223				
28.9	0.815	0.292				
30.6	0.932	0.372				
31.9	0.966	0.455				
33.2	1.000	0.540				
34.7	0.891	0.617				
35.9	0.787	0.684				
37.6	0.654	0.738				
40.1	0.499	0.781				
42.8	0.384	0.813				
45.3	0.337	0.842				
47.7	0.257	0.864				
48.9	0.282	0.888				
50.5	0.232	0.908				
51.7	0.178	0.916				
53.0	0.174	0.928				
54.6	0.150	0.939				
56.1	0.147	0.948				
57.5	0.131	0.956				
59.0	0.107	0.963				
60.8	0.096	0.971				
63.4	0.088	0.981				
65.8	0.071	0.988				
68.2	0.062	0.994				
70.5	0.052	0.999				
71.4	0.046	1.000				
.						
.						
.						
163					0.065	0.001
166					0.173	0.005
171					0.336	0.017
174					0.394	0.027
178					0.471	0.042
181					0.510	0.055
187					0.708	0.085
193					0.807	0.121
204					0.844	0.202
214					1.00	0.283

TABLE A-XXV (cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
219					0.912	0.321
224					0.859	0.360
229					0.850	0.396
233					0.799	0.430
237					0.669	0.455
239					0.752	0.466
242					0.712	0.483
247					0.609	0.508
250					0.503	0.523
254					0.314	0.539
257					0.423	0.550
262					0.401	0.568
269					0.314	0.594
274					0.314	0.611
279					0.294	0.615
283					0.271	0.625
292					0.235	0.644
299					0.219	0.657
307					0.175	0.671
321					0.151	0.691
332			0.110		0.154	0.721
347			0.107	0.0034	0.077	0.736
357			0.189	0.0063	0.113	0.745
385			0.235		0.117	0.766
402			0.312		0.073	0.772
423			0.324		0.058	0.781
440			0.560		0.058	0.787
478					0.024	0.796
485			0.424	0.0257		
494			0.465			
509			0.456			
515			0.476			
525			0.517	0.1002		
530			0.525			
539			0.536			
549			0.545			
553			0.554	0.1231		
560			0.571			
571			0.585			
582			0.628			
592			0.633			
600			0.679	0.1661		
618			0.670			
632			0.679			
636			0.731	0.2009		

TABLE A-XXV (cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
657			0.705			
691			0.693			
725			0.606			
751			0.583			
764			0.619	0.331		
804			0.717	0.366		
872			0.628	0.432		
886			1.000	0.455		
906			0.931	0.470		
912			0.913	0.477		
914			0.913	0.481		
917			0.968	0.485		
923			0.959	0.493		
928			0.931	0.500		
936			0.849	0.510		
962			0.904	0.542		
984			0.817	0.568		
999			0.716	0.586		
1025			0.702	0.610		
1066			0.596	0.649		
1091			0.583	0.671		
1159			0.417	0.712		
1165			0.367	0.743		
1203			0.280	0.758		
1213			0.275	0.764		
1293			0.211	0.792		
1404			0.188	0.824		
1443			0.151	0.833		
1554			0.128	0.853		
1606			0.165	0.865		
1638			0.151	0.872		
1694			0.110	0.883		
1809			0.083	0.898		
1894			0.161	0.904		
1961			0.188	0.909		
2246			0.156	0.918		
2321			0.128	0.922		
2341			0.138	0.923		
2390			0.078	0.924		

[a] C_o = 2.841×10^4 dpm/mℓ for ^{85}Sr, 2.18×10^2 dpm/mℓ for ^{137}Cs, and 3.213×10^3 dpm/mℓ for ^{133}Ba.

A_T = 6.641×10^5 dpm for ^{85}Sr, 1.491×10^5 dpm for ^{137}Cs, and 3.733×10^5 dpm for ^{133}Ba.

