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Date July 8, 1964

From H. C. Woodsum

F. Planinsek

Subject Analysis of Be Samples
Irradiated at the GTR

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PROBLEM

Eight beryllium samples were irradiated in the Ground Test Reactor (GTR) Facility at Ft. Worth in October, 1963. Four of these samples were of high purity Be and the other four were of NERVA grade Be. A 512 channel analyzer in the Flight Safety Laboratory at WANL was used to measure the decay gamma spectra of these samples at various times after shutdown ranging from 8 days up to about 6 months. Early analytical calculations in support of these experiments did not explain the observed data.

CONCLUSIONS

By using a vendor's activation rather than a chemical analysis, some 73 elements were included instead of the 12 originally considered. By considering more elements in the analysis, it was possible to include even those trace elements which, although low in concentration, are high in activation due to the peculiar combination of nuclear parameters of high activation cross section and intermediate to long half life. Although the experimental environment for the irradiation did not approximate the NERVA neutron spectra very well since the

thermal spectrum in the GTR was severely depressed by a boral plate between the reactor and the Be samples, some useful information can be gained from this test. For example, this experiment can provide a check on how well the ACT - II code calculates activation in a fast spectrum environment. Also this experiment points up the advantage of an activation experiment for determining trace quantities of elements in materials that do not themselves become very radioactive by exposure to high neutron flux. The main constituents which provided most of the activation in the samples irradiated at the GTR were Br and Au (for) shutdown times less than 8 days and Ta, Co58 and Ag-108 for longer times after shutdown. The experimental decay curves are fairly well approximated by calculations with the ACT II code when the more extensive vendor analysis is used as input. (see figures 6 and 7)

DISCUSSION:

EXPERIMENTAL DATA:

The experimental data was obtained from references 1 and 2. This data is also shown in Figures 1 through 5 and Tables 1 and 2 of this report. (These data consist of graphs and tables of the 512 channel analyzer results with typical results plotted in Figures 1 through 4 for 8 days and 164 days after shutdown.) The experimental conditions for the activation of the Be involved exposing 8 samples of Be, 4 of NERVA grade Be and 4 of pure grade Be, in the Ground Test Reactor for 100 hours. The irradiation was performed on the front face of the north dewar and has been designated Test No. 10. The neutron flux obtained at this position was predominantly a high energy flux since a $\frac{1}{4}$ -inch boral plate separates the reactor from the irradiation position. The irradiation was completed on October 29, 1963.

The samples were in the form of cylinders 1-inch in diameter and $\frac{1}{4}$ inch thick. After the irradiation was completed, the samples were shipped to WANL for analysis. The initial analysis was performed on November 6, 8 days after the irradiation, on the Flight Safety Laboratory 512 channel analyzer. Prior to the analysis all samples were cleaned to remove surface contamination.

OBSERVATIONS FROM THE EXPERIMENTAL DATA

The initial gamma spectra of all of the high purity Be samples were essentially identical. A representative spectrum is shown in Figure 1. Initially, the gamma spectra for the NERVA grade Be were significantly different from the high purity Be spectra, although all 4 samples exhibited nearly identical spectra (see figure 2 for a typical plot). After about 3 weeks decay, the NERVA grade changed so that the spectra of both grades of Be exhibited increasing similarity. Also it should be noted that the intensities of the gross gamma count rates which differed by about a factor of 5 at 8 days, differed by only about 10% at 24 days, but this difference again began to increase beyond 50 days after shutdown.

ANALYSIS OF THE DATA

Since the neutron flux spectra at the GTR is fairly well known, it should be possible to predict the activity of the samples of Be exposed at the GTR if an elemental analysis of the Be were also available.

The neutron flux spectrum at the GTR irradiation position was taken from reference 1 as follows:

ϕ (E)	$0.821 < E < 10 \text{ MEV.}$	$6.6 \times 10^{11} \text{ n/cm}^2 - \text{sec}$
ϕ (E)	$5 \text{ KEV} < E < 0.821 \text{ MEV.}$	$6.1 \times 10^{11} \text{ n/cm}^2 - \text{sec}$
ϕ (E)	$0.625 \text{ EV} < E < 5 \text{ KEV.}$	$3.4 \times 10^{11} \text{ n/cm}^2 - \text{sec}$
ϕ (E)	$E \leq 0.625 \text{ EV.}$	$5.3 \times 10^9 \text{ n/cm}^2 - \text{sec}$

Initial elemental analyses of the impurities in the Be samples were obtained from vendor chemical analyses of the materials as given in Tables 3 and 4, for NERVA and high grade material respectively.

