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**DETECTION SENSITIVITIES IN
NUCLEAR ACTIVATION WITH AN
ISOTOPIC NEUTRON SOURCE**

(with a collection of γ -ray spectra)

by

James A. Wing and M. A. Wahlgren

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

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9700 South Cass Avenue
Argonne, Illinois 60439DETECTION SENSITIVITIES IN
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Chemistry Division

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August 1966

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DETECTION SENSITIVITIES IN NUCLEAR ACTIVATION WITH AN ISOTOPIC NEUTRON SOURCE

(with a collection of γ -ray spectra)

by

James A. Wing and M. A. Wahlgren

ABSTRACT

The relative detection sensitivities of seventy-three chemical elements (all the radioactively stable elements except beryllium, lutetium, osmium, and the noble gases) have been determined with an $\text{Am}^{241}\text{-Cm}^{242}\text{-Be}$ neutron source. The sensitivities were obtained for three experimental conditions: (1) 5-min irradiation, 6-sec cooling, 2-min count; (2) 5-min irradiation, 4.9-min cooling, 20-min count; and (3) one-hour irradiation, one-hour cooling, 40-min count. The induced radioactivities were measured with a 10-cm by 10-cm NaI(Tl) crystal. The observed γ -ray spectra are presented. The counts in the photopeaks, per gram of target element, are tabulated versus the gamma energies of the product nuclides. Self-absorption of neutrons and attenuation of γ rays by the target matrices were investigated with Teflon and aluminum samples. Reproducibility of the analytical method was 0.92%.

INTRODUCTION

A high-output, isotopic neutron source offers many advantages in nuclear activation. In spite of a high initial cost of fabrication, such a source is inexpensively operated. It is mobile and requires essentially no maintenance once the source is secured with the necessary shieldings. The rate of decrease of the neutron output is predictable from the radioactive decay constant of the isotope. The energies of the neutrons cover a wide range. Although the neutron flux from an isotopic source may be low, it is now feasible to use it for activation analysis for macro amounts of some elements.^{2,4}

We have determined the relative detection sensitivities of seventy-three chemical elements (all the radioactively stable elements except beryllium, lutetium, osmium, and the noble gases) activated with an $\text{Am}^{241}\text{-Cm}^{242}\text{-Be}$ source. The experiments were carried out for three different

combinations of irradiation, cooling, and counting conditions for the purpose of differentiating the product nuclides on the basis of their half-lives. The sensitivities were obtained with γ -ray spectrometry. The γ -ray spectra of the irradiated target materials were examined for identification of the photopeaks. The counts in the photopeaks of these spectra, per gram of target element, are tabulated and plotted versus the gamma energies of the product nuclides.

EXPERIMENTAL

Isotopic Neutron Source. The design of the isotopic source for irradiation has been described previously.³ The twelve capsules containing americium (isotope 241) and curium (isotope 242) oxides mixed with beryllium had a total source strength of 7.5×10^9 neutrons per second as of May 1965. Six capsules were placed at hexagonal corners above the horizontal midplane of the target, and six below, as shown in Fig. 1. No source capsule was positioned directly under another.

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Fig. 1. Arrangement of the Neutron Source Capsules with Respect to the Target Capsule

The target capsule was transferred in the rabbit tube by compressed air. The average travel time of the capsule from the irradiation site to the counting position was 3 sec.

The detector was a cylindrical NaI(Tl) crystal, 10 cm in diameter and 10 cm long, with a Lucite absorber 3.16 cm thick. The detector was

Target Materials and Capsules.

Most of the target materials were oxides of reagent grade. Metallic hafnium, platinum, and gold foils were placed inside the target capsules to form cylindrical rings. Powdered boron, sulfur, and red phosphorus were used. The target materials, weighing from 4.8 to 45.8 g each, were packed inside polyethylene capsules which had an inside diameter of 13.5 mm and an overall length of 57 mm.

Rabbit Tube and Counting Equipment.

The rabbit tube consisted of a plastic hose, 13 m long, having an inside diameter of 25.4 mm, and, at the irradiation site, a steel tubing of the same diameter and 3.18-mm wall thickness.

shielded with 10 cm of lead lined with cadmium and copper. The distance between the centerline of the target capsule, which was placed parallel to the detector face, and the detector face was 4.5 cm. The induced γ radiations were recorded by an RIDL model 34-12B 400-channel pulse-height analyzer.

Procedure. The target material was irradiated for 5 min, cooled for 6 sec, and then counted for 2 min. The γ -ray spectrum was stored in the first 200 channels of the analyzer. At 4.9 min after the end of the same irradiation, the target was counted for 20 min. The spectrum from the second count was stored in the second 200 channels of the analyzer. About a month later, the target material was irradiated for one hour, cooled for another hour, and then counted for 40 min (indium was counted for 4 min).