TABLE A-XXVI
ELUTION OF GRANITE CS5-3[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
1.53	0.278	0.140				
4.59	1.000	0.642				
7.65	0.272	0.779				
10.7	0.091	0.825				
13.8	0.044	0.847				
16.8	0.039	0.866				
19.9	0.042	0.877				
23.0	0.045	0.910				
26.0	0.019	0.919				
29.1	0.033	0.936				
32.1	0.022	0.946				
35.2	0.018	0.956				
38.3	0.013	0.962				
41.3	0.0092	0.967			0.000	0.0000
44.4	0.0071	0.970			0.158	0.0083
47.4	0.0071	0.974			0.587	0.0392
50.5	0.0048	0.976			1.000	0.0918
53.6	0.0047	0.978	0.000	0.0000	0.805	0.134
56.6	0.0033	0.980	0.057	0.0023	0.765	0.174
59.7	0.0032	0.982	0.000	0.0023	0.825	0.218
62.7	0.0026	0.983	0.087	0.0036	0.820	0.266
65.8	0.0026	0.984	0.079	0.0053	0.735	0.300
68.9	0.0023	0.985	0.107	0.0082	0.685	0.336
71.9	0.0020	0.986	0.175	0.0112	0.678	0.371
75.0	0.0025	0.988	0.185	0.0162	0.548	0.400
78.0	0.0019	0.989	0.309	0.0217	0.607	0.432
81.1	0.0025	0.990	0.345	0.0298	0.582	0.463
84.1	0.0018	0.991	0.497	0.0372	0.677	0.498
87.2	0.0024	0.992	0.461	0.0489	0.591	0.529
90.3	0.0021	0.993	0.722	0.0610	0.672	0.565
93.3	0.0016	0.994	0.751	0.0742	0.670	0.600
96.4	0.0012	0.994	0.818	0.082	0.554	0.629
99.4	0.0017	0.994	0.867	0.102	0.502	0.656
103	0.0011	0.996	0.833	0.118	0.375	0.675
106	0.0013	0.997	1.000	0.132	0.333	0.693
109	0.0010	0.997	0.885	0.146	0.260	0.707
112	0.0009	0.998	0.884	0.160	0.220	0.718
115	0.0008	0.998	0.857	0.174	0.186	0.728
118	0.0008	0.999	0.839	0.189	0.162	0.739
121	0.0010	0.999	0.957	0.202	0.175	0.746
124	0.0009	1.000	0.815	0.212	0.162	0.754
127	0.0007	1.000	0.606	0.224	0.115	0.760
130	0.0005	1.000	0.752	0.237	0.137	0.768
133			0.810	0.249	0.126	0.774

TABLE A-XXVI (Cont)

Total Volume (mℓ)	^{85}Sr		^{137}Cs		^{133}Ba	
	C/C_o	A/A_T	C/C_o	A/A_T	C/C_o	A/A_T
136			0.690	0.260	0.102	0.780
139			0.690	0.271	0.079	0.784
142			0.704	0.282	0.076	0.788
145			0.680	0.294	0.052	0.790
148			0.728	0.305	0.054	0.793
151			0.715	0.316	0.055	0.796
155			0.627	0.330	0.044	0.799
158			0.891	0.345	0.066	0.802
161			0.961	0.360	0.078	0.806
164			0.919	0.372	0.085	0.811
167			0.694	0.381	0.064	0.814
170			0.574	0.391	0.052	0.817
173			0.650	0.400	0.051	0.819
176			0.556	0.409	0.036	0.821
179			0.533	0.418	0.039	0.823
182			0.596	0.427	0.040	0.825
185			0.534	0.436	0.030	0.827
188			0.531	0.445	0.030	0.829
191			0.552	0.452	0.038	0.831
194			0.430	0.460	0.034	0.832
197			0.534	0.468	0.024	0.834
200			0.490	0.473	0.025	0.835
203			0.375	0.480	0.019	0.836
207			0.516	0.487	0.023	0.837
210			0.444	0.494	0.025	0.838
213			0.438	0.500	0.022	0.840
216			0.418	0.507	0.027	0.841
219			0.388	0.514	0.024	0.842
222			0.415	0.519	0.028	0.844
225			0.440	0.524	0.033	0.846
228			0.315	0.530	0.024	0.847
231			0.306	0.535	0.020	0.848
234			0.332	0.540	0.024	0.849
237			0.317	0.546	0.000	0.849
240			0.341	0.551	0.013	0.850
243			0.331	0.554	0.000	0.850
246			0.324	0.559	0.000	0.850
249			0.340	0.564	0.000	0.850
252			0.315	0.569	0.000	0.850
256			0.330	0.574	0.014	0.851
259			0.330	0.580	0.000	0.851

[a] C_o = 8.637 x 10^4 dpm/mℓ for ^{85}Sr, 1.387 x 10^3 dpm/mℓ for ^{137}Cs, and 3.892 x 10^3 dpm/mℓ for ^{133}Ba.

A_T = 5.262 x 10^5 dpm for ^{85}Sr, 2.627 x 10^5 dpm for ^{137}Cs, and 2.264 x 10^5 dpm for ^{133}Ba.

TABLE A-XXVII
ELUTION OF ARGILLITE CN1[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs[b]	
	C/C_o	A/A_T	C/C_o	A/A_T
0.31	0.0000	0.0000		
1.24	0.0000	0.0000		
3.21	0.0000	0.0000		
5.06	0.0000	0.0000		
7.14	0.0000	0.0000		
10.25	0.0421	0.0127		
12.81	0.247	0.0632		
14.81	0.539	0.166		
16.21	0.781	0.232		
17.10	0.877	0.313		
18.28	1.000	0.454		
19.45	0.771	0.565		
20.67	0.629	0.625		
22.14	0.529	0.729		
24.55	0.394	0.839		
27.50	0.251	0.915		
29.60	0.163	0.934		
31.64	0.0991	0.963		
33.58	0.0657	0.969		
34.58	0.0592	0.975		
36.22	0.0430	0.985		
38.31	0.0210	0.989		
40.44	0.0157	0.992		
42.59	0.0119	0.995		
44.95	0.0069	0.996		
47.34	0.0053	0.997		
49.50	0.0037	0.998		
51.93	0.0030	0.999		
53.25	0.0000	0.999		
54.15	0.0000	0.999		
57.11	0.0025	1.000		
.			.	.
.			.	.
.			.	.
517.2			0.0000	0.0000

[a] $C_o = 1.009 \times 10^5$ dpm/mℓ for ^{85}Sr.
$A_T = 1.021 \times 10^6$ dpm for ^{85}Sr and 3.505×10^5 dpm for ^{137}Cs.