These impurity analyses and the flux levels given above were used together with an irradiation time of 100 hours as input to the ACT - II program (3), (4) in order to attempt a calculation of the measured activities. For the NERVA grade Be, initial calculations with the chemical analyses of impurities yielded the observed behavior in the range of 20 - 50 days after shutdown, but failed to predict the steep initial fall off in activity for decay times less than 10 days and the appreciably less rapid fall-off in activity with time after shutdown four times greater than 50 days. Hence, a more extensive impurity analysis was sought and was in fact obtained from R. Nadler of the Materials Group as shown in Table 5. This analysis includes a quantitative determination for a total of 73 elements rather than the 12 obtained by the chemical analysis. The activity calculations were then repeated for this analysis and several additional elements were found to contribute for times less than 20 days and times greater than 50 days after shutdown. These results as given in Table 6 for 0, 7, and 164 days after shutdown show that Br-82 from the $\text{Br}^{81} (n, \gamma) \text{Br}^{82}$ reaction is one of the most important contributors to the activation rate in NERVA grade Be for up to 8-10 days after shutdown. Beyond 10 days, Co-58 from the $\text{Ni}^{58} (n, p) \text{Co}^{58}$ reaction

is one of the most important contributors. At 164 days, the most important contributors are Cs-134 and Ta-182, from n, γ reactions in Cs and Ta, respectively.

Thus we can now explain, at least qualitatively, the behavior observed experimentally as shown in Figure 5. The initial steep fall-off in the activation rate which was measured in the range from 8-16 days after shutdown is believed to be due mainly to decay of Br^{82} with 36 hr. half life giving gammas of 0.76 and 0.61 MEV as well as several lower energy gammas. This fall-off is less pronounced for the pure grade Be than for the NERVA grade Be. Thus, existence of trace impurities is less apparent in the pure grade Be than in the NERVA grade Be and in fact have been ignored in the present analysis with favorable results. The results of the activation calculations for the "pure" grade Be with impurity analysis as given in Table 4 are presented in Table 7, indicating much less of this impurity in the pure grade. (none was assumed for the analysis of the pure grade Be - see Table 4) At 18 days after shutdown, the Co^{58} activity is the major activity with a 70 day half life and a gamma energy of 0.80 MEV.

Since the pure grade Be has essentially the same content of Ni as the NERVA grade, and since the major contributor to the activity in the range of 20 - 70 days after shutdown is due to a Ni n-p reaction, it is not surprising that the gross counting rates are very close to each other for both the high purity and NERVA grade Be samples in this time range. The deviation of the count rates for the two types of Be for times after shutdown > 70 days is attributed to impurities of Cs and Ta in the Be. It should be pointed out that although Ta is present in the Be in less than 0.5 ppm, it still is one of the major contributors to the activities in Be at long times after shutdown.

It is somewhat more difficult to compare quantitatively the calculated and measured activity of the Be samples since the experimental spectral data as shown in Figures 1 through 4 contain Compton scattering in the crystal superimposed on the actual emitted line spectra produced by the decaying atoms of the several impurities. Thus, in order to obtain the line spectra, the scattering effects would have to be subtracted out. This is a detailed and time consuming process which is usually accomplished by starting at the high energy end of the spectra and subtracting out the Compton Spectra for the known sources. If all of the contributing sources to the activation had been known prior to the test and samples of these individual source contributors were on hand (such as Co^{58} , Br^{82} , etc.), the spectra could have been easily decomposed by electronically subtracting known peaks and accompanying Compton scattering thus giving a relatively clean line spectra. Since this was not done, it is difficult to unfold the spectrum now and probably not worth the trouble since the test conditions were not closely related to NRX-A conditions and hence, interpretation of this data in terms of NRX-A activation is difficult if not impossible. However, in order to get a rough idea of the accuracy of the calculational method, we can use a calibration of the counter obtained with a Co-60 source to yield absolute count rates and compare calculated and experimental count rates for some peak such as the 0.8 MEV peak which is present from 0 to 10 days from Br^{82} decay and from 10 to about 70 days from the Co-58 decay. Since the experimental values show a spread around the line value and since the ACT-II code calculates the gamma energy decay rate in each of several energy groups, comparison was actually made by plotting the energy decay rate calculated by ACT-II in the energy range of 0.5 - 0.9 MEV. in units of MEV/cc - per second vs. the experimental decay rate

