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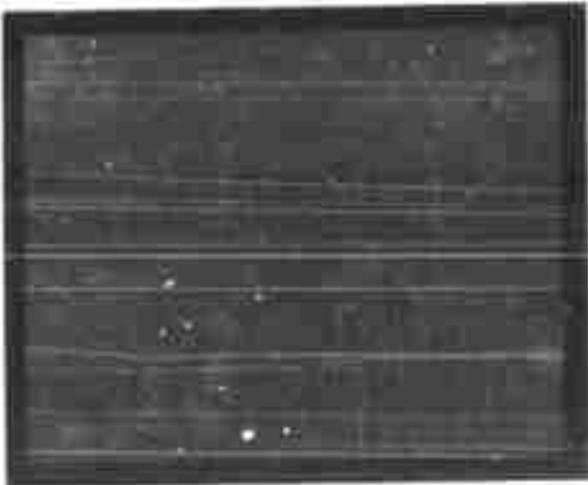
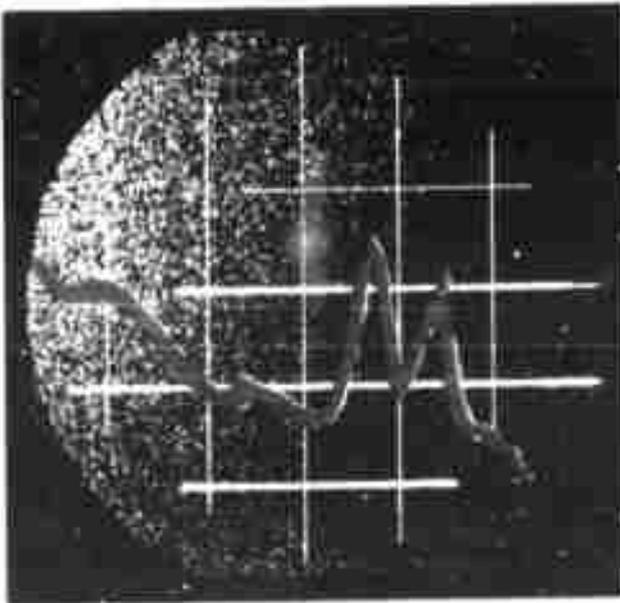
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ACTIVATION ANALYSIS  
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**GAMMA-RAY SPECTRA and SENSITIVITIES**  
**for**  
**14 MeV NEUTRON ACTIVATION ANALYSIS**  
**M. CUYPERS and J. CUYPERS**

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GAMMA RAY SPECTRA AND SENSITIVITIES

For

14 MEV NEUTRON ACTIVATION ANALYSIS,

~~By~~

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M. Cuypers  
J. Cuypers

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12 Apr ~~1966~~ 66

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## TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	
I. SUMMARY TABLE OF DETECTION SENSITIVITIES	
II. INTRODUCTION. . . . .	1
A. Statement of Purpose. . . . .	1
B. Experimental Arrangements . . . . .	3
C. Experimental Procedures . . . . .	7
D. Results . . . . .	11
E. Method of Presentation of Final Results . . . . .	15
F. Elements Producing no Detectable Gamma-Ray Activity. . . . .	17
III. SPECTRA AND SENSITIVITY TABLES	

### List Of Elements

Aluminum	Germanium	Potassium
Antimony	Gold	Praseodymium
Arsenic	Hafnium	Rubidium
Barium	Indium	Ruthenium
Bromine	Iridium	Samarium
Cadmium	Iron	Selenium
Cerium	Lead	Silicon
Cesium	Lutetium	Silver
Chlorine	Magnesium	Sodium
Chromium	Manganese	Strontium
Cobalt	Mercury	Tantalum
Copper	Molybdenum	Terbium
Dysprosium	Neodymium	Tin
Erbium	Nickel	Titanium
Europium	Niobium	Tungsten
Fluorine	Nitrogen	Vanadium
Gadolinium	Palladium	Yttrium
Gallium	Phosphorus	Zinc
		Zirconium

APPENDIX I - The Texas Convention on the Measurement of 14 Mev  
Neutron Fluxes from Accelerators

TABLE OF CONTENTS - (Cont'd.)

APPENDIX II - Counting Recommendations for the Measurement of  
14 Mev Neutron Flux from Accelerators

APPENDIX III - Elements Producing Positron Emitters

APPENDIX IV - Elements Emitting High Energy Gamma Rays: Oxygen,  
Fluorine, Boron

I. SUMMARY TABLE OF DETECTION SENSITIVITIES

SUMMARY TABLE OF DETECTION LIMITS FOR 14 m.e.v. NEUTRON ACTIVATION ANALYSIS

NEUTRON FLUX =  $2 \times 10^8$  n/cm<sup>2</sup>/sec.

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
Aluminum	Mg <sup>27</sup>	9.5 m	0.84	5 m	1 m	5 m	1145	0.14
	Mg <sup>27</sup>	9.5 m	1.01	5 m	1 m	5 m	364	0.35
	Na <sup>24</sup>	15 h	1.37	5 m	1 m	5 m	18	5.1
	Na <sup>24</sup>	15 h	2.75	5 m	1 m	5 m	9	4.3
Antimony	Sb <sup>120</sup>	15.9 m	0.51	5 m	1 m	5 m	950	0.17
Arsenic	Ge <sup>75m</sup>	49 s	0.14	2.4 m	49 s	2.4 m	45	4.6
Barium	Ba <sup>137m</sup>	2.6 m	0.662	5 m	1 m	5 m	5209	0.09
Boron	Be <sup>11</sup>	13.6 s	2.12	40.8 s	13.6 s	40.8 s	29	
Bromine	Br <sup>79m</sup>	4.8 s	0.21	15 s	5 s	15 s	106	1.0
	Br <sup>78</sup>	6.5 m	0.51	5 m	1 m	5 m	3327	0.05
	Br <sup>78</sup>	6.5 m	0.62	5 m	1 m	5 m	310	0.50
	Cd <sup>111m</sup>	49 m	0.15	5 m	1 m	5 m	107	1.2
Cadmium	Cd <sup>111m</sup>	49 m	0.25	5 m	1 m	5 m	363	0.39
Cerium	Ce <sup>139m</sup>	55 s	0.74	2.75 m	55 s	2.75 m	1320	0.11
Cesium	Cs <sup>132</sup>	6.58d	0.67	5 m	1 m	5 m	13	8.5
Chlorine	Cl <sup>34m</sup>	32 m	0.14	5 m	1 m	5 m	30	4.1
	Cl <sup>34m</sup>	32 m	0.51	5 m	1 m	5 m	8	21

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
Chromium	V <sup>52</sup>	3.77 m	1.43	5 m	l	5 m	710	0.21
Cobalt	Mn <sup>56</sup>	2.58 h	0.845	5 m	l	5 m	28	4.3
	Co <sup>58</sup>	71 d		0.81				
Copper	Cu <sup>62</sup>	9.9 m	0.51	5 m	l	5 m	3273	0.05
Dysprosium	Dy x-ray		0.05	3.75 m	75 s	3.75 m	1390	0.10
	Dy <sup>165m</sup>	75.4 s	0.108	3.75 m	75 s	3.75 m	388	0.25
Fluorine	O <sup>19</sup>	29 s	0.20	1.5 m	29 s	1.5 m	375	0.96
	O <sup>19</sup>	29 s	0.20	5 m	l	5 m	266	1.4
Erbium	F <sup>18</sup>	110 m	0.51	5 m	l	5 m	340	0.68
	N <sup>16</sup>	7.35 s	6.13	22 s	7.3 s	22 s	38	
Europium	Er <sup>167m</sup>	2.5 s	0.208	7.5 s	2.5 s	7.5 s	8	4 - 1.7
	Eu <sup>152m</sup>	96 m	0.09	5 m	l	5 m	32	2.9
Gadolinium	Pm <sup>150</sup>	2.7 h	0.33	5 m	l	5 m	6	18.0
	Gd <sup>161</sup>	3.7 m	0.36	5 m	l	5 m	12	14
Gallium	Gd <sup>159</sup>	18 h						
	Ga <sup>68</sup>	68 m	0.51	5 m	l	5 m	917	0.18

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
Germanium	Ge <sup>75m</sup>	49 s	0.14	2.4 m	49 s	2.4 m	198	0.38
	Ge <sup>75m</sup>	49 s	0.14	5 m	1 m	5 m	294	0.46
	Ge <sup>75</sup>	82 m	0.27	5 m	1 m	5 m	34	3.4
	Ga <sup>74</sup>	8 m	0.60	5 m	1 m	5 m	34	5.8
Gold	Au <sup>196</sup>	6.2 d	0.356 + 0.331	5 m	1 m	5 m	16	7.0
	Au <sup>196</sup>	6.2 d	0.43	5 m	1 m	5 m	7	19
Hafnium	Au <sup>197m</sup>	7.2 s	0.279	21.6 s	7.2 s	21.6 s	60	0.60
	Hf <sup>179m</sup>	19 s	0.217	57 s	19 s	57 s	171	1.0
	Yb <sup>176m</sup>	12 s	0.29	57 s	19 s	57 s	20	6.9
Indium	In <sup>116m</sup>	54 m	0.137	5 m	1 m	5 m	71	2.0
	In <sup>116m</sup>	54 m	0.406	5 m	1 m	5 m	250	0.30
	In <sup>116m</sup>	54 m	1.08	5 m	1 m	5 m	240	7.41
	In <sup>116m</sup>	54 m	1.27	5 m	1 m	5 m	252	0.40
Iron	Mn <sup>56</sup>	2.58 h	0.845	5 m	1 m	5 m	86	1.3
Iridium	Ir x-ray		0.065	15 s	4.9 s	15 s	5	14
	Ir x-ray	3.2 h	0.063	5 m	1 m	5 m	15	10
	Ir <sup>191m</sup>	4.9 s	0.129	15 s	4.9 s	15 s	2	18

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mq)
Lead	Pb x-ray		0.075	18.3 s	6.1 s	18.3 s	0.4	49 - 25
	Pb <sup>203m</sup>	6.1 s	0.83	18.3 s	6.1 s	18.3 s	1	22 - 12
	Pb <sup>207m</sup>	0.8 s	0.57	2.4 s	0.8 s	2.4 s	5	7.8 - 3.5
	Pb <sup>207m</sup>	0.8 s	1.06	2.4 s	0.8 s	2.4 s	3	7.5 - 5.0
Lutetium	Pb x-ray		0.075	5 m	1 m	5 m	1.8	132
	Pb <sup>203</sup>	52 h	0.28	5 m	1 m	5 m	0.5	217
	Lu x-ray		0.055	5 m	1 m	5 m	13	7.5
Magnesium	Lu <sup>176m</sup>	3.7 h	0.088	5 m	1 m	5 m	5	14.5
	Ne <sup>23</sup>	38 s	0.44	1.9 m	38 s	1.9 s	39	4.5
	Mg <sup>23</sup>	12 s	0.44					
	Na <sup>25</sup>	60 s	0.40					
Mg <sup>23</sup>	12 s	0.44	36 s	12 s	36 s	15	3.4	
Ne <sup>23</sup>	38 s	0.44						
Na <sup>25</sup>	60 s	0.98	3 m	1 m	3 m	16	8.3	
Na <sup>25</sup>	60 s	0.58	3 m	1 m	3 m	10	15	
Na <sup>24</sup>	15 h	1.37	3 m	1 m	3 m	12	10	
Na <sup>24</sup>	15 h	1.37	5 m	1 m	5 m	33	3.6	

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
Manganese	Mn <sup>56</sup>	2.56 h	0.84	5 m	1 m	5 m	208	3.8
	V <sup>52</sup>	3.77 m	1.43	5 m	1 m	5 m	35	0.49
Mercury	Hg x-ray		0.075	5 m	1 m	5 m	224	0.43
	Hg <sup>199m</sup>	44 m	0.158	5 m	1 m	5 m	210	0.46
	Hg <sup>199m</sup>	40 m	0.24	5 m	1 m	5 m	38	2.5
	Hg <sup>199m</sup>	44 m	0.37	5 m	1 m	5 m	30	3.8
Molybdenum	Mo <sup>91</sup>	15.5 m	0.51	5 m	1 m	5 m	161	1.0
Neodymium	Ce <sup>139m</sup>	55 s	0.76	3 m	1 m	3 m	375	0.32
	Nd <sup>141m</sup>	64 s	0.74					
Niobium	Y <sup>90m</sup>	3.2 h	0.20	5 m	1 m	5 m	7	18
Nickel	Ni <sup>57</sup>	36 h	0.51	5 m	1 m	5 m	320	0.52
Nitrogen	N <sup>13</sup>	9.96 m	0.51	5 m	1 m	5 m	350	0.47
Oxygen	N <sup>16</sup>	7.3 s	6.13	22 s	7.3 s	22 s	91	
Palladium	Pd <sup>109m</sup>	4.8 m	0.18					
	Ru <sup>107</sup>	4.2 m	0.19	1.2 m	22 s	1.2 m	308	0.54
	Pd <sup>107m</sup>	22 s	0.22					
	Pd <sup>109m</sup>	4.8 m	0.18					
	Ru <sup>107</sup>	4.2 m	0.19	5 m	1 m	5 m	732	0.40

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
Praseodymium	Pr <sup>140</sup>	3.4 m	0.51	5 m	1 m	5 m	5400	0.03
Phosphorus	P <sup>30</sup>	2.5 m	0.51	5 m	1 m	5 m	179	0.92
Potassium	K <sup>38</sup>	7.7 m	0.51	5 m	1 m	5 m	48	3.4
Rubidium	Rb <sup>84m</sup>	20 m	0.46	3 m	1 m	3 m	458	0.33
	Rb <sup>86m</sup>	1 m	0.56	3 m	1 m	3 m	490	0.29
	Rb <sup>84m</sup>	20 m	0.22 + 0.24	5 m	1 m	5 m	2000	0.11
	Rb <sup>84m</sup>	20 m	0.46	5 m	1 m	5 m	1490	0.12
	Rb <sup>86m</sup>	1 m	0.56	5 m	1 m	5 m	635	0.21
Ruthenium	Tc <sup>101</sup>	14 m	0.31 + 0.34	5 m	1 m	5 m	77	1.4
	Tc <sup>104</sup>	18 m						
	Ru <sup>95</sup>	99 m	0.75	3 m	1 m	3 m	43	2.3
Samarium	Nd <sup>141m</sup> +Sm <sup>143m</sup>	64s+1m						
	Nd <sup>141m</sup> +Sm <sup>143m</sup>	64s+1m	0.75	5 m	1 m	5 m	51	2.2
	Sm <sup>143</sup>	9 m	0.51	5 m	1 m	5 m	80	2.1
Selenium	Se <sup>77m</sup>	18 s	0.16	57 s	19 s	57 s	261	0.44
	Se <sup>77m</sup>	18 s	0.16	5 m	1 m	5 m	56	1.7
	Se <sup>79m</sup> +Se <sup>81m</sup>	3.9m+57m	0.10	5 m	1 m	5 m	496	0.24

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
Silicon	Al <sup>28</sup>	2.30 m	1.78	5 m	1 m	5 m	2360	0.07
Silver	Ag <sup>109m</sup>	40 s	0.088	2.2 m	44 s	2.2 m	146	2.2
	Ag <sup>107m</sup>	44 s						
Sodium	Ag x-ray		0.021	2.2 m	44 s	2.2 m	316	0.40
	Ag <sup>106</sup>	24 m	0.51	5 m	1 m	5 m	2127	0.08
	Ne <sup>23</sup>	38 s	0.44	1.9 m	38 s	1.9 m	200	0.37
	Ne <sup>23</sup>	38 s	0.44	33 s	11 s	33 s	75	0.50
	F <sup>20</sup>	11 s	1.63	33 s	11 s	33 s	93	0.25
Strontium	Sr <sup>85m</sup>	70 m	0.23	5 m	1 m	5 m	63	1.8
	Sr <sup>87m</sup>	2.8 h	0.39	5 m	1 m	5 m	198	0.80
Tantalum	Ta x-ray		0.06	5 m	1 m	5 m	165	0.48
Terbium	Te x-ray		0.044	33 s	11 s	33 s	123	0.93
Tin	Sn <sup>123</sup>	40 m	0.153	5 m	1 m	5 m	173	0.69
Titanium	Se <sup>46m</sup>	20 s	0.14	1 m	20 s	1 m	17	2.5
	Se <sup>46m</sup>	20 s	0.14	5 m	1 m	5 m	7	18
	Se <sup>50</sup>	1.8 m	0.52	5 m	1 m	5 m	9	18
	Se <sup>49</sup>	57.5 m	1.76	5 m	1 m	5 m	8	7.1

SUMMARY TABLE (Cont'd.)

ELEMENT	RADIOISOTOPE PRODUCED	HALF LIFE	GAMMA RAY ENERGY (m.e.v.)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/Mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
Tungsten	W x-ray		0.059	15.9 s	5.3 s	15.9 s	29	3.0 - 1.3
	W <sup>183m</sup>	5.3 s	0.11	15.9 s	5.3 s	15.9 s	2.5	15 - 8.0
	W <sup>185m</sup>	1.7 m	0.13					
	W <sup>183m</sup>	5.3 s	0.16	15.9 s	5.3 s	15.9 s	2	27 - 13
Vanadium	W x-ray		0.059	5 m	1 m	5 m	38	4.2
	W <sup>185m</sup>	1.7 m	0.175	5 m	1 m	5 m	15	9.3
	W <sup>185m</sup>	1.7 m	0.13	5 m	1 m	5 m	12	15
	Ti <sup>51</sup>	5.8 m	0.32	5 m	1 m	5 m	1150	0.14
	V <sup>52</sup>	3.77 m	1.43	5 m	1 m	5 m	144	0.70
Yttrium	Y <sup>89m</sup>	16 s	0.91	48 s	16 s	48 s	314	0.58
	Zn <sup>63</sup>	38 m	0.51	5 m	1 m	5 m	212	0.77
Zirconium	Zr <sup>89m</sup>	4.2 m	0.59	48 s	16 s	48 s	32	2.9
	Zr <sup>89m</sup>	4.2 m	0.59	5 m	1 m	5 m	645	0.25
	Y <sup>89m</sup>	16 s	0.91	48 s	16 s	48 s	15	2.9

II. INTRODUCTION

## INTRODUCTION

In recent years, the small Cockcroft-Walton and Van de Graaff accelerators, producing 14 Mev neutrons, have become more than a research tool. In many laboratories, these neutron generators are used to perform a large number of routine analyses based on 14 Mev neutron activation. The number of elements determined, however, has been somewhat limited. The technique of 14 Mev neutron activation has often been chosen because of its speed and in some cases for its sensitivities which may be between 50  $\mu\text{g}$  and 1000  $\mu\text{g}$  for most of the elements.

In order to predict the sensitivity for the determination of an element, several compilations have been published. Gillepsie and Hill<sup>1</sup> published a compilation of detection limits, for the different elements, based on theoretical calculations of the minimum amount of element required to produce 100 dpm. Kusaka et al<sup>2</sup> have compiled the gamma-ray spectra for 39 elements. However, the detection limits have not been calculated in that work.

Since the detection limit of a radioisotope depends on the region of the spectrum in which its emitted gamma ray is located, owing to differences in background at different energies, the ultimate sensitivity or detection limit should be evaluated as a function of the background.

The present study has been conducted mainly to determine experimentally the detection limits for elements under specified experimental conditions. This work has been instigated by the fact that the limits published by several authors for several elements have very often been found to be unrealistic for analytical purposes.

Two main factors have dictated the experimental conditions reported in this catalogue. The first is that the number of analyses to be performed is large. This means that the irradiation and counting time is limited. For long irradiation times (20 min.) it is suggested that reference be made to the work of Aude and Laverlochere<sup>3</sup>.

The second factor is that the highest sensitivity must be reached. For this reason, optimum conditions for irradiation, decay and counting time have been chosen. Also two 3" x 3" NaI(Tl) crystals were used to enhance the detection efficiency. The experimental data has not been taken at maximum output of the neutron generator, because of the limited life time of the tritium targets. These results can, however, easily be extrapolated for a higher flux.

Most attention has been given to the analytically useful photopeaks in the gamma-ray spectrum. For a more complete study of all the radioisotopes formed with 14 Mev neutron

activation and the evaluation of the cross sections for the nuclear reactions, reference should be made to the work of Strain and Ross<sup>4</sup>.

This catalogue is intended to serve as a basis to enable the experimenter to evaluate the type of spectrum and the activity to be expected from a particular element and from the matrix in which it is present. From this indication, the feasibility of an analysis can be evaluated.

#### EXPERIMENTAL ARRANGEMENTS

(1) Neutron Source: A 150 kv Cockcroft-Walton accelerator (Texas Nuclear Corporation) was used. The neutron flux was obtained by bombarding a target of tritiated zirconium (diameter 3.2 cm) with a deuteron beam of 100 - 500 $\mu$ A. The  $H_1^3(H_1^2, n_0^1)He_2^4$  reaction produced the 14 Mev neutrons used to irradiate the different elements. A thin tritium target holder was designed and the back of the tritium target was cooled with water.

(2) Sample Transfer System: Figure 1 shows the irradiation, transfer and counting system used. The samples were introduced at the counting station in a polyethylene pneumatic tube and transferred to the irradiation station using a vacuum cleaner. The distance between these two stations was approximately 28 m. When the sample passed in front of the photo-

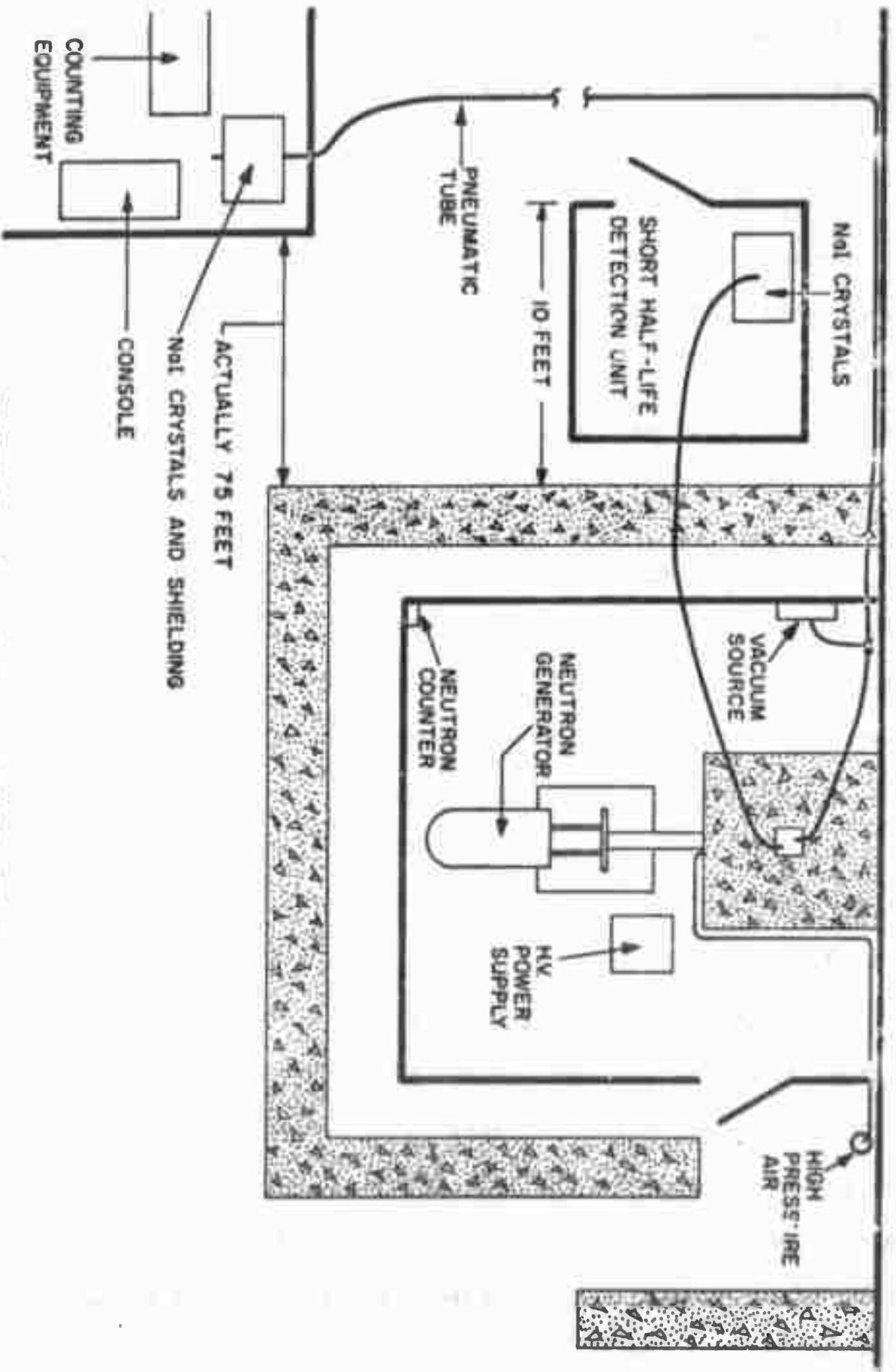


FIGURE 1. Acetylene Isotope Analysis System

electric cell located close to the target, the production of neutrons started. The pneumatic tube was positioned against the back of the target holder, so that the distance from the middle of the sample container to the target was 1.65 cm.

After a preset irradiation time, the beam was automatically switched off and the sample was transferred back to the counting station using compressed air (140 lbs/in<sup>2</sup>). The average transfer time of the sample was 4 seconds.

To study the radioisotopes with half lives shorter than 5 seconds, a different pneumatic system was used. In this case, the distance between the irradiation and the counting station was only 6.75 m, and the transfer path was virtually linear. The average transfer time in this system was 100 milliseconds.

(3) Counting Equipment: (a) Gamma-ray detectors. The gamma-rays from the radioisotopes produced were detected by two matched 3" x 3" NaI(Tl) crystals (Harshaw). After transfer from the irradiation station, the sample was positioned between the two crystals which were 2.4 cm apart.

Between each crystal and the sample, a sheet of lucite 0.75 cm thick was interposed to limit the interference of  $\beta^-$  radiation.

The detectors were connected to a 400-channel pulse

height analyzer (RIDL). The resolution of the detectors for the 0.662 Mev photopeak of Cs<sup>137</sup> was 9.0%.

(b) Neutron detectors. Two neutron detection systems were used: (1) A B<sup>10</sup>F<sub>3</sub> counter (N. Wood G10-5) enveloped in 4 cm of paraffine and located at 4.25 m from the target was connected to a counting scaler and gave the relative flux integrated over the irradiation time. (2) An ionization chamber (Anton type 813) enveloped in 4 cm of paraffine was located inside of the accelerator shielding (65 cm from the target). The latter neutron detector is connected to a micromicroammeter (Keithley), and enabled an average relative flux reading to be obtained at any time during irradiation.

(4) Shielding: The tritium target of the accelerator was located in the middle of a concrete castle. The distance from the target to the concrete was never less than 30 cm, in order to keep the thermal neutron production as low as possible. The thickness of the concrete wall was 57 cm.

The accelerator and its immediate shielding were located in a room constructed with 58 cm thick concrete walls.

The gamma-ray detectors were surrounded by a lead castle lined with a graded shield of cadmium and copper. The dimension

of the castle is 60 cm x 82 cm x 53 cm and the thickness of the lead is 5.2 cm.

#### EXPERIMENTAL PROCEDURES

(1) Sample Preparation: The samples were all packed in cylindrical polyethylene vials (2.4 cm long, 0.8 cm inner diameter with an 0.125 cm wall thickness) which were heat-sealed.

The samples were irradiated either in the elemental form, as in the case of the metals, or in the form of oxides, nitrates, or sulfates. On each spectrum given in the second part of this catalogue, the composition of the irradiated element is given.

(2) Irradiation, Decay And Counting Time: The radioisotopes formed after irradiation of the different elements in the flux of 14 Mev neutrons may be classified in two groups:

- (a) radioisotopes with a half life shorter than one minute
- (b) radioisotopes with a half life longer than one minute

Activation time - three half lives of the particular radioisotope under consideration. This irradiation time provided approximately 86% of the activity at saturation. For longer irradiation times, the rate of increase of the induced activity becomes smaller.

Waiting time - one half life of the produced radioisotopes.

The highest sensitivity would have been obtained by counting the sample as soon as possible after irradiation. The imposed waiting time of one half life permitted the determination of the sensitivities of the different elements under equivalent conditions from the point of view of the nuclear properties.

Counting time - three half lives of the produced radioisotopes. An increase in total count of only 7% would have been obtained by counting for four half lives. In addition the probability of accumulating more noise than signal becomes greater.

For the second group of radioisotopes, those with half lives longer than one minute, the activation time was standardized to five minutes, waiting time to one minute, and counting time to five minutes. These somewhat arbitrarily chosen conditions may be justified for the following reasons:

(a) The tritium targets possess a limited life time. Much longer irradiation times are not practical since the number of samples which can be irradiated with one target becomes smaller. In addition the time of analysis becomes prohibitively long if a large number of samples have to be run.

(b) One minute waiting time permits the decay of the shorter lived radioisotopes.

It should be noted that if more than one isotope was obtained by irradiating a particular element, the above procedure was carried out for each radioisotope.

(3) Neutron Flux Measurement: The scaler reading on the  $B^{10}F_3$  counter was related to the specific activity of copper discs taped against the target and thus to the neutron flux, using the Texas Convention criteria. These criteria were devised and defined in April, 1965 at the Second Conference on "Modern Trends in Activation Analysis". A complete description of the Texas Convention is given in Appendix I.

Under the irradiation conditions used, the ratio of specific activity obtained from the small copper discs (diameter 1 cm) to that from the large discs (diameter 5 cm) is 0.52.

In the second part of this work, the flux (T.C.) calculated using the small copper disc taped against the target is given on each spectrum. This size of disc was chosen because the vial has a height comparable to the diameter of the small disc.

Knowing the absolute number of counts at 0.51 Mev obtained from  $Cu^{62}$  following the Texas Convention, the absolute neutron dose (F) was easily determined for a particular disc.

Instead of calculating the activity for a decay time of one minute, this was calculated for a decay time equal to zero. The obtained value is divided by the area of the disc giving the activity/cm<sup>2</sup>/min (A). The flux F is then calculated from equation (1).

$$F = \frac{A}{\sigma n k (1-e^{-0.693t/T}) \times 60} \dots \dots (1)$$

where

$\sigma$  = cross section for the Cu<sup>63</sup>(n,2n)Cu<sup>62</sup> reaction = 0.55 barns

$n$  = number of atoms/cm<sup>2</sup> =  $\frac{6.02 \times 10^{23} \times w}{63.5}$

(w being the number of grams of copper per cm<sup>2</sup> in the copper disc)

$k$  = isotopic abundance of Cu<sup>63</sup> = 0.69

$t$  = irradiation time = 1 min

$T$  = half life of Cu<sup>62</sup> = 9.9 min

The factor  $\frac{1}{\sigma n k (1-e^{-0.693t/T}) \times 60} = 2 \times 10^2$

in these conditions:

The flux, F, obtained here, even when calculated from a disc of area 0.785 cm<sup>2</sup>, can be considered as very close to the absolute neutron flux (n/sec/cm<sup>2</sup>).

All the irradiations were performed with fluxes (T.C.) between  $3.9 \times 10^6$  to  $8.6 \times 10^6$  c/min/gm Cu, measured against

the tritium target holder, corresponding to an absolute neutron dose of  $2.9 \times 10^8$  to  $6.5 \times 10^8$  n/sec/cm<sup>2</sup>. A four times higher flux could have been obtained easily with the 14 Mev neutron generator. The life time of the target in these conditions, however, was reduced by half.

## RESULTS

(1) Calculation of Activity Under Photopeak: The area under the photopeaks was determined by drawing the base line across the bottom of the peak, and summing the counts between the photopeak and this base line.

A computer program was written by D. W. Berry to calculate the photopeak areas and normalize the data to the same neutron flux conditions.

No attempt has been made to make an absolute photopeak area determination using the method of Heath<sup>5</sup>, but the base line has always been determined using the same criteria being finally very close to that obtained with the method of Heath.

(2) Normalization Of The Data: To compare the spectra obtained from the different elements, a normalization of the data was necessary.

(a) All the photopeak counts were normalized to a neutron scaler reading equivalent to 200,000 counts/min corresponding to a flux (T.C.) of  $5.3 \times 10^6$  counts/min/gm Cu or

an absolute neutron dose of  $4.0 \times 10^8$  n/sec/cm<sup>2</sup> against the tritium target. This is a normalization to the neutron output of the accelerator.

(b) Because it was found that reproducible positioning of the samples relative to the target was difficult, each time the accelerator was moved, a second normalization appeared to be necessary. Every day four solutions of copper nitrate, each containing 128 mg of copper, were irradiated for one minute and counted for one minute, after a one minute decay time. The percent standard deviation for these four copper solutions was 4 to 5%. No variation in activity during a one-day period was observed. All the photopeak counts of the different elements were normalized to a copper solution photopeak activity of 13,000 counts/min.

This last procedure is thus a normalization for neutron dose on the sample. The following equation expresses both these normalizations:

$$A_n = \frac{A_r \times F_n \times t_{act}}{F_r} \times \frac{Cu_n}{Cu_r} \dots \dots \dots (2)$$

where

$A_n$  = normalized photopeak counts

$A_r$  = experimentally obtained photopeak counts

$F_n$  = Normalized neutron scaler reading ( $2 \times 10^5$  counts/min)

$F_r$  = experimental neutron scaler reading

$t_{act}$  = activation time

$Cu_n$  = normalized copper solution activity (13,000 counts/min)

$Cu_r$  = experimentally obtained activity for copper solution

(3) Calculation Of The Sensitivities: To estimate the sensitivity of determination of an element using a particular gamma-ray peak in the spectrum, decreasing amounts of the element were irradiated under similar conditions. After normalization of the activities a calibration curve expressing the photopeak activity as a function of the weight in mg was drawn. The slope of this curve gave the number of photopeak counts per milligram of the element. The intercept with the activation axis also provided the information on the residual photopeak activity due to trace elements in the vial and the effect of background activity.

This last point is of great importance especially when the sensitivity of an element producing a 0.51 Mev photopeak has to be determined. An empty polyethylene vial indeed produced, after irradiation, an activity at 0.51 Mev which decayed with a half life of 10 minutes. This was probably due to  $N^{13}$  which can be produced by collision of 14 Mev neutrons with hydrogen atoms in the vial. These high energy protons interact with the carbon of the vial and give the  $C^{13}(p,n)N^{13}$  reaction.

(4) Calculation Of The Detection Limits: The limit of sensitivity for the detection of a photopeak in a spectrum is highly dependent upon the region of the spectrum in which the photopeak is located and the matrix activity in that region. From 0 to 0.25 Mev, the natural background activity in the spectrum is much greater than in higher energy regions. To express this limit of sensitivity of an element, taking into consideration these facts, the following calculations were made:

- (a) The total counts in the photopeak region were summed.
- (b) The background in the photopeak region was determined using the base line method.
- (c) The value of three times the square root of the counts in this background were calculated. (Three time the standard deviation)
- (d) The limit of sensitivity was considered to have been reached when the photopeak counts equals to three sigma of the background count.

The justification for using this three sigma criterion is as follows: With 99% confidence, the number of counts due to background lies within the range bounded by the estimated means value plus or minus three times the calculated standard deviation of the mean value.

In practice it is more realistic to say that when the photopeak counts equal a value of six sigma of the background, a semi-quantitative analysis can be performed. For the three

sigma criterion the matrix activity has to be known very accurately, leaving even then some doubt about the presence of the element looked for.

