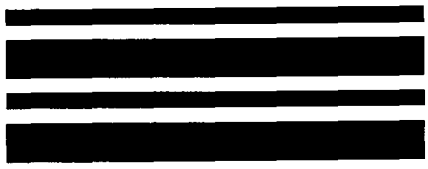

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RADIOCHEMICAL ANALYSIS OF A SAMPLE OF FALL-OUT FROM MONTE BELLO

by K. STEWART

ABSTRACT

The radiochemical examination of a sample of fall-out (from Bluebell Island) was carried out with the objects of determining the extent to which the fission product distribution was disturbed by condensation and other associated processes and the importance or otherwise of radioactive iron (Fe 59) formed by neutron capture.

The results obtained indicate :

1. The composition of the fall-out activity is modified to the extent that would be expected if the rare gas precursors which exist at the time do not condense with the remainder of the material.
2. The amount of radioactive iron formed was only about 0.1 (or possibly as high as 0.2) of the Ru 103 (similar half lives) and is therefore barely significant.

From MR ADAMS
To MR BARNES.
Ref. A.116. [OCT. 54.]

SECRET

RADIOCHEMICAL ANALYSIS OF A SAMPLE OF FALL-OUT FROM MONTE BELLO

by K. STEWART

1. Introduction

Although a very considerable effort was expended on charting the radioactive deposition from the explosion, the level of hazard produced and the decay of the gamma dose rate with time, a radiochemical analysis could not be made. Several samples were collected towards the end of the survey period and on return to the U.K. I was able to attempt the analysis of one of them (from Bluebell). The remainder were given to the R.C. Group at AWRE. The objects were to determine, if possible,

(a) whether fission product distribution was normal or depleted of those members whose rare gas precursors were relatively long lived.

(b) the extent to which active iron (Fe 59) was present.

Owing to the pressure of other work the analysis - carried out at AERE in conjunction with the Chemistry Division - was spread over a long period (February to July 1953) and suffered in consequence. Nevertheless the results do indicate answers to the problems.

2. Procedure

The active specimen was a rock fragment from Bluebell. Samples of the black deposit for analysis were readily scratched off (with a steel tool, but contamination insignificant) and in this way only a small amount of rock was present. The latter was undesirable as the analytical procedures to be used had been developed for air borne

samples using small amounts of carriers, so that the presence of a relatively large amount of other elements was to be avoided. The samples weighed about 10 mgm and gave something like 200 cts/sec on a laboratory beta probe instrument held about 1 in. away.

The analytical procedures were the standard ones employed by the team working on airborne bomb debris. Two series were performed, with two samples in each case: Series 1 - Sr, Y, Ce, Nd, Pr, Series 2 - Zr, Ru, Ce, Y. Unfortunately, neither was completed and the analysis for the elements common to both (Y and Ce) were never satisfactorily completed (owing to Totem). In each case known amounts of carriers (as nitrates, except Ru) were added, dried and heated to 500° in a muffle. In the first series the initial method of attack was wet oxidation with nitric acid followed by HF + $HClO_4$. Strontium and barium were separated as nitrates insoluble in fuming HNO_3. All other elements except Cs were precipitated by NH_4OH. Caesium was estimated as Chloroplatinate. The precipitated hydroxides were dissolved in HCl and the iron removed by extraction with isopropylether. The rare earths (Y, Pr, Nd and Ce) were separated on a kation exchange column (Zeocarb 225). In the second series the sample was fused with excess fusion mixture (KNO_3, KOH, K_2CO_3). The ruthenium was extracted as ruthenate, iron by isopropyl ether and the remainder (which would exclude in the more general case Cd, Ag) passed through a diacidite FF column. The first elutriate contains the rare earths, zirconium, strontium and barium, all of which may be separated on a kation column. The second, third and fourth elutriates are plutonium, neptunium and uranium. In all cases the customary purification procedures were used prior to final precipitation and

mounting of sample. The precipitate occupied a circular area of about 1 cm^2 on a filter paper stuck to a conventional Al tray: the surface of the precipitate was stabilised by a few drops of a solution of cellosolve in acetone.