[b] The column was stopped at 517.2 mℓ, before the elution of ^{137}Cs.

TABLE A-XXVIII
ELUTION OF ARGILLITE CN2-1[a]

Total Volume (mℓ)	^{85}Sr		^{137}Cs[b]	
	C/C_o	A/A_T	C/C_o	A/A_T
0.24				
1.00				
2.92				
4.86				
7.00	0.0000	0.0000		
10.14	0.0048	0.0007		
12.73	0.0686	0.0073		
14.77	0.2028	0.0260		
16.23	0.3691	0.0418		
17.16	0.7899	0.0762		
18.45	0.8192	0.139		
20.05	0.9789	0.208		
21.23	0.9780	0.246		
22.38	0.9710	0.312		
24.11	1.000	0.405		
26.42	0.9390	0.517		
28.24	0.8192	0.557		
30.13	0.7922	0.656		
31.97	0.6776	0.686		
32.78	0.6930	0.708		
34.11	0.6271	0.766		
36.37	0.4487	0.819		
38.80	0.3843	0.860		
40.99	0.3177	0.891		
42.03	0.2379	0.920		
43.11	0.1945	0.940		
44.19	0.1403	0.955		
45.51	0.1138	0.968		
46.82	0.0845	0.978		
47.72	0.0671	0.983		
50.61	0.0400	0.991		
53.78	0.0295	0.994		
55.47	0.0340	0.995		
57.37	0.0164	0.997		
60.53	0.0135	0.999		
62.62	0.0000	0.999		
67.83	0.0047	1.000		
⋮			⋮	⋮
1060			0.0000	0.0000

[a] $C_o = 4.762 \times 10^4$ dpm/mℓ for ^{85}Sr.
$A_T = 1.027 \times 10^6$ dpm for ^{85}Sr and 2.430×10^5 dpm for ^{137}Cs.

[b] The column was stopped at 1060 mℓ, before the elution of ^{137}Cs.

TABLE A-XXIX
ELUTION OF ARGILLITE CN2-2[a]

Total Volume (mℓ)	C/C_I, ^{95m}Tc	C/C_I, ^{131}I	C/C_I, HTO
0.025	0.000	0.000	0.001
0.076	0.000	0.000	0.000
0.127	0.000	0.0312	0.029
0.178	0.141	0.105	0.108
0.229	0.198	0.142	0.147
0.280	0.195	0.179	0.169
0.301	0.198	0.202	0.171
0.382		0.264	0.277
0.433	0.225	0.498	
0.484		0.667	
0.535	0.285	0.740	0.824
0.586	0.298	0.818	0.884
0.637	0.457	0.828	0.880
0.688	0.514	0.902	0.873
0.739	0.478	0.889	0.909
0.790	0.495	0.936	
0.841	0.649	0.914	0.907
0.892	0.643	0.956	0.930
0.943	0.732	0.939	0.952
1.020	0.786	0.996	0.960
1.122	0.763	0.940	0.985
1.224	0.844	0.977	1.000
1.326	0.926	1.023	1.005
1.479	0.803	0.877	1.010
1.632	0.996	1.016	0.895
1.683	1.009	1.004	0.947
1.734	0.922	0.988	0.987
1.785	1.013	1.000	0.994
1.836	1.010	0.987	1.000
1.913	0.993	1.004	0.993

[a] $C_I = 4.842 \times 10^5$ dpm/mℓ for ^{95m}Tc, 2.204×10^6 dpm/mℓ for ^{131}I, and 2.040×10^5 dpm/mℓ for HTO.

TABLE A-XXX
ELUTION OF ARGILLITE CN2-3[a]