#### METHOD OF PRESENTATION OF FINAL RESULTS

In the second part of this work, elements are presented and their behavior in a 14 Mev Neutron flux is explained. The elements are discussed in alphabetical order. Four tables are given for each element.

Table I - This table lists all the nuclear reactions which can be obtained from the element studied. Only  $(n,p)$ ,  $(n,\alpha)$ ,  $(n,2n)$  and  $(n,n')$  reactions have been considered. In a few cases  $(n,\gamma)$ ,  $(n,n'p)$  and  $(n,n'\alpha)$  reactions were observed. The compilation of this nuclear data has been made using the "Chart of Nuclides"<sup>6</sup> (Knolls Atomic Power Laboratory).

Table II - This table explains the experimentally obtained photopeaks given in the figure supplied for each element. Optimum irradiation, waiting and counting conditions have been chosen to produce the different nuclear reactions. When no detectable activity was observed, it has been noted in a remark following Table II. In a few cases the energies observed in the spectrum did not correspond to the energies given in the "Chart of Nuclides". It was often referred to data in ref (5) and (7).

Every time a photopeak was observed, a decay curve was made to check its origin. On each figure, the activation, waiting and counting times are given together with the composition of the compound irradiated and the flux (Texas Convention). All the spectra have been normalized to the activity produced by 1 gram of the element studied.

Table III - This table shows the sensitivities for the determination of the element based on the evaluation of the slope of the calibration curves of the photopeak area at a certain peak. The irradiation, waiting and counting conditions are given and the sensitivity is expressed in counts/milligram of the studied element during count time. The detection limit has been calculated as previously explained in the "RESULTS" section.

Table IV - This last table contains the observed interfering nuclear reactions for the photopeaks on which sensitivity calculations were based.

An interfering nuclear reaction is defined as:

- (1) One which produces the same radioisotope as is produced by the studied element, or
- (2) One which produces a radioisotope omitting gamma photons of the same energy and also having approximately the same half-life as the radioisotope produced by the studied element.

ELEMENTS PRODUCING NO DETECTABLE GAMMA-RAY ACTIVITY

For a certain number of elements, either no characteristic peaks were observed, or the activity for 300 milligrams of the element was too low to perform a good quantitative analysis.

In general, only the activity due to the vial was observed. The investigated elements are: calcium, bismuth, sulphur, holmium, thulium.

REMARKS

(1) Several elements having a high cross section for thermal neutrons produce an appreciable activity when irradiated in the 14 Mev neutrons flux. A thermalization of the neutrons can always be expected due to the low Z element present in the vial, pneumatic tube, sample itself and cooling water.

The reactions observed are listed in Table I.

(2) Only one  $(n,n'p)$  and one  $(n,n'\alpha)$  reaction was observed in this study:  $Zr^{90}(n,n'p)Y^{89m}$ ,  $Nb^{93}(n,n'\alpha)Y^{89m}$ .

(3) The activity due to an empty vial gives no photo-peaks in the spectrum. The half life of the produced radioisotope is 10 minutes and has been assigned to Nitrogen-13. Figure 2 shows a typical gamma-ray spectrum of an empty vial. The activity at an energy of 0.51 Mev for 5 minutes activation time, one minute waiting time and 5 minutes counting time

Table I  
Observed (n, γ) Reactions

Nuclear Reactions	Gamma Ray Energy (Mev)	Nuclear Reactions	Gamma Ray Energy (Mev)
$Al^{27}(n, \gamma)Al^{28}$	1.78	$Dy^{164}(n, \gamma)Dy^{165m}$	0.108, 0.51, 0.36, 0.15
$Mn^{55}(n, \gamma)Mn^{56}$	0.84	$In^{115}(n, \gamma)In^{116m}$	0.406, 0.137, 1.08, 1.27 0.81, 1.49, 1.77
$V^{51}(n, \gamma)V^{52}$	1.43	$Gd^{160}(n, \gamma)Gd^{161}$	0.044, 0.102, 0.165, 0.18 0.316, 0.363
$Sn^{122}(n, \gamma)Sn^{123}$	0.16	$Co^{59}(n, \gamma)Co^{60m}$	1.33

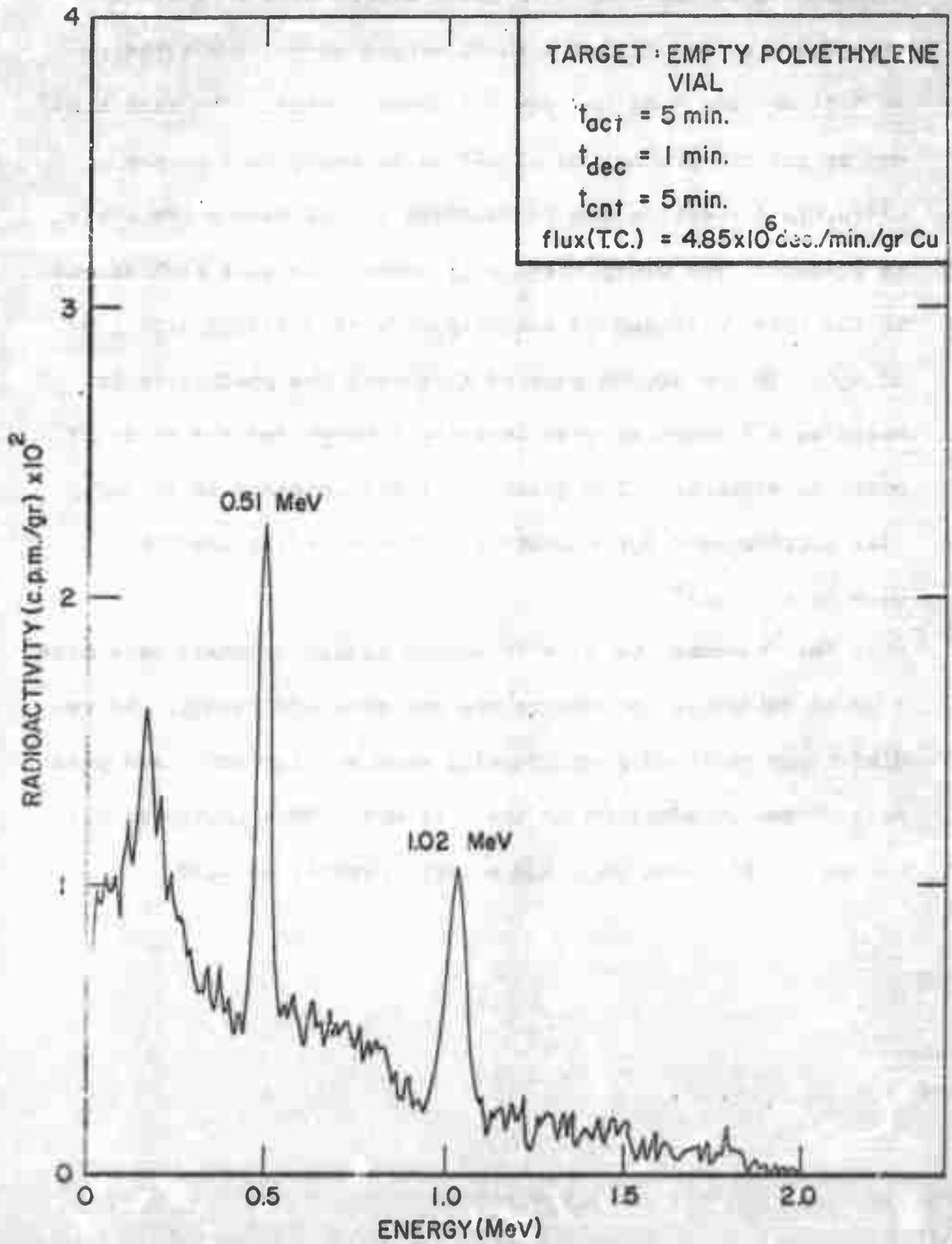


FIGURE 2

corresponds to 780 counts in our standard flux conditions. When the vial was filled with deionized water, the activity at 0.51 Mev and 1.02 Mev was 3.5 times higher. The same theory as for the production of  $N^{13}$  in an empty vial by the  $Cl^{35}(p,n)N^{13}$  reaction can be extended to the case where oxygen is present. The  $O^{16}(p,\alpha)N^{13}$  will contribute to a high extent to the total nitrogen-13 activity in a vial filled with 1 ml of  $H_2O$ . In the second part of this work the photopeaks labeled as  $N^{13}$  refer to vial activity (except for the study of nitrogen element). The quantity of  $N^{13}$  obtained in an empty vial corresponded approximately to the activity found by Gilmore and Hull<sup>8</sup>.

(4) Because two 3" x 3" sodium iodide crystals have been used as detectors to enhance the counting efficiency, the radioisotope emitting positron will show a coincidence sum peak at 1.02 Mev in addition to the 0.51 Mev. This photopeak will not be visible when only one NaI(Tl) crystal is used.

III. SPECTRA AND SENSITIVITY TABLES

ALUMINUMTABLE I-A1

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Al <sup>27</sup>	100%	Al <sup>27</sup> (n,p)Mg <sup>27</sup>	9.5 m	0.84, 1.01
		Al <sup>27</sup> (n,α)Na <sup>24m</sup>	0.02 s	IT 0.47
		Al <sup>27</sup> (n,α)Na <sup>24</sup>	15.00 h	2.75, 1.37
		Al <sup>27</sup> (n,2n)Al <sup>26m</sup>	6.5 s	β+
		Al <sup>27</sup> (n,2n)Al <sup>26</sup>	7.4 x 10 <sup>5</sup> y	1.83, 1.12, β+

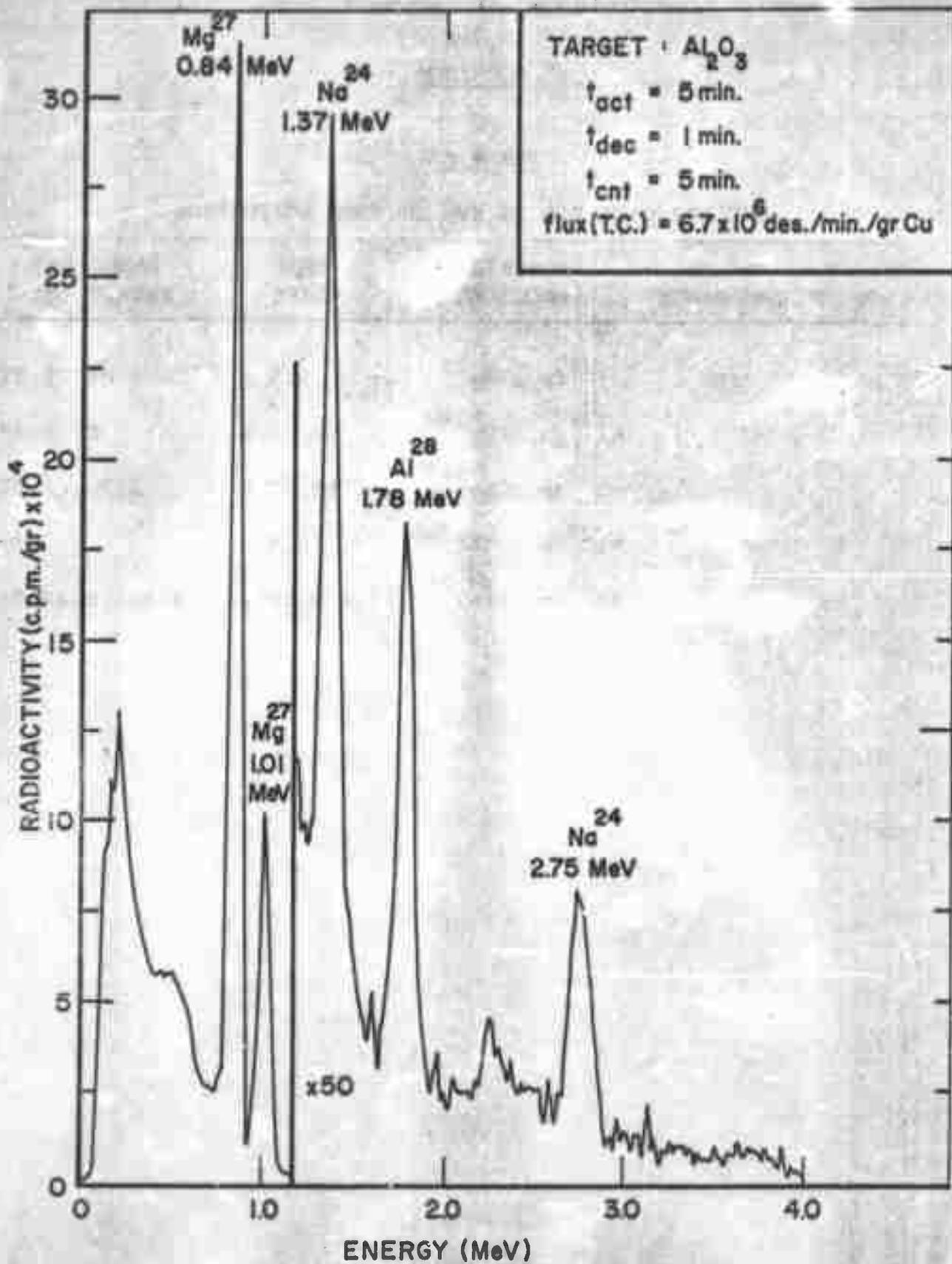


FIGURE I-A1

TABLE II-A1

## PEAKS OBSERVED IN FIGURE I-A1

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-A1	0.84	$\text{Al}^{27} (n, p) \text{Mg}^{27}$	9.5 m	
	1.01	$\text{Al}^{27} (n, p) \text{Mg}^{27}$	9.5 m	
	1.37	$\text{Al}^{27} (n, \alpha) \text{Na}^{24}$	15 h	
	1.78	$\text{Al}^{27} (n, \gamma) \text{Al}^{28}$	2.3 m	
	2.75	$\text{Al}^{27} (n, \alpha) \text{Na}^{24}$	15 h	

NOTE:  $\text{Al}^{26m}$  ( $T_{1/2} = 6.5\text{s}$ ) not detected for 19.5 sec irradiation, 6.5 sec decay and 19.5 sec counting time.

TABLE III-A1

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{\text{act}}$	$T_{\text{dec}}$	$T_{\text{cnt}}$	COUNTS/mg/ $T_{\text{cnt}}$	DETECTION LIMIT (mg)
0.84	5 m	1 m	5 m	1145	0.14
1.01	5 m	1 m	5 m	364	0.35
1.37	5 m	1 m	5 m	18	5.1
2.75	5 m	1 m	5 m	9	4.3

ALUMINUM

TABLE IV-A1

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.84	Silicon	$\text{Si}^{30} (n, \alpha) \text{Mg}^{27}$	very low
1.01	Silicon	$\text{Si}^{30} (n, \alpha) \text{Mg}^{27}$	very low
1.37	Magnesium	$\text{Mg}^{24} (n, p) \text{Na}^{24}$	
2.75	Magnesium	$\text{Mg}^{24} (n, p) \text{Na}^{24}$	

ANTIMONYTABLE I - SbNUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Sb <sup>121</sup>	57.25%	Sb <sup>121</sup> (n,p)Sn <sup>121m</sup>	25 y	0.037
		Sb <sup>121</sup> (n,p)Sn <sup>121</sup>	27 h	
		Sb <sup>121</sup> (n,α)In <sup>118m</sup>	4.4 m	1.22, 1.05, 0.2, 2.0
		Sb <sup>121</sup> (n,α)In <sup>118</sup>	5.1 s	1.22
		Sb <sup>121</sup> (n,2n)Sb <sup>120m</sup>	5.8 d	1.18, 1.03, 0.20, 0.09
		Sb <sup>121</sup> (n,2n)Sb <sup>120</sup>	15.9 m	1.18, β+
		Sb <sup>123</sup>	42.75%	Sb <sup>123</sup> (n,p)Sn <sup>123m</sup>
Sb <sup>123</sup> (n,p)Sn <sup>123</sup>	40 m	0.16		
Sb <sup>123</sup> (n,α)In <sup>120m</sup>	3.2 s	1.18		
Sb <sup>123</sup> (n,α)In <sup>120</sup>	44 s	0.73, 1.18		
Sb <sup>123</sup> (n,2n)Sb <sup>122m</sup>	4.1 m	IT 0.026		
Sb <sup>123</sup> (n,2n)Sb <sup>122m</sup>	530 μs	0.06, IT 0.08		
Sb <sup>123</sup> (n,2n)Sb <sup>122</sup>	2.8 d	0.56, 0.7, 1.1, β+		

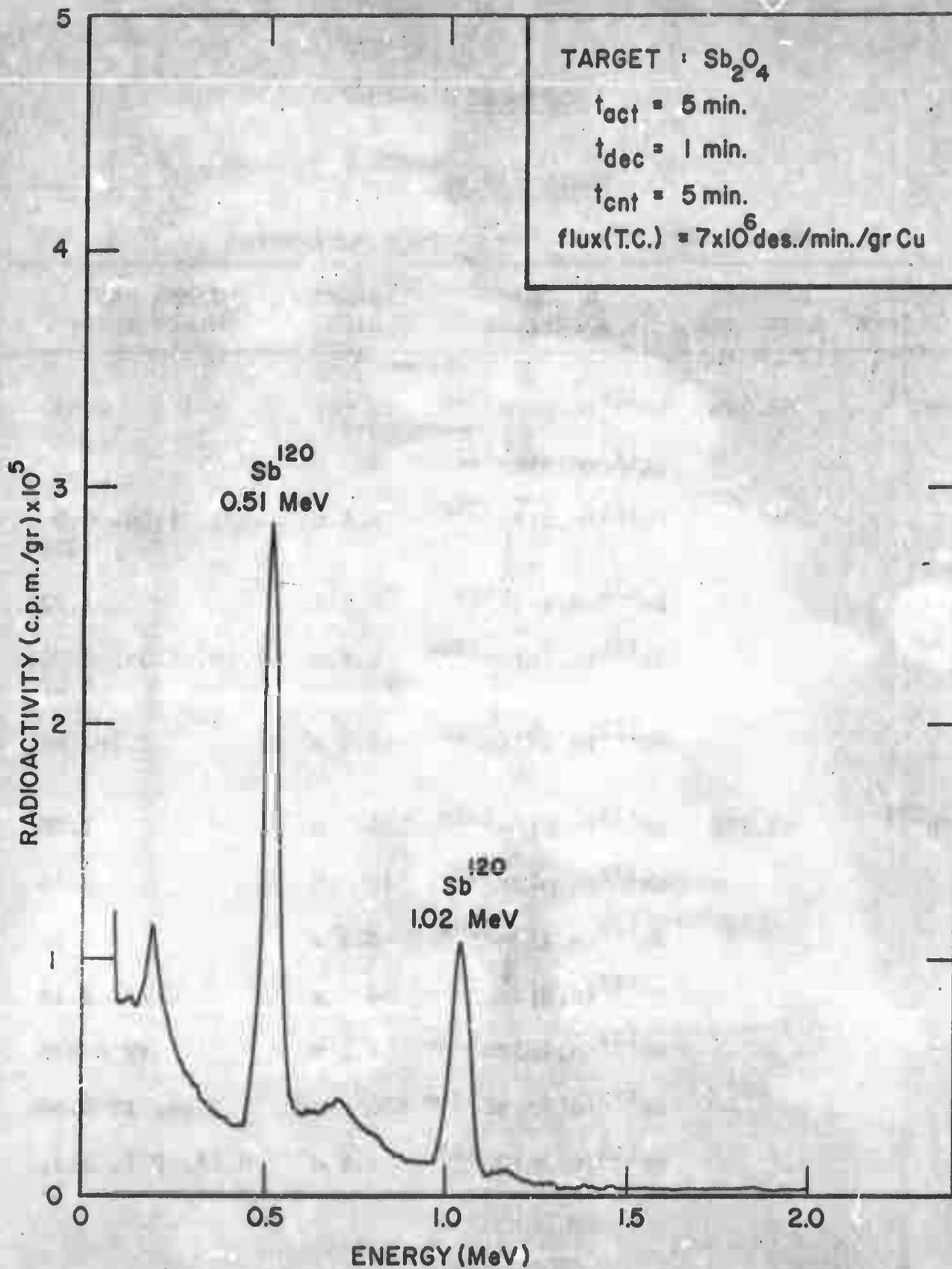


FIGURE I-Sb

TABLE II-Sb

## PEAKS OBSERVED IN FIGURE I-Sb

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Sb	0.51	$Sb^{121}(n, 2n)Sb^{120}$	15.9 m	
	1.02	$Sb^{121}(n, 2n)Sb^{120}$	15.9 m	0.51 Mev coincidence sum peak

NOTE:  $In^{118}$  ( $T_{1/2} = 5.1$  sec) and  $In^{120m}$  ( $T_{1/2} = 3.2$  sec) not detected for 15 sec irradiation, 5 sec decay and 15 sec counting time.

TABLE III-Sb

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{act}$	$T_{dec}$	$T_{cnt}$	COUNTS/mg/ $T_{cnt}$	DETECTION LIMIT(mg)
0.51	5 m	1 m	5 m	950	0.17

TABLE IV-Sb

## POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for antimony from any other element.

For other positron emitting radioisotopes than  $Sb^{120}$  see Section I, Appendix II.

ARSENICTABLE I - As

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
As <sup>75</sup>	100%	As <sup>75</sup> (n,p) Ge <sup>75m</sup>	49 s	IT 0.14
		As <sup>75</sup> (n,p) Ge <sup>75</sup>	82 m	0.27, 0.07, 0.63
		As <sup>75</sup> (n,α) Ga <sup>72m</sup>	0.04s	IT 0.10
		As <sup>75</sup> (n,α) Ga <sup>72</sup>	14.1 h	0.84, 0.69, 0.11, 2.82
		As <sup>75</sup> (n,2n) As <sup>74m</sup>	8 s	IT 0.28
		As <sup>75</sup> (n,2n) As <sup>74</sup>	18 d	0.60, 0.64, 2.53, β+
		As <sup>75</sup> (n,n') As <sup>75m</sup>	0.017s	0.28, IT 0.025, 0.305

TARGET :  $\text{As}_2\text{O}_3$   
 $t_{\text{act}}$  = 2.4 min.  
 $t_{\text{dec}}$  = 49 sec.  
 $t_{\text{cnt}}$  = 2.4 min.  
flux(T.C.) :  $5.6 \times 10^6$  des./min./gr Cu

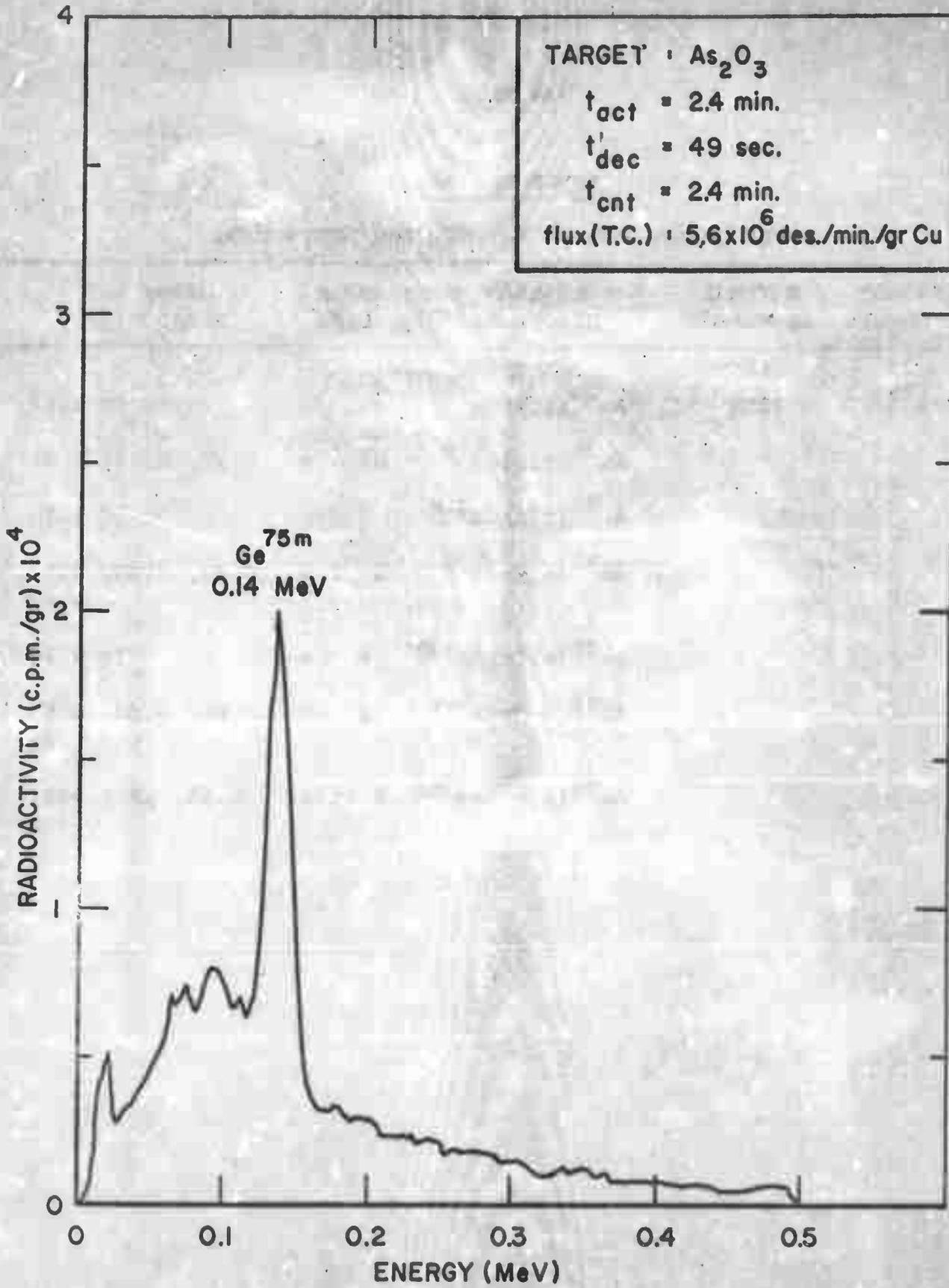


FIGURE I-As

TABLE II-As

## PEAKS OBSERVED IN FIGURE I-As

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-As	0.14	As <sup>75</sup> (n,p) Ge <sup>75m</sup>	49 s	

NOTE: As<sup>74m</sup> ( $T_{1/2} = 8$  sec) not detected for 24 sec irradiation, 8 sec decay and 24 sec counting time. No other radioisotope detectable in a 5 min irradiation.

TABLE III-As

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT(mg)
0.14	2.4 m	49 s	2.4 m	45	4.6

TABLE IV-As

## POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.14	Germanium	Ge <sup>76</sup> (n, 2n) Ge <sup>75m</sup>	

BARIUMTABLE I - Ba

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ba <sup>130</sup>	0.101%	Ba <sup>130</sup> (n,p)Cs <sup>130</sup>	30 m	β+
		Ba <sup>130</sup> (n,α)Xe <sup>127m</sup>	75 s	0.125, IT 0.175
		Ba <sup>130</sup> (n,α)Xe <sup>127</sup>	36.4 d	0.20, 0.17, 0.15, 0.06
		Ba <sup>130</sup> (n,2n)Ba <sup>129m</sup>	2.13h	0.182
		Ba <sup>130</sup> (n,2n)Ba <sup>129</sup>	2.2 h	0.21, 0.22, β+
Ba <sup>132</sup>	0.097%	Ba <sup>132</sup> (n,p)Cs <sup>132</sup>	6.58d	0.67, 0.46, 0.51, 2.0; β+
		Ba <sup>132</sup> (n,α)Xe <sup>129m</sup>	8 d	0.040, IT 0.196
		Ba <sup>132</sup> (n,2n)Ba <sup>131m</sup>	14.6 m	0.107, IT 0.078
		Ba <sup>132</sup> (n,2n)Ba <sup>131</sup>	11.6 d	0.50, 0.122, 0.216, 0.055, 1.03
Ba <sup>134</sup>	2.42%	Ba <sup>134</sup> (n,p)Cs <sup>134m</sup>	2.9 h	0.010, IT 0.13, 0.14
		Ba <sup>134</sup> (n,p)Cs <sup>134</sup>	2.1 y	0.60, 0.80, 0.20, 1.37
		Ba <sup>134</sup> (n,α)Xe <sup>131m</sup>	12 d	IT 0.164
		Ba <sup>134</sup> (n,2n)Ba <sup>133m</sup>	39 h	0.012, IT 0.276
		Ba <sup>134</sup> (n,2n)Ba <sup>133</sup>	7.2 y	0.081, 0.36, 0.30, 0.08, 0.38

BARIUM

TABLE I - Ba (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ba <sup>135</sup>	6.59%	Ba <sup>135</sup> (n,p) Cs <sup>135m</sup>	53 m	0.78, IT 0.84
		Ba <sup>135</sup> (n,p) Cs <sup>135</sup>	2.0 x 10 <sup>6</sup> y	
		Ba <sup>135</sup> (n,n') Ba <sup>135m</sup>	29 h	IT 0.268
		Ba <sup>135</sup> (n,n') Ba <sup>135m</sup>	0.33s	~0.7, ~0.8
Ba <sup>136</sup>	7.81%	Ba <sup>136</sup> (n,p) Cs <sup>136</sup>	13 d	1.04, 0.83, 0.065, 2.5
		Ba <sup>136</sup> (n,α) Xe <sup>133m</sup>	2.3 d	IT 0.233
		Ba <sup>136</sup> (n,α) Xe <sup>133</sup>	5.27d	0.081
		Ba <sup>136</sup> (n,2n) Ba <sup>135m</sup>	29 h	IT 0.268
Ba <sup>136</sup> (n,2n) Ba <sup>135m</sup>	0.33s	~0.7, ~0.8		
Ba <sup>137</sup>	11.32%	Ba <sup>137</sup> (n,p) Cs <sup>137</sup>	30 y	0.662
		Ba <sup>137</sup> (n,n') Ba <sup>137m</sup>	2.6 m	IT 0.662
Ba <sup>138</sup>	71.66%	Ba <sup>138</sup> (n,p) Cs <sup>138</sup>	32.2 m	1.43, 1.0, 0.46, 2.2, 0.11, 3.3
		Ba <sup>138</sup> (n,α) Xe <sup>135m</sup>	16 m	IT 0.53
		Ba <sup>138</sup> (n,α) Xe <sup>135</sup>	9.2 h	0.25, 0.61
		Ba <sup>138</sup> (n,2n) Ba <sup>137m</sup>	2.6 m	IT 0.662

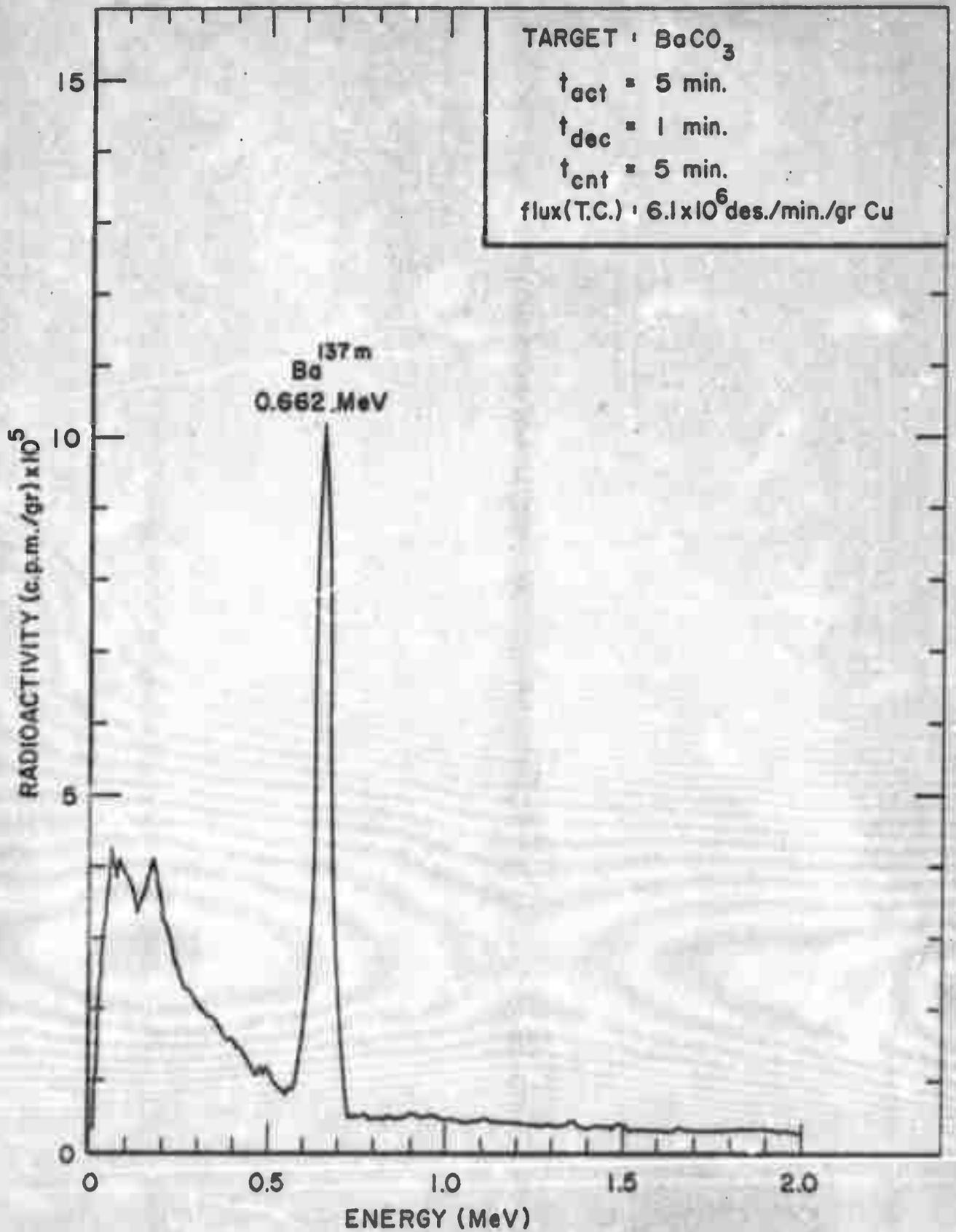


FIGURE I-Ba

TABLE II-Ba

## PEAKS OBSERVED IN FIGURE I-Ba

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ba	0.662	Ba <sup>137</sup> (n,n')Ba <sup>137m</sup>	2.6 m	
		Ba <sup>138</sup> (n,2n)Ba <sup>137m</sup>	2.6 m	

NOTE: -Xe<sup>127m</sup> (T<sub>1/2</sub>=75 sec) could be detected but the activity is very low.

-Ba<sup>135m</sup> (T<sub>1/2</sub>=.33 sec) not detected for 1 sec irradiation, 300 m sec decay and 1 sec counting time.

TABLE III-Ba

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.662	5 m	1 m	5 m	5209	0.09

NOTE: Based on the 3σ criterion for calculating the detection limit, it was found to be 46μg. Experimentally, the limit is ~92 μg.