A new sample was used for the long irradiation if the sample which had been irradiated for 5 min showed significant radioactivities. Because of the possibility of heat buildup, due to large thermal-neutron cross sections of boron, boron was not irradiated for one hour. The contributions from an irradiated blank polyethylene capsule and from the room-background radiations were subtracted from all the spectra obtained. The experiments were performed in January through April of 1966.

The reproducibility of the analytical method was determined with 13 runs on a Teflon sample. Two opposing, matched NaI(Tl) crystals of the same size, at the same counting geometry and with identical shields as described above, were used. The sample was irradiated for one minute and counted for 100 sec for the 0.20-MeV γ activities of O^{19} .

Self-absorption of neutrons and attenuation of γ rays by the target matrices were studied with hollow aluminum and Teflon cylinders, 5.2 cm long having an outside diameter of 1.35 cm. The inside diameters of the hollow cylinders were 0, 0.256, 0.318, 0.635, 0.794, 1.032, and 1.27 cm. The aluminum was irradiated for one minute, cooled for 5 min, and then counted for 20 min. The Teflon was irradiated for 2 min, cooled for 24 sec, and then counted for 2 min. Two opposing NaI(Tl) crystals were used. The γ rays detected were 0.84 MeV of Mg^{27} for aluminum and 0.20 MeV of O^{19} for Teflon.

The effects of the capsule material were studied by examining the γ activities of a piece of polyethylene irradiated for various periods up to one hour. The effects of oxygen in the target materials were investigated by comparing the Mg^{27} activities induced in aluminum oxide with those in aluminum, both irradiated for 5 min and counted for 20 min. The induced γ activities of carbon, hydrogen, and oxygen were also examined in 1-octadecanol, citric acid, and succinic acid, each of which was irradiated for 5 min and for one hour.

The decrease of neutron output of the source was followed by quartz and aluminum monitors. Both monitors were irradiated for 5 min at irregular intervals. The quartz was counted for 5 min for the 1.78-MeV γ activities of Al^{28} , and the aluminum was counted for 10 min for the 0.84-MeV γ activities of Mg^{27} . Two opposing NaI(Tl) crystals were used.

RESULTS AND DISCUSSION

Detection Sensitivities. The energies of the neutrons from the present source range from thermal energy to about 10 MeV. Figure 2 is the energy distribution of the unshielded source, determined with two different techniques by Strain⁵ and by Terrell.⁶ The radioactivities detected in our irradiated samples represent those induced by all of these neutrons. The observed γ -ray spectra are collected in the Appendix. The

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Fig. 2. Neutron Spectrum of the Unshielded Source^{5,6}

nuclides producing the photopeaks in these spectra are identified on the basis of their nuclear decay properties.⁷ The peaks at 0.48, 0.6, 1.1, and 1.4 MeV that frequently occurred are probably due to airborne natural radioactivities, such as radon and thoron. As the blank-capsule activities were not always measured at the same time as the samples, and these airborne activities fluctuated daily,¹ these peaks appeared in some spectra.

The results of the measurements of detection sensitivity are summarized in Table I. The first column in the table lists the

target elements, the second the target materials used, and the third the weights of the targets. The fourth column lists the identified product nuclides with their decay half-lives given in the fifth column and the γ energies detected in the sixth. (The abbreviations for half-lives are: s = second, m = minute, h = hour, d = day, y = year). Unidentified peaks are marked with ?. The next three columns give the detection sensitivities, expressed as counts in the observed photopeaks, per gram of target element, for the three experimental conditions. The seventh column is for 5-min irradiation, 6-sec cooling, 2-min count. The eighth column is for 5-min irradiation, 4.9-min cooling, 20-min count. The ninth column is for one-hour irradiation, one-hour cooling, 40-min count. The numbers in these three columns are expressed in an exponential form, i.e., 8.2E 3 means 8.2×10^3 . X rays and the airborne background activities are not included in Table I.