Total Volume (mℓ)	^{95m}Tc[b] C/C_o	^{95m}Tc[b] A/A_T
3.96	0.117	0.00038
4.13	0.136	0.0016
4.34	0.144	0.0026
4.55	0.166	0.0041
4.73	0.175	0.0044
5.54	0.209	0.0108
5.88	0.293	0.0145
6.26	0.373	0.0198
6.71	0.393	0.0264
7.08	0.430	0.0323
7.51	0.493	0.0402
8.52	0.522	0.0599
8.79	0.585	0.0658
9.19	0.660	0.0756
9.63	0.942	0.0911
9.96	0.982	0.103
10.3	0.974	0.117
11.1	0.941	0.144
11.5	0.991	0.160
12.0	0.986	0.177
12.3	1.000	0.189
12.7	0.992	0.203
13.1	0.976	0.218
14.1	0.903	0.251
14.6	0.949	0.270
15.1	0.933	0.285
15.5	0.875	0.298
15.9	0.813	0.310
17.1	0.697	0.342
17.5	0.792	0.354
17.9	0.850	0.366
18.3	0.761	0.378
18.7	0.781	0.389
19.9	0.657	0.399
20.3	0.649	0.429
21.2	0.602	0.437
21.7	0.590	0.457
22.9	0.568	0.468
23.3	0.484	0.488
23.7	0.480	0.496
24.4	0.459	0.504
25.6	0.455	0.514
26.0	0.435	0.534
26.4	0.415	0.541

TABLE A-XXX (Cont)

Total Volume (mℓ)	^{95m}Tc[b]	
	C/C_o	A/A_T
26.9	0.390	0.547
27.3	0.398	0.554
28.4	0.380	0.560
29.7	0.300	0.586
30.1	0.315	0.590
31.4	0.308	0.593
31.8	0.292	0.609
32.2	0.299	0.613
32.6	0.293	0.618
33.0	0.269	0.622
34.2	0.251	0.626

[a]Europium was also loaded on the column but not eluted.

[b]C_o = 880 cpm/mℓ and A_T = 2.360 x 10^4 cpm.

TABLE A-XXXI
ELUTION OF ARGILLITE CN3

Total Volume (mℓ)	C/C_I, HTO	C/C_I, ^{131}I	C/C_I, ^{95m}Tc
0.350	0.000	0.000	
0.400	0.004	0.005	
0.450	0.045	0.068	
0.500	0.185	0.217	0.000
0.550	0.348	0.397	0.060
0.600	0.590	0.545	0.140
0.650	0.680	0.668	0.175
0.700	0.791	0.835	0.277
0.750	0.889	0.930	0.415
0.800	0.945	0.910	0.518
0.850	0.970	0.954	0.500
0.900	0.996	0.968	0.570
0.950	0.999	0.980	0.607
1.000	1.000	0.990	0.677
1.050		0.962	0.740
1.100		1.000	0.780
1.175			0.800
1.250			0.914
1.363			0.935
1.413			0.920
1.450			0.940
1.500			0.926
1.613			0.976
1.650			0.996
1.700			0.999
1.750			1.000

APPENDIX B
SECTIONED COLUMN DATA

After elution, the majority of the columns were sectioned into pretared vials. The vials were reweighed when the rock samples had dried, in order to determine the amount of the column in each sample, and then counted with a Ge(Li) detector. In many cases, most of the radionuclide(s) had been removed from the column by elution, and data obtained from sectioning were used primarily to determine A_T, the total amount of activity loaded on the column. Sectioning the columns also gave the distribution of activity along the column and indicated whether or not a given radionuclide was being irreversibly sorbed at the load point. For those cases where <50% of a radionulcide had been eluted, the distribution of activity in the sectioned column was used to estimate a retardation factor and a sorption ratio. Those data are summarized with the column elution data in Tables IV through VIII, Sec. IV.

TABLE B-I
DATA FROM SECTIONED COLUMN YM38-3[a]

Percent of Column Sampled	^{137}Cs in Sample (%)
5.08	1.2
17.7	5.0
11.7	1.9
13.7	1.4
14.7	4.0
17.9	9.7
19.2	11.5

[a]The data are given from the load end to the exit point.

After elution 34.7% of the ^{137}Cs remained on the column.

TABLE B-II

DATA FROM SECTIONED COLUMN JA37[a]

Percent of Column Sampled	^{137}Cs in Sample (%)
6.4	0.85
11.0	1.25
4.2	1.89
13.5	2.06
16.1	3.92
16.1	5.26
16.1	5.02
6.4	3.42

[a]The data are given from the load end to the exit point.

After elution ~24% of the ^{137}Cs remained on the column.

TABLE B-III

DATA FROM SECTIONED COLUMN JA18-1[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)
21.1	10.6	20.7
21.1	31.7	64.8
23.7	54.1	12.8
18.4	75.1	0.64
15.8	92.2	1.06

[a]The data are given from the load end to the exit point.

No ^{137}Cs was removed from the column in 678 mℓ; 50% of the activity had moved 20 to 42% of the way through the column. Thus, 1614 to 3390 mℓ would be required to remove 50% of the activity from the column.

The ^{85}Sr decayed before the column was sectioned.

TABLE B-IV

DATA FROM SECTIONED COLUMN JA18-2[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{152}Eu in Sample (%)
12.6	6.3	14.5
10.7	17.9	16.8
10.8	28.7	12.2
9.81	39.0	10.5
6.57	47.2	6.24
8.57	54.8	9.10
12.0	65.1	8.97
10.4	76.3	6.37
9.38	89.2	4.40
9.22	95.5	3.27
Column itself with traces of rock		1.83

[a]The data are given from the load end to the exit point. After elution of 804 mℓ, 50% of the ^{152}Eu had moved 33.4 to 43.1% of the way through the column. Thus, 1870 to 2410 mℓ would be required to elute one-half of the europium.