TABLE IV-Ba

## POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for Barium from any other element.

BROMINETABLE I - Br

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)		
Br <sup>81</sup>	49.46%	Br <sup>81</sup> (n,p) Se <sup>81m</sup>	57 m	IT 0.10		
		Br <sup>81</sup> (n,p) Se <sup>81</sup>	18 m	0.28		
		Br <sup>81</sup> (n,α) As <sup>78m</sup>	6 m	IT 0.50		
		Br <sup>81</sup> (n,α) As <sup>78</sup>	91 m	0.62, 0.70, 1.31, 0.08, 2.68		
		Br <sup>81</sup> (n,2n) Br <sup>80m</sup>	4.5 h	0.037, IT 0.049		
		Br <sup>81</sup> (n,2n) Br <sup>80</sup>	18 m	0.62, 0.65, β+		
		Br <sup>81</sup> (n,n') Br <sup>81m</sup>	37 μs	0.28, IT 0.27		
		Br <sup>79</sup>	50.54%	Br <sup>79</sup> (n,p) Se <sup>79m</sup>	3.9 m	IT 0.096
				Br <sup>79</sup> (n,p) Se <sup>79</sup>	7 x 10 <sup>4</sup> y	
				Br <sup>79</sup> (n,α) As <sup>76</sup>	26.5 h	0.56, 1.21, 0.66, 0.64, 2.66
Br <sup>79</sup> (n,2n) Br <sup>78m</sup>	120 μs			IT 0.149		
Br <sup>79</sup> (n,2n) Br <sup>78</sup>	6.5 m			0.62, β+		
Br <sup>79</sup> (n,n') Br <sup>79m</sup>	4.8 s			IT 0.21		

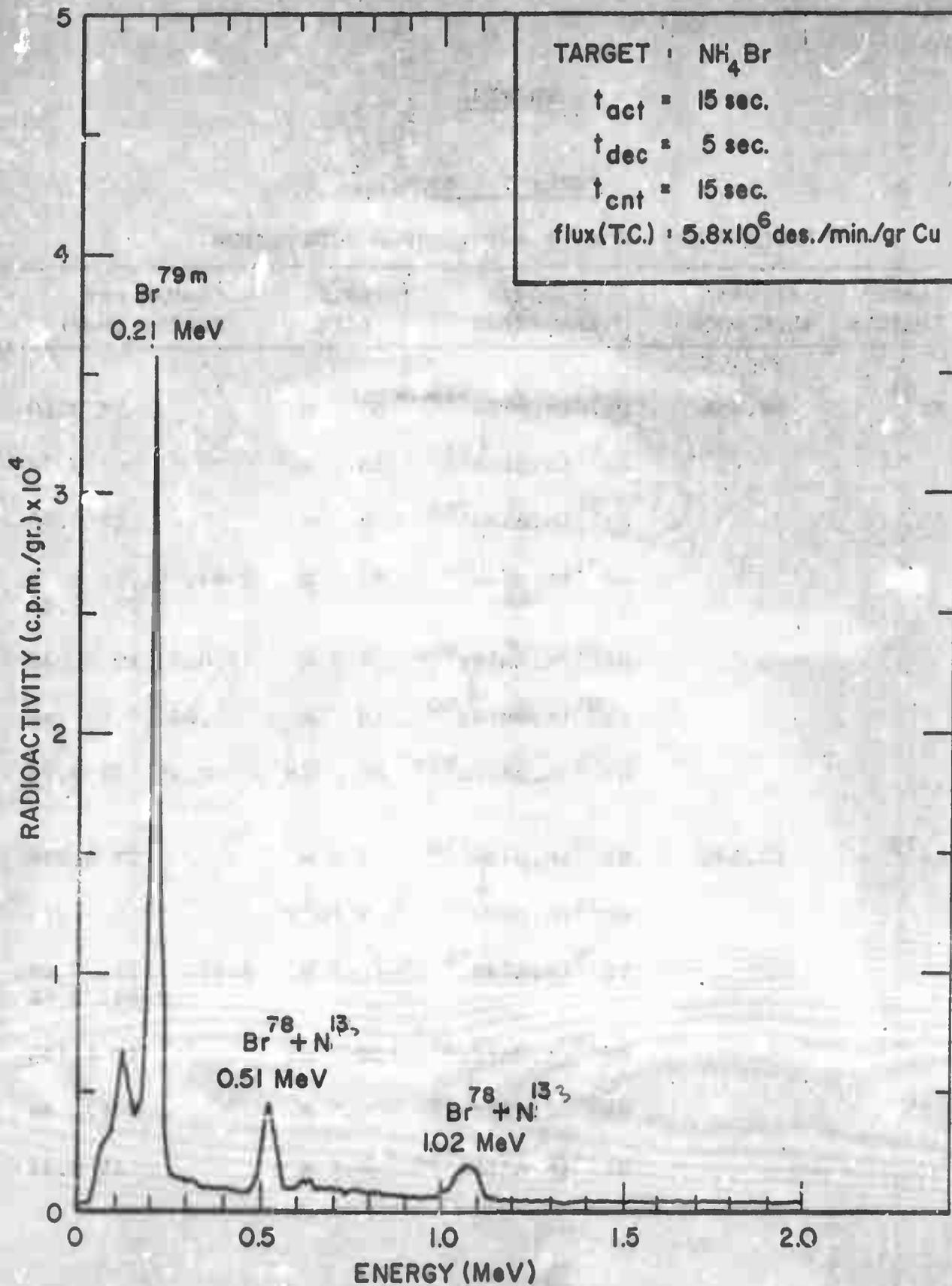


FIGURE I-Br

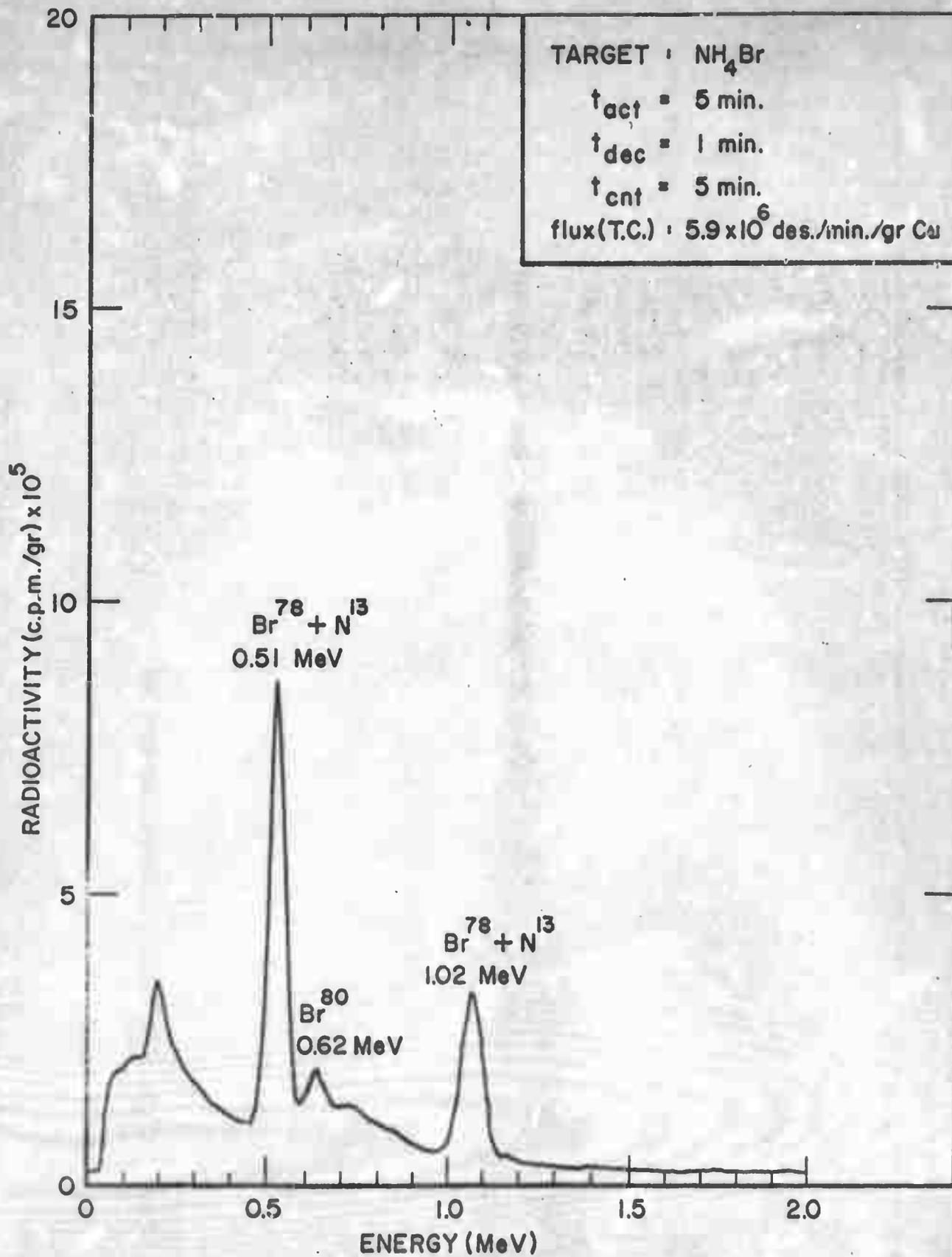


FIGURE II-Br

TABLE II-Br

PEAKS OBSERVED IN FIGURES I-Br and II-Br

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Br	0.21	$\text{Br}^{79}(n,n')\text{Br}^{79m}$	4.8 s	
	0.51	$\text{Br}^{79}(n,2n)\text{Br}^{78}$	6.5 m	
	1.02	$\text{Br}^{79}(n,2n)\text{Br}^{78}$	6.5 m	0.51 Mev coincidence sum peak
II-Br	0.51	$\text{Br}^{79}(n,2n)\text{Br}^{78}$	6.5 m	(1)
	0.62	$\text{Br}^{79}(n,2n)\text{Br}^{78}$	6.5 m	
	1.02	$\text{Br}^{79}(n,2n)\text{Br}^{78}$	6.5 m	0.51 Mev coincidence sum peak

(1)  $\text{Br}^{80}$  ( $T_{1/2}=18$  min) not detected in these conditions

TABLE III-Br

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{act}$	$T_{dec}$	$T_{cnt}$	COUNTS/mg/ $T_{cnt}$	DETECTION LIMIT (mg)
0.21	15 s	5 s	15 s	106	1.0
0.51	5 m	1 m	5 m	3327 (1)	0.05
0.62	5 m	1 m	5 m	310	~0.50

(1) The contribution of nitrogen (35 counts) to the 0.51 Mev photopeak has been considered and has been subtracted from the total activity.

BROMINE

TABLE IV-Br

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.51	Krypton	$Kr^{78}(n,p)Br^{78}$	(1)

This reaction has not been investigated because all the other radioisotopes emitting positrons are more probable interferences (see Appendix II in Section I).

CADMIUM

TABLE I - Cd

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Cd <sup>106</sup>	1.22%	Cd <sup>106</sup> (n,p) Ag <sup>106m</sup>	8.3 d	0.51, 2.63
		Cd <sup>106</sup> (n,p) Ag <sup>106</sup>	24 m	0.51, β+
		Cd <sup>106</sup> (n,α) Pd <sup>103</sup>	17 d	0.04, 0.052, 0.36
		Cd <sup>106</sup> (n,2n) Cd <sup>105</sup>	55 m	0.025, 2.32, β+
Cd <sup>108</sup>	0.88%	Cd <sup>108</sup> (n,p) Ag <sup>108</sup>	5 y	0.72, 0.62, 0.43
		Cd <sup>108</sup> (n,p) Ag <sup>108</sup>	2.4 m	0.63, β+
		Cd <sup>108</sup> (n,α) Pd <sup>105m</sup>	37 μs	0.32, IT 0.18
		Cd <sup>108</sup> (n,2n) Cd <sup>107</sup>	6.5 h	0.093, 0.033, 1.22, β+
Cd <sup>110</sup>	12.39%	Cd <sup>110</sup> (n,p) Ag <sup>110m</sup>	260 d	0.66, 0.88, IT 0.12
		Cd <sup>110</sup> (n,p) Ag <sup>110</sup>	24 s	0.66
		Cd <sup>110</sup> (n,α) Pd <sup>107m</sup>	22 s	IT 0.22
		Cd <sup>110</sup> (n,α) Pd <sup>107</sup>	7 x 10 <sup>6</sup> y	
		Cd <sup>110</sup> (n,2n) Cd <sup>109m</sup>	12 μs	IT 0.058
		Cd <sup>110</sup> (n,2n) Cd <sup>109</sup>	1.3 y	0.088
Cd <sup>111</sup>	12.75%	Cd <sup>111</sup> (n,p) Ag <sup>111m</sup>	74 s	IT 0.065

CADMIUM

TABLE I - Cd (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$Cd^{111}(n,p)Ag^{111}$	7.5 d	0.34 0.25
		$Cd^{111}(n,n')Cd^{111m}$	49 m	0.247, IT 0.15
$Cd^{112}$	24.07%	$Cd^{112}(n,p)Ag^{112}$	3.2 h	0.62, 1.4, 0.69, 3.28
		$Cd^{112}(n,\alpha)Pd^{109m}$	4.8 m	IT 0.18
		$Cd^{112}(n,\alpha)Pd^{109}$	13.5 h	0.088
		$Cd^{112}(n,2n)Cd^{111m}$	49 m	0.247, IT 0.15
$Cd^{113}$	12.26%	$Cd^{113}(n,p)Ag^{113m}$	1.2 m	0.31, 0.70
		$Cd^{113}(n,p)Ag^{113}$	5.3 h	0.31, 0.12, 1.18
		$Cd^{113}(n,n')Cd^{113m}$	14 y	IT 0.27
$Cd^{114}$	28.86%	$Cd^{114}(n,p)Ag^{114}$	5 s	0.56
		$Cd^{114}(n,\alpha)Pd^{111m}$	5.5 h	1.69, 0.5, IT 0.17, 0.28
		$Cd^{114}(n,\alpha)Pd^{111}$	22 m	0.065
		$Cd^{114}(n,2n)Cd^{113m}$	14 y	IT 0.27
$Cd^{116}$	7.58%	$Cd^{116}(n,p)Ag^{106}$	2.5 m	1.8, 0.5, 2.6
		$Cd^{116}(n,\alpha)Pd^{113}$	1.5 m	
		$Cd^{116}(n,2n)Cd^{115m}$	43 d	0.94, 0.17, 1.56
		$Cd^{116}(n,2n)Cd^{115}$	2.3 d	0.52, 0.34

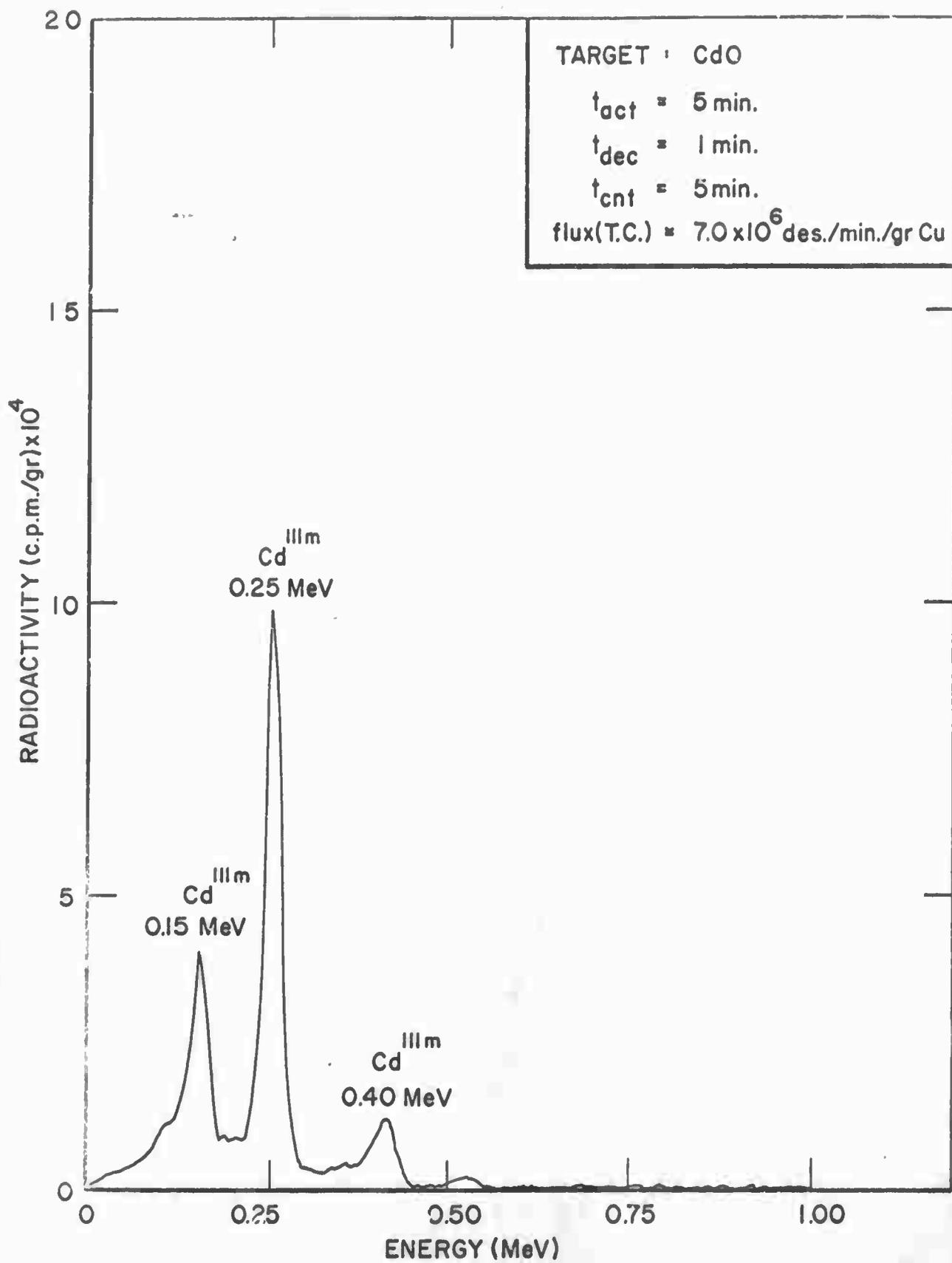


FIGURE I-Cd

CADMIUM

TABLE II-Cd

PEAKS OBSERVED IN FIGURE I-Cd

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Cd	0.15	$Cd^{111}(n,n')Cd^{111m}$	49 m	
		$Cd^{112}(n,2n)Cd^{111m}$	49 m	
	0.25	$Cd^{111}(n,n')Cd^{111m}$	49 m	
		$Cd^{112}(n,2n)Cd^{111m}$	49 m	
	0.40	$Cd^{111}(n,n')Cd^{111m}$	49 m	sum peak of 0.15 + 0.25 Mev
		$Cd^{112}(n,2n)Cd^{111m}$	49 m	

- NOTE: (a)  $Ag^{114}$  ( $T_{1/2}=5$  sec) not detected for 15 sec irradiation, 5 sec decay and 15 sec counting time.
- (b)  $Ag^{110}$  ( $T_{1/2}=24$  sec) and  $Pd^{107m}$  ( $T_{1/2}=22$  sec) not detected for 1 min irradiation, 20 sec decay and 1 minute counting time.

TABLE III-Cd

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{act}$	$T_{dec}$	$T_{cnt}$	COUNTS/mg/ $T_{cnt}$	DETECTION LIMIT (mg)
0.25	5 m	1 m	5 m	363	0.39
0.15	5 m	1 m	5 m	107	1.2

CADMIUM

TABLE IV-Cd

POSSIBLE INTERFERING REACTIONS

---

No detectable interferences could be derived for Cadmium from any other element.

CERIUM

TABLE 1 - Ce

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ce <sup>136</sup>	0.193%	Ce <sup>136</sup> (n,p) La <sup>136</sup>	9.5 m	0.83, β+
		Ce <sup>136</sup> (n,α) Ba <sup>133m</sup>	39 h	0.012, IT 0.276
		Ce <sup>136</sup> (n,α) Ba <sup>133</sup>	7.2 y	0.081, 0.36, 0.30, 0.08, 0.38
		Ce <sup>136</sup> (n,2n) Ce <sup>135</sup>	18 h	0.09, 0.27, β+
Ce <sup>138</sup>	0.250%	Ce <sup>138</sup> (n,α) Ba <sup>135m</sup>	0.35s	~0.7, ~0.8
		Ce <sup>138</sup> (n,α) Ba <sup>135m</sup>	29 h	IT 0.268
		Ce <sup>138</sup> (n,2n) Ce <sup>137m</sup>	34 h	0.7, 0.8, 0.9, IT 0.26
		Ce <sup>138</sup> (n,2n) Ce <sup>137</sup>	9 h	0.01, 0.46
Ce <sup>140</sup>	88.48%	Ce <sup>140</sup> (n,p) La <sup>140</sup>	40.2 h	1.6, 0.49, 0.81, 0.33, 0.065, 3.1
		Ce <sup>140</sup> (n,α) Ba <sup>137m</sup>	2.6 m	IT 0.662
		Ce <sup>140</sup> (n,2n) Ce <sup>139m</sup>	55 s	IT 0.74
		Ce <sup>140</sup> (n,2n) Ce <sup>139</sup>	140 d	0.166
		Ce <sup>142</sup>	11.07%	Ce <sup>142</sup> (n,p) La <sup>142</sup>
Ce <sup>142</sup> (n,α) Ba <sup>139</sup>	83 m	0.166, 1.43		
Ce <sup>142</sup> (n,2n) Ce <sup>141</sup>	32.5 d	0.145		

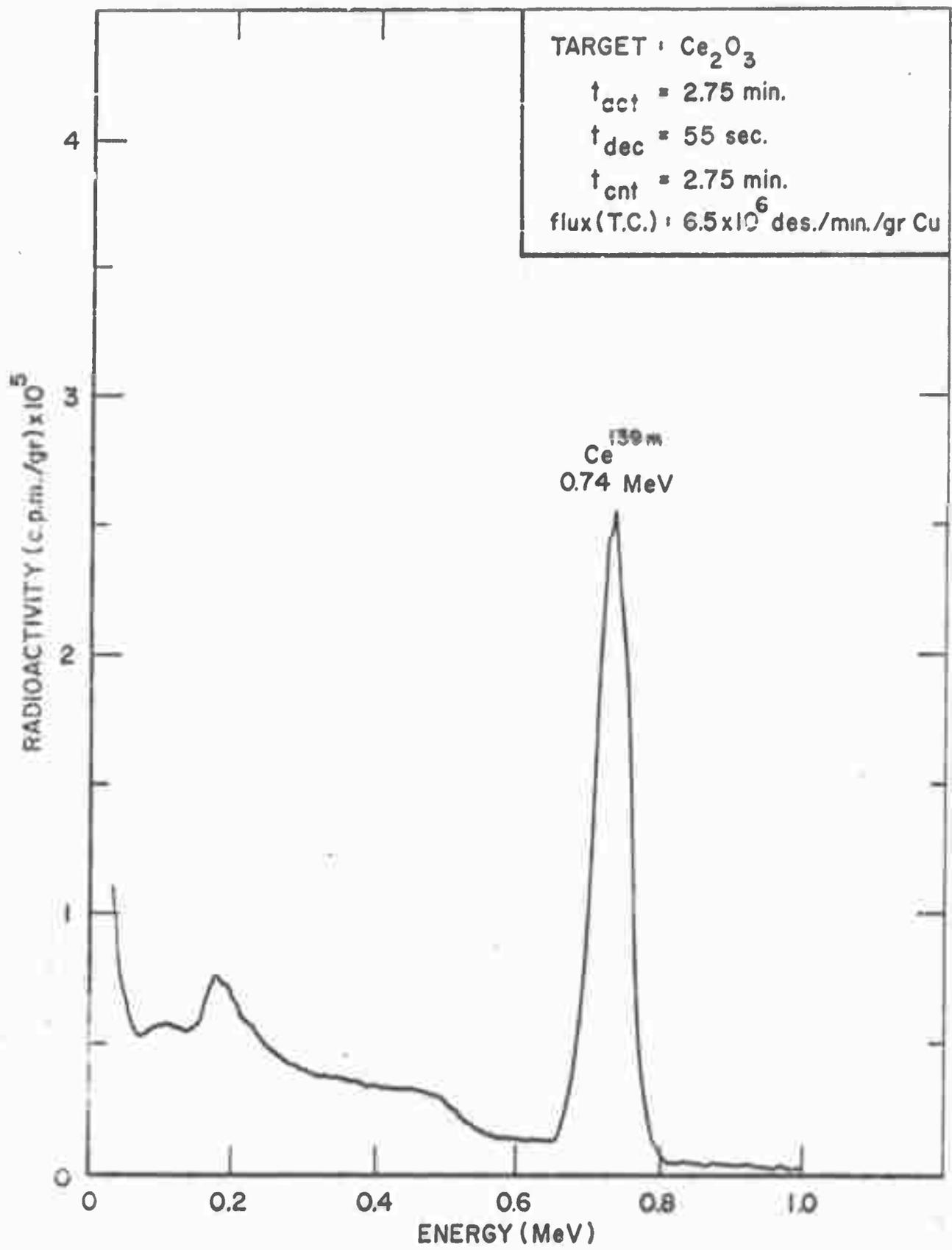


FIGURE I-Ce

TABLE II-Ce

## PEAKS OBSERVED IN FIGURE I-Ce

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ce	0.74	Ce <sup>140</sup> (n, 2n) Ce <sup>139m</sup>	55 s	

NOTE: Upon five minutes irradiation, no other characteristic peaks can be observed.

TABLE III-Ce

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.74	2.75m	55 s	2.75m	1320	0.11

TABLE IV-Ce

## POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.74	Neodymium	Nd <sup>142</sup> (n, α) Ce <sup>139m</sup>	
	Neodymium	Nd <sup>142</sup> (n, 2n) Nd <sup>141m</sup>	(1)
	Samarium	Sm <sup>144</sup> (n, 2n) Sm <sup>143m</sup>	(1)
	Samarium	Sm <sup>144</sup> (n, α) Nd <sup>141m</sup>	

(1) Nd<sup>141m</sup> and Sm<sup>143</sup> have half lives respectively of 64 seconds and 60 seconds, making their identification from Ce<sup>139</sup> very difficult.

CESIUMTABLE I - Cs

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Cs <sup>133</sup>	100%	Cs <sup>133</sup> (n,p)Xe <sup>132m</sup>	2.3 d	IT 0.233
		Cs <sup>133</sup> (n,p)Xe <sup>133</sup>	5.27d	0.081
		Cs <sup>133</sup> (n,α)I <sup>130</sup>	12.5 h	0.66, 0.53, 0.74, 1.15, 0.41
		Cs <sup>133</sup> (n,2n)Cs <sup>132</sup>	6.58d	0.6', 0.46, 0.51, 2.0 β+

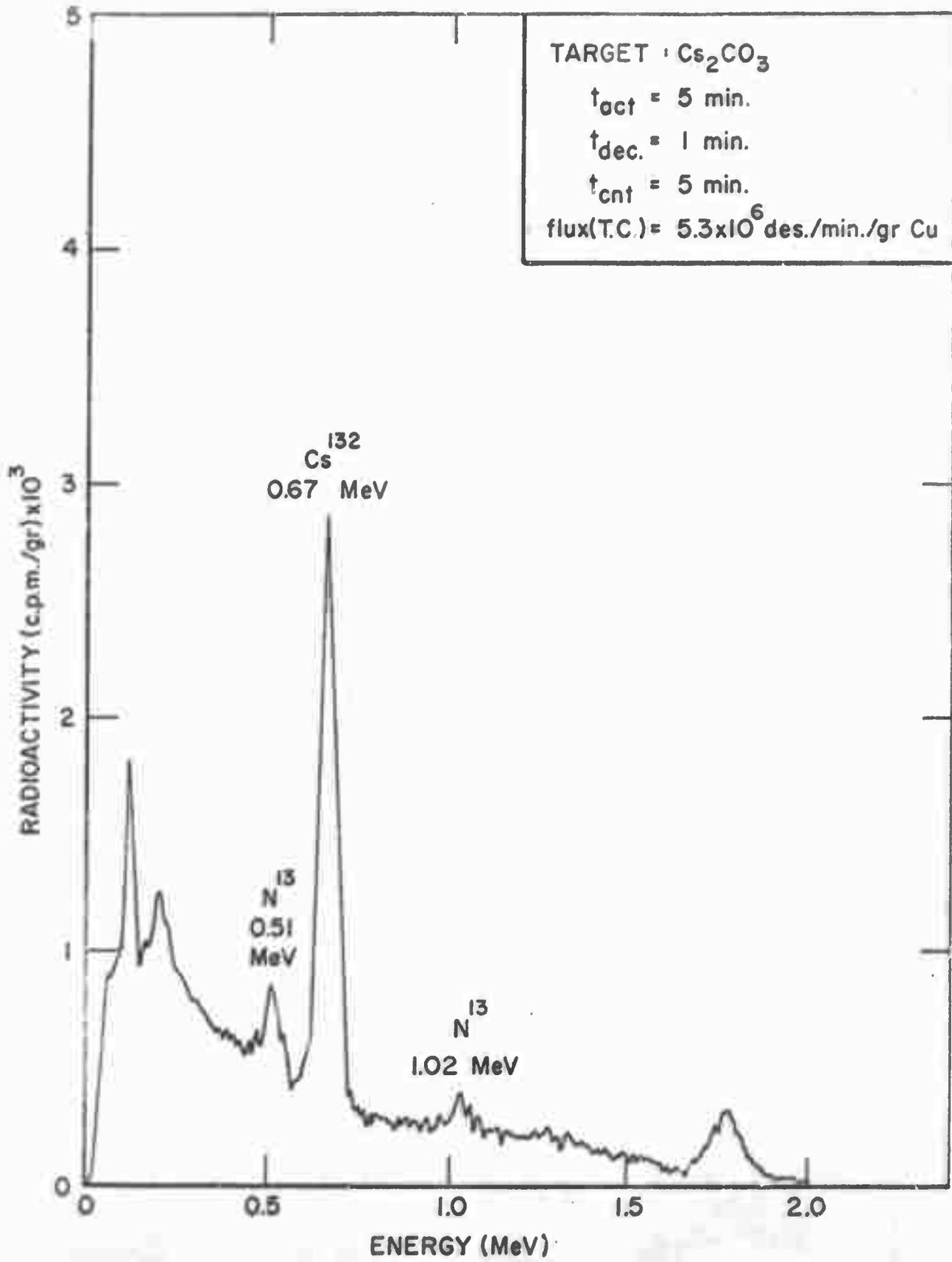


FIGURE I-Cs

## CESIUM

TABLE II-Cs

## PEAKS OBSERVED IN FIGURE I-Cs

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Cs	0.67	$Cs^{133}(n, 2n)Cs^{132}$	6.58 d	

TABLE III-Cs

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.67	5 m	1 m	5 m	13	8.5

TABLE IV-Cs

## POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for cerium from any other element.

## CHLORINE

CHLORINETABLE I - Cl

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
$\text{Cl}^{35}$	75.53%	$\text{Cl}^{35}(n,p)\text{S}^{35}$	86.7 d	
		$\text{Cl}^{35}(n,\alpha)\text{P}^{32}$	14.3 d	
		$\text{Cl}^{35}(n,2n)\text{Cl}^{34m}$	32.0 m	2.04, $\beta^+$ IT 0.14
		$\text{Cl}^{35}(n,2n)\text{Cl}^{34}$	1.5 s	$\beta^+$
$\text{Cl}^{37}$	24.47%	$\text{Cl}^{37}(n,p)\text{S}^{37}$	5.1 m	3.1
		$\text{Cl}^{37}(n,\alpha)\text{P}^{34}$	12.4 s	2.1, 4.0
		$\text{Cl}^{37}(n,2n)\text{Cl}^{36}$	$3 \times 10^5 \text{y}$	

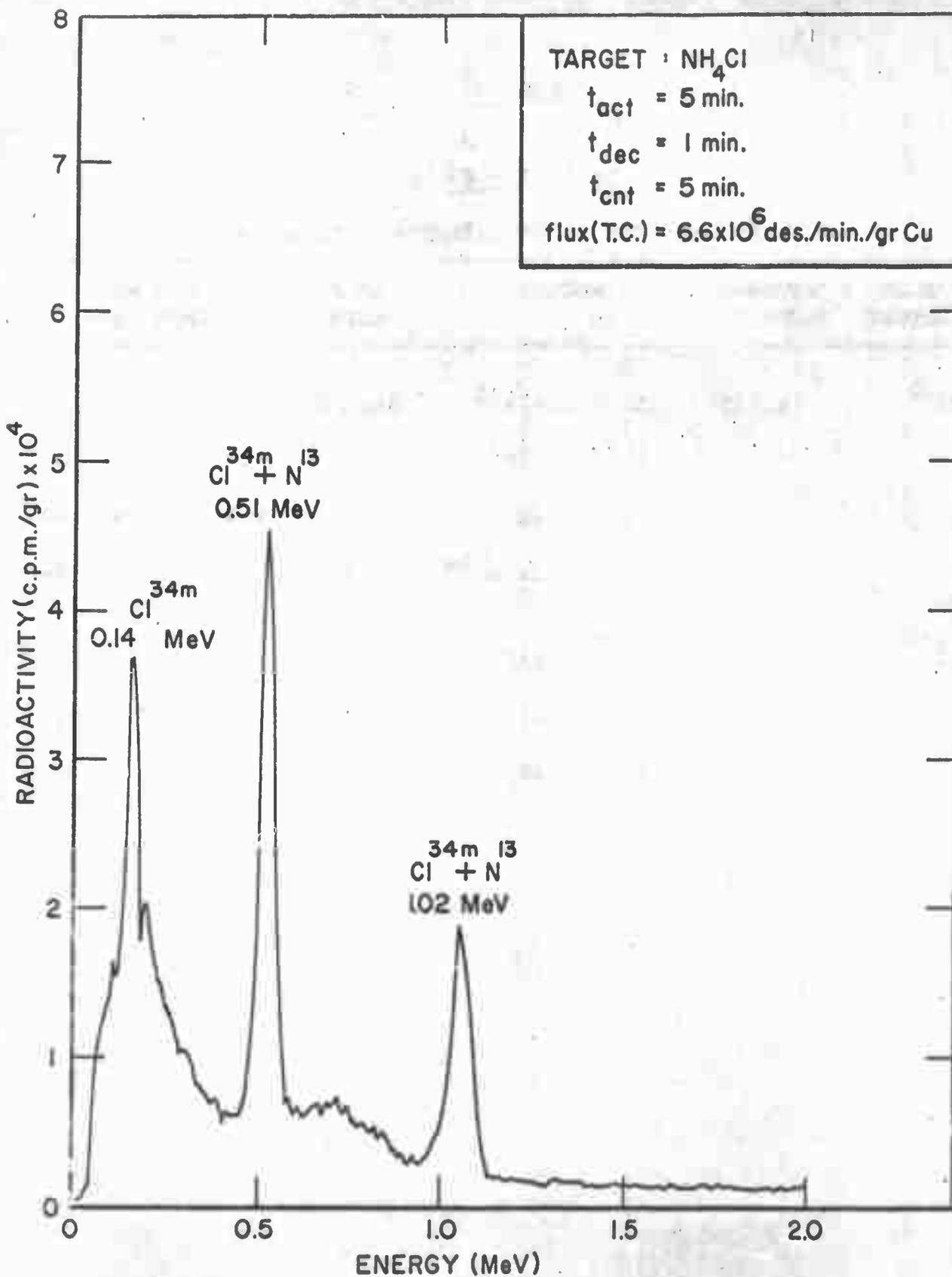


FIGURE I-C1

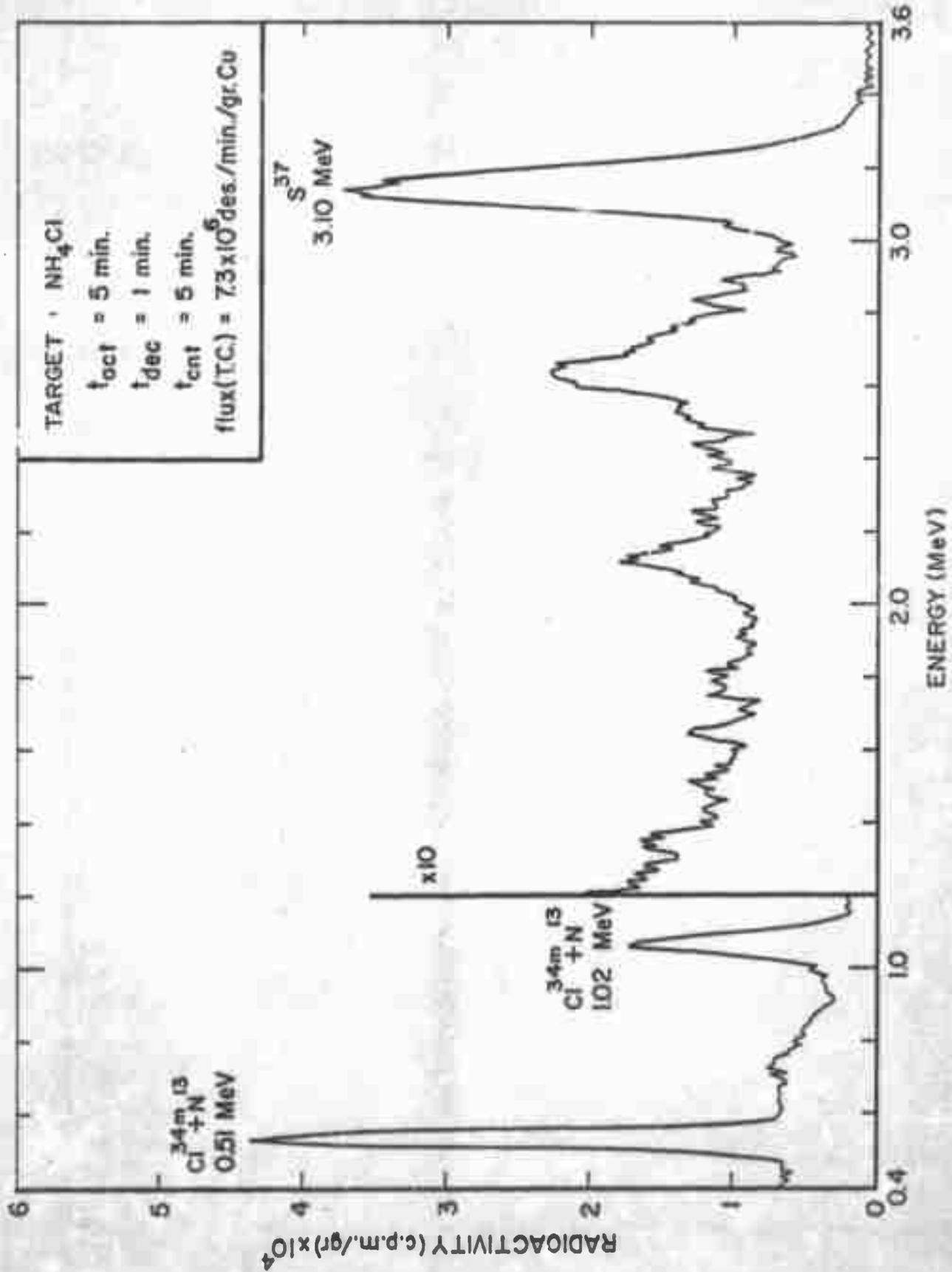


FIGURE II-C1

TABLE II-C1

## PEAKS OBSERVED IN FIGURE I-C1

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-C1	0.14	$\text{Cl}^{35}(\text{n}, 2\text{n})\text{Cl}^{34\text{m}}$	32 m	
	0.51	$\text{Cl}^{35}(\text{n}, 2\text{n})\text{Cl}^{34\text{m}}$	32 m	
	1.02	$\text{Cl}^{35}(\text{n}, 2\text{n})\text{Cl}^{34\text{m}}$	32 m	0.51 Mev coincidence sum peak
II-C1	0.51	$\text{Cl}^{35}(\text{n}, 2\text{n})\text{Cl}^{34\text{m}}$	32 m	
	1.02	$\text{Cl}^{35}(\text{m}, 2\text{n})\text{Cl}^{34\text{m}}$	32 m	
	3.10	$\text{Cl}^{37}(\text{n}, \text{p})\text{S}^{37}$	5.1m	

NOTE:  $\text{P}^{34}$  ( $T_{1/2} = 12.4$  sec) is detectable for 37 sec irradiation, 12 sec decay and 37 sec counting time, but activity is low.