3. Results

The analytical results are summarised in Tables 1 and 5-11. Essentially the result obtained is a count rate, decay curve and one or more absorption curves for one or a mixture of radioactive species for a sample of known weight. The chemical separations lead to a precipitate which contains only one of the elements at the time of formation; but there may be two nuclides present (e.g. Ru 103, 106) and successors may grow with the decay of the other (e.g. Ba-La). The gravimetric part of the analysis allows the relative activities in the original sample to be deduced.

3.1 The following nuclides were determined :

(Sr 89
(Sr 90 with Y 90 as a daughter product

Y 91

Zr 95 with Nb 95 as a daughter product

(Ru 103 with Rh 103
(Ru 106 Rh 106 as daughter products

Cs 137

Ba 140 with La 140 as daughter product

(Ce 141
(Ce 144 with Pr 144 as daughter product.

Pr 143

Na 147.

The analysis of the decay and absorption curves is theoretically straightforward, but in practice contains a number of uncertainties. The mounted samples need corrections for both backscatter and self absorption: the rough rule is to

neglect these, although arbitrary corrections are applied in certain cases. The mass of the precipitate is usually less than 50 mgm/cm^2 so that only nuclides emitting hard betas (in excess of 1 Mev) will be easily determined. There are two of these - Rh 106, Pr 144 - which are used to estimate relative yields. The analysis of the data is now briefly described. The radioactive properties are summarised in Table 2 and the final nuclide analysis in Table 3.

3.2 Strontium-yttrium mixture

The element chemically separated is strontium: the yttrium grows from the decay of Sr 90. For two nuclides related in this way if N_o is the initial number of atoms of Sr 90, λ_1 and λ_2 are the coefficients of the decay exponents ($\lambda = \frac{0.693}{t_{\frac{1}{2}}}$) and N_1 and N_2 the numbers of atoms of Sr 90, Y 90 at any time, t, then

$$N_1 = N_0 e^{-\lambda_1 t}$$

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} \cdot N_0 \left(e^{-\lambda_1 t} - e^{-\lambda_2 t} \right)$$

and the total disintegration rate

$$\frac{dN}{dt} = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_0 \left(\overline{2\lambda_2 - \lambda_1} \cdot e^{-\lambda_1 t} - \lambda_2 e^{-\lambda_2 t} \right)$$

In our case $\lambda \ll \lambda_2$ (λ_1 for Sr 90 = 7.6 x 10^{-5}, λ_2 for Y 90 = 0.273 times in days) and it is found that the maximum in the plot of count rate against time occurs at 27.5 days. Thereafter the decay is

$$\simeq 2\lambda_1 N_0 e^{-\lambda_1 t}$$

Therefore at times later than 27.5 days the decay curve may be analysed for the Sr 89 and Sr/Y 90 contribution is assumed to be constant. The results are given in Table 3. The

specific activities of the two samples are somewhat different, whereas the ratio of Sr 89 to Sr 90 is the same for both. The slow fission yields of mass numbers 89 and 90 are 1.8 and 2.3% (latter by interpolation) which lead to a value of 27 for the ratio of the Sr 89/Sr 90 activities on the day of the analysis. The observed value is 14; and this may be somewhat too high as the Sr 90 beta radiation is relatively soft (Emax = 0.5 Mev) and the observed long lived component may be due mainly to Y 90 (Emax = 2.24 Mev). The decay curves for the two samples are given in Fig.1, the absorption curve for sample A in Fig.2. It is not justifiable to attempt an analysis of the absorption curve (three beta 0.5, 1.5 and 2.24 Mev) but it is clear from inspection that the hardest beta radiation constitutes only a small fraction of the total.