TABLE B-V

DATA FROM SECTIONED COLUMN JA18-3[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)	^{133}Ba in Sample (%)
1.88	0.94	25.8	54.5
2.30	3.03	27.5	25.2
4.12	6.24	32.7	11.1
8.87	12.7	12.9	9.20
6.71	20.5	0.23	
11.9	29.8	0.02	
11.8	41.7	0.09	
11.2	53.1	0.01	
14.8	66.2	0.01	
6.38	76.7	0.14	
20.0	89.8	0.27	

[a]The data are given from the load end to the exit point.

Occasionally, small amounts of ^{137}Cs were detected in the eluate, but essentially all the ^{137}Cs and ^{133}Ba remained on the column. The total volume eluted was 655 mℓ; 50% of the ^{133}Ba and 50% of the ^{137}Cs had moved 0.7 to 3% and 2.8 to 5.8% of the way through the column, respectively. Therefore, 21 800 to 93 600 mℓ would be required to remove 50% of the ^{133}Ba, and 11 300 to 24 300 mℓ would be necessary to remove 50% of the ^{137}Cs.

The ^{85}Sr decayed before the column was sectioned.

TABLE B-VI

DATA FROM SECTIONED COLUMN G1-3658[a]

Percent of Column Sampled	^{137}Cs in Sample (%)	^{133}Ba in Sample (%)
1.27	0.24	0.16
2.89	0.52	0.59
2.51	0.36	0.48
6.01	0.77	0.76
5.64	0.59	0.52
13.1	0.91	1.11
8.20	0.43	1.15
11.9	0.67	2.51
9.04	0.64	2.62
6.99	0.71	2.96
8.31	0.95	3.97
24.1 + exit frit[b]	6.49	17.7

[a]The data are given from the load end to the exit point. After elution, ~13% ^{137}Cs and ~35% ^{133}Ba remained on the column. Approximately 82% ^{137}Cs and 57% ^{133}Ba were removed by elution. Thus of the total activity, 95% ^{137}Cs and 92% ^{133}Ba were removed; these numbers probably differ from 100% because of the large number of samples with poor counting statistics taken over the broad peaks.

[b]There was algae in the exit frit and fitting of this column.

TABLE B-VII

DATA FROM SECTIONED COLUMN G1-3116[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{85}Sr Loaded in Sample (%)	^{85}Sr on Column in Sample (%)[b]	^{137}Cs in Sample (%)	^{137}Ba in Sample (%)
4.59	2.29	11.3	14.9	2.0	27.6
6.79	7.99	21.2	27.9	2.2	19.2
7.00	14.9	16.7	22.0	1.6	3.7
8.72	22.7	1.4	1.84	17.5	2.0
11.7	32.9	12.3	16.2	1.2	3.7
10.7	44.1	6.5	8.56	0.6	2.7
15.4	57.2	4.0	5.27	0.6	3.5
10.8	70.3	1.4	1.84	0.4	2.4
8.52	80.0	--	--	0.3	1.8
6.36	87.4	1.1	1.45	0.2	1.4
9.40	95.3	--	--	0.7	2.0
Empty column with traces of rock				0.1	0.4

[a]The data are given from the load end to the exit point.

The total volume eluted was 6727 mℓ. Approximately 73% of the ^{137}Cs was eluted, and one-half of the ^{133}Ba moved 17 to 24% of the way through the column, indicating 28 000 to 39 600 mℓ would be required to move that much completely.

[b]Because ~24% of the ^{85}Sr was removed from the column in a distinct peak before elution was stopped, the ^{85}Sr remaining on the column is treated separately. One-half of strontium on the column moved 11.5 to 20% of the way through the column, indicating 33 600 to 58 500 mℓ would be required to remove 50% of the ^{85}Sr completely.

TABLE B-VIII

DATA FROM SECTIONED COLUMN G1-2901[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)	^{133}Ba in Sample (%)
7.12	3.56	2.22	4.07
10.2	12.2	3.87	2.07
11.3	23.0	7.44	1.76
9.65	33.4	9.41	1.57
12.6	44.6	16.9	1.94
5.72	53.7	8.50	0.86
10.9	62.0	16.0	1.81
9.85	72.4	13.2	1.98
7.67	81.2	8.45	1.86
6.90	88.5	5.60	1.98
3.09	93.4	1.14	0.97
2.29	96.1	1.05	0.78
2.71	98.9	1.10	1.42
Empty column with traces of rock		1.81	5.82

[a]The data are given from the loaded end of the exit point.

After elution of 308 mℓ, essentially all of the ^{137}Cs, and 29% of the ^{133}Ba remained on the column. One-half of the ^{137}Cs had moved 53 to 59% of the way through the column. Therefore, 522 to 581 mℓ would be required to remove 50% of the cesium activity from the column.