TABLE 1. Relative Detection Sensitivities of Chemical Elements

Target Element	Target Material	Target Weight (g)	Reaction Product	Half-life	Energy of γ ray Counted (MeV)	Counts/g Target Element			Remark
						5-min Irrad; 2-min Count	5-min Irrad; 20-min Count	1-hr Irrad; 40-min Count	
H	(CH ₂) _x	18.19							Si contamination
Li	LiCl	7.33	(See Cl)						
B	B	4.79	Al ²⁸	2.3 m	1.78	3.3E 1			
C	(CH ₂) _x	18.19							
N	NH ₄ I	10.41	(See I)						
O	C ₄ H ₆ O ₄	18.20							
F	(CF ₂) _x	14.52	Ol ¹⁹	29 s	0.20	8.2E 3			
			?		1.37	1.2E 3			
					0.51	8.1E 2			
Na	Na ₂ C ₂ O ₄	8.70	Ne ²³	38 s	0.44	4.1E 3			
			Ne ²³	38 s	1.65	6.6E 2			
			F ²⁰	11 s					
			Na ²⁴	15 h	1.37			9.0E 3	
					2.75			3.9E 3	
Mg	MgO	5.94	Na ²⁵	60 s	0.41	3.6E 2			Also pair peak of Al ²⁸
					0.58	2.2E 2			
					0.98	1.4E 2			
					1.60	5.6E 1			
			Na ²⁴	15 h	1.37	6.3E 1	4.9E 2	1.2E 4	
					2.75		2.7E 2	5.4E 3	
Al	Al	19.39	Mg ²⁷	9.5 m	0.83	6.7E 3	2.6E 4	4.7E 3	
					1.01	2.2E 3	8.0E 3	2.9E 3	
			Al ²⁸	2.3 m	1.78	4.1E 2	2.6E 2	2.6E 2	
			Na ²⁴	15 h	1.37		3.8E 2	6.8E 3	
					2.75		1.7E 2	3.3E 3	
Si	SiO ₂	14.06	Al ²⁸	2.3 m	1.78	1.8E 4	9.5E 3		Pair peak
			Al ²⁹	6.6 m	1.27		2.8E 3		
					2.43	1.4E 1	1.2E 2		
			?		3.1	1.7E 1	2.6E 2		
P	P	9.42	Al ²⁸	2.3 m	1.78	7.1E 3	3.6E 3		
			Si ³¹	2.6 h	1.27			1.5E 2	
S	S	10.59	S ³⁷	5.1 m	3.1	1.6E 1	1.2E 2		
Cl	LiCl	7.33	Cl ³⁸	37 m	1.65	4.6E 1	1.4E 2	8.1E 2	
					2.16	6.4E 1	1.7E 2	6.0E 2	
			S ³⁷	5.1 m	3.1	1.0E 2	1.9E 2		
					2.6	8.5E 1	2.2E 2		
K	K ₂ CO ₃	10.59	Cl ^{38m}	0.7 s	0.66	1.2E 2			Sum peak
			Cl ³⁸	37 m	1.65		1.7E 2	1.5E 3	
					2.16	1.5E 1	1.2E 2	1.3E 3	
					3.8			8.0E 1	
			Ar ⁴¹	1.8 h	1.29	5.2E 1	3.9E 2		
			K ⁴²	12 h	1.52		2.1E 2		
Ca	CaO	5.55							
Sc	Sc ₂ O ₃	9.14	Sc ^{46m}	20 s	0.14	2.8E 3		1.9E 3	
			Sc ⁴⁶	84 d	0.89			1.3E 3	
					1.11				
Ti	TiO ₂	9.91	Sc ^{46m}	20 s	0.14	4.0E 2			Not Sc ⁴⁶
			Sc ⁴⁷	3.4 d	0.16		2.4E 2	1.5E 3	
			Sc ⁴⁸	44 h	1.0		6.7E 1	9.3E 2	
					1.31			3.0E 2	
			Sc ⁵⁰	1.8 m	1.58	3.1E 1			
			?		0.85		5.5E 1		
V	V ₂ O ₅	10.32	Ti ⁵¹	5.8 m	0.32	3.0E 3	6.0E 3		
			V ⁵²	3.8 m	1.43	2.8E 3	3.7E 3		
Cr	CrO ₃	16.97	V ⁵²	3.8 m	1.43	1.9E 3	2.7E 3		
Mn	MnO ₂	23.60	Mn ⁵⁶	2.6 h	0.85	4.8E 2	3.8E 3	3.8E 5	
					1.81	7.0E 1	5.4E 2	6.7E 4	
					2.11		3.2E 2	2.8E 4	
			V ⁵²	3.8 m	1.43	2.5E 2	6.5E 2		
Fe	Fe ₂ O ₃	13.15	Mn ⁵⁶	2.6 h	0.85	1.2E 2	1.1E 3	2.1E 4	One hour run used, 10.91 g, Fe ₂ O ₃
					1.81	2.8E 1	1.8E 2	3.2E 3	
					2.11		1.3E 2	1.2E 3	
Co	CoO	23.63	Mn ⁵⁶	2.6 h	0.85	1.9E 1	2.0E 2	2.8E 3	
					1.81	4.0E 0	2.7E 1	8.0E 2	
					2.11		3.3E 1	2.2E 2	
			Co ^{60m}	10 m	1.33	6.3E 0	4.2E 1		
			Co ⁵⁸	72 d	0.81	6.0E 0	2.8E 1	1.1E 3	
					0.511			1.3E 3	
Ni	NiO	19.86	Ni ⁶⁵	2.5 h	1.11			1.2E 2	
					1.5			7.6E 1	

TABLE I (Contd.)