3.3 Yttrium 91

Over a period in excess of four half lives the decay curve agrees closely with the value of 57 days for the half life (Fig.3). The absorption curve indicates a value of about 1.5 Mev proving that the active material is Y 91. (Fig.4)

3.4 Zirconium - Niobium 95

Both beta emissions are weak: the niobium one particularly so, with a maximum energy of 0.146 Mev with a range of perhaps 16 mg/cm^2 (in Al) and the counter air space and window alone account for 3 or 4 mgm. It is customary to assume that the Nb does not contribute to the count and it is observed that the Zr yield is only 1/2.3 of the true value when determined in this way. The observed decay curve does not exhibit the maxima demanded by the equation deduced above: the log-linear plot of count rate against time is not quite linear (convex upwards) and indicates a half life of about

80 days (Fig.5). This is in agreement with the idea that the niobium only contributes to the count to a minor extent. With this assumption it is found by calculation that relative to the Zr 95 only about 10% of the Nb 95 is counted; i.e. if 1/2.3 of the Zr 95 beta particles are counted the corresponding figure for the Nb is 4.3%. The precipitate of zirconium mandelate was 28 mgm which leads to an inherent absorber thickness of about 15-20 mgm (including air and window), which is of the right order to cause these reductions.

3.5 Ruthenium - Rhodium mixture

At the time when the ruthenium was separated the long lived component (Ru 106) was predominant. Inspection of the beta energies shows that the observed count of the long lived component will be due solely to the energetic beta radiation from Rh 106. The count rate for the long lived component, which is easily deduced from the decay curve, will be equivalent to the yield of mass 106. The 103 component will be found by difference: and the count will be due entirely to Ru 103 (Figs. 6 and 7). At 23/24 June '53 the ratio of activities Ru 103/Ru 106 is about 1/16, whereas the ratio obtained from accepted yield data is 1/4.6. The soft component (Ru 103, Rh 103) estimated by difference in this way is generally only about 1/3 the value expected from known yield. If this adjustment is made the observed ratio is in agreement with theory.

3.6 Caesium 137

This nuclide has a very long half life so that the low count rate observed did not permit an absorption curve to be determined.

3.7 Barium-Lanthanium Pair

The decay and absorption curves followed the expected pattern (Figs. 8 and 9).

3.8 Cerium-Praseodymium Mixture

The decay and absorption curves are in good agreement (see Figs 10 and 11). The values for Ce 144 and 141 are taken from the decay curve: the differences between the observed line and that due to the long lived activities follow a decay law with a 28-day half life (Ce 141).

3.9 Praseodymium/Neodymium

The activities of both these nuclides were so low that decay curves were impracticable. However the three observations made with the Praseodymium sample were in good agreement with a half life of 13.8 days. In the case of neodymium there were two samples and these were counted some 22 days apart. The difference when adjusted for recovery was in agreement with a half life of 11.6 days.

3.10 Radioactive Iron

The fall-out from the Monte Bello explosion was black and quite early shown to contain considerable quantities of iron - probably as Fe_3O_4. A fragment of steel plate had been found to contain rather less than 1 μc Fe 59 per gm of iron, but it was possible that the vapourised metal would be more highly radioactive. A considerable part of each sample consisted of iron from this source - possibly as much as half, but no direct analysis could be attempted as the proportion depended entirely on the removal of the black deposit from the rock. The precipitates of iron hydroxide ($Fe(OH)_3$ plus some H_2O probably - dried at 110°C) were found

to be very active; but on examination the decay curves were not those of Fe 59, but included at least a large amount of longer lived activity. Bearing in mind that the iron is extracted from a solution of chlorides with isopropyl ether, there is only one real possibility in this case, i.e. Ru. The decay and absorption curves (Figs. 12 and 13) do not permit a breakdown into two components, one with a half life of one year and the other about 40 days. The half lives of Fe 59 and Ru 103 are quite close this figure (Ru 103 39.8 days, Fe 59 46 days). From the 40 day component it is possible to estimate the Fe 59 and Ru 103 fractions. From the long lived component (Ru 106 - Rh 106) we know the amount of Ru 103 - Rh 103 to be expected from the mass yields and its contribution to the count will be obtained by the multiplying by a factor to take into account the softness of the radiation. In RuI_3 this factor is $\sim 1/3$, but in $Fe(OH)_3$ it may well be larger. There were two samples in series 1 and the use of both permits the evaluation of the Fe 59 fraction and the factor. The latter is found to be about 0.6, which is a reasonable figure and the Fe 59 count for the sample was about 700 cts/min on 2 Feb 53. The total count for Ru 103 at the same time was about 5500 cts/min. Hence the effect of the iron is only just significant: even though because of the nature of the calculation the iron activity is at fault by a factor of two too small. Assuming a counter efficiency of 25% (topmost position used for counting) and 2.5 mgms of Fe (from the ship) in sample, the specific activity is found to be about 0.5 μc/gm, which is in good agreement with the value found for the steel fragment.