obtained by multiplying each of the channel results converted to disintegrations per second - cc by the appropriate energy in the energy range 0.5 - 0.9 MEV by use of a calibration with a standard Co-60 source. These comparisons are shown in Figures 5 and 6. The ratio between the calculated and experimental curves for the NERVA grade Be ranges from 1.4 to 2.0. For the high purity Be, the ratio of experimental to calculated activity is about 2.5.

Since most of the activity in the range from 10 to 70 days is from the Ni 58 (n,p) Co 58 reaction, the cross section for this reaction was checked with current best values. The ACT-II Program uses a value of 0.14 b⁽⁵⁾ for the

n,p reaction in Ni 58 averaged over a fission spectrum. Motteff gives value of 0.093 b⁽⁶⁾ for the same reaction. Hence, the ACT-II value may be high by a ratio of 1.5. If the ratios between the experimental and calculated values were decreased by this ratio, the calculated values are then in fairly good agreement with the measurements.

SIGNED H. C. Woodson

J. Planisek (HCW)

REFERENCES

1. REP-207 Activation Analysis of Beryllium
Samples D. E. Solberg November 20, 1963
2. REP-2000 Activation Analysis of Beryllium
Samples D. E. Solberg June 16, 1964
3. WANL - TNR - 063 Addendum 1 Activation
Source Strength Program ACT-II
4. WANL - TME - 590 Materials Activation
Program ACT-II, revised November, 1963
5. Nucleonics Data Sheet No. 28 Handbook of
Nuclear Technology April, 1961
6. Nucleonics Vol. 20, No. 12, pp56-60 "Neutron
Flux and Spectrum Measurement with Radioactivants"
J. Moteff December, 1962

Figure 2

Figure 3

GROSS GAMMA DECAY RATE OF NERVA AND HIGH PURITY BE SAMPLES

FIGURE 5

FIGURE 6

FIGURE 7

Table 1

GAMMA SPECTRUM HIGH PURITY BERYLLIUM

<u>Date</u>	<u>Sample Number</u>	<u>Gross Counting Rate (cpm)</u>	<u>Gamma Peaks</u>	
			<u>(E), Mev)</u>	<u>(cpm)</u>
11/6	5	133,134	0.08	7423
			0.31	3006
			0.49	981
			0.80	835
			1.1-1.2	103
11/6	6	124,626	0.07	6912
			0.31	2736
			0.50	928
			0.79	706
			1.1-1.2	115
11/6	7	120,623	0.08	6610
			0.31	2690
			0.51	907
			0.80	733
			1.1-1.2	96
11/6	8	112,612	0.08	6135
			0.31	2412
			0.49	845
			0.81	687
			1.1-1.2	93
11/12	7	88,920	0.10	4458
			0.32	2168
			0.52	656
			0.81	636
			1.1-1.2	81
11/15	7	82,968	0.09	4165
			0.31	2041
			0.51	621
			0.81	607
			1.1-1.2	78
11/18	7	79,952	0.10	3924
			0.32	1904
			0.52	618
			0.81	608
			1.1-1.2	80