Element	Target Material	Target Weight (g)	Reaction Product	Half-life	Energy of γ ray Counted (MeV)	Counts/g Target Element			Remark
						5-min Irrad; 2-min Count	5-min Irrad; 20-min Count	1-hr Irrad; 40-min Count	
Cu	CuO	29.90	Cu ⁶⁴	13 h	0.511	4.1E 1	1.6E 2	1.4E 4	
			Cu ⁶⁶	5.1 m	1.04	7.2E 1	1.4E 2		
			Co ⁶²	14 m	1.17	5.0E 0	1.7E 1	2.5E 2	
					1.47		1.4E 1	2.3E 2	
Zn	ZnO	17.28	Cu ⁶⁴	13 h	0.511	8.9E 1	7.3E 2	1.8E 4	
			Cu ⁶⁶	5.1 m	1.34 1.04	3.6E 1	6.3E 1	9.7E 1	
Ga	Ga ₂ O ₃	11.48	Ga ⁷²	14 h	0.63 0.83	2.1E 1 3.6E 1	1.5E 2 1.8E 2	1.2E 4 2.1E 4	
			Zn ⁷¹	2.5 m	0.51	4.8E 1	2.5E 2		
			Ga ⁷⁰	21 m	1.03	3.7E 1	1.4E 2		
Ge	GeO ₂	17.11	Ge ^{75m}	49 s	0.14	4.4E 2	1.8E 2	3.4E 3 1.9E 2 1.4E 2	
			Ge ^{77m}	54 s	0.16				
			Ge ⁷⁵	82 m	0.26				
			Ga ⁷²	14 h	0.63 0.83				
As	As ₂ O ₃	14.75	Ge ^{75m}	49 s	0.14	3.6E 2	2.4E 2 2.9E 2	1.8E 4 1.4E 3	
			Ge ⁷⁵	82 m	0.26	2.2E 1			
			As ⁷⁶	26 h	0.56 1.21	2.3E 1			
Se	SeO ₂	18.10	Se ^{79m}	3.9 m	0.1	3.2E 3 5.9E 3	3.8E 2	2.6E 3 3.7E 2	
			Se ^{81m}	57 m	0.1				
			Se ^{77m}	18 s	0.16				
			As ⁷⁸	91 m	0.62				
Br	CaBr ₂	13.98	Br ^{79m}	4.8 s	0.21	2.5E 3	1.6E 3 1.9E 3 1.4E 2 5.3E 1 5.2E 1	1.4E 4 1.0E 4 6.6E 3 2.6E 3 2.1E 3	Also Br ⁸²
			Br ⁸⁰	18 m	0.51 0.62	2.5E 2 3.0E 2			
			Br ⁸²	35 h	0.78 1.04 1.3				
Rb	Rb ₂ O	16.57	Rb ^{86m}	1.0 m	0.56	9.0E 2	7.0E 1	6.1E 2 1.9E 2	Sum peak
			Rb ⁸⁸	18 m	0.91 1.85	4.7E 1 1.4E 2	8.7E 1 1.0E 2		
			Kr ^{85m}	4.4 h	0.15 0.31				
Sr	Sr(NO ₃) ₂	15.92	Sr ^{87m}	2.8 h	0.39	1.8E 2	1.7E 3	3.0E 4	
Y	Y ₂ O ₃	13.88	Y ^{89m}	16 s	0.91	1.6E 4		1.8E 3	
			Y ^{90m}	3.2 h	0.20 0.48			7.5E 2	
			?		0.28			6.6E 2	
			?		0.35			5.4E 2	
Zr	ZrO ₂	13.77	Y ^{90m}	3.2 h	0.20 0.48	2.8E 1	9.0E 1	8.8E 2 4.3E 2	Grown from Nb ^{94m}
Nb	Nb ₂ O ₅	7.46	Nb ⁹⁴	2 x 10 ⁴ y	0.87		7.3E 1	1.3E 2	
			?		0.15			7.1E 2	
			?		0.37			3.6E 2	
Mo	MoO ₃	21.02	Mo ¹⁰¹	15 m	0.18	1.5E 2	9.9E 2	2.4E 3	Product uncertain
			Tc ¹⁰¹	14 m	0.39 0.51	9.4E 1 3.8E 1	1.0E 3 2.7E 2		
					0.59 0.7	4.9E 1 2.4E 1	2.6E 2 1.2E 2		
					1.02 1.5 0.26	1.9E 1	1.3E 2 6.3E 1		
Ru	Ru ₂ O ₅ Ru ₄ O ₉	7.17	Mo ^{93m}	6.9 h					
			Ru ¹⁰⁵	4.4 h	0.13		4.2E 2	5.8E 3	
			Rh ^{105m}	30 s	0.31 0.48 0.73		1.9E 2 1.8E 2 1.4E 2	2.7E 3 2.9E 3 4.0E 3	
					0.9 1.9		7.2E 1		
Rh	Rh ₂ O ₃	11.35	?			3.2E 1			Isotope not certain
			Rh ^{104m}	4.4 m					
			Rh ¹⁰⁴	42 s	0.56 1.24	6.7E 3 1.9E 2	1.3E 3 3.7E 1		
			Ru ¹⁰³	40 d	0.50 0.7			1.2E 2 2.7E 2	
Pd	PdO	16.84	?		1.4		2.4E 2	1.1E 2	
			Pd ^{109m}	4.8 m	0.18	4.8E 2	6.2E 2		
			Rh ^{106m}	2.2 h	0.51 0.62			1.9E 2 2.2E 2	
			?		1.4 1.6			1.1E 2 9.0E 1	

TABLE I (Contd.)