4. Discussion

4.1 From the activities (expressed as counts/min) of the various nuclides present in the sample at known times after the explosion it is a simple matter to calculate the activities at the time of the explosion (t_o). A measure, N_o, of the number of atoms of a particular mass number formed at t_o is obtained by the relationship

$$\text{Disintegration rate} = \lambda N_o$$

and from the values of N_o the mass yields can be estimated provided certain ones are assumed to be known. These results are given in Table 3. The assumed yields are for Ce 144 (series 1) and Ru 106 (series 2). These were selected as they are among the more acceptable results generally and do not have rare gas precursors (or only very short lived ones). Examination of the results in Table 3 shows that the agreement with known yields is, perhaps surprisingly, quite good. The only marked discrepancies are for mass numbers 89, 90 and 137.

4.2 It is quite easy to account for the low yields of Sr 89 and Cs 137 as both of these elements have relatively long lived rare gas precursors; i.e. Kr 89, 3.14 mins; Xe 137, 3.9 mins. These times are long when the condensation and other processes which took place as the fireball cooled and mixed with air and water are taken into account. It is reasonable to assume that the noble gases do not condense along with the other elements. If the same argument is applied to account for the low apparent yield of Sr 90 it becomes necessary to consider also the yields of Ba 140 and Y 91 as their precursors have somewhat similar half lives, but these are in almost expected yields !

4.3 Therefore, it is necessary to consider the problem a little more explicitly. It is not only the half lives of the

rare gas precursors which exert a controlling influence, but also the distribution of elements about a given mass number. Apparently, the only attempt to deal with this problem is the one made by Glendinin and others about 10 years ago.* Consideration of the known yields of certain shielded nuclides led to the hypothesis that the chain length will be essentially independent of mass number (i.e. about 3-4). Then if Z_A is the most stable change for one mass fragment and Z_p is the most probable change of that fragment on fission, $Z_A - Z_p$ is the chain length and

$$Z_p = Z_A - \frac{Z_A + Z_{237-A} - 94}{2}$$

Using this expression and the yields of the shielded nuclei a curve is constructed which gives the fraction of the mass yield with a certain charge number at fission. Although this method is open to serious question it is to be remembered that all computations on gross disintegration rates for fission products which employ known data use this method to complete the picture at very early times. The comparison with the observed results is shown in Table 4. Bearing in mind the various uncertainties, not only about the yields measured but also the reference ones, it is seen that the observed yields are all in agreement if condensation and other processes (such as coagulation of solid particles with water droplets) are complete in about 10 seconds. Once a cloud of particles and/or droplets is formed the pick up of rare gas descendants will be essentially a diffusion process. They will be picked

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* Report CL-LEG-1 by L.E. Glendenin, C.D. Coryell, R.R. Edwards and M.H. Feldman. Secret - Limited.

up by the very small particles which remain with the radioactive cloud and possess the greater fraction of the total particle surface area.

5. Conclusions

5.1 The composition of the fall-out activity is modified to the extent that would be expected if the rare gas precursors which exist at the time do not condense with the remainder of the material.

5.2 The amount of radioactive iron formed was only about 0.1 (or possibly as high as 0.2) of the Ru 103 (similar half lives) and is therefore barely significant.

6. I wish to record my appreciation to Dr. Spence for the facilities provided me by the Chemistry Division and to Mr. E.A. Crouch for much useful advice and discussion.

AERE)
AWRE) 1953
BJSM, Washington 1954.