TABLE III-C1

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{\text{act}}$	$T_{\text{dec}}$	$T_{\text{cnt}}$	COUNTS/mg/ $T_{\text{cnt}}$	DETECTION LIMIT (mg)
0.14	5 m	1 m	5 m	30	4.1
0.51	5 m	1 m	5 m	8 <sup>(1)</sup>	21

(1) The contribution of nitrogen, present in  $\text{NH}_4\text{Cl}$ , to the 0.51 Mev photopeak is equal to 138 counts. This value has been subtracted from the  $\text{N}^{13} + \text{Cl}^{34\text{m}}$  activity.

CHLORINE

TABLE IV-C1

POSSIBLE INTERFERING REACTIONS

---

No detectable interference could be derived for chlorine from any other element.

For other positron emitting radioisotopes than  $\text{Cl}^{34\text{m}}$ , see Section I, Appendix II.

## CHROMIUM

CHROMIUMTABLE I - Cr

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Cr <sup>50</sup>	4.31%	Cr <sup>50</sup> (n,2n)Cr <sup>49</sup>	42 m	0.09, 0.06, 0.15, β+
Cr <sup>52</sup>	83.76%	Cr <sup>52</sup> (n,p)V <sup>52</sup>	3.77m	1.43
		Cr <sup>52</sup> (n,2n)Cr <sup>51</sup>	27.8 d	0.32
Cr <sup>53</sup>	9.55%	Cr <sup>53</sup> (n,p)V <sup>53</sup>	2 m	1.01
Cr <sup>54</sup>	2.38%	Cr <sup>54</sup> (n,p)V <sup>54</sup>	55 s	0.99, 0.84, 2.21
		Cr <sup>54</sup> (n,α)Ti <sup>51</sup>	5.8 m	0.32, 0.93, 0.61

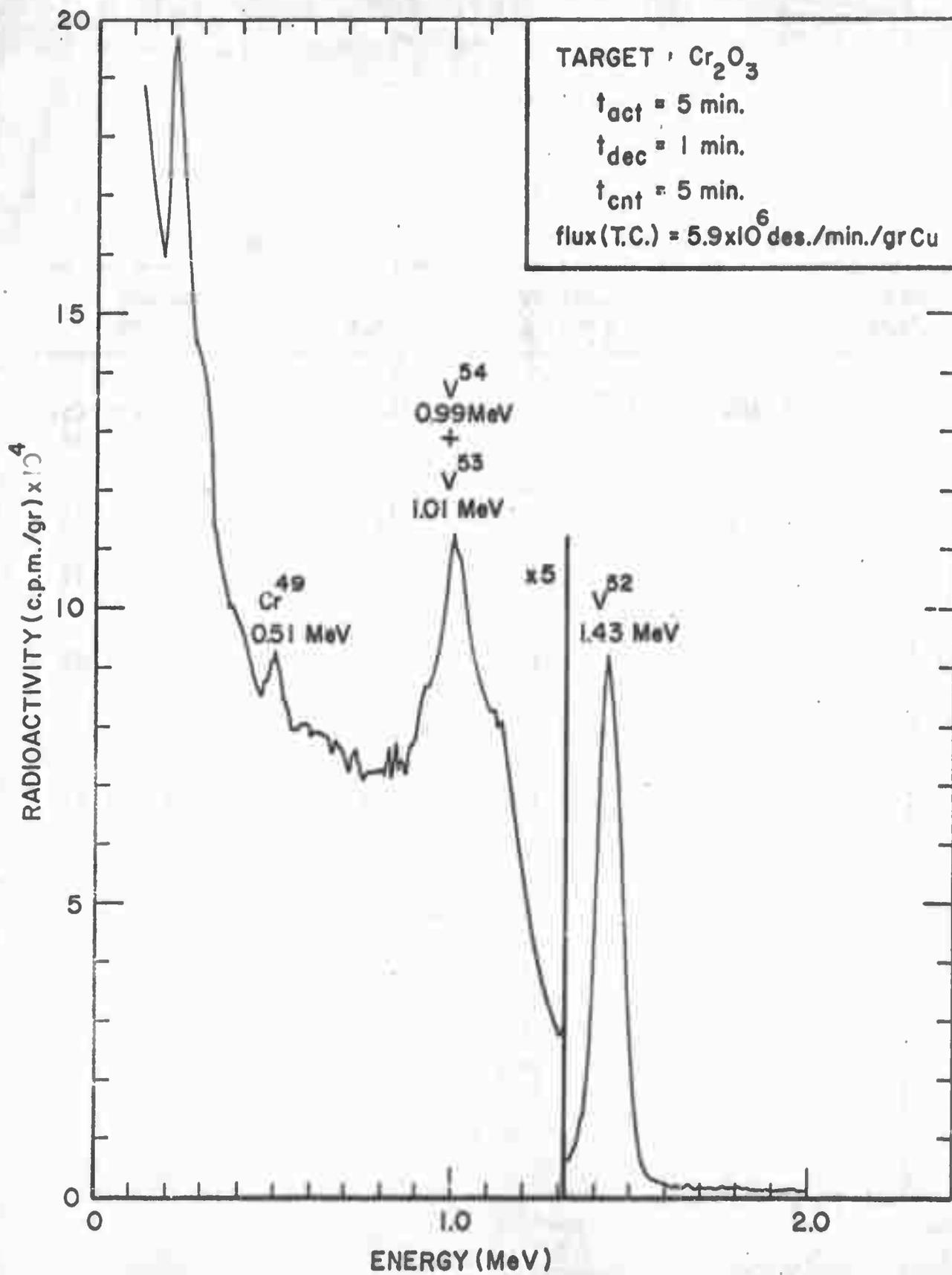


FIGURE I-Cr

TABLE II-Cr

## PEAKS OBSERVED IN FIGURE I-Cr

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Cr	0.51	$\text{Cr}^{50} (n, 2n) \text{Cr}^{49}$	42 m	
	0.99 + 1.01	$\text{Cr}^{54} (n, p) \text{V}^{54}$	55 s	(1)
		$\text{Cr}^{53} (n, p) \text{V}^{53}$	2 m	(1)
	1.43	$\text{Cr}^{52} (n, p) \text{V}^{52}$	3.77m	

(1) The half life found for the 1.01 + 0.99 Mev photopeaks is 1.5 m, indicating that both isotopes  $\text{V}^{54}$  and  $\text{V}^{53}$  are present.

TABLE III-Cr

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{\text{act}}$	$T_{\text{dec}}$	$T_{\text{cnt}}$	COUNTS/mg/ $T_{\text{cnt}}$	DETECTION LIMIT (mg)
1.43	5 m	1 m	5 m	710	0.21

TABLE IV-Cr

## POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
1.43	Manganese	$\text{Mn}^{55} (n, \alpha) \text{V}^{52}$	
1.43	Vanadium	$\text{V}^{51} (n, \gamma) \text{V}^{52}$	

COBALTTABLE I - Co

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY, (Mev)
Co <sup>59</sup>	100%	Co <sup>59</sup> (n,p) Fe <sup>59</sup>	45 d	1.10, 1.29, 0.19
		Co <sup>59</sup> (n,α) Mn <sup>56</sup>	2.58h	0.845, 1.81, 2.11
		Co <sup>59</sup> (n,2n) Co <sup>58m</sup>	9 h	IT 0.025
		Co <sup>59</sup> (n,2n) Co <sup>58</sup>	71 d	0.81, 1.65, β+

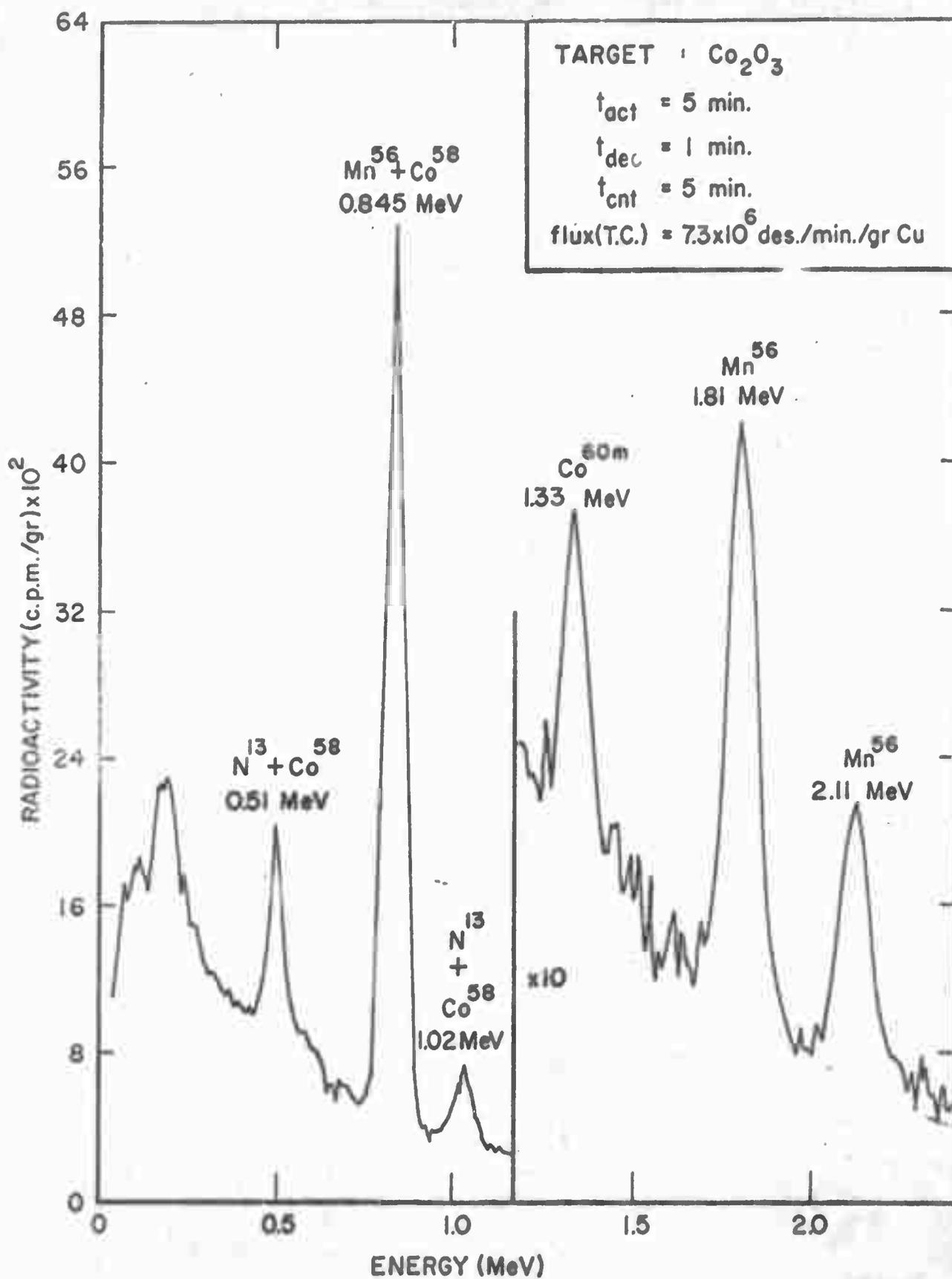


FIGURE I-Co

TABLE II-Co

## PEAKS OBSERVED IN FIGURE I-Co

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Co	0.51	$\text{Co}^{59} (n, 2n) \text{Co}^{58}$	71 d	(1)
	1.02	$\text{Co}^{59} (n, 2n) \text{Co}^{58}$	71 d	0.51 Mev coincidence sum peak
	0.81	$\text{Co}^{59} (n, 2n) \text{Co}^{58}$	71 d	Visible after decay of 24 hours
	0.845	$\text{Co}^{59} (n, \alpha) \text{Mn}^{56}$	2.58h	
	1.33	$\text{Co}^{59} (n, \gamma) \text{Co}^{60m}$	10.5 m	
	1.81	$\text{Co}^{59} (n, \alpha) \text{Mn}^{56}$	2.58h	
	2.11	$\text{Co}^{59} (n, \alpha) \text{Mn}^{56}$	2.58h	

(1) Most of 0.51 Mev activity is due to the  $\text{N}^{13}$  activity in the vial. A decay curve on this gamma-ray peak shows, after 24 hours, a small activity due probably to the  $\text{Co}^{58}$ .

TABLE III-Co

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{act}$	$T_{dec}$	$T_{cnt}$	COUNTS/mg/ $T_{cnt}$	DETECTION LIMIT (mg)
0.80 + 0.845	5 m	1 m	5 m	28	4.3

COBALT

TABLE IV-Cc

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.845	Iron	$\text{Fe}^{56} (n, p) \text{Mn}^{56}$	
0.845	Manganese	$\text{Mn}^{55} (n, \gamma) \text{Mn}^{56}$	

COPPERTABLE I - Cu

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Cu <sup>63</sup>	60.09%	Cu <sup>63</sup> (n,p)Ni <sup>63</sup>	92 y	
		Cu <sup>63</sup> (n,α)Co <sup>60m</sup>	10.5 m	1.33, IT 0.059
		Cu <sup>63</sup> (n,α)Co <sup>60</sup>	5.26y	1.33, 1.17
		Cu <sup>63</sup> (n,2n)Cu <sup>62</sup>	9.9 m	β+
Cu <sup>65</sup>	30.91%	Cu <sup>65</sup> (n,p)Ni <sup>65</sup>	2.56h	1.49, 1.12, 0.37
		Cu <sup>65</sup> (n,α)Co <sup>62m</sup>	1.9 m	
		Cu <sup>65</sup> (n,α)Co <sup>62</sup>	13.9 m	1.17, 1.47, 1.74, 2.03
		Cu <sup>65</sup> (n,2n)Cu <sup>64</sup>	12.9 h	1.34, β+

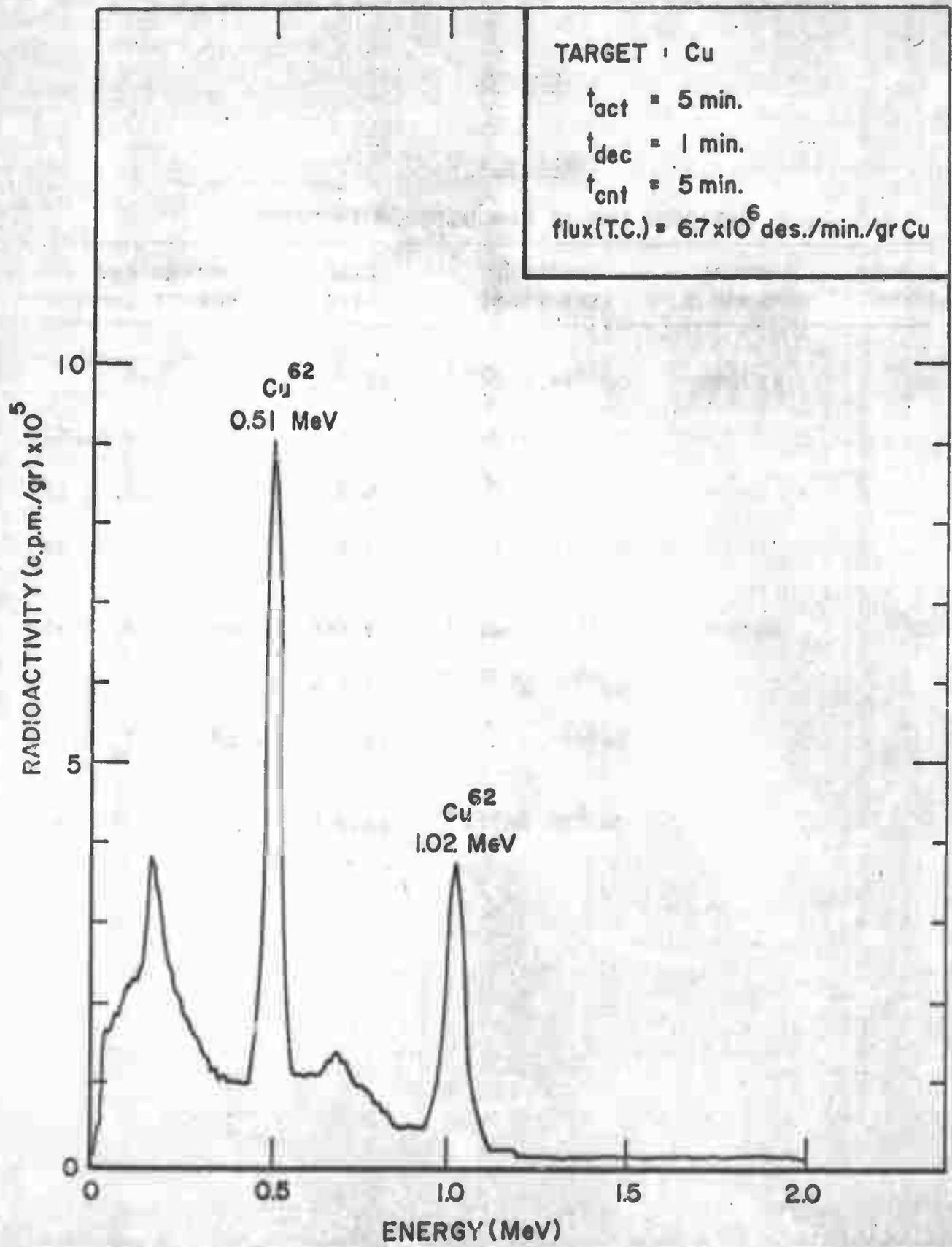


FIGURE I-Cu

## COPPER

TABLE II-Cu

## PEAKS OBSERVED IN FIGURE I-Cu

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Cu	0.51	$\text{Cu}^{63} (n, 2n) \text{Cu}^{62}$	9.9 m	
	1.02	$\text{Cu}^{63} (n, 2n) \text{Cu}^{62}$	9.9 m	0.51 Mev coincidence sum peak

TABLE III-Cu

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{act}$	$T_{dec}$	$T_{cnt}$	COUNTS/mg/ $T_{cnt}$	DETECTION LIMIT (mg)
0.51	5 m	1 m	5 m	3273	0.05

TABLE IV-Cu

## POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.51	Nitrogen	$\text{N}^{14} (n, 2n) \text{N}^{13}$	(1)
	Samarium	$\text{Sm}^{144} (n, 2n) \text{Sm}^{143}$	(1)

(1)  $\text{N}^{13}$  and  $\text{Sm}^{143}$  have a half life respectively of 9.96 and 9 m, making their identification from  $\text{Cu}^{62}$  very difficult.

For other positron emitting radioisotopes, see Section I, Appendix II.

DYSPROSIUM

DYSPROSIUM

TABLE I - Dy

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION .

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Dy <sup>156</sup>	0.052%	Dy <sup>156</sup> (n,p) Tb <sup>156m</sup>	5 h	IT 0.088 β+
		Dy <sup>156</sup> (n,p) Tb <sup>156</sup>	5.4 d	0.089, 0.53, 0.11, 2.0
		Dy <sup>156</sup> (n,α) Gd <sup>153</sup>	240 d	0.097, 0.103, 0.070
		Dy <sup>156</sup> (n,2n) Dy <sup>155</sup>	10 h	0.23, 0.090, 1.67, β+
Dy <sup>158</sup>	0.090%	Dy <sup>158</sup> (n,p) Tb <sup>158m</sup>	11 s	IT 0.111
		Dy <sup>158</sup> (n,p) Tb <sup>158</sup>	150 y	0.08, 1.19
		Dy <sup>158</sup> (n,2n) Dy <sup>157</sup>	8.5 h	0.327, 0.083, 0.061, 0.144, 0.182, 0.266
Dy <sup>160</sup>	2.29%	Dy <sup>160</sup> (n,p) Tb <sup>160</sup>	72 d	0.97, 0.56, 0.88, 0.087, 1.34
		Dy <sup>160</sup> (n,2n) Dy <sup>159</sup>	144 d	0.058, 0.36, 0.29, 0.20
Dy <sup>161</sup>	18.88%	Dy <sup>161</sup> (n,p) Tb <sup>161</sup>	6.9 d	0.049, 0.026, 0.020, 0.27
Dy <sup>162</sup>	25.53%	Dy <sup>162</sup> (n,p) Tb <sup>162m</sup>	8 m	0.04, 0.89
		Dy <sup>162</sup> (n,p) Tb <sup>162</sup>	2 h	

DYSPROSIUM

TABLE I - (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$\text{Dy}^{162} (n, \alpha) \text{Gd}^{159}$	18 h	0.058, 0.36
$\text{Dy}^{163}$	24.97%	$\text{Dy}^{163} (n, p) \text{Tb}^{163m}$	16 m	0.08, 0.50
		$\text{Dy}^{163} (n, p) \text{Tb}^{163}$	6.5 h	0.33, 0.03, 0.16, 0.51
$\text{Dy}^{164}$	28.18%	$\text{Dy}^{164} (n, p) \text{Tb}^{164}$	1 d	
		$\text{Dy}^{164} (n, \alpha) \text{Gd}^{161}$	3.7 m	0.057, 0.078, 0.53

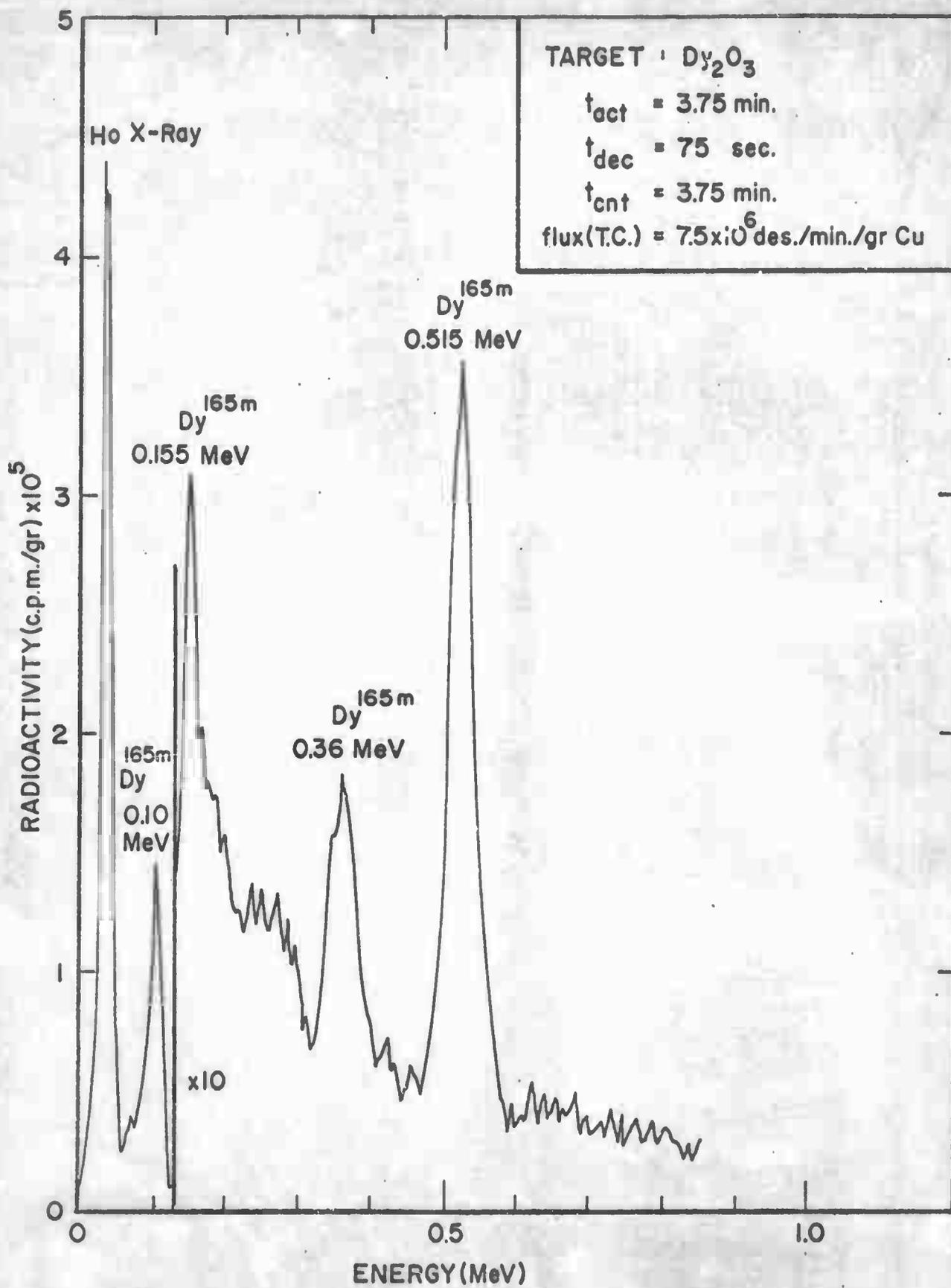


FIGURE I-Dy

DYSPROSIUM

TABLE II-Dy

PEAKS OBSERVED IN FIGURE I-Dy

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Dy	0.05			Ho x-ray
	0.108	$Dy^{164} (n, \gamma) Dy^{165m}$	75.4 s	
	0.155	$Dy^{164} (n, \gamma) Dy^{165m}$	75.4 s	
	0.36	$Dy^{164} (n, \gamma) Dy^{165m}$	75.4 s	
	0.515	$Dy^{164} (n, \gamma) Dy^{165m}$	75.4 s	

TABLE III-Dy

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.05	3.75 m	75 s	3.75 m	1390	0.10
0.108	3.75 m	75 s	3.75 m	388	0.25

TABLE IV-Dy

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for dysprosium from any other element.

## ERBIUM

ERBIUMTABLE I - Er

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Er <sup>162</sup>	0.136%	Er <sup>162</sup> (n,p)Ho <sup>162m</sup>	68 m	0.08, 0.04, 1.34, IT 0.01
		Er <sup>162</sup> (n,p)Ho <sup>162</sup>	12 m	0.08, β+
		Er <sup>162</sup> (n,α)Dy <sup>159</sup>	144 d	0.058, 0.36, 0.29, 0.20
		Er <sup>162</sup> (n,2n)Er <sup>161</sup>	3.1 h	0.067, 0.211, 0.83, 1.12 β+
Er <sup>164</sup>	1.56%	Er <sup>164</sup> (n,p)Ho <sup>164</sup>	35 m	0.073, 0.09, 0.037, IT 0.046
		Er <sup>164</sup> (n,2n)Er <sup>163</sup>	75 m	0.43, 1.1, 0.3, β+
Er <sup>166</sup>	33.41%	Er <sup>166</sup> (n,p)Ho <sup>166m</sup>	1.2 x 10 <sup>3</sup> y	0.08, 0.184, 0.71
		Er <sup>166</sup> (n,p)Ho <sup>166</sup>	27.2 h	0.08, 1.4, 0.7, 1.8
		Er <sup>166</sup> (n,2n)Er <sup>165</sup>	10.36h	
Er <sup>167</sup>	22.94%	Er <sup>167</sup> (n,p)Ho <sup>167</sup>	3.1 h	0.079, 0.083, 0.057, 0.074, 0.532
		Er <sup>167</sup> (n,n')Er <sup>167m</sup>	2.5 s	IT 0.208

ERBIUM

TABLE I - Er (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Er <sup>168</sup>	27.07	Er <sup>168</sup> (n,p)Ho <sup>168</sup>	3 m	0.85
		Er <sup>168</sup> (n,α)Dy <sup>165m</sup>	75.4 s	0.51, 0.36, 0.15, IT 0.108
		↓		
		Er <sup>168</sup> (n,α)Dy <sup>165</sup>	2.35h	0.095, 0.028, 1.1
		Er <sup>168</sup> (n,2n)Er <sup>167m</sup>	2.5 s	IT 0.208
Er <sup>170</sup>	14.88%	Er <sup>170</sup> (n,p)Ho <sup>170</sup>	44 s	0.43
		Er <sup>170</sup> (n,α)Dy <sup>167</sup>	4.4 m	0.19, 0.26, 0.31, 0.51, 0.57
		Er <sup>170</sup> (n,2n)Er <sup>169</sup>	9.4 d	0.008

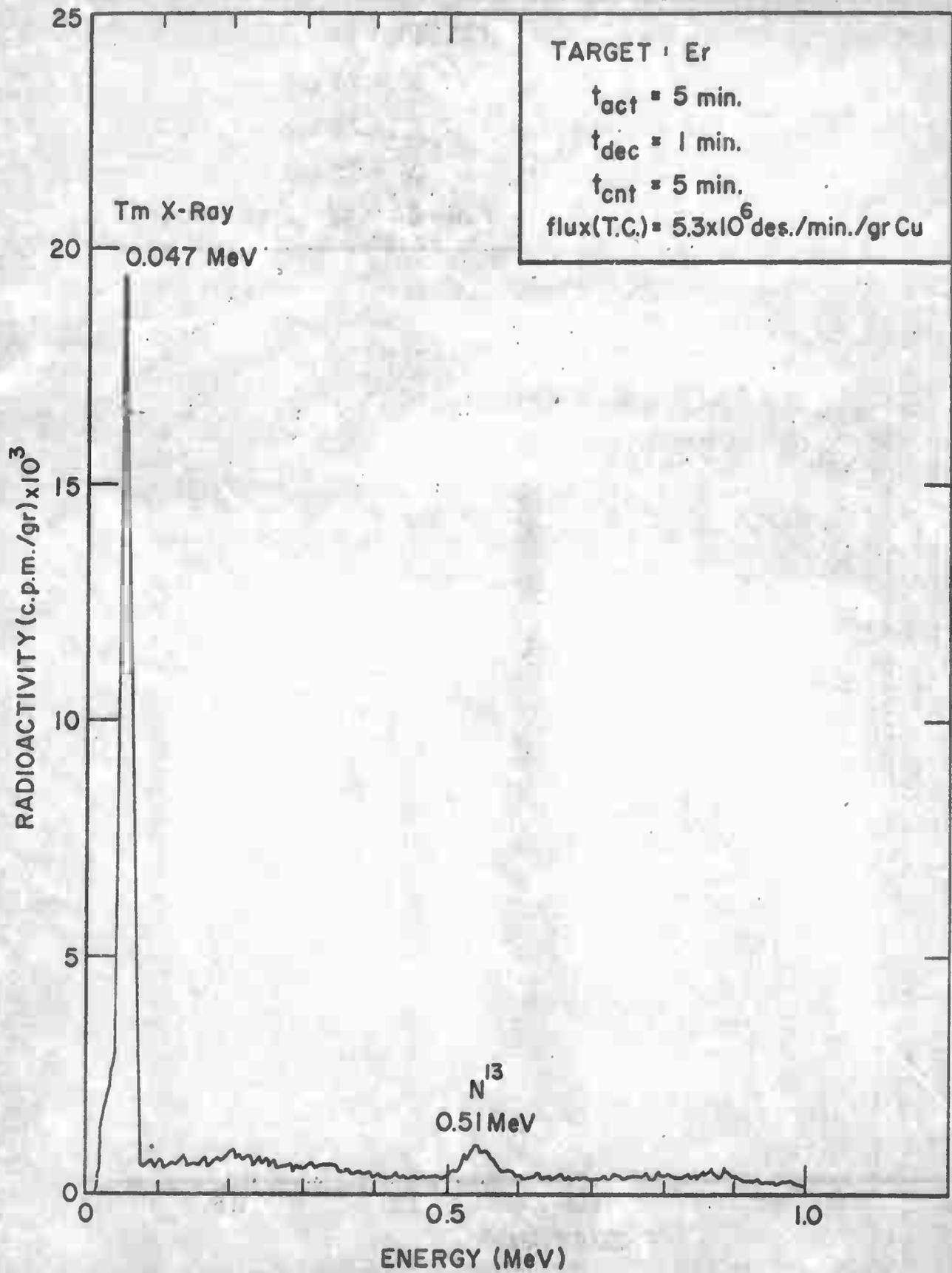


FIGURE I-Er

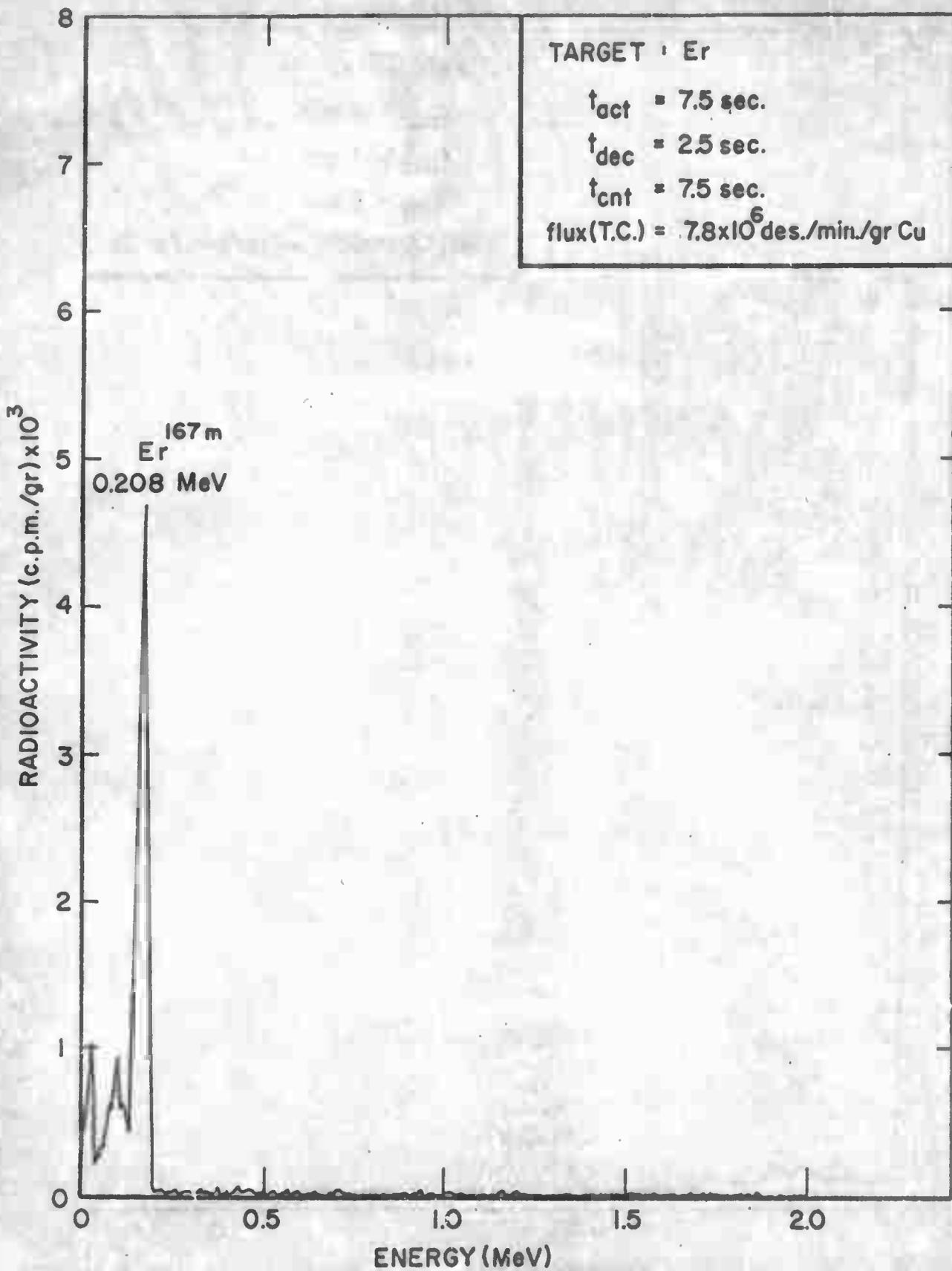


FIGURE II-Er

TABLE II-Er

## PEAKS OBSERVED IN FIGURE I-Er

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Er	0.208	$\text{Er}^{167} (n, n') \text{Er}^{167m}$	2.5 s	
II-Er	0.049			Tm x-ray

TABLE III-Er

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)	
0.049	5 m	1 m	5 m	58	1X 1.8	5X
0.208	7.5s	2.5 s	7.5 s	8	4	1.7

NOTE: Because of the very short half life of  $\text{Er}^{167m}$ , five irradiation have been performed, and their spectra accumulated. The seventh column refers to the sensitivities obtained after five irradiations.