TABLE B-IX

DATA FROM SECTIONED COLUMN G1-2476[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)	^{133}Ba in Sample (%)
4.11	2.05	0.52	0.27
4.37	6.29	0.34	0.00
5.66	11.3	0.53	0.00
5.38	16.8	0.58	0.30
5.11	22.1	0.64	0.01
7.87	28.6	1.31	0.45
5.18	33.7	1.20	0.36
10.5	41.6	3.32	0.89
8.50	51.1	4.42	0.51
12.3	61.5	9.37	1.99
9.30	72.3	9.23	1.62
6.79	80.3	8.05	1.75
6.38	86.9	8.84	2.11
5.26	92.7	7.09	2.31
3.33	97.0	6.42	1.62
Empty column with traces of rock		2.30	2.14

[a]The data are given from the load end to the exit point.

After elution of 355 mℓ, ~16 of the ^{133}Ba remained on the column. One-half of the ^{137}Cs had moved 88 to 93% of the way through the column. Therefore, 382 to 403 mℓ would be required to remove 50% of the cesium activity from the column.

TABLE B-X

DATA FROM SECTIONED COLUMN G1-2363[a]

Percent of Column Sampled	^{137}Cs in Sample (%)	^{133}Ba in Sample (%)
5.33	0.85	0.00
7.11	0.52	0.00
7.73	0.50	0.00
9.51	0.62	0.41
8.45	0.61	0.38
8.39	0.67	0.14
11.4	1.10	0.99
10.9	1.48	1.01
9.32	1.98	0.92
8.16	2.66	1.35
7.57	3.34	1.32
4.13	2.36	0.78
2.03	1.42	1.14

[a]The data are given from the load end to the exit point.

After elution ~18% of the ^{137}Cs and ~8% of the ^{133}Ba remained on the column.

TABLE B-XI

DATA FROM SECTIONED COLUMN G1-2289[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{152}Eu in Sample (%)
6.79	3.39	6.23
9.80	11.7	13.3
8.41	20.8	28.7
5.94	28.0	22.0
6.83	34.4	9.42
5.52	40.5	7.63
3.70	45.1	0.93
10.6	52.3	0.80
5.99	60.6	0.65
9.63	68.4	0.39
11.2	78.8	0.36
8.84	88.8	0.36
6.66	96.6	0.36
Empty column with traces of rock		6.41

[a]The data are given from the load end to the exit point.

Although a small peak of ^{152}Eu was removed on elution, the majority of the europium remained on the column after 366 mℓ. One-half of this activity had moved 21.2 to 28% of the way through the column, indicating 1307 to 1726 mℓ would be required to remove 50% of the europium from the column.

TABLE B-XII

DATA FROM SECTIONED COLUMN G1-2233[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)	^{133}Ba in Sample (%)	^{85}Sr in Sample (%)
3.74	1.87	21.7	64.9	28.2
6.20	6.84	43.0	15.7	11.8
10.4	15.2	22.3	6.77	6.44
12.5	26.7	6.06	4.03	5.94
14.9	40.4	4.25	3.22	4.62
11.7	53.7	1.49	1.45	3.38
12.7	65.9	0.69	0.77	3.31
9.73	77.1	0.33	0.41	2.36
7.25	85.6		0.08	1.09
6.38	92.4		0.01	1.05
4.46	97.8			1.05
Empty column with tracers of rock			0.79	

[a]The data are given from the loaded end to the exit point.

There was visible algae throughout this column.

After elution of 4881 mℓ, ~30% of the ^{85}Sr had been eluted, and 50% of the cesium had moved 6.5 to 10% of the way through the column. One-half of the ^{133}Ba and ^{85}Sr had moved 1.25 to 5% and 22 to 35% of the way through the column, respectively. Therefore, 9.762×10^4 to 3.905×10^5 mℓ would be required to remove 50% of the ^{133}Ba, 1.395×10^4 to 2.219×10^4 mℓ would be required to remove 50% of the ^{85}Sr, and 4.881×10^4 to 7.51×10^5 mℓ would be required to remove one-half of the ^{137}Cs.

TABLE B-XIII

DATA FROM SECTIONED COLUMN G1-1982[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)	^{133}Ba in Sample (%)
5.1	2.5	2.55	0.62
6.9	8.5	4.72	0.82
9.1	16.6	9.66	1.21
10.8	26.5	16.1	1.70
7.9	35.8	14.1	1.27
16.1	47.8	27.6	3.66
8.8	60.3	11.2	2.08
6.5	67.9	5.71	1.73
6.2	74.3	3.68	1.81
4.4	79.6	1.66	1.44
5.9	84.7	1.41	2.09
12.3	93.9	1.43	6.16

[a]The data are given from the load end to the exit point.

After elution of 355 mℓ, 24.6% ^{133}Ba and 99.8% ^{137}Cs remained on the column. One-half of the cesium had moved 37 to 47% of the way through the column, indicating 755 to 960 mℓ would be required to remove 50% of the ^{137}Cs completely.