TABLE 1

SUMMARY OF RESULTS

Series	Date of Initial Count, t_m	Elements	Compound Precipitated	Weight of Precipitate mgm	Fraction Recovered	Count rate at t_m given by sample	Decay/ Absorption Results (see Fig.)	Estimated count rate for each component at t_m for initial wt of carrier	
1	2 Feb 53	Sr/Y	$SrSO_4$	(a) 9.9	0.476	450	1, 2	Sr 89	760
	2 Feb 53			(b) 11.9	0.572	390		Sr 90	55
1	19 Mar 53	Y	$Y_2(C_2O_4)_3,9H_2O$	18.7	0.635	4000	3, 4	Y 91	6300
2	19 Aug 53	Zr/Nb	$Zr(C_6H_5CH(OH)COO)_4$	28.4	0.373	4000	5	Zr 95	10,700
2	23 Jun 53	Ru/Rh	RuI_3	(a) 6.7	0.141	1300	6, 7	Ru 103	590
	24 Jun 53			(b) 18.5	0.390	3640		Ru 106	8690
1	19 Mar 53	Cs	Cs_2PbCl_6	2.49	0.254	15.5		Cs 137	61
1	28 Jan 53	Ba/La	$BaSO_4$	(a) 12.3	0.688	788	8, 9	Ba 140	900
	28 Jan 53			(b) 13.7	0.766	506			
1	17 Apr 53	Ce/Pr	$Ce_z(C_2O_4)_3,9H_2O$	2.84	0.115	2100	10,11	Ce 141	2,170
								Ce 144	11,300
1	27 Mar 53	Pr	$Pr_2(C_2O_4)_3,10H_2O$	27.8	all !	93	-	Pr 143	90
1	27 Mar 53	Nd	$Nd_2(C_2O_4)_3,10H_2O$	3.9	0.768	6.8	-	Nd 147	8.8
1	2 Feb 53	Fe	$Fe(OH)_3$ (hydrated ?)	(a) 19.3	all !	7800		Fe 59	about 700
				(b) 14.7	0.764	1000		remainder Ru/Rh	

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TABLE 2

NUCLEAR DATA

Nuclide	Half Life	Decay Scheme		
		Beta		Gamma
SR 89	53 days	Beta	1.50 Mev.	No gammas.
Sr 90	19.9 years (or 25 years)	Beta	0.54 Mev.	No gammas.
Y 90	61 hrs.	Beta	2.24 Mev.	No gammas.
Y 91	t_1 51 min. t_2 57 days	I.T. Beta	 1.56 Mev.	Gamma 0.61 Mev. Only weak or no gammas.
Zr 95	65 days	Beta	0.40 Mev. 0.89 Mev. (2%) to 90h Nb95	Gamma 0.708 Mev.
Nb 95	t_1 90 hrs (only 2% from Zr 95) t_2 35 days	I.T. Beta	 0.146 Mev. (or 0.163)	Gamma 0.216 Mev. Gamma 0.758 Mev. (or 0.771)
Ru 103	39.8 days	Beta 1 (94%) 2 (6%)	0.222 Mev. 0.684 Mev.	Gamma 0.494
Rh 103	57 min.	I.T.		Gamma 0.0404 Mev.
Ru 106	1 year	Beta	0.041 Mev.	
Rh 106	30 secs	Beta 1 (82%) 2 (18%)	3.5 Mev. 2.3 Mev.	Gamma 0.51 and 0.73 Mev.
Cs 137	37 years	Beta 1 (8%) 2 (92%)	1.17 Mev. 0.51 Mev.	Gamma 0.669 Mev.
Ba 140	12.8 days	Beta 1 (60%) 2 (40%)	1.022 Mev. 0.48 Mev.	Gamma 0.306 and 0.160 Mev.