TABLE IV-Er

## POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for Erbium from any other element.

## EUROPIUM

EUROPIUM

TABLE I - Eu

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Eu <sup>151</sup>	47.82%	Eu <sup>151</sup> (n,p)Sm <sup>151</sup>	90 y	0.022
		Eu <sup>151</sup> (n,α)Pm <sup>148m</sup>	41 d	0.08, 1.0, IT 0.06
		Eu <sup>151</sup> (n,α)Pm <sup>148</sup>	5.4d	0.55, 0.91, 1.46
		Eu <sup>151</sup> (n,2n)Eu <sup>150m</sup>	12.8h	0.33, 1.99, β+
		Eu <sup>151</sup> (n,2n)Eu <sup>150</sup>	25 y	0.33, 0.44, 0.30, 1.64
		Eu <sup>151</sup> (n,n')Eu <sup>151m</sup>	58 μs	0.02, IT 0.18
Eu <sup>153</sup>	52.18%	Eu <sup>153</sup> (n,p)Sm <sup>153</sup>	47 h	0.103, 0.07, 0.02, 0.64
		Eu <sup>153</sup> (n,α)Pm <sup>150</sup>	2.7h	0.33, 1.17, 1.33, 0.83, 1.75, 0.41, 3.1
		Eu <sup>153</sup> (n,2n)Eu <sup>152m</sup>	96 m	0.02, 0.09, IT 0.04
		Eu <sup>153</sup> (n,2n)Eu <sup>152m</sup>	9.3h	0.12, 0.84, 0.96, β+
		Eu <sup>153</sup> (n,2n)Eu <sup>152</sup>	12.4y	0.12, 0.34, β+

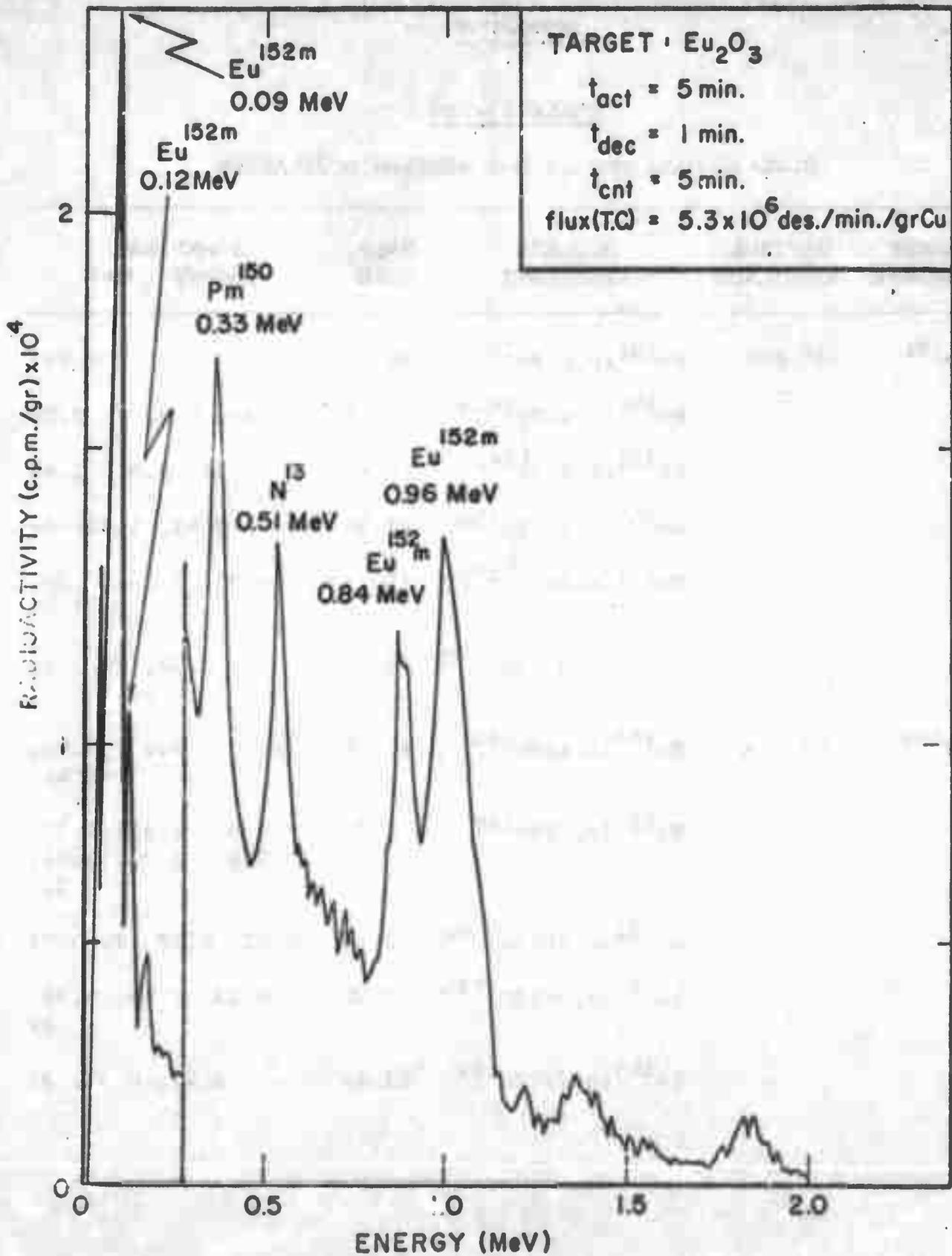


FIGURE I-Eu

## EUROPIUM

TABLE II-Eu

## PEAKS OBSERVED IN FIGURE I-Eu

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Eu	0.09	$\text{Eu}^{153} (n, 2n) \text{Eu}^{152m}$	96 m	
	0.12	$\text{Eu}^{153} (n, 2n) \text{Eu}^{152m}$	9.3 h	
	0.33	$\text{Eu}^{153} (n, \alpha) \text{Pm}^{150}$	2.7 h	
	0.84	$\text{Eu}^{153} (n, 2n) \text{Eu}^{152m}$	9.3 h	
	0.96	$\text{Eu}^{163} (n, 2n) \text{Eu}^{152m}$	9.3 h	

TABLE III-Eu

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{\text{act}}$	$T_{\text{dec}}$	$T_{\text{cnt}}$	COUNTS/ mg/ $T_{\text{cnt}}$	DETECTION LIMIT, mg
0.09	5 m	1 m	5 m	32	2.9
0.33	5 m	1 m	5 m	6	18

TABLE IV-Eu

## POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived from europium from any other element.

FLUORINE

FLUORINE

TABLE I - F

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
F <sup>19</sup>	100%	F <sup>19</sup> (n,p)O <sup>19</sup>	29 s	0.20, 1.36
		F <sup>19</sup> (n,α)N <sup>16</sup>	7.35s	6.13, 7.12
		F <sup>19</sup> (n,2n)F <sup>18</sup>	110 m	0.65, β+

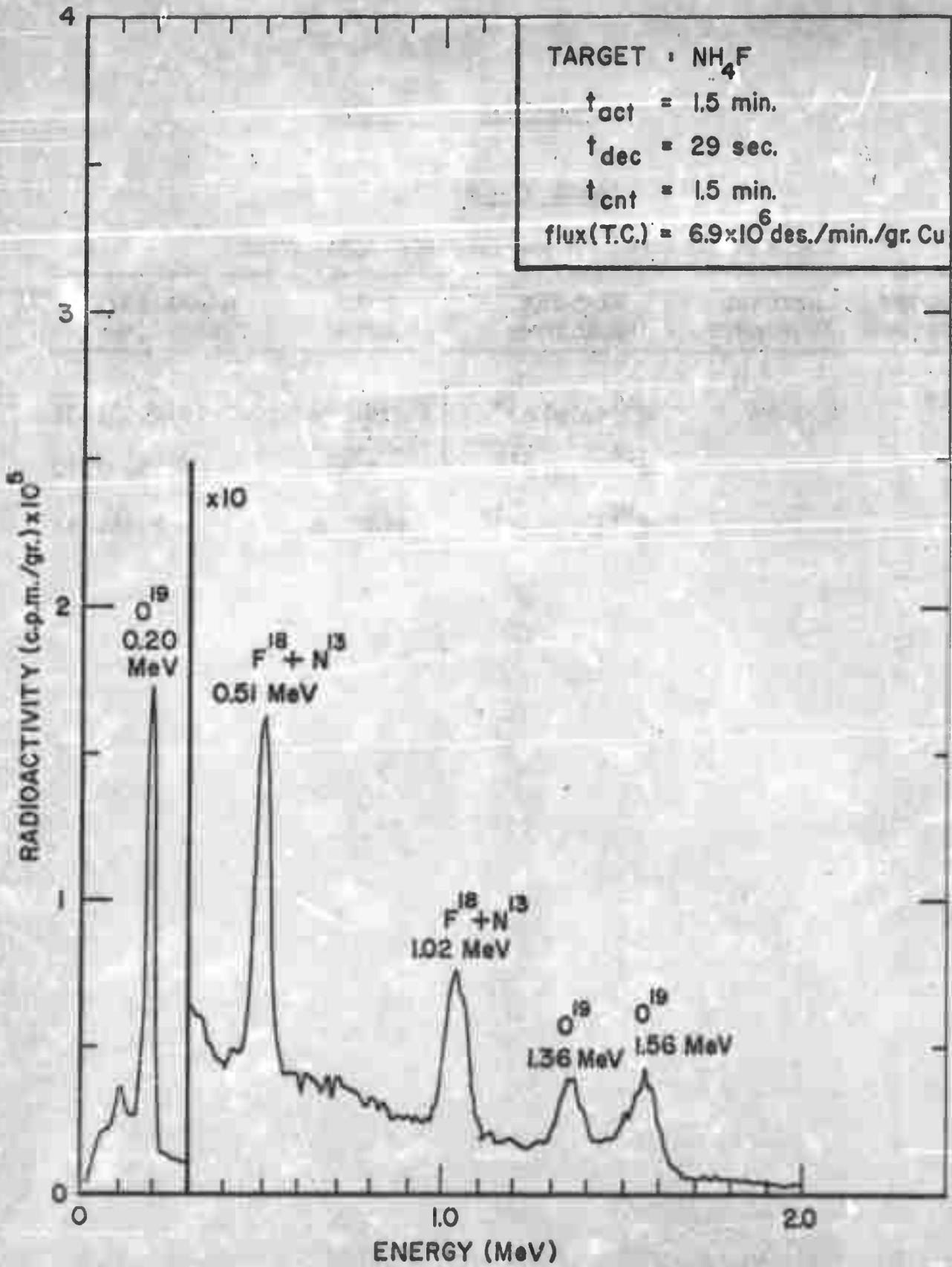


FIGURE I-F

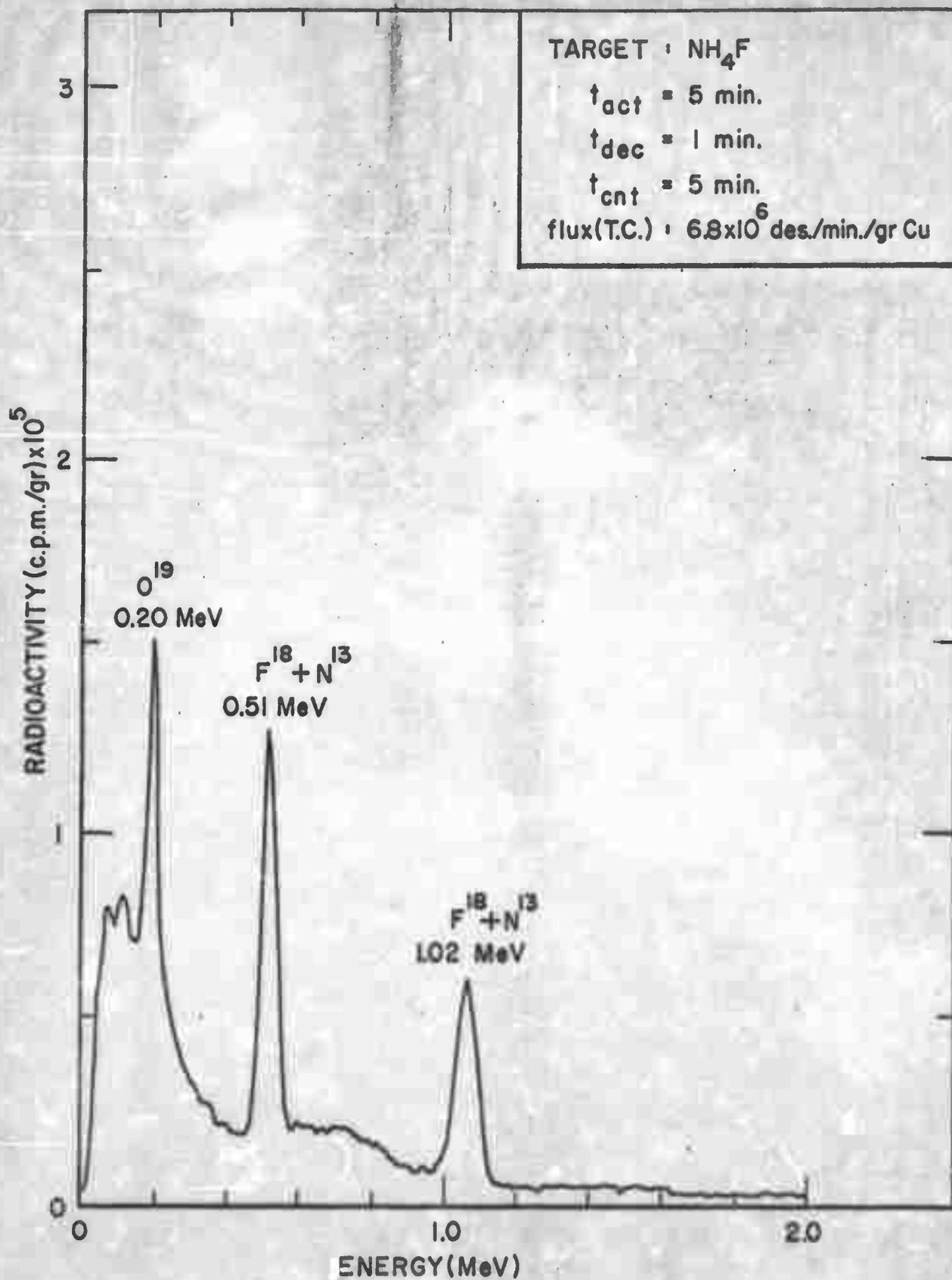


FIGURE II-F

TABLE II-F

PEAKS OBSERVED IN FIGURES I-F and II-F

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-F	0.20	$F^{19}(n,p)O^{19}$	29 s	
	0.51	$F^{19}(n,2n)F^{18}$	110 m	
	1.02	$F^{19}(n,2n)F^{18}$	110 m	0.51 Mev coincidence sum peak
	1.36	$F^{19}(n,p)O^{19}$	29 s	
	1.56	$F^{19}(n,p)O^{19}$	29 s	sum peak (1.36 Mev + 0.2 Mev)
II-F	0.20	$F^{19}(n,p)O^{19}$	29 s	
	0.51	$F^{19}(n,2n)F^{18}$	110 m	
	1.02	$F^{19}(n,2n)F^{18}$	110 m	0.51 Mev coincidence sum peak

NOTE: The  $F^{19}(n,\alpha)N^{16}$  reaction will be discussed at the end of Part II

FLUORINE

TABLE III-F

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.21	1.5 m	29 s	1.5 m	375	0.96
0.51	5 m	1 m	5 m	340 (1)	0.68
0.20	5 m	1 m	5 m	266	1.4

- (1) The contribution of nitrogen present in  $\text{NH}_4\text{F}$  to the 0.51 Mev peak is equal to 132 counts. This value has been subtracted from the  $\text{N}^{13} + \text{F}^{18}$  activity.

TABLE IF-F

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for fluorine from any other element.

For other positron emitting radioisotopes than  $\text{F}^{18}$ , see Section I, Appendix II.

## GADOLINIUM

GADOLINIUM

TABLE I - Gd

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (MeV)
Gd <sup>152</sup>	0.20%	Gd <sup>152</sup> (n,p)Eu <sup>152m</sup>	96 m	0.02, 0.09, IT 0.04
		Gd <sup>152</sup> (n,p)Eu <sup>152m</sup>	9.3 h	0.12, 0.84, 0.96, β+
		Gd <sup>152</sup> (n,p)Eu <sup>152</sup>	12.4 y	0.12, 0.34, β+
		Ge <sup>152</sup> (n,2n)Gd <sup>151</sup>	120 d	0.022, 0.175, 0.08, 0.035
Gd <sup>154</sup>	2.15%	Gd <sup>154</sup> (n,p)Eu <sup>154</sup>	16 y	1.28, 0.123, 0.72, 0.25, 1.61
		Gd <sup>154</sup> (n,α)Sm <sup>151</sup>	90 y	0.022
		Gd <sup>154</sup> (n,2n)Gd <sup>153</sup>	240 d	0.097, 0.103 0.070
Gd <sup>155</sup>	14.73%	Gd <sup>155</sup> (n,p)Eu <sup>155</sup>	1.8 y	0.087, 0.015, 0.137
Gd <sup>156</sup>	20.47%	Gd <sup>156</sup> (n,p)Eu <sup>156</sup>	15.2 d	0.089, 1.23, 0.20, 2.19
		Gd <sup>156</sup> (n,α)Sm <sup>153</sup>	47 h	0.105, 0.07, 0.02, 0.64
Gd <sup>157</sup>	15.68%	Gd <sup>157</sup> (n,p)Eu <sup>157</sup>	15.2 h	0.065, 0.41, 0.16, 0.97
Gd <sup>158</sup>	24.87%	Gd <sup>158</sup> (n,p)Eu <sup>158</sup>	46 m	0.080, 0.95, 0.89, 0.18, 2.8

## GADOLINIUM

TABLE I - Gd (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$Gd^{158} (n, \alpha) Sm^{155}$	22 m	0.10, 0.25, 0.14
$Gd^{160}$	21.90%	$Gd^{160} (n, p) Eu^{160}$	~2.5 m	
		$Gd^{160} (n, \alpha) Sm^{157}$	0.5 m	0.57
		$Gd^{160} (n, 2n) Gd^{159}$	18 h	0.058, 0.36

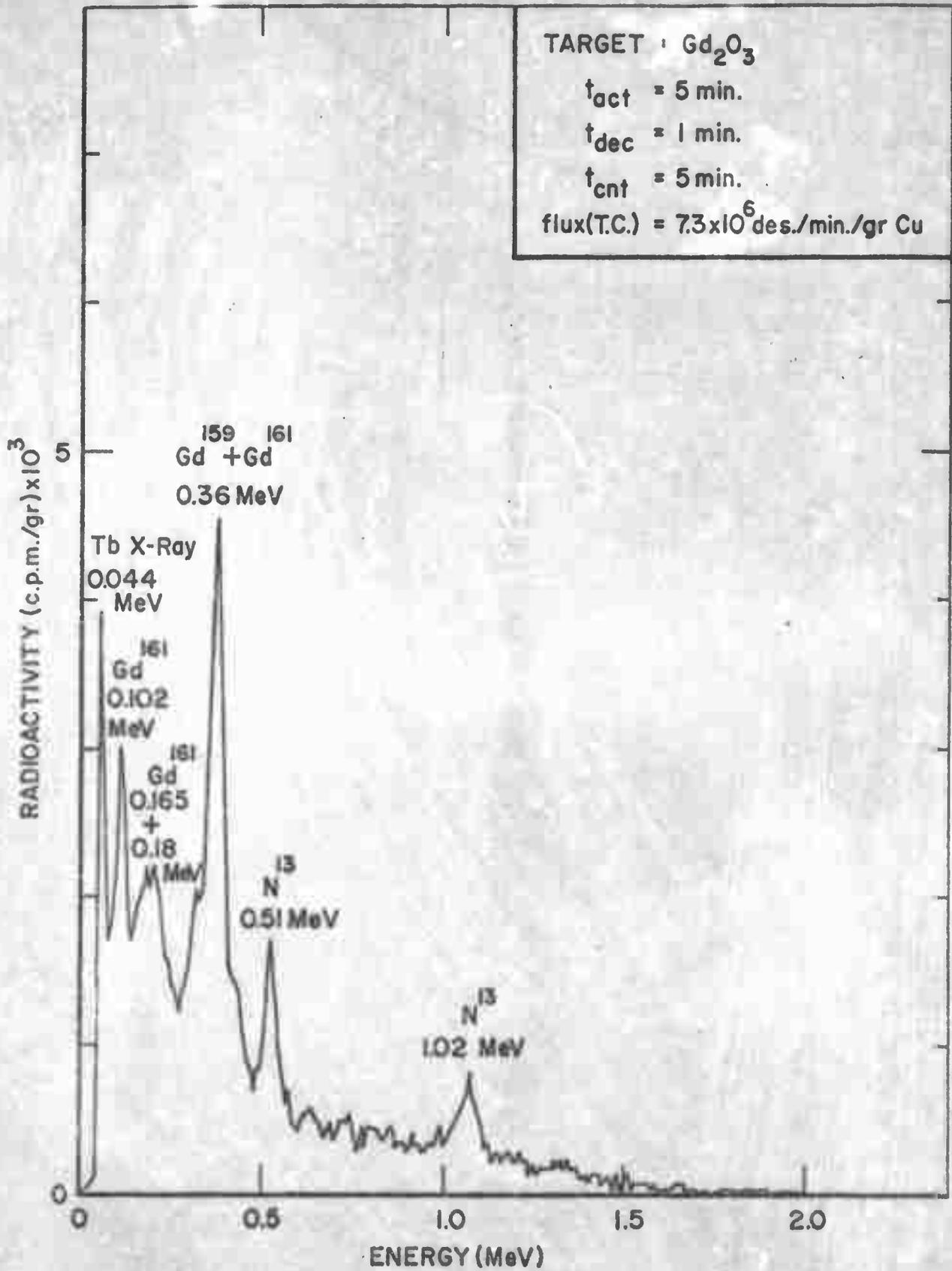


FIGURE I-Gd

## GADOLINIUM

TABLE II-Gd

## PEAKS OBSERVED IN FIGURE I-Gd

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Gd	0.044			Tb x-ray
	0.102	$Gd^{160}(n, \gamma)Gd^{161}$	3.7 m	
	0.165 + 0.18	$Gd^{160}(n, \gamma)Gd^{161}$	3.7 m	
	0.36	$Gd^{160}(n, \gamma)Gd^{161}$	3.7 m	
		$Gd^{160}(n, 2n)Gd^{159}$	18 h	

TABLE III-Gd

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.36	5 m	1 m	5 m	12	14

TABLE IV-Gd

## POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for gadolinium from any other element.

GALLIUM

GALLIUM

TABLE I -- Ga

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ga <sup>69</sup>	60.40%	Ga <sup>69</sup> (n,p)Zn <sup>69m</sup>	14 h	IT 0.44
		Ga <sup>69</sup> (n,p)Zn <sup>69</sup>	55 m	
		Ga <sup>69</sup> (n,α)Cu <sup>66</sup>	5.1 m	1.04, 0.83
		Ga <sup>69</sup> (n,2n)Ga <sup>68</sup>	68 m	1.08, 0.81, 1.88 β+
Ga <sup>71</sup>	39.60%	Ga <sup>71</sup> (n,p)Zn <sup>71m</sup>	3.9 h	0.39, 0.49, 0.61
		Ga <sup>71</sup> (n,p)Zn <sup>71</sup>	2.5 m	0.51
		Ga <sup>71</sup> (n,α)Cu <sup>68</sup>	30 s	1.08, 0.81, 1.88, 1.24
		Ga <sup>71</sup> (n,2n)Ga <sup>70</sup>	21 m	1.04 0.17

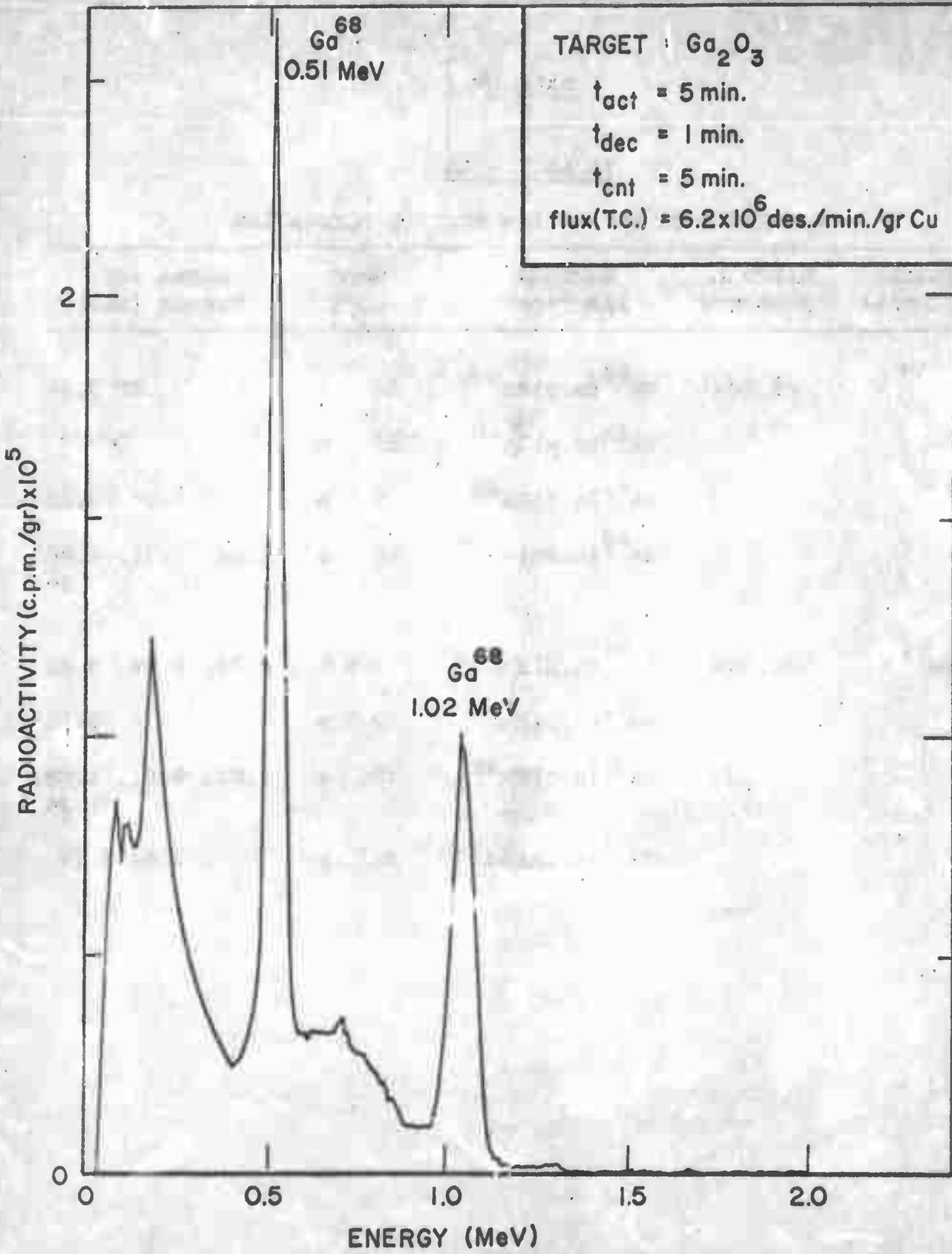


FIGURE I-Ga

TABLE II-Ga

## PEAKS OBSERVED IN FIGURE I-Ga

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ga	0.51	$\text{Ga}^{69} (n, 2n) \text{Ga}^{68}$	68 m	
	1.02	$\text{Ga}^{69} (n, 2n) \text{Ga}^{68}$	68 m	0.51 Mev coincidence sum peak

REMARK:  $\text{Cu}^{68}$  ( $T_{1/2} = 30$  sec) not detected for 1.5 min irradiation, 30 sec decay and 1.5 min counting time.

TABLE III-Ga

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{act}$	$T_{dec}$	$T_{cnt}$	COUNTS/mg/ $T_{cnt}$	DETECTION LIMIT (mg)
0.51	5 m	1 m	5 m	917	0.18

TABLE IV-Ga

## POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for gallium from any other element.

For other positron emitting radioisotopes than  $\text{Ga}^{68}$ , see Section I, Appendix II.