Table 2

GAMMA SPECTRUM OF NERVA GRADE BERYLLIUM

<u>Date</u>	<u>Sample Number</u>	<u>Gross Counting Rate (cpm)</u>	<u>Gamma Peaks</u>	
			<u>(E_γ, Mev)</u>	<u>(cpm)</u>
11/6	1	685,998	0.11	23961
			0.24	10835
			0.56	7767
			0.79	5080
			1.06	1401
			1.31	664
			1.47	342
11/6	2	640,580	0.11	22567
			0.23	10040
			0.56	7232
			0.79	4794
			1.06	1255
			1.31	597
			1.44	285
11/6	3	653,920	0.11	22751
			0.23	10523
			0.56	7448
			0.79	4959
			1.06	1300
			1.31	616
			1.46	325
11/6	4	600,325	0.11	21594
			0.23	9499
			0.56	6971
			0.79	4497
			1.03	1210
			1.31	589
			1.46	288
11/13	4	116,088	0.11	3743
			0.22	1795
			0.51	1018
			0.79	896
			1.08	386
11/15	4	99,636	0.09	3279
			0.22	1493
			0.52	884
			0.81	768
			1.11	365
11/18	4	87,350	0.07	2933
			0.23	1283
			0.52	818
			0.82	728
			1.12	353

Table 3

Chemical Assay of NERVA Grade Be

Element	Composition % By Weight
Be	98.5
BeO	1.7
Fe	.18
Al	.07
Mg	.01
Si	.04
C	.13
Cr	.013
Mn	.015
Ni	.020
Ti	.022
Cu	.013

TABLE 4

Chemical Assay of Electrolytically Processed "PURE" Be

Element	Composition % By Weight
Cr	$\leq .003$
Ni	$< .025$
Co	$< .0002$
Zn	.005
Fe	.029
Sc	$< .0000002$
Ag	$\leq .01$

Table 5

Composition of NERVA Grade Be from Activation

Analysis Vendor Spec.

(values given in PPM unless
otherwise marked.)

Al	420	Ir	-	1	In	-	4
K	20	Pt	-	5	I	-	40
V	1	Tl	-	5	Ce	-	10
As	-	Eu	-	1	Cd	-	.8
Nb	-	Dy	-	5	Ta	-	.5
Mo	-	Gd	-	40	Na	-	5
Rh	-	Sm	-	1.5	Mg	-	90 to 600
Pd	-	Sb	-	1	Si	-	300
Rb	-	Cs	-	5	Cr	-	70
La	-	Li	-	1	Mn	-	125
Pr	-	O2	-	.25-1.28%	Fe	-	400 to 1800
Nd	-	Y	-	5	Co	-	3
Tb	-	Te	-	5	Cu	-	80
Sc	-	Se	-	5	Zn	-	100
P	-	Sr	-	5	Ga	-	4
C	600-1500	N	-	150	Br	-	100
Au	-	Cl	-	100	Zr	-	10
Ho	-	B	-	1	Ru	-	20
Er	-	Ba	-	5	Ag	-	1
Tm	-	Ti	-	10	Th	-	1.4
Pb	-	Ca	-	10	U	-	6
L	-	Ge	-	5	Hg	-	10
Hf	-	Zr	-	10	W	-	2
Re	-	Sn	-	50			
Os	-	Ni	-	200			

Table 6

Calculated Activity of NERVA Grade Be

Target Element	REACTIONS Reaction Product	ACTIVITY (MEV/CC-SEC)		
		Time After Shutdown		
		0	7 Days	164 Days
Al	Al ²⁸	6.685 (5)		
	Mg ²⁷	3.465 (4)		
	Na ²⁴	2.788 (4)	1.185 (1)	
	Al ²⁶	0		
Si	Al ²⁶	1.91 (3)		
	Si ³¹	2.10 (0)	2.9 (-18)	
	Al ²⁸	6.84 (4)		
	Mg ²⁷	3.47 (3)		
Cd	In ^{115M}	2.748 (1)	9.413 (0)	
	In ¹¹⁷	8.862 (1)	5.565 (-16)	
	Ag ¹¹⁰	1.941 (-3)	1.907 (-3)	7.910 (-4)
	Cd ¹⁰⁷	2.729 (-2)	7.742 (-10)	
	Cd ¹¹³	1.893 (-5)	1.891 (-5)	1.883 (-5)
	In ¹¹⁵	1.552 (-5)	1.386 (-5)	
Ca	Sc ⁴⁷	1.288	5.177 (-1)	
	Sc ⁴⁹	4.890 (2)		
	K ⁴²	1.880 (2)	1.629 (-2)	
Cl	Cl ³⁸	6.887 (4)		
	Cl ³⁴	1.630 (3)		
	S ³⁷			
Cr	Cr ⁵¹	1.10 (2)	9.26 (1)	1.820 (-2)
	V ⁵²	7.42 (4)		
Ni	Co ⁵⁷	9.36 (1)	9.19 (1)	3.816 (1)
	Co ⁵⁸	7.39 (3)	6.90 (3)	2.438 (2)
	Co ^{58M} - Co ⁵⁸	6.85 (2)	6.79 (2)	3.178 (0)
	Co ⁵⁸	1.22 (1)	1.22 (1)	
	Fe ⁵⁹	9.45 (-1)	8.43 (-1)	2.513 (-5)
	Ni ⁶⁵	6.50 (2)	1.14 (-17)	