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TABLE 2 (continued)

NUCLEAR DATA

Nuclide	Half Life	Decay Scheme		
		Beta		Gamma
La 140	40 hrs	Beta 1 (70%)	1.32 Mev.	Gamma numerous
		2 (20%)	1.67 Mev.	
		3 (10%)	2.26 Mev.	
Ce 141	28 days	Beta 1 (1%?)		Gamma 0.315 Mev.
		2 (66%)	0.442 Mev.	Gamma 0.141 Mev.
		3 (33%)	0.581 Mev.	
Ce 144	275 days	Beta	0.348 Mev.	No gammas
Pr 144	17 mins.	Beta	2.87 Mev.	Gamma 0.135
Pr 143	13.8 days	Beta	0.932 Mev.	No gammas.
Nd 147	11.6 days	Beta 1 (32%)	0.350 Mev.	Gamma 0.520 Mev.
		2 (65%)	0.780 Mev.	Gamma 0.091 Mev.

Note: In many cases slightly different half lives and decay schemes have been published.

Fe 59	46 days	Beta 1 (50%)	0.26 Mev.	Gamma 1.3 Mev.
		2 (50%)	0.46 Mev.	Gamma 1.1 Mev.

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TABLE 3

ESTIMATION OF FISSION YIELDS

Nuclide	Count rate c at t_o	λ (mins^{-1})	$N_o = \frac{c}{\lambda}$	Yield	Published Yield	Remarks
Sr 89	3750	9.1×10^{-6}	0.41×10^{9}	0.14	1.8	Kr precursor half life 2.6 min.
Sr 90	55	5.28×10^{-8}	1.04×10^{9}	0.36	2.3 ?	Kr precursor half life 33 secs.
Y 91	4.85×10^{4}	8.45×10^{-6}	0.575×10^{10}	2.0	2.8	Kr precursor $t_{\frac{1}{2}}$ 9.8 or 5.7 sec.
Zr 95	3.27×10^{5}	7.41×10^{-6}	4.41×10^{10}	2.6	5.6	Usually observed to be 1/2.3 of yield.
Ru 103	3.35×10^{5}	1.15×10^{-5}	2.92×10^{10}	1.7	5.5	Very weak beta.
Ru 106	1.07×10^{5}	1.34×10^{-6}	8.0×10^{10}	4.7	4.7	
Cs 137	61	3.57×10^{-8}	1.71×10^{9}	0.6	5.6 ?	Xe precursor $t_{\frac{1}{2}}$ 3.9 min.
Ba 140	5.11×10^{5}	3.77×10^{-5}	1.35×10^{10}	4.7	5.36	Xe precursor $t_{\frac{1}{2}} \sim 16$ sec - unlikely to be earlier precursors and hence only partly as Xe in any case.
Ce 141	2.76×10^{5}	1.72×10^{-5}	1.62×10^{10}	5.6	4.9	Xe precursor $t_{\frac{1}{2}}$ 3 sec.
Pr 143	5.97×10^{5}	3.49×10^{-5}	1.71×10^{10}	6.0	5.1	Xe precursor $t_{\frac{1}{2}} \sim 1$ sec.
Ce 144	1.85×10^{4}	1.75×10^{-6}	1.06×10^{10}	3.7	3.7	
Nd 147	2.93×10^{5}	4.37×10^{-5}	1.34×10^{10}	2.3	2.3	

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TABLE 4

EFFECT OF PRECURSOR DISTRIBUTION ON YIELD

Mass Number	Element Distribution at Fission					Rare Gas Half Life	Expected Fraction of Yield if condensation and other processes are complete in			
	Sc	Br	Kr	Rb	Sr		5	10	15	30 secs
Z	34	35	36	37	38					
89	0.09	0.39	0.41	0.11		3.14 mins	0.11	0.13	.16	0.21
90	0.02	0.23	0,50	0.23	0.02	33 secs.	0.33	0.40	0.47	0.62
91		0.10	0.40	0.40	0.10	10 secs	0.65	0.75	0.82	0.93
	Te	I	Xe	Cs	Ba					
Z	52	53	54	55	56					
137	0.15	0.45	0.34	0.06		3.9 mins		~ 0.06		
140		0.06	0.34	0.45	0.15	16 secs	0.68	0.74	0.80	0.90

Notes: (i) All precursors of Kr and Xe are very short lived.

(ii) The Sr 89/90 ratio for all condensation times is 0.33 and the observed value is 0.39.