GERMANIUMTABLE I - Ge

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ge <sup>70</sup>	20.52%	Ge <sup>70</sup> (n,p) Ga <sup>70</sup>	21 m	1.04, 0.17
		Ge <sup>70</sup> (n,2n) Ge <sup>69</sup>	40 h	1.12, 0.58, 0.88, 0.09, 2.0, β+
Ge <sup>72</sup>	27.43%	Ge <sup>72</sup> (n,p) Ga <sup>72m</sup>	0.04s	IT 0.10
		Ge <sup>72</sup> (n,p) ↓ Ga <sup>72</sup>	14.1 h	0.84, 0.69, 0.11, 2.82
		Ge <sup>72</sup> (n,α) Zn <sup>69m</sup>	14 h	IT 0.44
		Ge <sup>72</sup> (n,α) ↓ Zn <sup>69</sup>	55 m	
		Ge <sup>72</sup> (n,2n) Ge <sup>71m</sup>	0.02s	0.175, IT 0.023
		Ge <sup>72</sup> (n,2n) ↓ Ge <sup>71</sup>	11 d	
Ge <sup>73</sup>	7.76%	Ge <sup>73</sup> (n,p) Ga <sup>73</sup>	4.8 h	0.30, 0.74, 0.054, 0.014
		Ge <sup>73</sup> (n,n') Ge <sup>73m</sup>	0.53s	IT 0.054
Ge <sup>74</sup>	36.54%	Ge <sup>74</sup> (n,p) Ga <sup>74</sup>	8 m	0.60, 2.35, 0.38, 3.4
		Ge <sup>74</sup> (n,α) Zn <sup>71m</sup>	3.9 h	0.39, 0.49, 0.61
		Ge <sup>74</sup> (n,α) ↓ Zn <sup>71</sup>	2.5 m	0.51
		Ge <sup>74</sup> (n,2n) Ge <sup>73m</sup>	0.53s	IT 0.054

## GERMANIUM

TABLE I - Ge (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
$\text{Ge}^{76}$	7.76%	$\text{Ge}^{76}(\text{n}, \text{p})\text{Ga}^{76}$	32 s	0.57, 0.96, 1.12
		$\text{Ge}^{76}(\text{n}, 2\text{n})\text{Ge}^{75\text{m}}$	49 s	IT 0.14
		$\text{Ge}^{76}(\text{n}, 2\text{n})\text{Ge}^{75}$	82 m	0.27, 0.07, 0.63

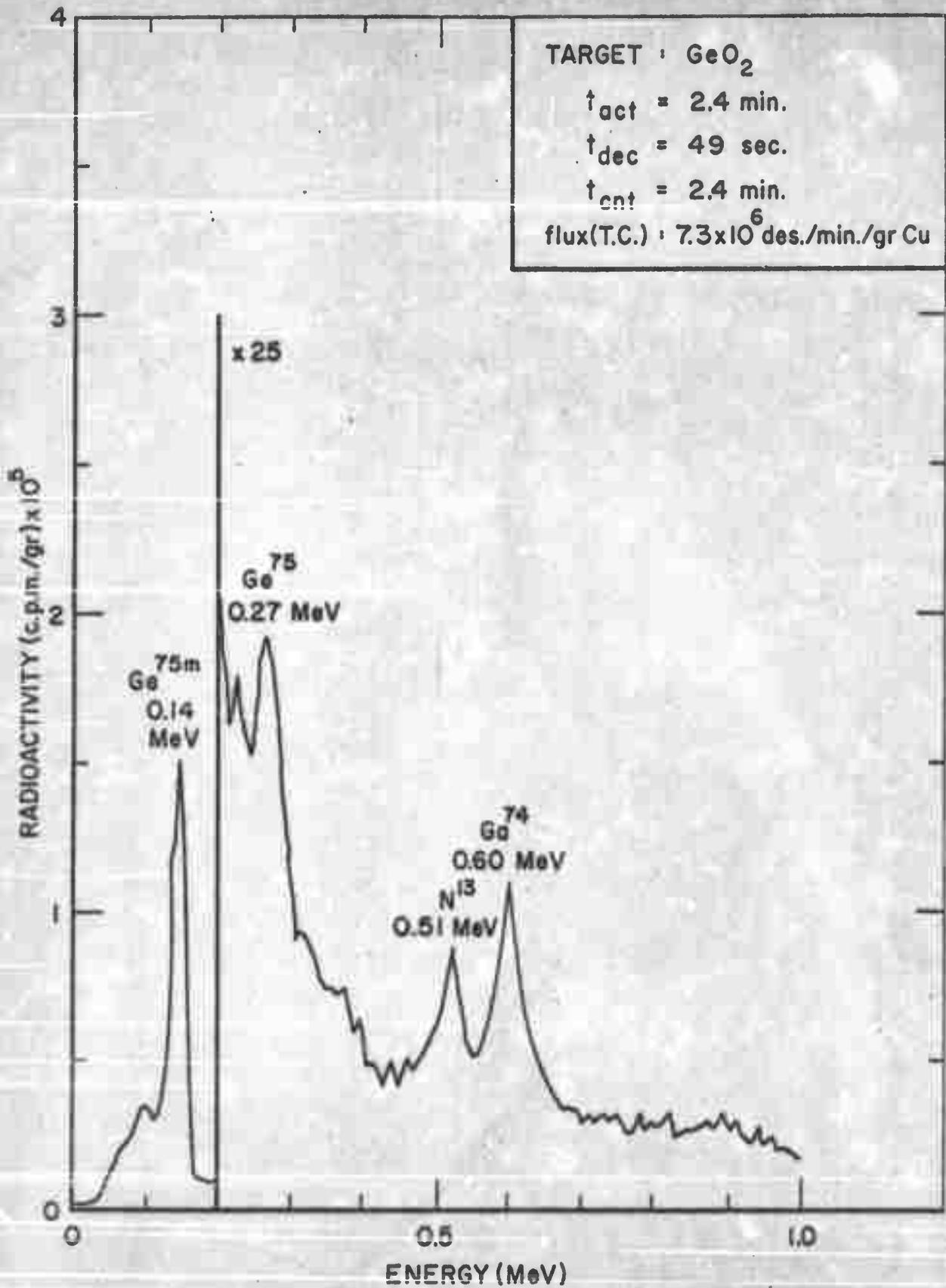


FIGURE I-Ge

TABLE II-Ge

## PEAKS OBSERVED IN FIGURE I-Ge

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ge	0.14	$\text{Ge}^{76} (n, 2n) \text{Ge}^{75m}$	49 s	
	0.27	$\text{Ge}^{76} (n, 2n) \text{Ge}^{75}$	82 m	
	0.60	$\text{Ge}^{74} (n, p) \text{Ga}^{74}$	8 m	

NOTE: A 5 minute irradiation does not bring any new gamma ray peaks.

TABLE III-Ge

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.14	2.4 m	49 s	2.4 m	198	0.38
0.14	5 m	1 m	5 m	294	0.46
0.27	5 m	1 m	5 m	34	3.4
0.60	5 m	1 m	5 m	34	5.8

TABLE IV-Ge

## POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.14	Arsenic	$\text{As}^{75} (n, p) \text{Ge}^{75m}$	

GOLD

TABLE I - Au

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Au <sup>197</sup>	100%	Au <sup>197</sup> (n,p) Pt <sup>197m</sup>	2.8 h	
		Au <sup>197</sup> (n,p) Pt <sup>197m</sup>	1.5 h	0.05, 0.28, 0.13 IT 0.346
		Au <sup>197</sup> (n,p) Pt <sup>197</sup>	20 h	0.077, 0.19, 0.27
		Au <sup>197</sup> (n,α) Ir <sup>194m</sup>	0.05s	IT 0.10
		Au <sup>197</sup> (n,α) Ir <sup>194m</sup>	19 h	0.33, 0.29, 0.65
		Au <sup>197</sup> (n,2n) Au <sup>196m</sup>	10 h	0.15, 0.19, IT 0.175
		Au <sup>197</sup> (n,2n) Au <sup>196</sup>	6.2 d	0.356, 0.333, 0.43
		Au <sup>197</sup> (n,n') Au <sup>197m</sup>	7.2 s	0.279, IT 0.130, 0.409

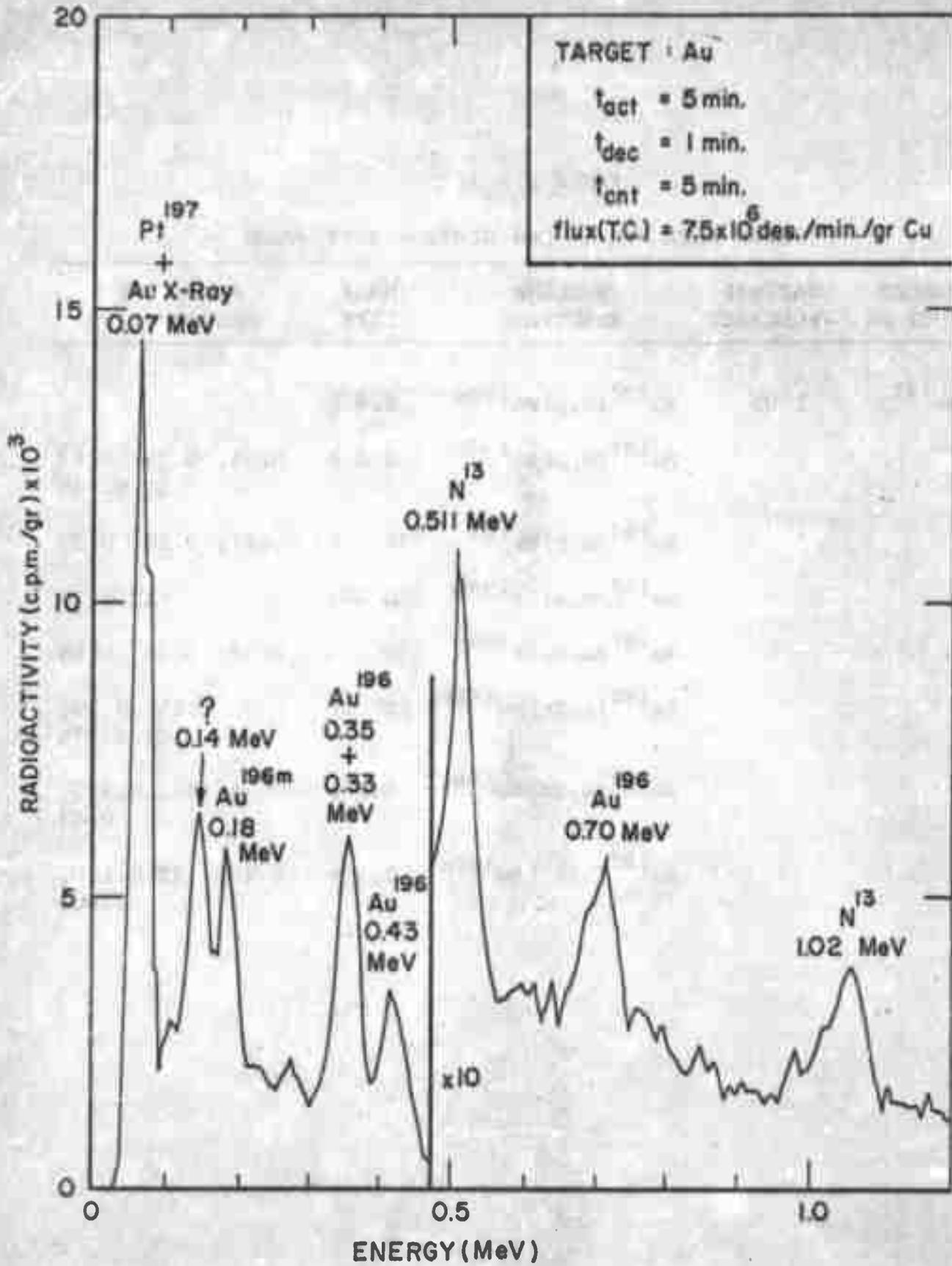


FIGURE I-Au

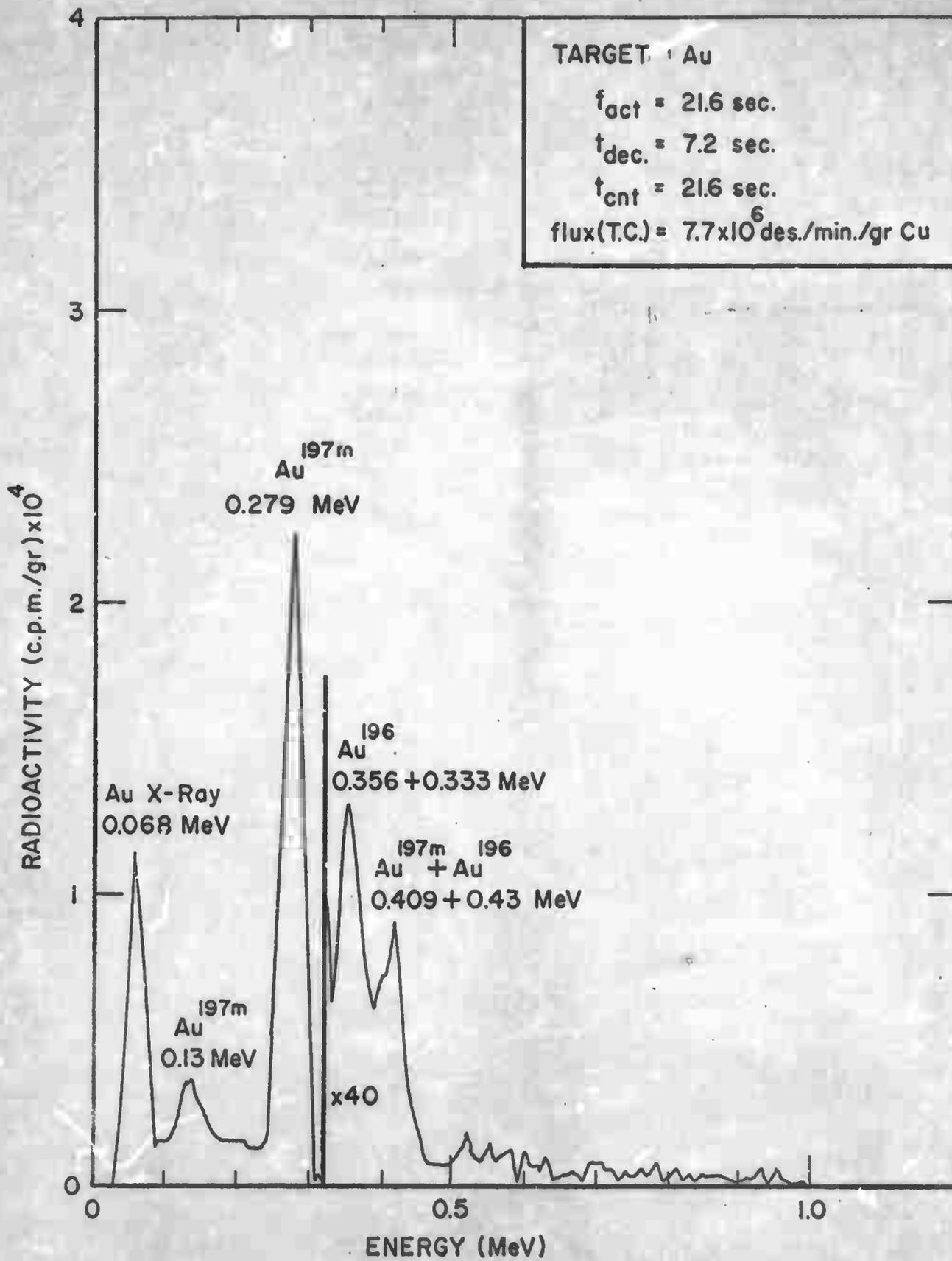


FIGURE II-Au

TABLE II-Au

## PEAKS OBSERVED IN FIGURES I-II Au

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Au	0.07 + 0.077	$\text{Au}^{197} (n,p) \text{Pt}^{197}$	20 h	Also Au x-ray
	0.14			$T_{1/2} \sim 20$ h
	0.18	$\text{Au}^{197} (n,2n) \text{Au}^{196m}$	10 h	
	0.356 + 0.331	$\text{Au}^{197} (n,2n) \text{Au}^{196}$	6.2d	
	0.43	$\text{Au}^{197} (n,2n) \text{Au}^{196}$	6.2d	
	$\sim 0.70$	$\text{Au}^{197} (n,2n) \text{Au}^{196}$	6.2d	Sum peak of 0.356 + 0.331
II-Au	0.068			Au x-ray
	0.13	$\text{Au}^{197} (n,n') \text{Au}^{197m}$	7.2s	
	0.279	$\text{Au}^{197} (n,n') \text{Au}^{197m}$	7.2s	
	0.356 + 0.333	$\text{Au}^{197} (n,2n) \text{Au}^{196}$	6.2d	
	0.409 + 0.43	$\text{Au}^{197} (n,2n) \text{Au}^{196}$	6.2d	
		$\text{Au}^{197} (n,n') \text{Au}^{197m}$	7.2s	

GOLD

TABLE III-Au

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T act	T dec	T cnt	COUNTS/mg/T cnt	DETECTION LIMIT(mg)
0.356 + 0.331	5 m	1 m	5 m	16	7.0
0.43	5 m	1 m	5 m	7	19
0.279	21,6s	7.2s	21.6s	60	0.60

TABLE IV-Au

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for gold from any other element.

## HAFNIUM

HAFNIUM

TABLE I - Hf

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Hf <sup>174</sup>	0.18%	Hf <sup>174</sup> (n,p)Lu <sup>174m</sup>	75 μs	IT 0.133
		Hf <sup>174</sup> (n,p)Lu <sup>174m</sup>	165 d	0.044, 0.99, IT 0.059
		Hf <sup>174</sup> (n,p)Lu <sup>174</sup>	300 d	0.077, 1.2
		Hf <sup>174</sup> (n,2n)Hf <sup>173</sup>	24 h	0.140, 0.124, 0.135, 0.163, 1.2
Hf <sup>176</sup>	5.2%	Hf <sup>176</sup> (n,p)Lu <sup>176m</sup>	3.7h	0.088
		Hf <sup>176</sup> (n,2n)Hf <sup>175</sup>	70 d	0.343, 0.089, 0.113, 0.432
Hf <sup>177</sup>	18.50%	Hf <sup>177</sup> (n,p)Lu <sup>177m</sup>	155 d	IT 0.12, 0.055, 0.47
		Hf <sup>177</sup> (n,p)Lu <sup>177</sup>	6.8d	0.208, 0.113, 0.07, 0.32
		Hf <sup>177</sup> (n,α)Yb <sup>174</sup>	0.001s	0.27, 0.18, 0.076, IT 1.00 1.28
Hf <sup>178</sup>	27.14%	Hf <sup>178</sup> (n,p)Lu <sup>178m</sup>	30 m	0.089, 0.093, 0.43
		Hf <sup>178</sup> (n,p)Lu <sup>178</sup>	5 m	0.33, 0.089, 0.093, 0.43
		Hf <sup>178</sup> (n,α)Yb <sup>175m</sup>	0.067s	IT 0.50

## HAFNIUM

TABLE I - Hf (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$\text{Hf}^{178} (n, \alpha) \text{Yb}^{175}$	4.2 d	0.40, 0.11, 0.28, 0.14, 0.25
		$\text{Hf}^{178} (n, n') \text{Hf}^{178m}$	4.3 s	0.093, 0.43, IT 0.089
$\text{Hf}^{179}$	13.95%	$\text{Hf}^{179} (n, p) \text{Lu}^{179}$	4.6 h	0.22, 0.05
		$\text{Hf}^{179} (n, \alpha) \text{Yb}^{176m}$	12 s	0.29, 0.39, IT 0.19
		$\text{Hf}^{179} (n, 2n) \text{Hf}^{178m}$	4.3 s	0.093, 0.43, IT 0.089
		$\text{Hf}^{179} (n, n') \text{Hf}^{179m}$	19 s	0.217, IT 0.161
$\text{Hf}^{180}$	35.24%	$\text{Hf}^{180} (n, p) \text{Lu}^{180}$	2.5 m	
		$\text{Hf}^{180} (n, \alpha) \text{Yb}^{177m}$	6.5 s	0.10, IT 0.23
		$\text{Hf}^{180} (n, \alpha) \text{Yb}^{177}$	1.9 h	0.15, 0.12, 0.11, 0.14, 1.24
		$\text{Hf}^{180} (n, 2n) \text{Hf}^{179m}$	19 s	IT 0.161, 0.217
		$\text{Hf}^{180} (n, n') \text{Hf}^{180m}$	5.5 h	0.093, 0.44, IT 0.058, 0.50

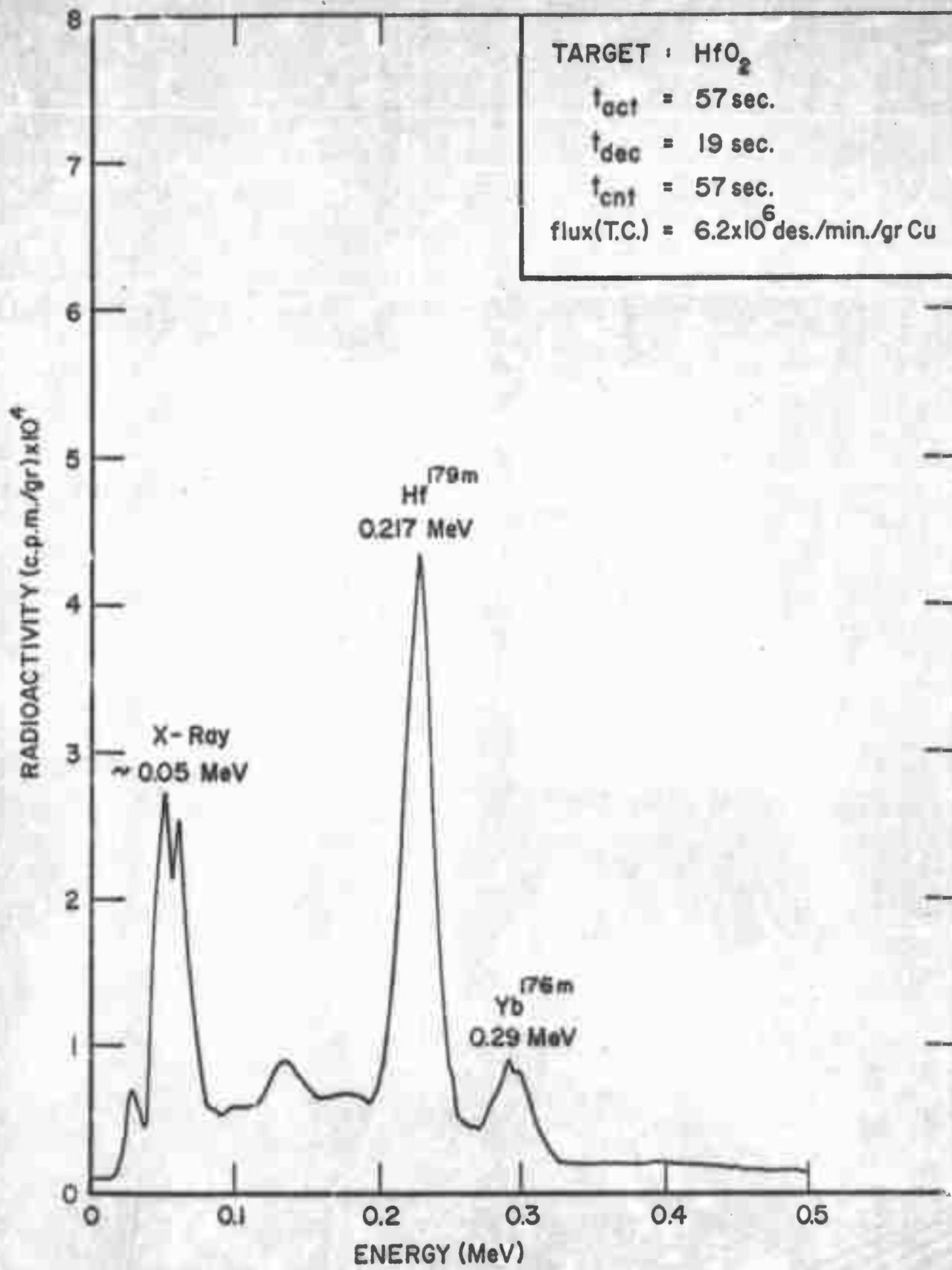


FIGURE I-Hf

TABLE II-Hf

## PEAKS OBSERVED IN FIGURE I-Hf

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Hf	0.217	Hf <sup>180</sup> (n, 2n) Hf <sup>179m</sup>	19 s	(1)
		Hf <sup>179</sup> (n, n') Hf <sup>179m</sup>	19 s	
	0.29	Hf <sup>179</sup> (n, α) Yb <sup>176m</sup>	12 s	
	~0.05			Hf x-ray

REMARKS: The decay curve on the 0.217 Mev photopeak shows a 19 second half life. This means that the activity due to Yb<sup>177m</sup> (T<sub>1/2</sub> = 6.5 s) is negligible.

A five minute irradiation of hafnium does not show up other useful analytical gamma ray peaks.

A 10 second irradiation shows up a very low level of activity at 0.32 Mev and 0.43 Mev due to Hf<sup>178m</sup> (T = 4.3 s).

TABLE III-Hf

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.217	57 s	19 s	57 s	171	1.0
0.29	57 s	19 s	57 s	20	6.9

HAFNIUM

TABLE IV-Hf

POSSIBLE INTERFERING REACTIONS

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No detectable interferences could be derived for hafnium from any other element.

INDIUMTABLE I - In

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (MeV)
In <sup>113</sup>	4.28%	In <sup>113</sup> (n,p)Cd <sup>113</sup>	14 y	IT 0.27
		In <sup>113</sup> (n,α)Ag <sup>110m</sup>	260 d	0.66, 0.88, IT 0.12
		In <sup>113</sup> (n,α)Ag <sup>110</sup>	24 s	0.66
		In <sup>113</sup> (n,2n)In <sup>112m</sup>	0.042s	IT 0.31
		In <sup>113</sup> (n,2n)In <sup>112m</sup>	21 m	IT 0.155
		In <sup>113</sup> (n,2n)In <sup>112</sup>	14 m	0.62, 0.71, β+
		In <sup>113</sup> (n,n')In <sup>113m</sup>	1.73h	IT 0.39
In <sup>115</sup>	95.72%	In <sup>115</sup> (n,p)Cd <sup>115m</sup>	43 d	0.94, 0.17, 1.56
		In <sup>115</sup> (n,p)Cd <sup>115</sup>	2.3 d	0.52, 0.34
		In <sup>115</sup> (n,α)Ag <sup>112</sup>	3.2 h	0.62, 1.4, 0.69, 3.28
		In <sup>115</sup> (n,2n)In <sup>114m</sup>	2.5 s	IT 0.150
		In <sup>115</sup> (n,2n)In <sup>114m</sup>	50 d	0.72, 0.56, IT 0.191
		In <sup>115</sup> (n,2n)In <sup>114</sup>	72 s	β+
		In <sup>115</sup> (n,n')In <sup>115m</sup>	4.4 h	IT 0.34

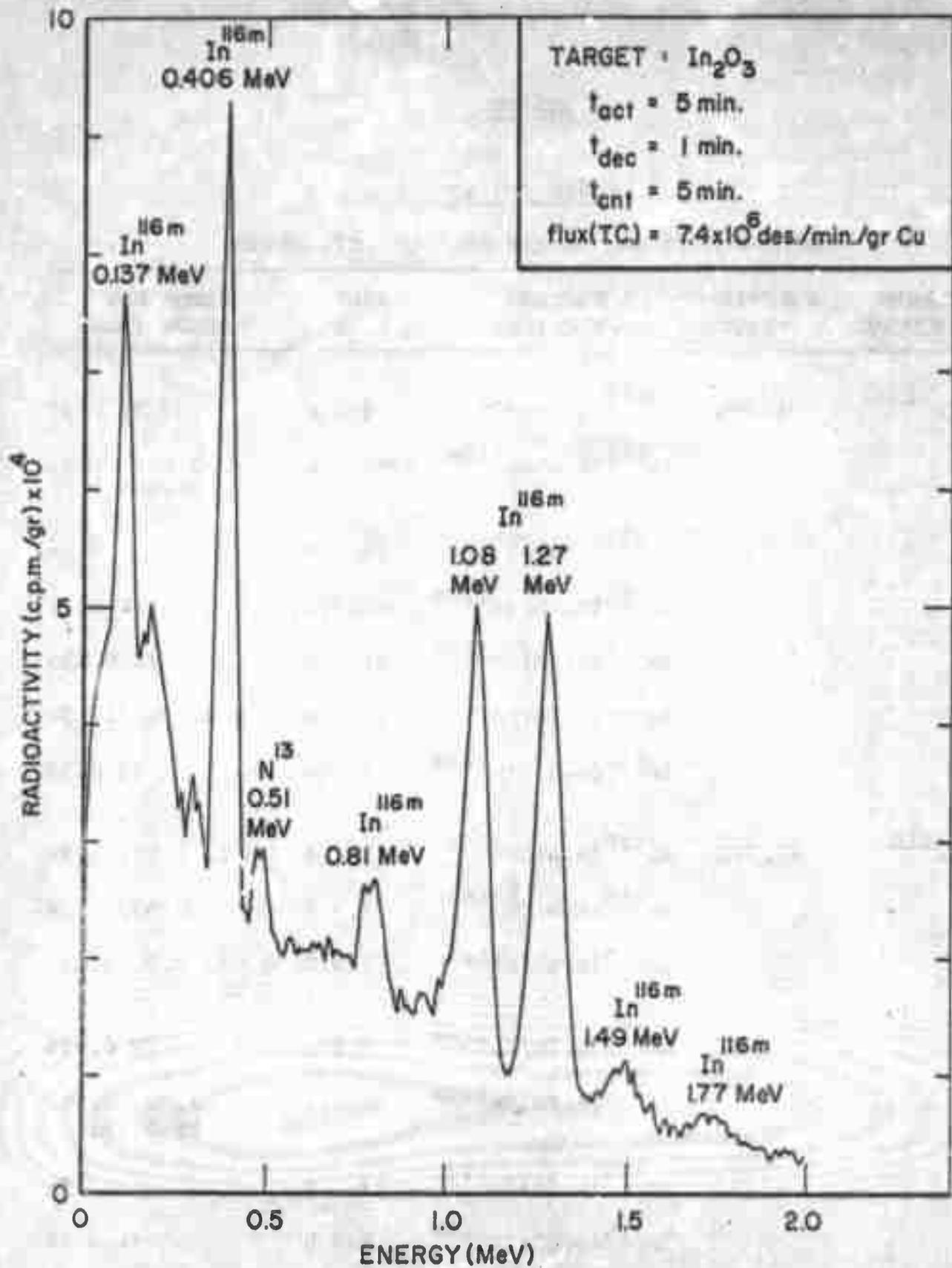


FIGURE I-In

TABLE II-In

## PEAKS OBSERVED IN FIGURE I-In

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-In	0.137	$\text{In}^{115} (n, \gamma) \text{In}^{116m}$	54 m	
	0.406	$\text{In}^{115} (n, \gamma) \text{In}^{116m}$	54 m	
	0.81	$\text{In}^{115} (n, \gamma) \text{In}^{116m}$	54 m	
	1.08	$\text{In}^{115} (n, \gamma) \text{In}^{116m}$	54 m	
	1.27	$\text{In}^{115} (n, \gamma) \text{In}^{116m}$	54 m	
	1.49	$\text{In}^{115} (n, \gamma) \text{In}^{116m}$	54 m	
	1.77	$\text{In}^{115} (n, \gamma) \text{In}^{116m}$	54 m	

TABLE III-In

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.137	5 m	1 m	5 m	71	2.0
0.406	5 m	1 m	5 m	250	0.30
1.08	5 m	1 m	5 m	240	0.41
1.27	5 m	1 m	5 m	252	0.40

REMARK: The activity induced will depend largely from the thermal neutron flux present at the sample.

INDIUM

TABLE IV-In

POSSIBLE INTERFERING REACTIONS

---

No detectable interferences could be derived for Indium from any other element.

IRIDIUM

IRIDIUM

TABLE I - Ir

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)		
Ir <sup>191</sup>	37.3%	Ir <sup>191</sup> (n,p) Os <sup>191m</sup>	14 h	IT 0.014		
		Ir <sup>191</sup> (n,p) Os <sup>191</sup>	15 d	0.042, 0.129		
		Ir <sup>191</sup> (n,α) Re <sup>188m</sup>	19 m	0.06, 0.11, 0.09, IT 0.002, 0.02		
		Ir <sup>191</sup> (n,α) Re <sup>188</sup>	17 h	0.155, 0.218, 1.96		
		Ir <sup>191</sup> (n,2n) Ir <sup>190m</sup>	3.2 h	0.19, 0.36, β+		
		Ir <sup>191</sup> (n,2n) Ir <sup>190m</sup>	1.2 h	IT 0.026		
		Ir <sup>191</sup> (n,2n) Ir <sup>190</sup>	12 d	0.19, 0.60, 0.56, 0.2, 1.3, 0.52		
		Ir <sup>191</sup> (n,n') Ir <sup>191m</sup>	4.9 s	0.129, 0.047, 0.082, IT 0.042		
		Ir <sup>193</sup>	62.7%	Ir <sup>193</sup> (n,p) Os <sup>193</sup>	32 h	0.139, 0.073, 0.107, 0.56
				Ir <sup>193</sup> (n,α) Re <sup>190m</sup>	2.8 h	
Ir <sup>193</sup> (n,α) Re <sup>190</sup>	3 m			0.19, 0.57, 0.39, 0.83		
Ir <sup>193</sup> (n,2n) Ir <sup>192m</sup>	~600 y			IT 0.161		
Ir <sup>193</sup> (n,2n) Ir <sup>192m</sup>	1.4 m			IT 0.058		
Ir <sup>193</sup> (n,2n) Ir <sup>192</sup>	74 d			0.32, 0.47, 0.2, 2.0		
Ir <sup>193</sup> (n,n') Ir <sup>193m</sup>	12 d			IT 0.08		

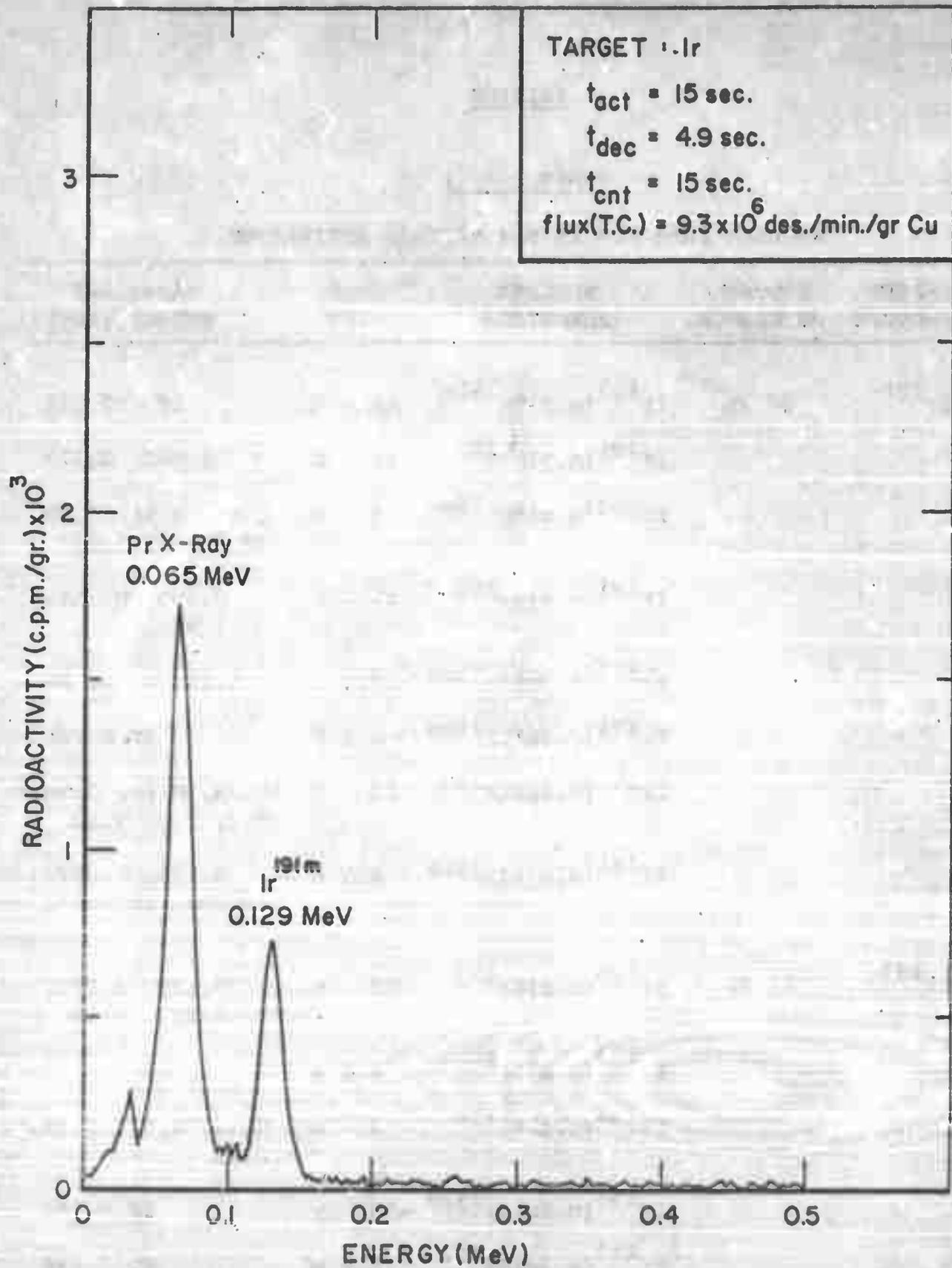


FIGURE I-Ir

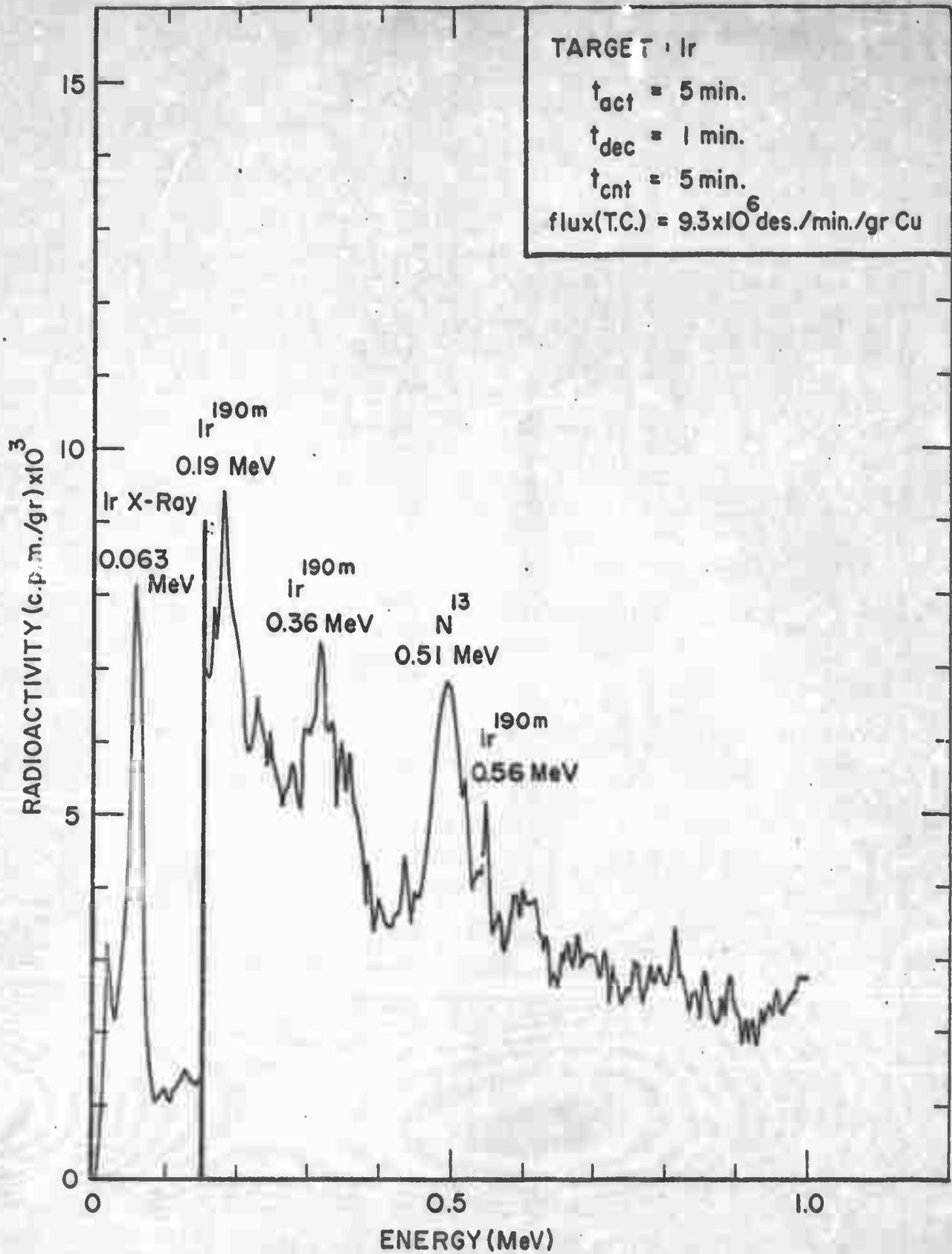


FIGURE II-Ir

TABLE II-Ir

## PEAKS OBSERVED IN FIGURE I-Ir

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ir	0.065			Ir x-ray
	0.129	$\text{Ir}^{191}(n,n')\text{Ir}^{191m}$	4.9 s	
II-Ir	0.063			Ir x-ray
	0.19	$\text{Ir}^{191}(n,2n)\text{Ir}^{190m}$	3.2 h	
	0.36	$\text{Ir}^{191}(n,2n)\text{Ir}^{190m}$	3.2 h	
	0.56	$\text{Ir}^{191}(n,2n)\text{Ir}^{190m}$	3.2 h	