TABLE B-XIV

DATA FROM SECTIONED COLUMN 1883-1[a]

Percent of Column Sampled	^{137}Cs in Sample (%)	^{133}Ba in Sample (%)
27.7	0.94	0.89
34.0	1.64	1.10
22.0	1.33	0.74
16.3	1.60	0.69

[a]The data are given from the load end to the exit point.

After elution, ~5% of the ^{137}Cs and ~3% of the ^{133}Ba remained on the column.

TABLE B-XV

DATA FROM SECTIONED COLUMN G1-1883-2[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)	^{133}Ba in Sample (%)
5.43	2.71	0.84	0.61
4.34	7.60	0.58	0.45
5.97	12.8	0.54	0.49
6.52	19.0	0.81	0.60
8.15	26.3	1.21	0.69
8.69	34.8	1.88	0.90
8.69	43.4	3.36	4.83
8.15	51.9	4.23	1.27
8.15	60.0	4.63	1.03
8.15	68.2	5.95	1.27
11.1	77.8	11.0	2.03
8.69	87.9	9.77	1.78
4.89	94.5	6.23	1.21
3.04	98.1	6.25	1.22

[a]The data are given from the loaded end to the exit point.

After elution of 449.4 mℓ, ~18% of ^{133}Ba and ~60% of the ^{137}Cs remained on the column. One-half of the cesium had moved 92 to 93.4% of the way through the column, indicating 481 to 488 mℓ would be required to remove 50% of the ^{137}Cs completely.

TABLE B-XVI

DATA FROM SECTIONED COLUMN G1-1292[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)	^{133}Ba in Sample (%)
5.58	2.79	0.91	0.77
7.43	9.29	1.20	1.29
10.8	18.4	2.54	3.37
11.2	29.4	5.03	9.03
13.0	41.5	9.28	19.1
14.9	55.5	16.0	32.2
7.43	66.6	9.51	15.5
9.29	75.0	12.3	13.3
9.29	84.3	9.42	4.50
5.58	91.2	5.05	0.75
5.58	97.3	4.66	0.21

[a]The data are given from the load end to the exit point.

After elution of 428 mℓ, ~100% of the ^{133}Ba and ~75% of the ^{137}Cs remained on the column. One-half of the ^{137}Cs and ^{133}Ba had moved 70 to 79% and 49 to 62% of the way through the column, respectively. Therefore, 542 to 611 mℓ would be required to removed 50% of the barium completely, and 690 to 873 mℓ would be required for the cesium.

TABLE B-XVII

DATA FROM SECTIONED COLUMN GT-U12G[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{95m}Tc in Sample (%)	^{152}Eu in Sample (%)[b]
12.1	6.1		41.8
14.1	19.1		44.7
12.1	32.2		5.94
16.2	46.4	0.00	1.14
13.1	61.0	0.81	0.66
14.1	74.7	0.58	0.58
14.1	88.7	0.50	0.38
4.04	97.8	1.77	0.68

[a]The data are given from the load end to the exit point.

The column, also loaded with ^{85}Sr, ^{137}Cs, and ^{133}Ba, was terminated after the elution of 187.3 mℓ. The sample (12.1%) closest to the load point contained 78.4% of the ^{85}Sr, 74.8% of the ^{137}Cs, and 84% of the ^{133}Ba. The remaining strontium, cesium, and barium was all in the second sample.

[b]One-half of the ^{152}Eu had moved 8.2 to 21% of the way through the column; therefore, 892 to 2284 mℓ would be required to remove 50% of the ^{152}Eu from the column.

TABLE B-XVIII

DATA FROM SECTIONED COLUMN CS7[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)
24.1	12.0	43.8
11.1	29.6	5.8
18.5	44.2	7.5
13.0	60.2	3.0
11.1	77.2	2.8
22.2	88.9	2.6

[a]The data are given from the load end to the exit point.

After elution of 845 mℓ, ~66% of the ^{137}Cs remained on the column. One-half of the ^{137}Cs had moved ~15 to 29% of the way through the column; therefore, 2914 to 3841 mℓ would be required to elute 50% of the ^{137}Cs completely.

TABLE B-XIX

DATA FROM SECTIONED COLUMN CS5-1[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)	^{133}Ba in Sample (%)
21.5	10.7	55.9	16.9
12.2	27.6	8.10	0.25
7.8	37.6	2.01	0.08
24.7	53.8	2.89	0.11
14.3	73.3	1.28	0.13
12.0	86.5	1.15	0.33
7.6	96.5	0.07	4.82
Column itself with traces of rock		1.04	1.40

[a]The data are given from the load end to the exit point.

After elution of 900 mℓ, ~72% of ^{137}Cs and ~24% ^{133}Ba remained on the column. One-half of the cesium had moved ~9 to 26% of the way through the column; therefore, ~3500 to 10 000 mℓ would be required to remove 50% of the ^{137}Cs completely.