Target Element	Target Material	Target Weight (g)	Reaction Product	Half-life	Energy of γ ray Counted (MeV)	Counts/g Target Element			Remark
						5-min Irrad; 2-min Count	5-min Irrad; 20-min Count	1-hr Irrad; 40-min Count	
Eu	Eu_2O_3	6.81	$\text{Eu}^{152\text{m}}$	9.3 h	0.12	6.8E 2	7.2E 3	2.0E 5	
					0.34	2.5E 2	2.3E 3	6.4E 4	
					0.84	4.4E 2	4.0E 3	9.5E 4	
					0.96	2.5E 2	2.6E 3	5.6E 4	
					1.33	3.1E 1	3.3E 2	7.8E 3	
Gd	Gd_2O_3	13.29	Gd^{161}	3.7 m	0.10	2.7E 2	4.0E 2		Also 0.32 Sum peak
					0.17	3.9E 2	6.6E 2		
					0.36	9.2E 2	1.2E 3		
					0.41	3.2E 1	4.2E 1		
Tb	Tb_2O_3	11.50	Gd^{159}	19 h	0.36			1.4E 3	Sum peak
			Tb^{160}	73 d	0.3			1.1E 3	
					0.88			4.4E 2	
Dy	Dy_2O_3	20.05	$\text{Dy}^{165\text{m}}$	1.3 m	0.97			3.2E 2	Sum peak
					1.2			3.8E 2	
					0.09	3.3E 3			
					0.11	8.9E 2			
Ho	Ho_2O_3	14.28	Ho^{166}	27 h	0.37	1.1E 3			
					0.56	1.7E 3			
					0.09		3.7E 3	1.7E 5	
					0.28		1.5E 3	2.1E 4	
					0.37		1.3E 3	1.9E 4	
					0.56		6.2E 2	8.6E 3	
					0.66		6.7E 2	6.7E 3	
					0.76		6.3E 3	6.3E 3	
					1.04-1.1	2.6E 1	1.0E 2	1.9E 3	
Er	Er_2O_3	21.79	$\text{Er}^{167\text{m}}$ Er^{171}	2.5 s 7.5 h	0.08	3.2E 2	2.6E 3	2.8E 4	
					1.36			8.6E 2	
					0.21	1.1E 2		3.8E 3	
					0.11	4.4E 1	1.8E 2	7.0E 3	
Tm	Tm_2O_3	24.41	$\text{Yb}^{177\text{m}}$	6.5 s	0.31	2.6E 1	2.4E 2	8.3E 1	
					0.80			8.1E 1	
					0.91				
Yb	Yb_2O_3	25.78	Yb^{177}	1.9 h	0.10	7.8E 1			
					0.21	8.0E 1			
					0.15		1.6E 2	3.0E 3	
					1.09			4.1E 2	
Hf	Hf	12.19	Yb^{175}	4.2 d	1.24			2.1E 2	Also Yb^{169}
					0.11		1.0E 2	3.0E 3	
					0.28	9.3E 1	9.2E 1	1.2E 3	
					0.40	1.0E 2	1.2E 2	1.7E 3	
Hf	Hf	12.19	Yb^{169}	32 d	0.20		8.0E 1		
Ta	Ta_2O_5	22.35	$\text{Hf}^{178\text{m}}$	4.8 s	0.43	7.2E 1			
					0.33	9.3E 1			
					0.21				
					0.22				
Ta	Ta_2O_5	22.35	$\text{Hf}^{179\text{m}}$	19 s	0.16	4.4E 3			
					0.22	1.5E 3			
					0.33				
					0.43				
Ta	Ta_2O_5	22.35	$\text{Hf}^{180\text{m}}$	5.5 h	0.78				Also Hf^{181} Sum peak
					0.1-0.2			6.1E 2	
					0.32			3.5E 2	
					1.1-1.2			4.4E 2	
Ta	Ta_2O_5	22.35	Ta^{182}	115 d	0.2	8.2E 1	1.1E 2		Isotope not certain
					0.5	1.9E 1			
					1.7	6.0E 1	2.3E 1		
W	H_2WO_4	15.32	$\text{Ta}^{182\text{m}}$	16 m	0.10				
					0.10				
					0.16				
					0.18				
W	H_2WO_4	15.32	$\text{W}^{183\text{m}}$ $\text{W}^{185\text{m}}$ $\text{W}^{183\text{m}}$ $\text{W}^{185\text{m}}$ W^{187}	5.3 s 1.7 m 5.3 s 1.7 m 24 h	0.13				
					0.48		8.7E 1	1.2E 4	
					0.69		8.7E 1	1.1E 4	
							9.7E 1	9.2E 3	
Re	Re_2O_7	20.79	$\text{Re}^{188\text{m}}$ Re^{188}	20 m 17 h	0.10	2.0E 1	1.7E 2	1.6E 4	Sum peak
					0.16	2.6E 1	2.2E 2	2.5E 3	
					0.48		5.8E 1	2.7E 3	
					0.63			6.6E 2	
Re	Re_2O_7	20.79	$\text{Re}^{188\text{m}}$ Re^{188}	20 m 17 h	0.83			6.7E 2	Sum peak
					0.93			2.3E 2	
					1.13			1.7E 2	
					1.31				

TABLE I (Contd.)