TABLE III-Ir

## SENSITIVITIES FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT(mg)
0.065	15 s	4.9s	15 s	5	14
0.129	15 s	4.9s	15 s	2	18
0.063	5 m	1 m	5 m	15	10

TABLE IV-Ir

## POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for iridium from any other element.

IRONTABLE I - Fe

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Fe <sup>54</sup>	5.82%	Fe <sup>54</sup> (n,p)Mn <sup>54</sup>	303 d	0.84
		Fe <sup>54</sup> (n,α)Cr <sup>51</sup>	27.8 d	0.32
		Fe <sup>54</sup> (n,2n)Fe <sup>53</sup>	8.5 m	0.38 β+
Fe <sup>56</sup>	91.66%	Fe <sup>56</sup> (n,p)Mn <sup>56</sup>	2.58h	0.845, 1.81, 2.11
		Fe <sup>56</sup> (n,2n)Fe <sup>55</sup>	2.7 y	
Fe <sup>57</sup>	2.19%	Fe <sup>57</sup> (n,p)Mn <sup>57</sup>	1.7 m	1.22, 0.014, 0.137, 0.22, 0.71
Fe <sup>58</sup>	0.33%	Fe <sup>58</sup> (n,p)Mn <sup>58</sup>	1.1 m	
		Fe <sup>58</sup> (n,α)Cr <sup>55</sup>	3.5 m	

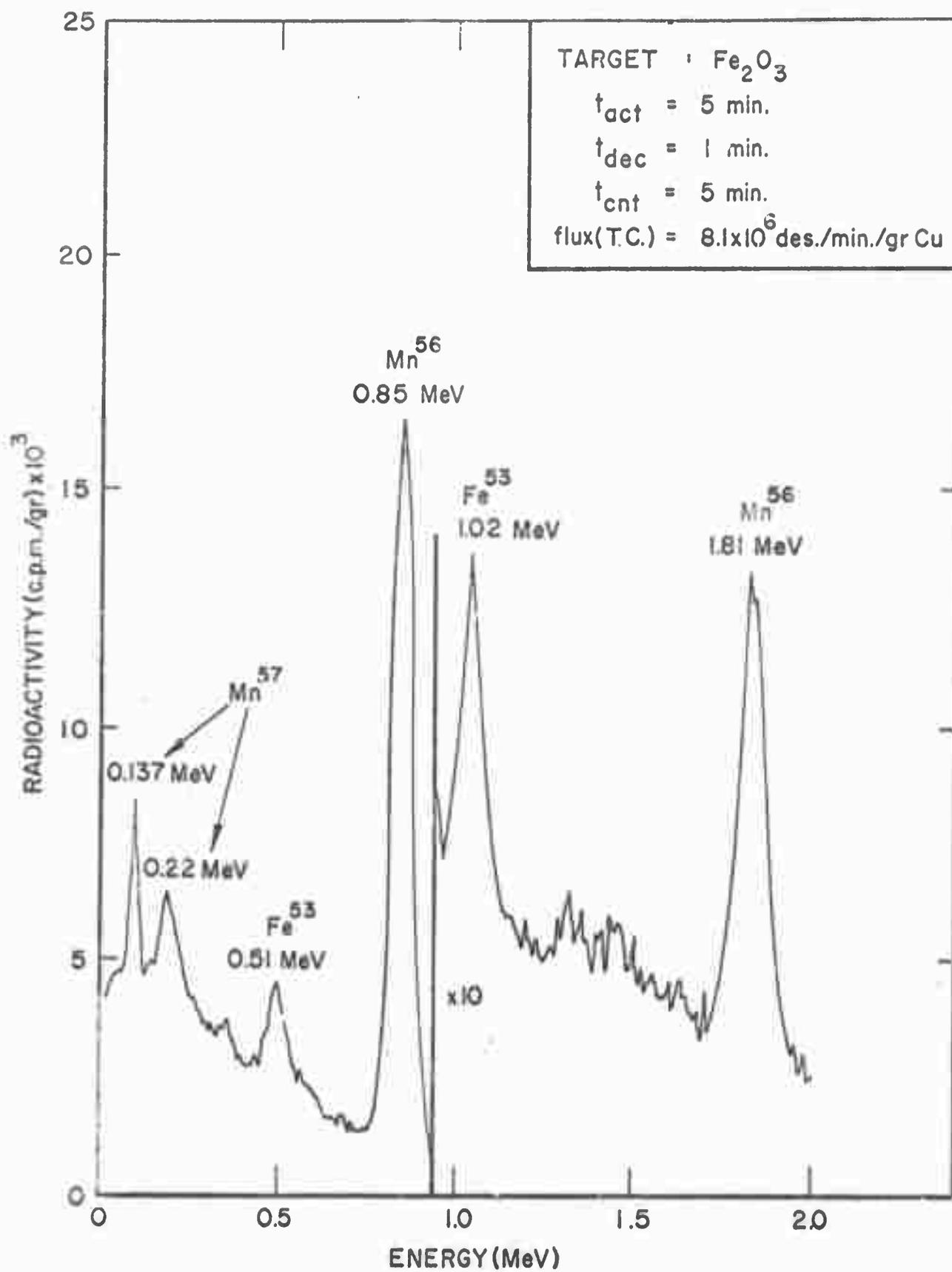


FIGURE I-Fe

TABLE II-Fe

## PEAKS OBSERVED IN FIGURE I-Fe

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Fe	0.137	$Fe^{57} (n,p) Mn^{57}$	1.7 m	
	0.22	$Fe^{57} (n,p) Mn^{57}$	1.7 m	
	0.51	$Fe^{54} (n,2n) Fe^{53}$	8.5 m	
	1.02	$Fe^{54} (n,2n) Fe^{53}$	8.5 m	0.51 Mev coincidence sum peak
	0.845	$Fe^{56} (n,p) Mn^{56}$	2.58h	
	1.81	$Fe^{56} (n,p) Mn^{56}$	2.58h	

TABLE III-Fe

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.845	5 m	1 m	5 m	86	1.3

TABLE IV-Fe

## POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.845	Cobalt	$Co^{59} (n,\alpha) Mn^{56}$	
	Manganese	$Mn^{55} (n,\gamma) Mn^{56}$	

## LEAD

LEADTABLE I-Pb

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (MeV)
Pb <sup>204</sup>	1.48%	Pb <sup>204</sup> (n,p) Tl <sup>204</sup>	3.8 y	
		Pb <sup>204</sup> (n,α) Hg <sup>201m</sup>	100μs	IT 0.53
		Pb <sup>204</sup> (n,2n) Pb <sup>203m</sup>	6.1 s	IT 0.83
		Pb <sup>204</sup> (n,2n) Pb <sup>203</sup>	52 h	0.28, 0.40, 0.68
		Pb <sup>204</sup> (n,n') Pb <sup>204m</sup>	67 m	0.29, 0.90, 0.375, IT 0.91
Pb <sup>206</sup>	23.60%	Pb <sup>206</sup> (n,p) Tl <sup>206</sup>	4.3 m	
		Pb <sup>206</sup> (n,α) Hg <sup>203</sup>	47 d	0.279
		Pb <sup>206</sup> (n,2n) Pb <sup>205m</sup>	0.004 s	0.99, IT 0.026
		Pb <sup>206</sup> (n,2n) Pb <sup>205</sup>	3 x 10 <sup>7</sup> y	
Pb <sup>207</sup>	22.60%	Pb <sup>207</sup> (n,p) Tl <sup>207</sup>	4.78 m	0.89
		Pb <sup>207</sup> (n,n') Pb <sup>207m</sup>	0.8 s	0.57, IT 1.06
Pb <sup>208</sup>	52.30%	Pb <sup>208</sup> (n,p) Tl <sup>208</sup>	3.1 m	2.61, 0.58, 0.51, 0.23, 1.09
		Pb <sup>208</sup> (n,α) Hg <sup>205</sup>	5.2 m	0.20
		Pb <sup>208</sup> (n,2n) Pb <sup>207m</sup>	0.8 s	0.57, IT 1.06

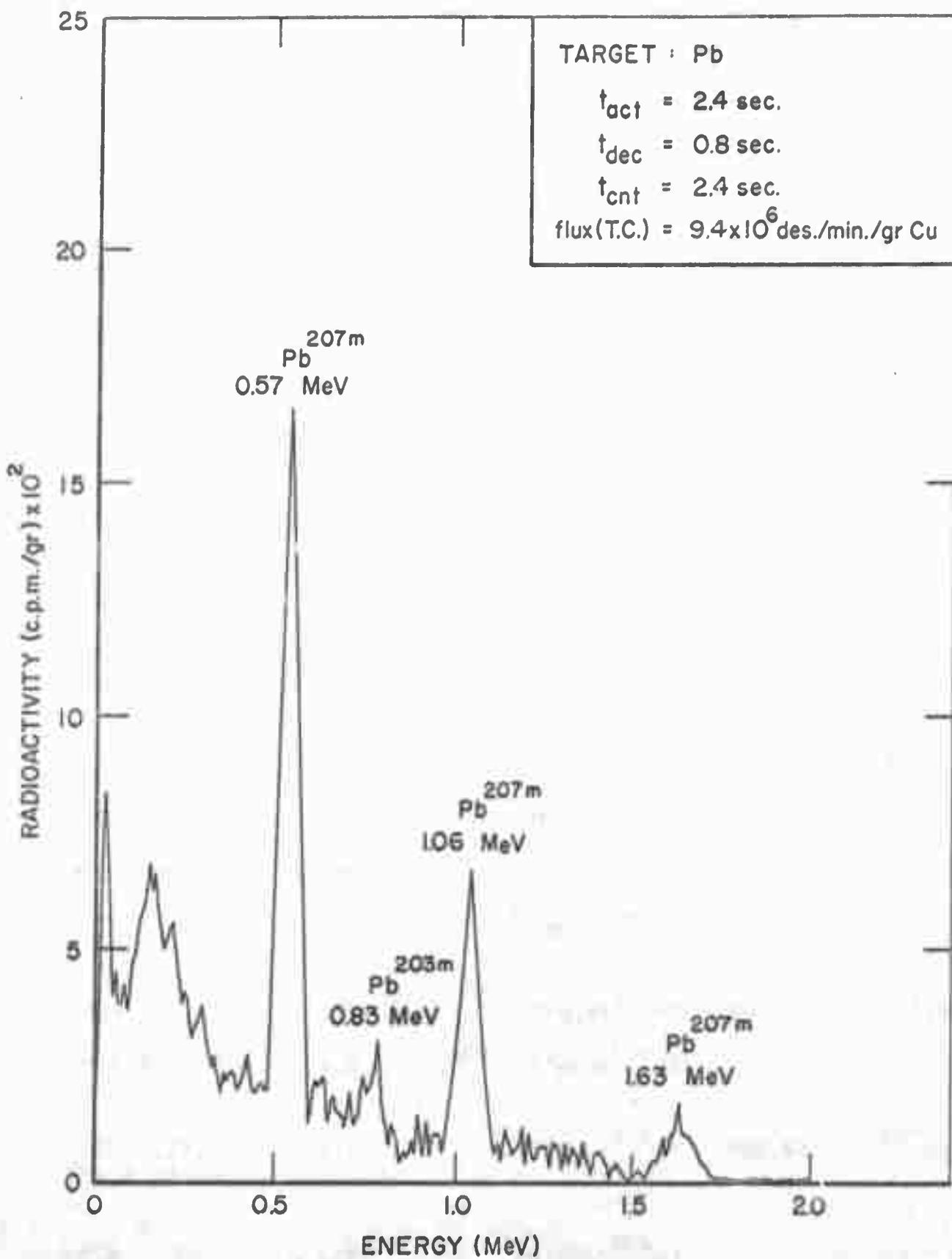


FIGURE I-Pb

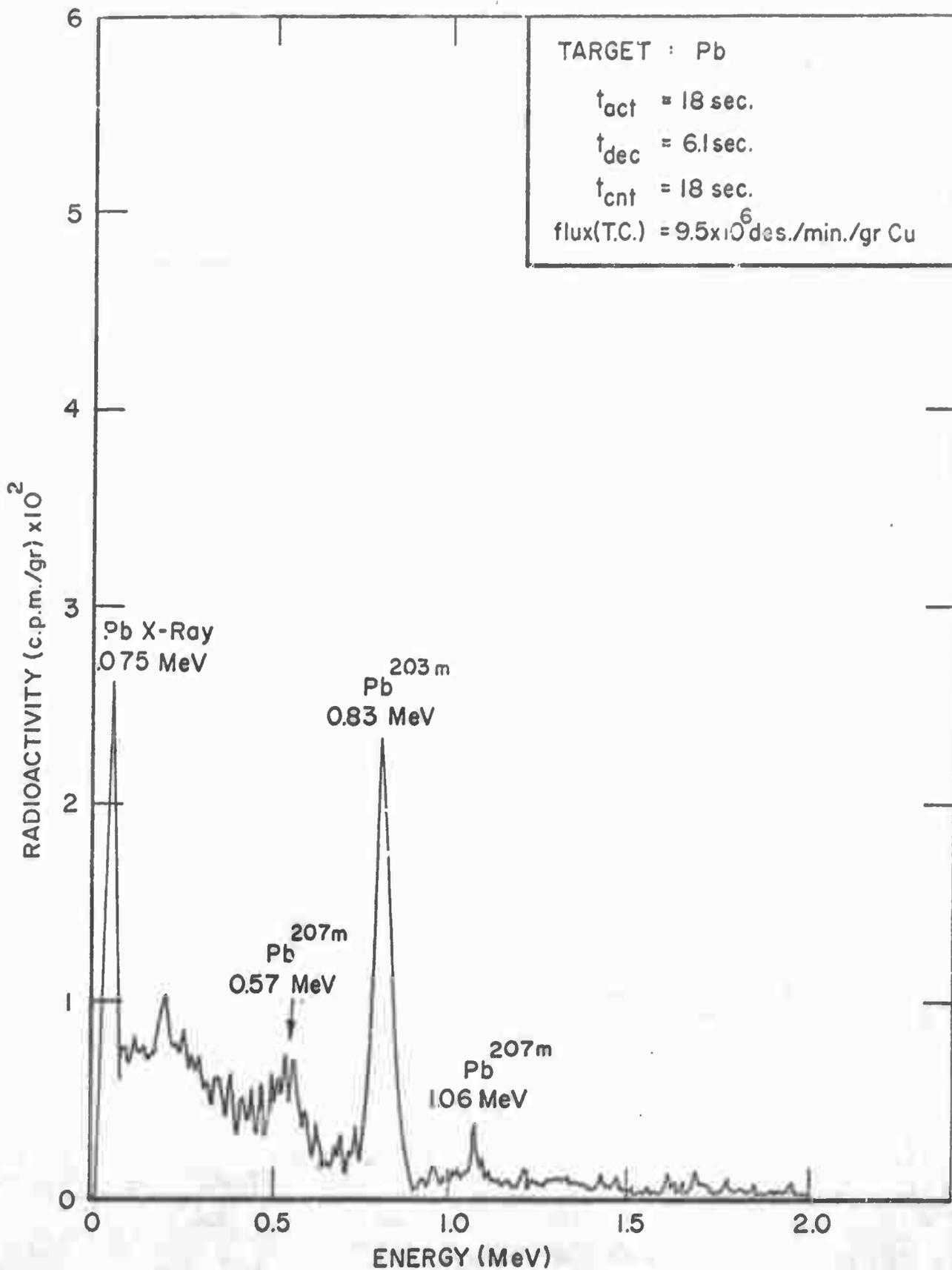


FIGURE II-Pb

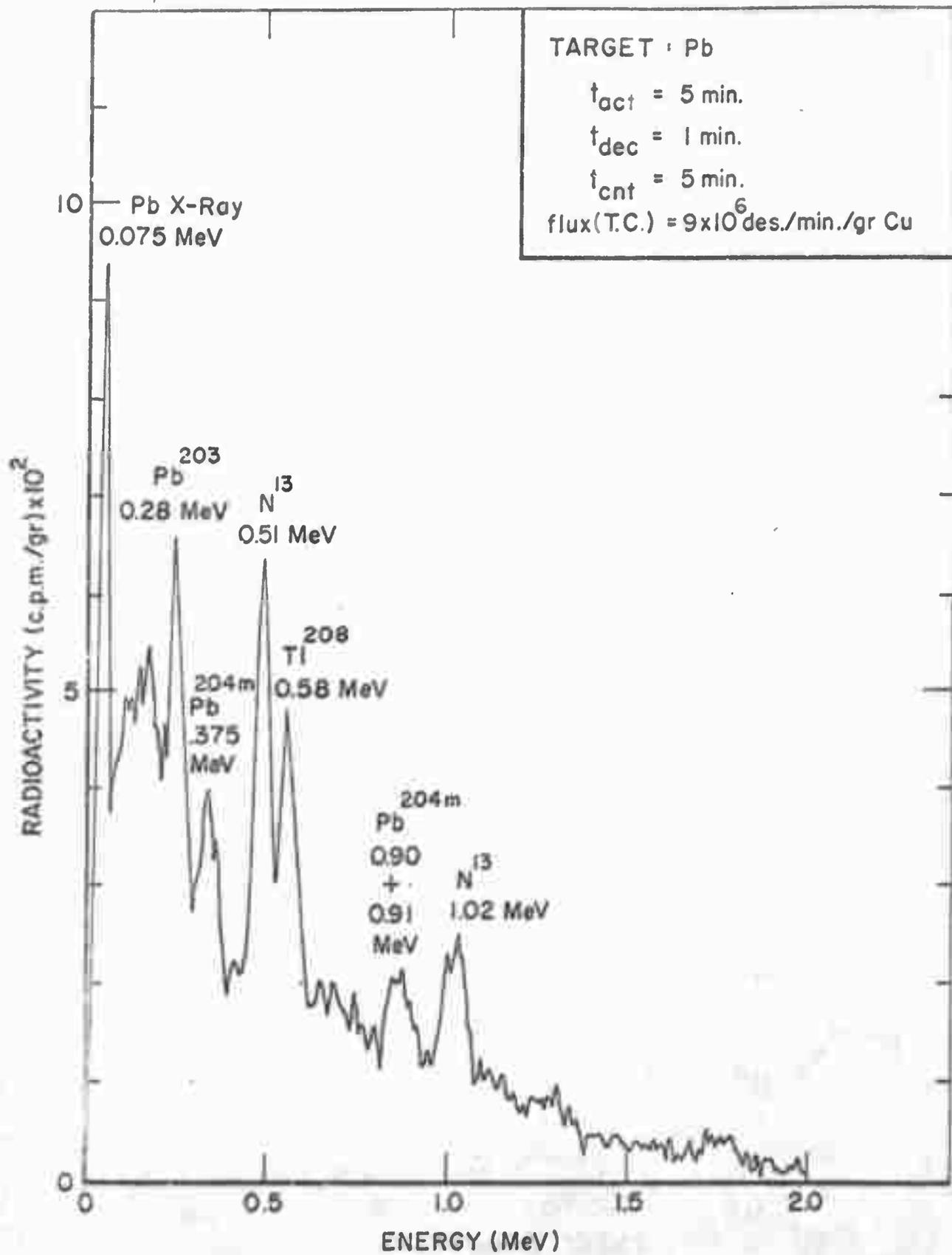


FIGURE III-Pb

TABLE II-Pb

PEAKS OBSERVED IN FIGURES I, II, and III-Pb

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Pb	0.57	$\text{Pb}^{207} (n, n') \text{Pb}^{207m}$	0.8 s	
		$\text{Pb}^{208} (n, 2n) \text{Pb}^{207m}$	0.8 s	
	0.83	$\text{Pb}^{204} (n, 2n) \text{Pb}^{203m}$	6.1 s	
	1.06	$\text{Pb}^{207} (n, n') \text{Pb}^{207m}$	0.8 s	
		$\text{Pb}^{208} (n, 2n) \text{Pb}^{207m}$	0.8 s	
	1.63	$\text{Pb}^{207} (n, n') \text{Pb}^{207m}$	0.8 s	1.06 + 0.57 sum peak
		$\text{Pb}^{208} (n, 2n) \text{Pb}^{207m}$	0.8 s	
II-Pb	0.075			Pb x-ray
	0.59	$\text{Pb}^{207} (n, n') \text{Pb}^{207m}$	0.8 s	
		$\text{Pb}^{208} (n, 2n) \text{Pb}^{207m}$	0.8 s	
	0.83	$\text{Pb}^{204} (n, 2n) \text{Pb}^{203m}$	6.1 s	
	1.06	$\text{Pb}^{207} (n, n') \text{Pb}^{207m}$	0.8 s	
		$\text{Pb}^{208} (n, 2n) \text{Pb}^{207m}$	0.8 s	
III-Pb	0.075			Pb x-ray
	0.28	$\text{Pb}^{204} (n, 2n) \text{Pb}^{203}$	52 h	
	0.375	$\text{Pb}^{204} (n, n') \text{Pb}^{204m}$	64 m	
	0.58	$\text{Pb}^{208} (n, p) \text{Tl}^{208}$	3.1 m	
	0.90 + 0.91	$\text{Pb}^{204} (n, n') \text{Pb}^{204m}$	52 h	

## LEAD

TABLE III-Pb

## SENSITIVITIES FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)	
					1X	5X
0.075	18.3s	6.1s	18.3s	0.4	49	25
0.83	18.3s	6.1s	18.3s	1.0	22	12
0.57	2.4s	0.8s	2.4s	5	7.8	3.5
1.06	2.4s	0.8s	2.4s	3	7.5	5.0
0.075	5 m	1 m	5 m	0.8	132	
0.28	5 m	1 m	5 m	0.5	217	

REMARK: Because of the very short half life of Pb<sup>207m</sup> (0.8 sec) and Pb<sup>203m</sup> (6.1sec) five irradiations have been performed, and their spectra accumulated. The 7<sup>th</sup> column refers to the sensitivities obtained after five irradiations.

TABLE IV-Pb

## POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for lead from any other element.

## LUTETIUM

LUTETIUMTABLE I - Lu

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Lu <sup>175</sup>	97.41%	Lu <sup>175</sup> (n,p)Yb <sup>175m</sup>	0.067 s	IT 0.50
		↓		
		Yb <sup>175</sup>	4.2 d	0.40, 0.11, 0.28, 0.14, 0.25
		Lu <sup>175</sup> (n,α)Tm <sup>172</sup>	64 h	0.79, 0.18, 1.09
		Lu <sup>175</sup> (n,2n)Lu <sup>174m</sup>	75 μs	IT 0.133
		Lu <sup>175</sup> (n,2n)Lu <sup>174m</sup>	165 d-	0.044, 0.99, IT 0.059
		Lu <sup>175</sup> (n,2n)Lu <sup>174</sup>	300 d	0.077, 1.2
Lu <sup>176</sup>	2.59%	Lu <sup>176</sup> (n,p)Yb <sup>176m</sup>	12 s	0.29, 0.39, IT 0.19
		Lu <sup>176</sup> (n,α)Tm <sup>173</sup>	8.2 h	0.40, 0.47
		Lu <sup>176</sup> (n,n')Lu <sup>176m</sup>	3.7 h	0.088(?)

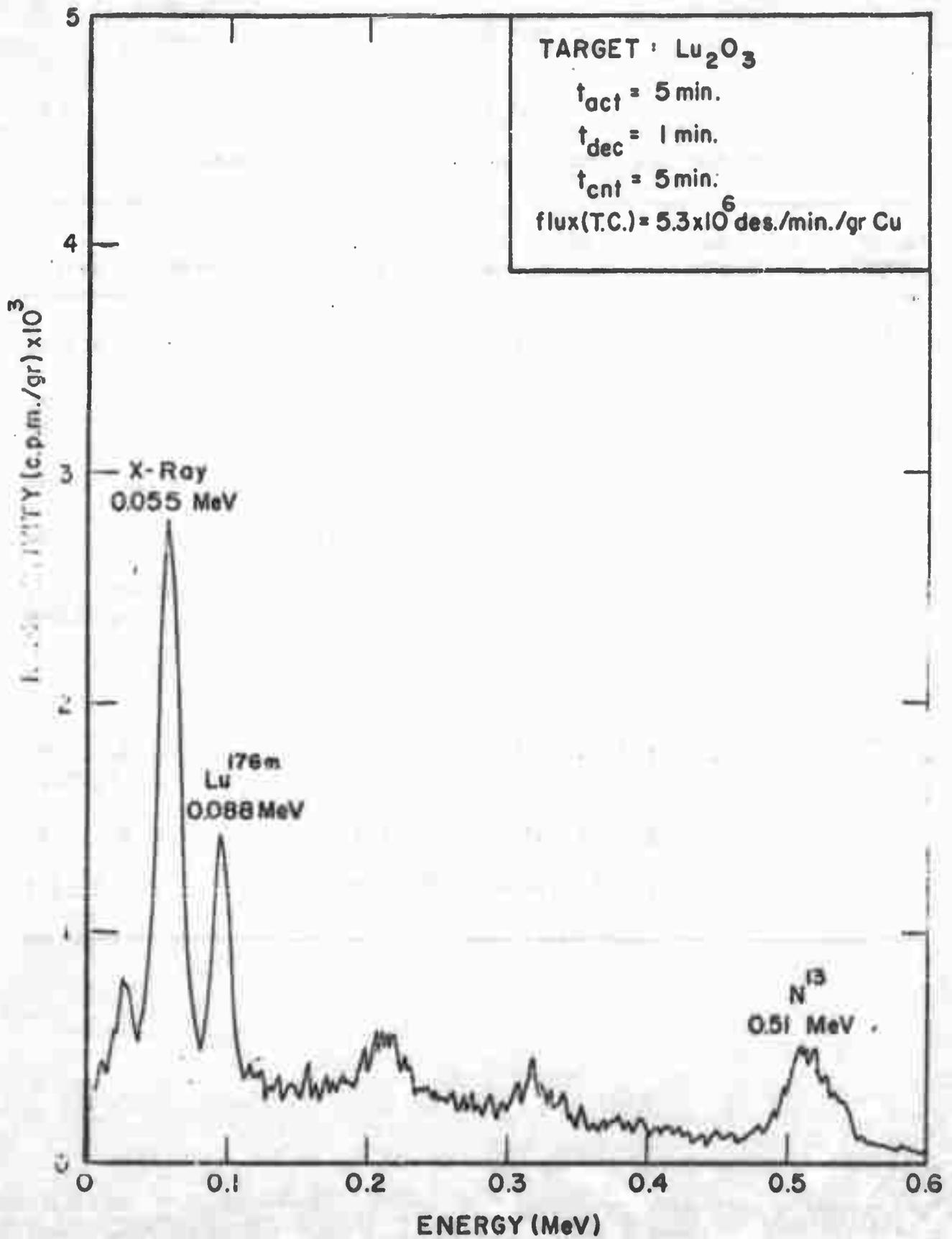


FIGURE I-Lu

## LUTETIUM

TABLE II-Lu

PEAKS OBSERVED IN FIGURE I-Lu

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Lu	0.055			x-ray
	0.088	$\text{Lu}^{176}(\text{n}, \text{n}')\text{Lu}^{176\text{m}}$	3.7 h	0.088

NOTE:  $\text{Yb}^{176\text{m}}$  ( $T_{1/2}+12$  sec) not detected for 36 sec irradiation, 12 sec decay and 36 sec counting time.

TABLE III-Lu

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{\text{act}}$	$T_{\text{dec}}$	$T_{\text{cnt}}$	COUNTS/ mg/ $T_{\text{cnt}}$	DETECTION LIMIT, mg
0.055	5 m	1 m	5 m	13	7.5
0.088	5 m	1 m	5 m	5	14.5

TABLE IV-Lu

POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for lutetium from any other element.

MAGNESIUMTABLE I-Mg

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Mg <sup>24</sup>	78.7 %	Mg <sup>24</sup> (n,p)Na <sup>24m</sup>	0.02 s	IT 0.47
		Mg <sup>24</sup> (n,p)Na <sup>24</sup>	15 h	2.75, 1.37
		Mg <sup>24</sup> (n,2n)Mg <sup>23</sup>	12 s	0.44, β+
Mg <sup>25</sup>	10.13%	Mg <sup>25</sup> (n,p)Na <sup>25</sup>	60 s	0.98, 0.58, 0.40, 1.61
Mg <sup>26</sup>	11.17%	Mg <sup>26</sup> (n,p)Na <sup>26</sup>	1 s	1.83
		Mg <sup>26</sup> (n,α)Ne <sup>23</sup>	38 s	0.44, 1.65

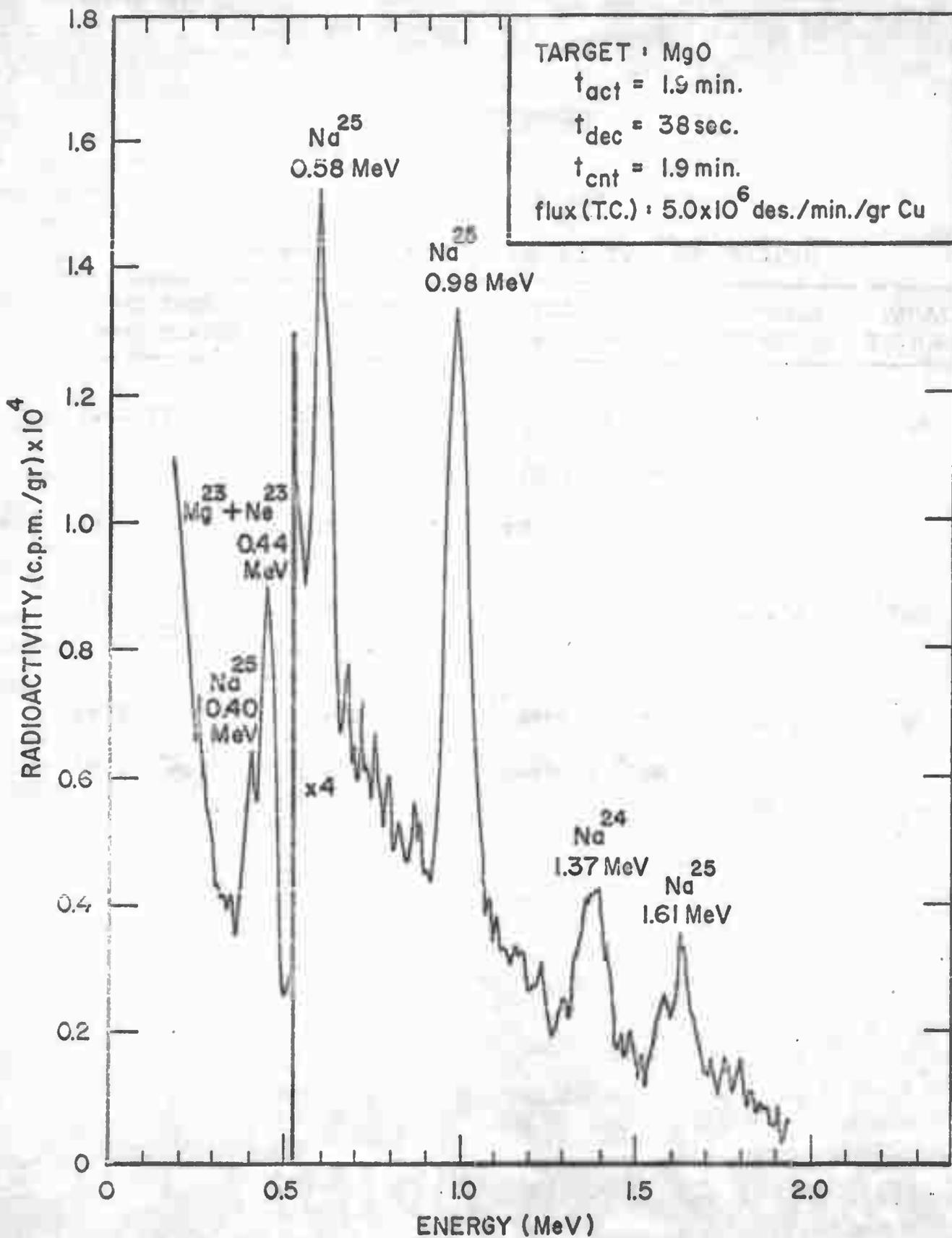


FIGURE I-Mg

TABLE II-Mg

## PEAKS OBSERVED IN FIGURE I-Mg

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Mg	0.40	$Mg^{25} (n, p) Na^{25}$	60 s	
	0.44	$Mg^{24} (n, 2n) Mg^{23}$	12 s	
		$Mg^{26} (n, \alpha) Ne^{23}$	38 s	
	0.58	$Mg^{25} (n, p) Na^{25}$	60 s	
	0.98	$Mg^{25} (n, p) Na^{25}$	60 s	
	1.37	$Mg^{24} (n, p) Na^{24}$	15 h	
	1.61	$Mg^{25} (n, p) Na^{25}$	60 s	

NOTE: The photopeak at 2.75 Mev due to  $Na^{24}$  is not shown.