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TABLE 5

STRONTIUM/YTTRIUM RESULTS

Decay Data

Sample A		Sample B	
Time (days)	Counts/ min.	Time (days)	Counts/ min.
0	473.5	0.0	417.8
		1.81	406.7
0.88	448.8	8.88	388.8
		21.84	331.9
8.90	430.1	30.87	303.2
21.85	369.2	37.9	280.0
30.88	344.1	43.8	262.5
37.91	304.5	52.0	234.1
44.82	291.9	72.8	191.5
72.04	214.4	85.9	148.9
85.875	191.6	92.9	157.5
92.885	180.0	100.8	152.0
100.055	167.2	105.	120.6
105.05	138.1	113.8	133.3
113.81	151.4	128.8	118.8
128.81	136.9	133.8	119.2
133.84	130.4	140.9	109.9
140.88	128.5	148.8	104.8
148.86	119.2	156.8	94.3
156.82	109.7	164.8	95.2
162.84	108.9	168.8	89.7
168.85	100.8	175.8	89.5
175.86	99.6	183.8	86.4
183.81	92.9		

Absorption Data

Sample A

Absorber Thickness mgm/cm^2	Counts/ min.
0.0	38.8
1.84	37.7
6.34	36.0
4.00	35.9
6.46	35.5
9.52	32.9
18.1	28.9
33.5	24.0
39.4	22.0
49.7	20.4
69.6	16.6
77.6	15.3
93.4	12.9
113.2	11.0
144	7.9
196	4.4
268.5	2.2
328	1.6
478	0.9
516	1.1

TABLE 6

YTTRIUM 91 RESULTS

Decay Data

Sample A

Time (days)	Counts/ min.
0.0	3950
6.06	3640
26.9	2900
	2840
40.1	2390
	2340
47.0	2200
	2210
54.8	2000
58.8	1880
67.8	1740
82.8	1470
88.1	1350
95.1	1240
103.	1140
111	1030
117	945
123.8	876
130.8	818
137.9	783
143.8	700
151.8	645
157.8	598
165.8	538
171.8	509
178.8	483
194.8	393
202	350
206.1	328
215.8	292
222	272
234	237
250	200

Absorption Data

Sample A

Absorber Thickness mgm/cm^2	Counts/ min.
0	477.5
1.88	476
2.29	469
5.35	452
6.44	450
15.8	409.8
29.6	366.5
54.0	306.3
63.1	287.4
79.6	268.4
95.1	233.4
112	210.1
129	191.2
154	161.3
187	129.3
240	86.1
318	43.0
443	10.85
524	3.93
709	0.72
857	0.59
1076	0.75
1302	0.61
1576	0.70

T A B L E 7

ZIRCONIUM/NIOBIUM RESULTS

Decay Data

Sample A

Time (days)	Counts/ min.
0.0	546*
0.0	4030
5.8	512*
	3860
13.95	477*
	3550
19.8	3425
	451*
26.95	430*
	3190
42.8	374*
	2770
50.8	347*
	2630
54	2480
64	2290
71	2140
86	1860
98	1650

Note: Figures marked * should be multiplied by 7.49: the counter position factor.

TABLE 8

RUTHENIUM/RHODIUM RESULTS

Decay Data

Sample A		Sample B	
Time (days)	Counts/ min.	Time (days)	Counts/ min.
0.0	1310	0.0	3645
8.0	1304	6.98	3604
16.0	1246	14.99	3467
22.8	1239	21.78	3384
28.8	1190	27.8	3365
35.8	1177	34.8	3295
43.0	1159	41.98	3258
48.8	1132	47.8	3203
56.8	1142	55.8	3131
62.8	1108	61.8	3117
70.8	1093	69.8	3054
76.8	1075	75.8	3014
83.8	1050	82.9	2962
99.8	1021	98.8	2907
107	1010	105.8	2715
111	971	109.8	2778
120.8	971	119.8	2764
127.8	966	126.8	2826
140.8	928	140.8	2641
154.8	918	154.8	2510
162.8	863	161.8	2436
182.8	880	181.8	2439