Table 6 (Cont.)

<u>REACTIONS</u>		<u>ACTIVITY (MEV/CC-SEC)</u>		
<u>Target Element</u>	<u>Reaction Product</u>	<u>0</u>	<u>7 Days</u>	<u>164 Days</u>
Co	Co ⁶⁰	3.678 (2)	3.669 (2)	3.225 (2)
	Co ^{60m} -Co ⁶⁰	4.693 (3)	7.06 (-1)	6.209 (-1)
	Fe ⁵⁹	1.571 (1)	1.41 (1)	5.679 (-2)
	Mn ⁵⁶	8.283 (0)	2.071 (-19)	
Cu	Cu ⁶⁴	2.65 (3)	2.97 (-1)	
	Cu ⁶⁶	6.35 (3)		
	Co ⁶⁰	2.79 (0)	2.79 (0)	2.45 (0)
Zn	Cu ⁶⁷	1.089 (0)	1.513 (-1)	
	Cu ⁶⁴	1.523 (2)	1.705 (-2)	
	Ni ⁶⁵	1.790 (0)	3.146 (-20)	
	Zn ⁶⁵	1.745 (2)	1.711 (2)	6.463 (1)
	Zn ^{69m} -Zn ⁶⁹	2.666 (3)	1.21 (0)	
	Zn ⁷¹	5.245 (1)		
Fe	Fe ⁵⁹	2.03 (2)	1.83 (2)	9.407 (-1)
	Mn ⁵⁴	6.40 (2)	6.29 (2)	2.789 (2)
	Cr ⁵¹	1.30 (0)	1.09 (0)	2.160 (-4)
	Mn ⁵⁶	1.51 (4)	3.78 (-16)	
Mn	Mn ⁵⁶	3.01 (6)	7.53 (-14)	
	Mn ⁵⁴	8.29 (-1)	8.15 (-1)	3.614 (-1)
Mg	Mg ²⁷	1.953 (4)		
	Na ²⁴	7.465 (4)	2.084 (-4)	
Sc	Sc ⁴⁶	4.347 (2)	3.84 (-3)	2.433 (1)
	K ⁴²	4.435 (1)	4.103 (2)	
Ti	Ti ⁵¹	5.51 (2)		
	Sc ⁴⁶	7.44 (1)	7.02 (1)	4.166 (0)
	Sc ⁴⁷	3.64 (0)	8.75 (-1)	
	Sc ⁴⁸	5.07 (2)	3.60 (1)	
	Sc ⁴⁷	1.86 (-2)	7.37 (-3)	

Table 6 (Cont.)