TABLE B-XX

DATA FROM SECTIONED COLUMN CS5-3[a]

Percent of Column Sampled	^{137}Cs in Sample (%)	^{133}Ba in Sample (%)
10	8.3	5.8
11	9.4	4.3
24	5.2	1.5
15	7.9	0.96
4.2	2.6	2.2
30	4.0	0.30
5.4	6.8	3.6

[a]The data are given from the load end to the exit point.

After elution ~43% of the ^{137}Cs and ~18% of the ^{133}Ba remained on the column.

TABLE B-XXI

DATA FROM SECTIONED COLUMN CS5-4[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{95m}Tc in Sample (%)	^{152}Eu in Sample (%)
0.39	0.20	0.00	33.5
9.83	5.31	0.00	32.5
13.3	16.9	86.3	18.4
15.4	31.2	8.47	5.33
18.3	48.1	3.31	5.43
20.5	67.5	1.20	1.79
22.2	88.9	0.79	2.59

[a]The data are given from the load end to the exit point.

One-half of the ^{152}Eu had moved ~2.6 to 5% of the way through the column after eluting 111 mℓ, indicating that 2220 to 4269 mℓ would be required to remove 50% of the europium conpletely. The ^{95m}Tc appears in a narrow band. One-half of the technetium had moved 10 to 25% of the way through the column; therefore, the volume required to elute 50% would be 444 to 1110 mℓ.

TABLE B-XXII

DATA FROM SECTIONED COLUMN CN1[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)
Load frit and trace rock	0	0.8
~41	20.5	56.9
~18	50.0	32.4
~41	79.5	9.8

[a]The data are given from the load end to the exit point.

No ^{137}Cs was removed from the column by elution in 524 days (total volume = 517 mℓ). One-half of the ^{137}Cs moved 18 to 45% of the way through the column, indicating 1150 to 2870 mℓ would be required to elute 50% ^{137}Cs.

TABLE B-XXIII

DATA FROM SECTIONED COLUMN CN2-1[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)
3.87	1.94	2.09
6.43	7.09	3.35
10.3	15.4	9.21
20.1	30.6	3.09
10.6	46.0	18.9
10.8	56.7	15.8
16.8	70.5	14.8
22.1	89.4	0.53
Column itself with traces of rock		0.36

[a]The data are given from the load end to the exit point.

After elution of 1067.5 mℓ, 50% of the ^{137}Cs had moved 30 to 55% of the way through the column. Thus, ~1940 to 3560 mℓ would be required to elute one-half of the cesium completely.

TABLE B-XXIV

DATA FROM SECTIONED COLUMN CN2-3[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{152}Eu in Sample (%)	^{95m}Tc in Sample (%)	^{95m}Tc on column In Sample (%)
17.5	8.75	38.0	0.00	0.00
5.58	20.3	45.9	0.0	0.00
6.71	26.4	11.4	0.00	0.00
9.22	34.4	3.22	12.0	32.1
10.0	44.0	4.74	8.33	22.3
14.2	56.1	0.39	9.27	24.8
28.7	77.6	0.27	7.81	20.9
8.05	95.9	0.31	0.00	0.00

[a]The data are given from the load end to the exit point.

After elution of 111 mℓ, one-half of the ^{152}Eu had moved 12 to 22% of the way through the column; therefore, 505 to 925 mℓ would be required to elute 50% of the ^{152}Eu completely. In the last column, the ^{95m}Tc remaining on the column is treated independently from the ^{95m}Tc eluted: one-half had moved 42 to 53% of the way through the column; therefore, the ^{95m}Tc remaining on the column would require 209 to 264 mℓ for one-half to be eluted.

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TABLE B-XXII

DATA FROM SECTIONED COLUMN CN1[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)
Load frit and trace rock	0	0.8
~41	20.5	56.9
~18	50.0	32.4
~41	79.5	9.8

[a]The data are given from the load end to the exit point.

No ^{137}Cs was removed from the column by elution in 524 days (total volume = 517 mℓ). One-half of the ^{137}Cs moved 18 to 45% of the way through the column, indicating 1150 to 2870 mℓ would be required to elute 50% ^{137}Cs.

TABLE B-XXIII

DATA FROM SECTIONED COLUMN CN2-1[a]

Percent of Column Sampled	Average Distance Through Column (%)	^{137}Cs in Sample (%)
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DATA FROM SECTIONED COLUMN CN2-3[a]

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[a]The data are given from the load end to the exit point.

After elution of 111 mℓ, one-half of the ^{152}Eu had moved 12 to 22% of the way through the column; therefore, 505 to 925 mℓ would be required to elute 50% of the ^{152}Eu completely. In the last column, the ^{95m}Tc remaining on the column is treated independently from the ^{95m}Tc eluted: one-half had moved 42 to 53% of the way through the column; therefore, the ^{95m}Tc remaining on the column would require 209 to 264 mℓ for one-half to be eluted.

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