Absorption Data

Sample A		Sample B	
Absorber Thickness mgm/cm^2	Counts/ min.	Absorber Thickness mgm/cm^2	Counts/ min.
0.0	1251	0.0	3368
1.93	1222	1.88	3338
2.29	1222	2.29	3322
5.52	1182	5.35	3345
6.44	1169	6.44	3224
15.6	1111	15.8	3080
29.9	1059	29.6	2950
53.3	992	54.0	2746
63.1	970	63.1	2682
79.6	950	79.6	2625
85.1	923	95.1	2478
112	892	112	2395
129	848	129	2347
154	809	154	2227
187	755	187	2094
240	673	240	1867
318	566	318	1604
443	431	443	1165
524	337	524	928
709	192	709	509
857	110	857	301
		1076	117

TABLE 10

CERIUM/PRASEODYMIUM RESULTS

Decay Data

Sample B

Time (days)	Counts/ min.
0.0	2060
6.19	2090
12.2	2070,2100
19.15	1900,1920
27	1860,1850
30.95	1817.9
40.0	1764.4
55	1684.8
60.21	1658.2
67.2	1619.3
75.15	1559.7
83.2	1518.9
89.95	1520.3
96	1480.2
103	1436.3
110	1401.3
116	1402.1
124	1300.0
130	1293.2
138	1319.9
144	1283.2
151	1272
167	1232
174	1177.7
178	1161.3
188	1145.1
194	1139.4
208	1114.1
222	1014.5
230	1002.7
250	1035

Absorption Data

Sample B

Absorber Thickness mgm/cm^2	Counts/ min.
0.0	248
1.93	230
2.29	230
5.52	204
6.44	200
15.6	167
29.9	147
53.3	129
63.1	130
78.7	119
92.6	116
108.8	113
127	106
155	102
188	95
244	81
325	64
445	45
528	33
732	12.5
857	6.4
1071	1.5
1309	0.2
1576	

TABLE 11

IRON RESULTS

Decay Data

Sample A		Sample B	
Time (days)	Counts/ min.	Time (days)	Counts/ min.
0.0	7920	0.0	982
1.77	7650	8.0	886
8.75	7050	20.14	800
21.8	6400	29.1	700
30.94	5700	36.16	646
37.9	5580	43.	613
44.77	5240	50.2	553
51.9	5020	71.	457
72.77	4350	76.2	406
85.8	3990	84.	390
92.8	3820	91.1	370
100.75	3630	98.1	343
105	3530	103.	329
113.8	3410	112	315
128.8	3170	127	273
133.8	3070	132	265
140.8	3010	140	248
148.8	2850	147	236
156.8	2770	155	222
163	2670	161	219
169.8	2610	167	206
176.8	2520	174	195
183.8	2450	182	184
189.8	2430	188	186
		196	176

Absorption Data

Sample A	
Absorber Thickness mgm/cm^2	Counts/ min.
0.0	665
1.93	615
2.29	620
5.52	564
6.44	565
15.6	470
29.9	414
53.3	354
63.1	335
78.7	316
92.6	306
108.8	285
127	262
155	242
188	220
244	183
325	142
445	94
528	69
732	33
857	18
1071	7
1309	5
1576	4

TABLE 9

BARIUM/LANTHANIUM RESULTS

Decay Data

Sample A		Sample B	
Time (days)	Counts/ min.	Time (days)	Counts/ min.
0.045	715	0.045	548
0.85	985	0.84	698
1.87	1040	1.86	730
5.82	1160	4.5	803
12.8	850	5.8	792
26.8	400	12.8	565
35.8	243	13.8	561
42.8	170	26.8	280
49.0	121	35.8	168
56.8	123	42.8	120
77.0	30	49.0	83.6
		57	60.8

Absorption Data

Sample A	
Absorber Thickness mgm/cm^2	Counts/ min.
0	151
1.84	146
6.34	133
4.00	133
6.46	133
9.52	117
18.1	95
33.5	68.4
39.4	63.4
49.7	53.2
69.6	38.3
77.6	32.8
93.4	24.8
113	18.0
144	11.5
196	5.0
268	2.1
328	2.0
478	1.6
516	1.7
640	1.7
794	1.7
955	1.1