Target Element	Reactions Reaction Product	Activity (MEV/CC-Sec)		
		0	7 Days	164 Days
Ag	Ag ¹⁰⁸	1.94 (3)		
	Ag ^{110M} -Ag ¹¹⁰	1.75 (3)	1.72 (3)	7.069 (1)
	Ag ¹⁰⁸	6.66 (1)		
Na	Na ²²	3.713 (-3)	3.706 (-3)	2.844 (-3)
	Na ²⁴	1.148 (4)	7.172 (2)	
	Ne ²³	1.617 (1)		
As	As ⁷⁶	3.610 (4)	4.457 (2)	
	Ga ⁷²	4.213 (2)	1.091 (-1)	
Br	As ⁷⁸	5.841 (3)		
	Br ⁸²	2.263 (6)	8.909 (4)	
	As ⁷⁶	4.530 (2)	5.593 (0)	
	Br ^{80M} -Br ⁸⁰	3.457 (3)		
Ba	Cs ¹³⁸	3.672 (1)		
	Cs ¹³²	3.411 (-2)	1.560 (-2)	
	Cs ¹³⁶	3.183 (-4)	2.192 (-4)	
	Ba ^{133M} -Ba ¹³³	5.33 (-3)	1.254 (-2)	1.181 (-5)
	Ba ¹³⁹	4.917 (3)		
Eu	Eu ^{152M} -Gd ¹⁵² +Sm ¹⁵²	2.001 (5)	7.316 (-1)	
	Eu ¹⁵⁴ -Eu ¹⁵⁵	1.006 (2)	1.005 (2)	9.636 (1)
Ga	Ga ¹⁰	7.315 (1)		
	Ga ⁷²	3.846 (4)	9.960 (0)	
Ge	Ge ⁷⁷ -As ⁷⁷	9.035 (1)	1.831 (-2)	
	Ga ⁷²	3.711 (-1)	9.609 (-5)	
	Ga ⁷⁰	1.993 (0)		
	Ga ⁷³	4.696 (1)	1.366 (-9)	
	Zn ⁷¹	3.785 (1)		
	Ge ⁶⁹	1.187 (1)	6.274 (-1)	

Table 6 (Cont.)

Target Element	REACTIONS Reaction Product	ACTIVITY (MEV/CC-SEC)		
		0	7 Days	164 Days
Au	Au ¹⁹⁸	1.401 (5)	2.323 (4)	
	Au ¹⁹⁶	3.044 (2)	1.280 (2)	5.386 (-17)
Pt	Pt ¹⁹⁷	2.039 (1)	6.037 (-2)	
	Pt ¹⁹⁷	1.751 (1)	5.185 (-2)	
	Pt ¹⁹⁹ -Au ¹⁹⁹	1.818 (2)	3.510 (-2)	
Hf	Hf ¹⁷⁵	4.108 (0)	3.833 (0)	1.298 (-1)
	Hf ^{180m}	3.393 (4)	2.164 (-5)	
	Hf ¹⁸¹	1.961 (2)	1.749 (2)	6.622 (-1)
In	Cd ¹¹⁵	1.321 (1)	1.602 (0)	
	In ^{114m} -In ¹¹⁴	2.076 (1)	1.894 (1)	1.352 (-1)
	In ^{116m}	8.699 (6)		
I	Sb ¹²⁴	9.816 (1)	9.053 (1)	1.735 (0)
	I ¹²⁸	1.633 (5)		
Cs	I ¹³⁰	2.948 (1)	2.857 (-3)	
	Cs ¹³⁴	3.331 (3)	3.310 (3)	2.427 (3)
Hg	Au ²⁰⁰	3.376 (0)		
	Hg ^{197m} -Hg ¹⁹⁷	5.139 (1)	1.437 (0)	
	Hg ²⁰³	2.164 (1)	1.952 (1)	1.262 (-1)
Mo	Mo ⁹⁹ -Tc ⁹⁹	8.697 (2)	1.529 (2)	3.476 (-5)
	Mo ¹⁰¹ -Tc ¹⁰¹	2.344 (3)		
	Nb ⁹²	3.768 (0)	2.320 (0)	
	Zr ⁸⁹	1.094 (-1)	2.506 (-2)	
	Nb ⁹⁵	7.134 (-2)	6.211 (-2)	7.143 (-5)
	Nb ⁹⁷	1.419 (2)		
Zr	Zr ⁹⁵ -Nb ⁹⁵	3.200 (1)	3.382 (1)	2.454 (0)
	Zr ⁹⁷ -Nb ⁹⁷	1.081 (2)	2.275 (-1)	
	Y ⁹⁰	6.116 (-1)	9.970 (-2)	
	Y ⁹⁴	1.920 (1)		

Table 6 (Cont.)