Target Element	Target Material	Target Weight (g)	Reaction Product	Half-life	Energy of γ ray Counted (MeV)	Counts/g Target Element			Remark
						5-min Irrad; 2-min Count	5-min Irrad; 20-min Count	1-hr Irrad; 40-min Count	
Ir	IrO ₂	11.03	Ir ^{191m} Ir ¹⁹⁴	4.9 s 19 h	0.13	4.4E 2		3.4E 4	Also Ir ¹⁹² ? Also Ir ¹⁹² ?
					0.32	1.7E 2	1.3E 3	4.2E 3	
					0.64		1.3E 2	8.2E 2	
					0.94			9.7E 2	
					1.2			6.2E 2	
Pt	Pt	15.21	?		1.5			4.8E 3	
					0.42	1.4E 2	1.8E 2		
					0.35				
					0.32	2.7E 1	8.7E 1	1.0E 3	
					0.54	1.7E 1	1.1E 2	1.0E 3	
Au	Au	11.56	Pt ¹⁹⁷ Au ^{197m} Au ¹⁹⁸	20 h 7.2 s 65 h	0.19			1.1E 3	Sum peak
					0.28	6.6E 3		6.8E 4	
					0.41	6.5E 1	6.3E 2	7.2E 2	
Hg	HgO	45.82	Hg ^{199m}	44 m	0.68			1.6E 2	
					1.09				
					0.16	2.5E 2	2.0E 3	1.3E 4	
Tl	Ti ₂ O ₃	20.68			0.37	1.5E 2	1.2E 3	7.7E 3	
					0.53			1.0E 2	
Pb	PbO	27.16	Pb ^{204m}	67 m	0.38	2.4E 1	1.6E 2	1.5E 3	
					0.91	1.8E 1	1.5E 2	1.5E 3	
Bi	BiONO ₃ ·H ₂ O	13.88							

The detection sensitivities are plotted versus the gamma energies in Figs. 3 to 5 for convenient comparison.

121-1394

Fig. 3. Detection Sensitivities of Chemical Elements versus the Gamma Energies Detected, for 5-min Irradiation, 6-sec Cooling, 2-min Count

121-1393

Fig. 4. Detection Sensitivities of Chemical Elements versus the Gamma Energies Detected, for 5-min Irradiation, 4.9-min Cooling, 20-min Count

121-1395

Fig. 5. Detection Sensitivities of Chemical Elements versus the Gamma Energies Detected for One-hour Irradiation, One-hour Cooling, 40-min Count

We have some comments on the identification and counting of the product nuclides of the following elements:

Ti. The 0.85-MeV peak detected in the 5-min irradiation is not due to Sc^{46} (half-life 85 days) since this peak was not observed in the one-hour irradiation.

Co. The 1.33-MeV peak is of $\text{Co}^{60\text{m}}$ and not Fe^{59} , because the latter (half-life 45 days) was not observed in the one-hour irradiation.

Cu. The 1.17- and 1.47-MeV activities are of Co^{62} and not Ni^{65} . The ratio of the 0.511-MeV (Cu^{64} , half-life 12 hr) to the 1.47-MeV activities is 12 in the 5-min irradiation. The same ratio is greater than 100 in the one-hour irradiation. This means that the 1.47-MeV activity has a shorter half-life than Ni^{65} (2.56 hr). There is also an absence of the 0.37-MeV radiation characteristic of Ni^{65} in all the runs, although the 0.511-MeV activities of Cu^{64} are so high that the low abundance of Ni^{65} activities, if present, could not be easily seen.

Mo. In the one-hour irradiation, the observed 0.26-MeV activities are tentatively assigned to $\text{Mo}^{93\text{m}}$. However, the two other γ rays of $\text{Mo}^{93\text{m}}$, of 0.68- and 1.5-MeV energy, are not apparent in the spectrum.

Ag. The long-lived 0.51- and 0.62-MeV activities are tentatively assigned to $\text{Rh}^{106\text{m}}$ (2.2 hr) and Ag^{106} (8.2 days). The reported ratios of the 0.51- to 0.62-MeV activities are 4 in $\text{Rh}^{106\text{m}}$ and 5 in Ag^{106} . The same ratios observed are 4 and 8 in the 20- and 40-min counts, respectively. Thus, the 0.62-MeV activities seem to have a shorter half-life than the 0.51-MeV activities. Furthermore, the 0.51-MeV peak in the 40-min count appears complex.

In. For the one-hour irradiation, the count time was 4 min instead of 40 min. In Table I, the counts for this run have been multiplied by 10 to give the sensitivities corresponding to 40-min count.

Pr. The observed short-lived 0.511-MeV activities are tentatively assigned to Pr^{140} . The threshold energy of the $\text{Pr}^{141}(\text{n},2\text{n})\text{Pr}^{140}$ reaction is 9.4 MeV.

Ir. The activity ratios of the 0.33-MeV to the 0.42-MeV peaks in the 2-min, 20-min, and 40-min counts are 1.3, 6, and 7, respectively. The same ratio reported for Ir^{192} (half-life 74 days) is 3. This means that the observed 0.42-MeV activities are short-lived and are not of Ir^{192} .

Reproducibility, Effects of Target Matrices, and Neutron Output. The relative standard deviation of the counts in the 13 runs with Teflon is $\pm 0.92\%$. The major source of error in the present experiment lies in the uncertainty of the irradiation and cooling times, as the travel time of the same capsule may vary from run to run. The present reproducibility could be improved with a device for precise timing the arrival and departure of the target capsule in the irradiation site and for timing the arrival of the capsule in the counting site.

Figure 6 shows the combined effects of neutron absorption and γ -ray attenuation by aluminum and Teflon. The relative decrease in counts per gram of sample is larger for Teflon than for aluminum. This may be

121-1392

Fig. 6. Neutron Absorption and γ -ray Attenuation of Aluminum and Teflon

explained by the lower γ energy (0.20 MeV) detected in Teflon than in aluminum (0.84 MeV), and by the fact that carbon and fluorine are better moderators for neutrons than aluminum. As neutron absorption and γ -ray attenuation greatly depend on the individual elements and γ energies and we do not possess complete information about them, we have not made any corrections for these two effects in the calculation of the detection sensitivities reported in Table I.

The ratio of the 0.84-MeV activities of Mg^{27} induced in aluminum oxide to those in the aluminum sample is 1.15, on the basis of the same weight of aluminum. The reason for this large effect of oxygen in count rates is not apparent.

No significant radioactivities were observed in the irradiated polyethylene, 1-octadecanol, citric acid, and succinic acid samples. This indicates that the relative flux of neutrons with energies greater than 10 MeV is small [absence of the $\text{O}^{16}(\text{n},\text{p})\text{N}^{16}$ reaction with a threshold of 10.2 MeV], and that the probability of the reactions induced by recoiling protons, such as $\text{C}^{12}(\text{p},\gamma)\text{N}^{13}$ and $\text{O}^{16}(\text{p},\gamma)\text{F}^{17}$, is negligible.

The rates of decrease of the neutron output as measured by the aluminum and quartz monitors follow essentially the exponential decay rate of Cm^{242} . The detection sensitivities reported in Table I and Figs. 3 to 5 have been normalized to the neutron output of 2.7×10^9 neutrons/sec as of January 6, 1966.

FUTURE WORKS

Much of the uncertainty and difficulties in the identification of the product nuclides are results of low count rates and poor energy resolution of the detector. These difficulties may be reduced by the use of a neutron source of greater strength than the present one for high detection sensitivity and by the use of a semiconductor detector for better γ -energy resolution. We are planning to have the present source reactivated and to obtain additional sources. For the purpose of reducing interferences and further differentiating the product nuclides, a cadmium shield may be placed between the neutron source and the target to absorb the thermal neutrons.

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APPENDIX

The γ -ray Spectra of the Irradiated Targets

The γ -ray spectra collected here are divided into two sections: (1) 5-min irradiation and (2) one-hour irradiation. The graphs in each section are arranged in the order of the atomic number of the target element. The vertical coordinate is counts per channel. The peaks are labelled with the identified nuclides and with their γ energies in MeV. In the 5-min irradiation, the 2-min counts are stored in the first 200 channels and the 20-min counts in the second.

The format for the heading of the graphs is: chemical symbol of the target element, amplifier gain of the analyzer, irradiation time (and cooling time, in the one-hour irradiation), count time, and the date of performance of the experiment. Thus, "LA GAIN $1/2$ 5 MIN IRRAD 2+20 MIN COUNT 1-14" means the target element was lanthanum, amplifier gain set at $1/2$, 5-min irradiation, 0.1-min and 4.9-min cooling, 2-min and 20-min counts, performed on January 14, 1966. Again, "CL GAIN $1/8$ TR=1 HR TC=1 HR 40 MIN COUNT 3-22" means the target element was chlorine, amplifier gain set at $1/8$, one-hour irradiation, one-hour cooling, 40-min count, performed on March 22, 1966.

The graphs were plotted by an IBM-1620 II computer equipped with an IBM-1626 plotter. They have not been normalized to the neutron output of the isotopic source.