Target Element	REACTIONS Reaction Product	ACTIVITY (MEV/CC - SEC)		
		0	7 Days	164 Days
P	S_{28}^{31}	6.500 (0)		
	A	6.012 (2)		
K	K^{38}	1.953 (1)		
	K^{42}	4.854 (2)	4.207 (-2)	
	Cl^{38}	3.228 (2)		
Se	Se^{75}	2.071 (1)	1.990 (1)	2.789 (0)
	$Se^{81m}-Se^{81}$	1.133 (1)		
	As^{77}	3.633 (-1)	1.793 (-2)	
	$Se^{83m}-Se^{83}$	2.546 (0)		
Ta	Ta^{182}	1.952 (3)	1.871 (3)	7.256 (2)
Sn	Sn^{123}	2.921 (2)		
	Sn^{113}	2.124 (0)	2.039 (0)	8.115 (-1)
	Sn^{125}	7.649 (0)	4.565 (0)	4.240 (-5)
	Sn^{125m}	1.225 (2)		
	Sn^{123m}	6.920 (-5)	6.656 (5)	9.147 (-6)
W	$W^{187}-W^{188}$	2.412 (4)	2.043 (-17)	
	W^{185}	2.068 (-3)	1.937 (-3)	4.446 (-4)
V	V^{52}	4.537 (3)		
	Sc^{48}	3.034 (0)	2.151 (-1)	8.432 (-30)
	T^{51}	3.653 (1)		
Tl	Hg^{203}	1.458 (-4)	1.315 (-4)	1.292 (-5)
Gd	Gd^{159}	4.478 (2)	6.950 (-1)	
	$Gd^{161}-Tb^{161}$	2.073 (3)		
Nb	$Nb^{94m}-Nb^{94}$	3.018 (1)		
Sr	Sr^{85}	3.336 (-1)	3.096 (-1)	5.799 (-2)
	Sr^{89}	1.731 (3)	1.515 (-15)	

TABLE 7

Target Element	REACTIONS Reaction Product	ACTIVITY (MEV/CC - SEC)		
		0	7 Days	164 Days
Cr	Cr ⁵¹	2.545 (1)	2.137 (1)	4.246 (-1)
	V ⁵²	1.712 (4)		
	Cr ⁵⁵			
	Cr ^{49*}			
Ni	Co ⁵⁷	1.170 (2)	1.149 (2)	7.674 (1)
	Co ⁵⁸	9.233 (3)	8.623 (3)	1.859 (3)
	Co ^{58m} -Co ⁵⁸	8.567 (2)	8.484 (2)	1.829 (2)
	Co ⁶⁰	1.528 (1)	1.524 (1)	1.440 (1)
	Co ⁵⁹	1.181 (0)	1.060 (0)	9.421 (-2)
	Fe ⁶⁵	8.121 (2)		
	Ni ⁶³			
	Co ^{61*}			
Co	Co ⁶⁰	6.131 (2)	6.115 (2)	5.779 (2)
	Co ^{60m} -Co ⁶⁰	8.288 (3)	4.659 (2)	4.403 (2)
	Fe ⁵⁹	2.618 (1)	2.350 (1)	2.088 (0)
	Mn ⁵⁶	8.941 (3)		
Zn	Cu ⁶⁷	1.089 (0)	1.513 (-1)	
	Cu ⁶⁴	1.523 (2)	1.705 (-2)	
	Ni ⁶⁵	1.790 (0)		
	Zn ⁶⁵	1.745 (2)	1.711 (2)	1.097 (2)
	Zn ^{69m} -Zn ⁶⁹	2.762 (3)	1.210 (0)	
	Zn ⁷¹	5.245 (1)		
	Zn ⁶⁹			
	Cu ^{66*}			
	Zn ^{63*}			
Fe	Fe ⁵⁹	7.903 (1)	7.095 (1)	6.303 (0)
	Mn ⁵⁴	2.488 (2)	2.447 (2)	1.683 (2)
	Cr ⁵¹	5.054 (-1)	4.244 (-1)	8.432 (-3)
	Mn ⁵⁶	5.879 (3)		
Sc	Sc ⁴⁶	2.174 (1)	2.051 (1)	5.608 (0)
	K ⁴²	2.218 (0)	1.922 (-4)	
Ag	Ag ¹⁰⁸	9.675 (2)		
	Ag ^{110m} -Ag ¹¹⁰	8.768 (2)	8.610 (2)	5.726 (2)
	Ag ¹⁰⁸	3.333 (1)		
	Ag ^{109m} -Pd ^{109*}			
	Pd ^{106m*}			

* = 0