Section 1. Five-minute Irradiation

B GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 1-19

F GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-6

NA GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-6

MG GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-7

MG GAIN 1/4 5 MIN IRRAD 20 MIN COUNT 1-7

AL GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-7

SI GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-7

SI GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 1-25

P GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-18

S GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 1-25

CL GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-19

CL GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-10

CL GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 1-10

K GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-24

K GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 1-10

CA GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-10

SC GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-19

SC GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-10

TI GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-19

TI GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-10

V GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-11

CR GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-24

CR GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-11

MN GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-11

MN GAIN 1/4 5 MIN IRRAD 20 MIN COUNT 1-11

FE GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-11

FE GAIN 1/4 5 MIN IRRAD 20 MIN COUNT 1-11

CO GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-11

CO GAIN 1/4 5 MIN IRRAD 20 MIN COUNT 1-11

NI GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-11

CU GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-24

CU GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-12

ZN GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-24

ZN GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-12

GA GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-19

GA GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-12

GE GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-19

GE GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-12

AS GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-19

AS GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-12

SE GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-24

SE GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-12

BR GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-24

BR GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-12

RB GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-12

SR GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-13

Y GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-13

ZR GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-20

ZR GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-13

NB GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-20

NB GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-13

MO GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-20

MO GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-13

RU GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-20

RU GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-13

RH GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 3-11

PD GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-20

PD GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-13

AG GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-13

CD GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-20

CD GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-13

IN GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-24

IN GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-13

IN GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 1-19

SN GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-20

SN GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-14

SB GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-14

TE GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-20

TE GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-14

I GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-14

CS GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-20

CS GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-14

BA GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-14

LA GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 3-10

CE GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-24

CE GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-14

PR GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 3-11

PR GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 3-10

ND GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 3-10

ND GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 3-11

SM GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 3-10

EU GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 3-11

EU GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 3-10

GD GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 3-10

TB GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 3-10

DY GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 3-10

DY GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 3-11

HO GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-24

ER GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 3-10

TM GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 3-11

YB GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 3-11

HF GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-21

HF GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-19

TA GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-14

W GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-21

W GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-18

RE GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-21

RE GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-18

IR GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 3-10

PT GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-21

PT GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-18

AU GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-24

AU GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-18

HG GAIN 1 5 MIN IRRAD 2+20 MIN COUNT 1-21

HG GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-18

TL GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-18

PB GAIN 1/2 5 MIN IRRAD 2+20 MIN COUNT 1-18

BI GAIN 1/4 5 MIN IRRAD 2+20 MIN COUNT 3-11

Section 2. One-hour Irradiation

CH GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-6

CHO GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-7

F GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-21

NA GAIN 1/16 TR=1 HR TC=1 HR 40 MIN COUNT 3-22

MG GAIN 1/16 TR=1 HR TC=1 HR 40 MIN COUNT 3-22

AL GAIN 1/16 TR=1 HR TC=1 HR 40 MIN COUNT 3-22

SI GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-13

P GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-13

P GAIN 1/16 TR=1 HR TC=1 HR 40 MIN COUNT 3-22

S GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-13

CL GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-22

K GAIN 1/16 TR=1 HR TC=1 HR 40 MIN COUNT 3-24

CA GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-13

SC GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-24

II GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-12

V GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-12

CR GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-12

FE GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-5

CO GAIN 1/16 TR=1 HR TC=1 HR 40 MIN COUNT 3-25

NI GAIN 1/16 TR=1 HR TC=1 HR 40 MIN COUNT 3-25

CU GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-12

CU GAIN 1/16 TR=1 HR TC=1 HR 40 MIN COUNT 3-25

ZN GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-12

ZN GAIN 1/16 TR=1 HR TC=1 HR 40 MIN COUNT 3-25

GA GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-12

GA GAIN 1/16 TR=1 HR TC=1 HR 40 MIN COUNT 3-25

GE GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-12

GE GAIN 1/16 TR=1 HR TC=1 HR 40 MIN COUNT 3-25

AS GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-28

SE GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-28

BR GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-28

RB GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-28

SR GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-28

Y GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-28

ZR GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-28

NB GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-29

MO GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-29

RU GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-29

RH GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-29

PD GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-29

AG GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-30

CD GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-30

IN GAIN 1/8 TR=1 HR TC=1 HR 4 MIN COUNT 3-30

SN GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-30

SB GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-30

TE GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-30

I GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-30

CS GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-31

BA GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-5

LA GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-31

CE GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-31

PR GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-31

ND GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-31

SM GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-31

EU GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 3-31

GD GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-1

TB GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-1

ER GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-1

TM GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-1

YB GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-4

HF GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-4

TA GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-4

W GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-4

RE GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-4

IR GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-4

PT GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-4

AU GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-5

HG GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-5

TL GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-5

PB GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-5

BI GAIN 1/8 TR=1 HR TC=1 HR 40 MIN COUNT 4-5