$Na^{26}$  ( $T_{1/2} = 1$  sec) not detected for 3 sec irradiation, 1 sec decay and 3 sec counting time.

TABLE III-Mg

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{act}$	$T_{dec}$	$T_{cnt}$	COUNTS/mg/ $T_{cnt}$	DETECTION LIMIT(mg)
0.40 + 0.44	1.9 m	38 s	1.9 m	39	4.5
0.44	36 s	12 s	36 s	15	3.4
0.98	3 m	1 m	3 m	16	8.3
0.58	3 m	1 m	3 m	10	15
1.37	3 m	1 m	3 m	12	10
1.37	5 m	1 m	5 m	33	3.6

MAGNESIUM

TABLE III-Mg (Cont'd.)

NOTE: The peak area for the photopeaks at 0.40 and 0.44 Mev have been combined because of the fact that the NaI(Tl) gamma ray detector cannot resolve these peaks very well. The relative height of the 0.40 and 0.44 Mev peaks will largely depend on the working conditions. To do a quantitative analysis, these conditions have to be rigorously the same because there are three different half lives involved in this dual peak.

The photopeak at 0.98 Mev seems to be the most reliable peak to work with because of the low noise in the spectrum in this region.

TABLE IV-Mg

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.44	Sodium	$\text{Na}^{23}(n,p)\text{Ne}^{23}$	
1.37	Aluminum	$\text{Al}^{27}(n,\alpha)\text{Na}^{24}$	

## MANGANESE

MANGANESETABLE I-Mn

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Mn <sup>55</sup>	100%	Mn <sup>55</sup> (n,p)Cr <sup>55</sup>	3.5 m	
		Mn <sup>55</sup> (n,α)V <sup>52</sup>	3.77 m	1.43
		Mn <sup>55</sup> (n,2n)Mn <sup>54</sup>	303 d	0.84

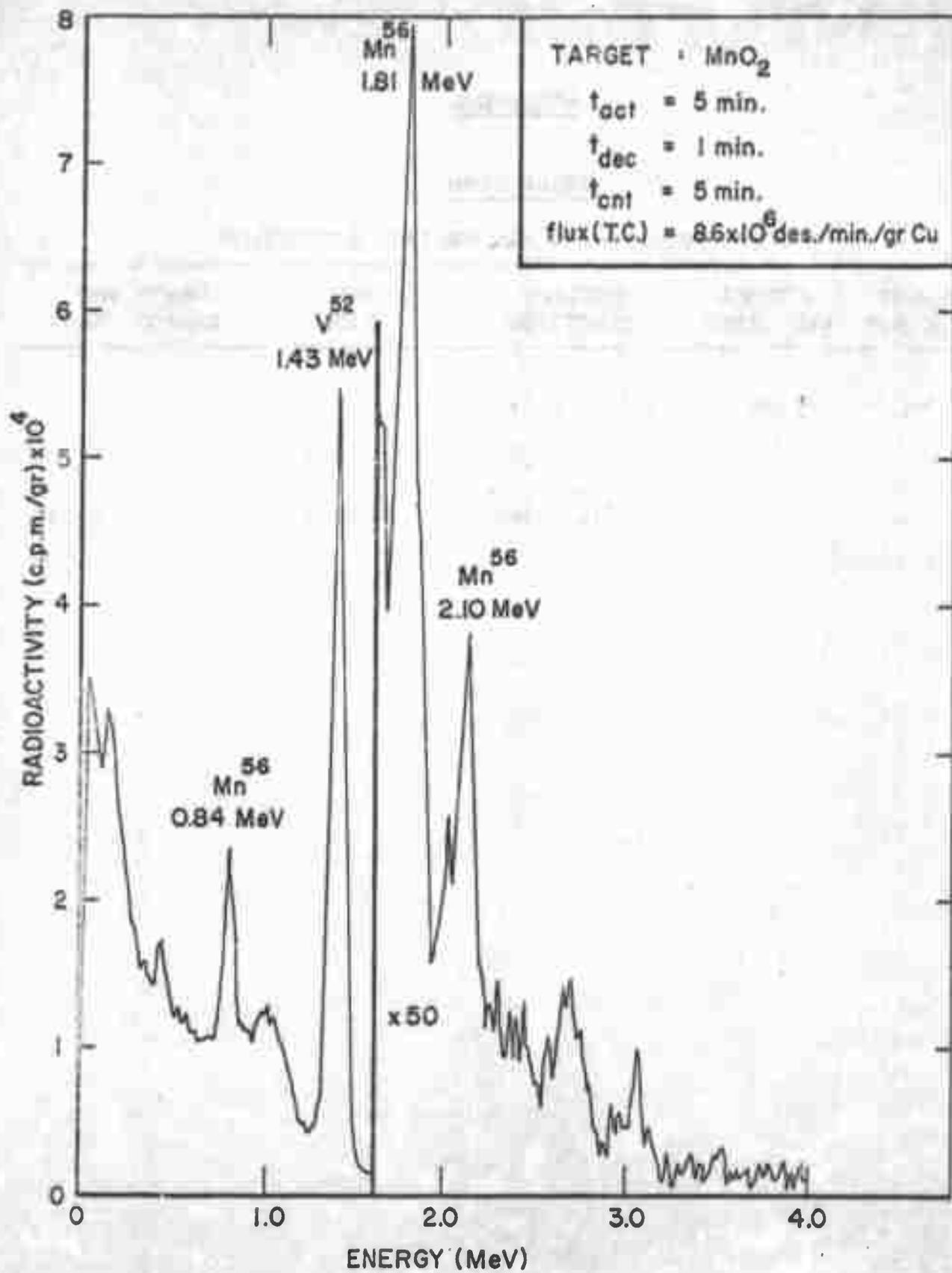


FIGURE I-Mn

TABLE II-Mn

## PEAKS OBSERVED IN FIGURE I-Mn

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Mn	0.84	$Mn^{55} (n, \gamma) Mn^{56}$	2.56 h	(1)
	1.43	$Mn^{55} (n, \alpha) V^{52}$	3.77 m	
	1.81	$Mn^{55} (n, \gamma) Mn^{56}$	2.56 h	(1)
	2.11	$Mn^{55} (n, \gamma) Mn^{56}$	2.56 h	(1)

(1) The activity due to  $Mn^{56}$  will be largely dependent on the flux of thermal neutrons present at the irradiation site.

TABLE III-Mn

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
1.43	5 m	1 m	5 m	208	0.49
0.84	5 m	1 m	5 m	35	3.8

## MANGANESE

TABLE IV-Mn

## POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.84	Iron	$\text{Fe}^{56}(n,p)\text{Mn}^{56}$	
0.84	Cobalt	$\text{Co}^{59}(n,\alpha)\text{Mn}^{56}$	
1.43	Chromium	$\text{Cr}^{52}(n,p)\text{V}^{52}$	
1.43	Vanadium	$\text{V}^{51}(n,\gamma)\text{V}^{52}$	

MERCURYTABLE I-Hg

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (MeV)
Hg <sup>196</sup>	0.146%	Hg <sup>196</sup> (n,p)Au <sup>196m</sup>	10 h	0.15, 0.19 IT 0.175
		Hg <sup>196</sup> (n,p)Au <sup>196</sup>	6.2 d	0.356, 0.333, 0.43
		Hg <sup>196</sup> (n,α)Pt <sup>193m</sup>	4.4 d	0.013, IT 0.136
		Hg <sup>196</sup> (n,α)Pt <sup>193</sup>	<500 y	
		Hg <sup>196</sup> (n,2n)Hg <sup>195m</sup>	40 h	0.016, 0.037, IT 0.123
		Hg <sup>196</sup> (n,2n)Hg <sup>195</sup>	9.5 h	0.061, 0.18, 0.78, 0.20, 1.17
Hg <sup>198</sup>	10.02 %	Hg <sup>198</sup> (n,p)Au <sup>198</sup>	64.8 h	0.412, 0.674
		Hg <sup>198</sup> (n,α)Pt <sup>195m</sup>	4.1 d	0.099, IT 0.030
		Hg <sup>198</sup> (n,2n)Hg <sup>197m</sup>	24 h	0.130, 0.41, 0.28, IT 0.165
		Hg <sup>198</sup> (n,2n)Hg <sup>197</sup>	65 h	0.077, 0.191
Hg <sup>199</sup>	16.84 %	Hg <sup>199</sup> (n,p)Au <sup>199</sup>	3.15 d	0.158, 0.208, 0.050
		Hg <sup>199</sup> (n,n')Hg <sup>199m</sup>	44 m	0.158, IT 0.370

## MERCURY

TABLE I-Hg (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (MeV)
$\text{Hg}^{200}$	23.13%	$\text{Hg}^{200} (n,p)\text{Au}^{200}$	48 m	1.23, 0.37
		$\text{Hg}^{200} (n,\alpha)\text{Pt}^{197m}$	2.8 h	
		$\text{Hg}^{200} (n,\alpha)\text{Pt}^{197m}$	1.5 h	0.05, IT 0.346
		$\text{Hg}^{200} (n,\alpha)\text{Pt}^{197}$	20 h	0.077, 0.19, 0.27
		$\text{Hg}^{200} (n,2n)\text{Hg}^{199m}$	44 m	0.158, IT 0.37
$\text{Hg}^{201}$	13.22%	$\text{Hg}^{201} (n,p)\text{Au}^{201}$	22 m	0.53
		$\text{Hg}^{201} (n,n')\text{Hg}^{201m}$	100 $\mu$ s	IT 0.53
$\text{Hg}^{202}$		$\text{Hg}^{202} (n,p)\text{Au}^{202}$	~25 s	
		$\text{Hg}^{202} (n,\alpha)\text{Pt}^{199m}$	14 s	0.032, IT 0.39
		$\text{Hg}^{202} (n,\alpha)\text{Pt}^{199}$	30 m	0.54, 0.075, 0.96
		$\text{Hg}^{202} (n,2n)\text{Hg}^{201m}$	100 $\mu$ s	IT 0.53
$\text{Hg}^{204}$	6.85%	$\text{Hg}^{204} (n,\alpha)\text{Pt}^{201}$	2.5 m	1.76, 0.23
		$\text{Hg}^{204} (n,2n)\text{Hg}^{203}$	47 d	0.279

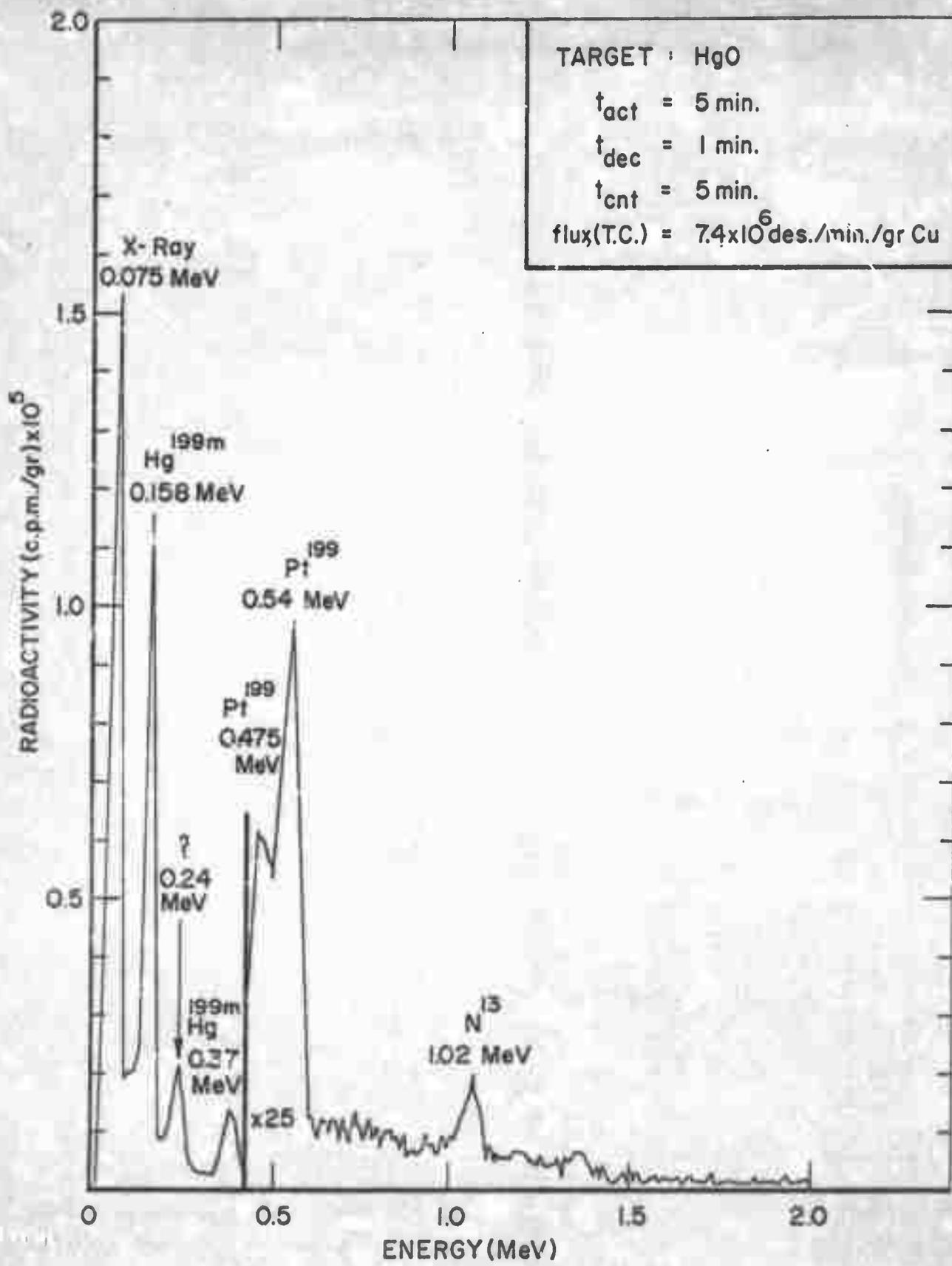


FIGURE I-Hg

TABLE II-Hg

## PEAKS OBSERVED IN FIGURE I-Hg

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Hg	0.075			x-ray
	0.158	Hg <sup>199</sup> (n, n') Hg <sup>199m</sup>	44 m	
		Hg <sup>200</sup> (n, 2n) Hg <sup>199m</sup>	44 m	
	0.24		~40 m	
	0.37	Hg <sup>199</sup> (n, n') Hg <sup>199m</sup>	44 m	
		Hg <sup>200</sup> (n, 2n) Hg <sup>199m</sup>	44 m	
	0.475	Hg <sup>202</sup> (n, α) Pt <sup>199</sup>	30 m	
	0.54	Hg <sup>202</sup> (n, α) Pt <sup>199</sup>	30 m	

NOTE: Pt<sup>199m</sup> (T<sub>1/2</sub> = 14 sec) not detected for 43 sec irradiation, 14 sec decay and 43 sec counting time.

TABLE III-Hg

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.075	5 m	1 m	5 m	224	0.43
0.158	5 m	1 m	5 m	210	0.46
0.24	5 m	1 m	5 m	38	2.5
0.37	5 m	1 m	5 m	30	3.8

MERCURY

TABLE IV-Hg

POSSIBLE INTERFERING REACTIONS

---

No detectable interferences could be derived for mercury from any other element.

MOLYBDENUMTABLE I-Mo

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (MeV)
Mo <sup>92</sup>	15.84%	Mo <sup>92</sup> (n,p)Nb <sup>92</sup>	10.1 d	0.93, 0.89, 1.82
		Mo <sup>92</sup> (n,α)Zr <sup>89m</sup>	4.2 m	1.5, IT 0.59 β+
		Mo <sup>92</sup> (n,α)Zr <sup>89</sup>	78.4 h	0.91, 1.7, β+
		Mo <sup>92</sup> (n,2n)Mo <sup>91m</sup>	65 s	1.54, 1.21, IT 0.65, β+
		Mo <sup>92</sup> (n,2n)Mo <sup>91</sup>	15.5 m	β+
Mo <sup>94</sup>	9.04%	Mo <sup>94</sup> (n,p)Nb <sup>94m</sup>	6.3 m	0.87, IT 0.042
		Mo <sup>94</sup> (n,p)Nb <sup>94</sup>	2 x 10 <sup>4</sup> y	0.87, 0.70
		Mo <sup>94</sup> (n,2n)Mo <sup>93m</sup>	6.9 h	0.69, 1.48, IT 0.26
		Mo <sup>94</sup> (n,2n)Mo <sup>93</sup>	10 <sup>4</sup> y	
Mo <sup>95</sup>	15.72%	Mo <sup>95</sup> (n,p)Nb <sup>95m</sup>	90 h	IT 0.23
		Mo <sup>95</sup> (n,p)Nb <sup>95</sup>	35 d	0.77
Mo <sup>96</sup>	16.53%	Mo <sup>96</sup> (n,p)Nb <sup>96</sup>	23 h	0.77, 0.56, 1.08, 0.22, 1.19
		Mo <sup>96</sup> (n,α)Zr <sup>93</sup>	9.5 x 10 <sup>5</sup> y	0.029

MOLYBDENUM

TABLE I-Mo (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Mo <sup>97</sup>	9.46%	Mo <sup>97</sup> (n,p) Nb <sup>97m</sup>	1 m	IT 0.75
		Mo <sup>97</sup> (n,p) Nb <sup>97</sup>	72 m	0.66
Mo <sup>98</sup>	23.78%	Mo <sup>98</sup> (n,p) Nb <sup>98</sup>	51.5 m	0.78, 0.72, 0.33, 2.7
		Mo <sup>98</sup> (n,α) Zr <sup>95</sup>	65 d	0.72, 0.76, 0.23, 0.77
Mo <sup>100</sup>	9.63%	Mo <sup>100</sup> (n,γ) Nb <sup>100m</sup>	11.5 m	0.53
		Mo <sup>100</sup> (n,p) Nb <sup>100</sup>	3 m	0.53, 0.36, 0.45, 0.14, 2.9
		Mo <sup>100</sup> (n,α) Zr <sup>97</sup>	17 h	0.5, 2.6, 0.75
		Mo <sup>100</sup> (n,2n) Mo <sup>99</sup>	66 h	0.14, 0.74, 0.041, 0.78

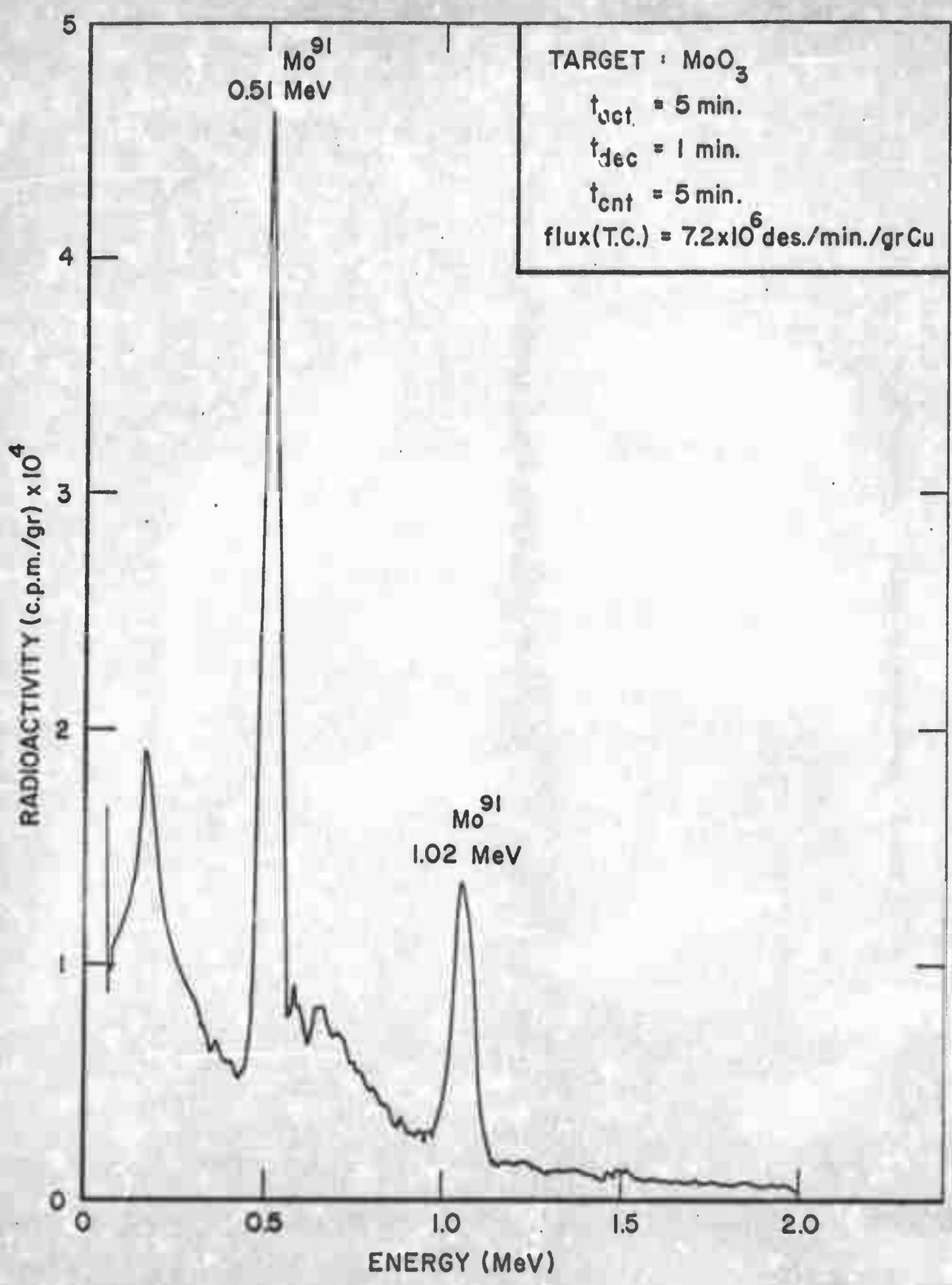


FIGURE I-Mo

TABLE II-Mo

## PEAKS OBSERVED IN FIGURE Mo-I

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Mo	0.51	$\text{Mo}^{92} (n, 2n) \text{Mo}^{91}$	15.5 m	
	1.02	$\text{Mo}^{92} (n, 2n) \text{Mo}^{91}$	15.5 m	0.51 Mev coincidence sum peak

NOTE:  $\text{Nb}^{97m}$  ( $T_{1/2} = 1$  m) not detected for 3 min irradiation, 1 min decay and 3 min counting time.

TABLE III-Mo

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{act}$	$T_{dec}$	$T_{cnt}$	COUNTS/mg/ $T_{cnt}$	DETECTION LIMIT (mg)
0.51	5 m	1 m	5 m	161	1.0

TABLE IV-Mo

## POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for molybdenum from any other element.

For other positron emitting radioisotopes than  $\text{Mo}^{91}$ , see Section I, Appendix II.

## NEODYMIUM

NEODYMIUMTABLE I-Nd

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Nd <sup>142</sup>	27.11%	Nd <sup>142</sup> (n,p)Pr <sup>142</sup>	19.2 h	1.57
		Nd <sup>142</sup> (n,α)Ce <sup>139m</sup>	55 s	IT 0.74
		Nd <sup>142</sup> (n,α)Ce <sup>139</sup>	140 d	0.166
		Nd <sup>142</sup> (n,2n)Nd <sup>141m</sup>	64 s	IT 0.76
		Nd <sup>142</sup> (n,2n)Nd <sup>141</sup>	2.5 h	1.15, 1.30, β+
Nd <sup>143</sup>	12.17%	Nd <sup>143</sup> (n,p)Pr <sup>143</sup>	13.7 d	
Nd <sup>144</sup>	23.85%	Nd <sup>144</sup> (n,p)Pr <sup>144</sup>	17.3 m	0.69, 2.18, 1.49
		Nd <sup>144</sup> (n,α)Ce <sup>141</sup>	32.5 d	0.145
Nd <sup>145</sup>	8.30%	Nd <sup>145</sup> (n,p)Pr <sup>145</sup>	5.9 h	0.072, 1.15
Nd <sup>146</sup>	17.22%	Nd <sup>146</sup> (n,p)Pr <sup>146</sup>	24 m	0.46, 1.49, 0.75
		Nd <sup>146</sup> (n,α)Ce <sup>143</sup>	33 h	0.058, 0.29, 0.66
Nd <sup>148</sup>	5.73%	Nd <sup>148</sup> (n,p)Pr <sup>148</sup>	2 m	0.3
		Nd <sup>148</sup> (n,α)Ce <sup>145</sup>	3 m	

## NEODYMIUM

TABLE I-Nd (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$\text{Nd}^{148} (n, 2n) \text{Nd}^{147}$	11.1 d	0.091, 0.53, 0.12, 0.69
$\text{Nd}^{150}$	5.62%	$\text{Nd}^{150} (n, \alpha) \text{Ce}^{147}$	1.1 m	
		$\text{Nd}^{150} (n, 2n) \text{Nd}^{149}$	1.8 h	0.21, 0.27, 0.11, 0.65

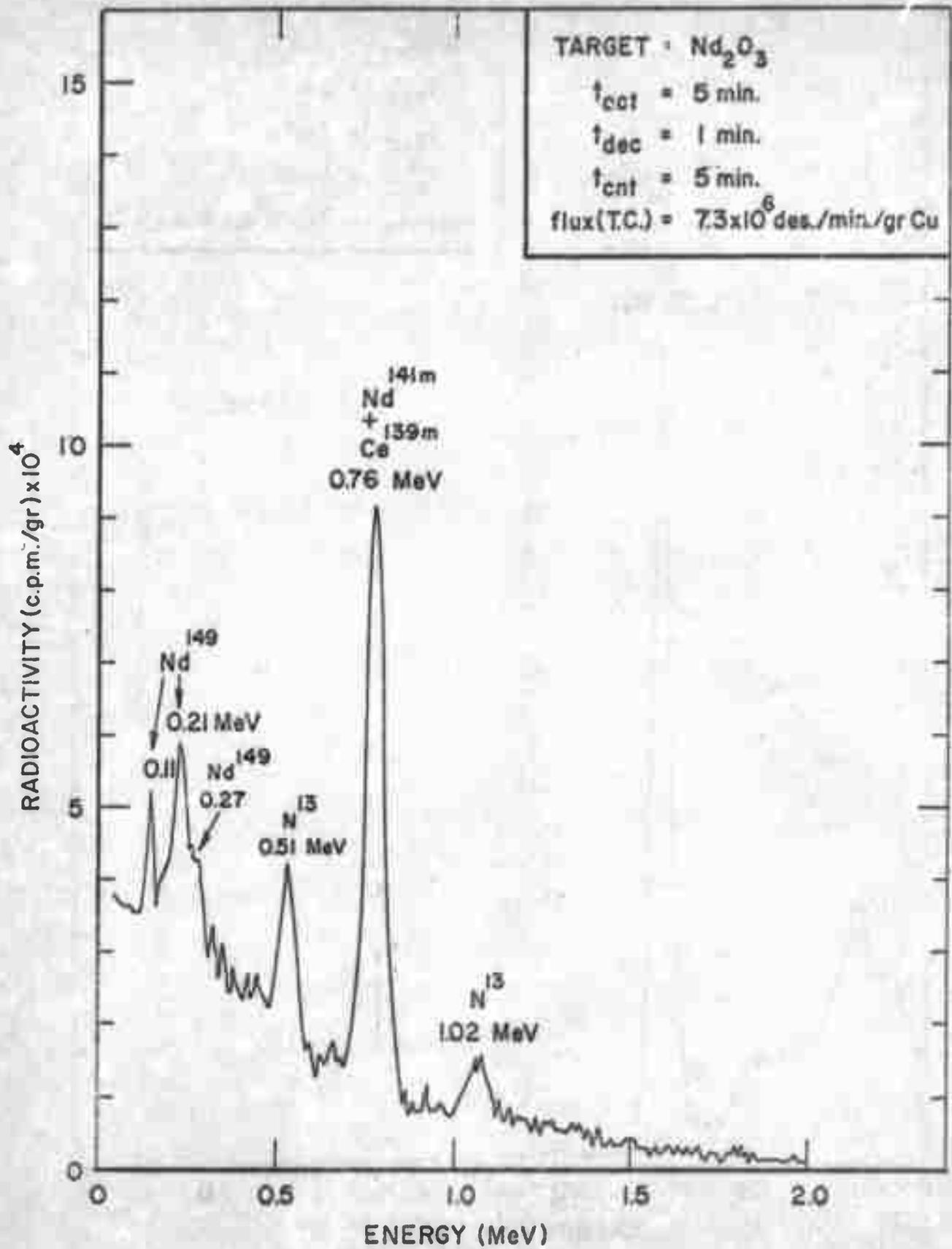


FIGURE I-Nd

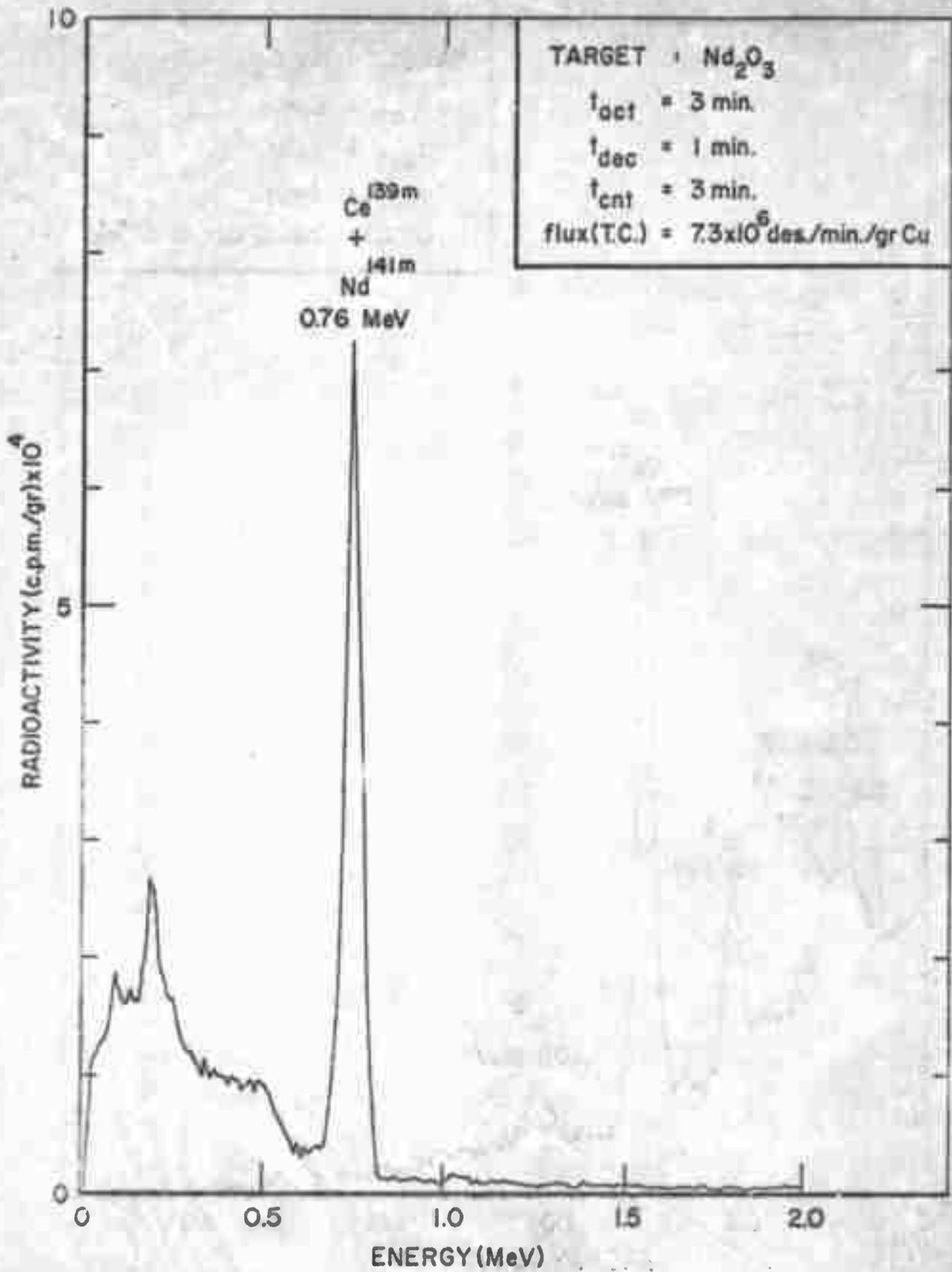


FIGURE II-Nd

TABLE II-Nd

## PEAKS OBSERVED IN FIGURE I-Nd and II-Nd

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Nd	0.11	$\text{Nd}^{150} (n, 2n) \text{Nd}^{149}$	1.8 h	
	0.21	$\text{Nd}^{150} (n, 2n) \text{Nd}^{149}$	1.8 h	
	0.27	$\text{Nd}^{150} (n, 2n) \text{Nd}^{149}$	1.8 h	
	0.76 + 0.74	$\text{Nd}^{142} (n, \alpha) \text{Ce}^{139m}$	55 s	
		$\text{Nd}^{142} (n, 2n) \text{Nd}^{141m}$	64 s	
II-Nd	0.74 + 0.76	$\text{Nd}^{142} (n, 2n) \text{Nd}^{141m}$	64 s	(1)
		$\text{Nd}^{142} (n, \alpha) \text{Ce}^{139m}$	55 s	

(1) The sensitivity has been calculated from Figure II-Nd, and Figure I-Nd shows the other photopeaks obtained by longer irradiations.

TABLE III-Nd

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.74 + 0.76	3 m	1 m	3 m	375	0.32

## NEODYMIUM

TABLE IV-Nd

## POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
~0.76	Cerium	$Ce^{140}(n, 2n)Ce^{139m}$	(1)
	Samarium	$Sm^{144}(n, 2n)Sm^{143m}$	(1)
	Samarium	$Sm^{144}(n, \alpha)Nd^{141m}$	

- (1)  $Ce^{139m}$  and  $Sm^{143m}$  have a half life respectively of 55 sec and 60 sec, making their identification from  $Nd^{141m}$  very difficult.

NICKEL

NICKEL

TABLE I-Ni

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ni <sup>58</sup>	67.88%	Ni <sup>58</sup> (n,p)Co <sup>58m</sup>	9 h	IT 0.025
		Ni <sup>58</sup> (n,p)Co <sup>58</sup>	71 d	0.81, 1.65, β+
		Ni <sup>58</sup> (n,α)Fe <sup>55</sup>	2.7 y	
		Ni <sup>58</sup> (n,2n)Ni <sup>57</sup>	36 h	1.37, 1.89, 0.127, 1.75 β+
Ni <sup>60</sup>	26.23%	Ni <sup>60</sup> (n,p)Co <sup>60m</sup>	10.5 m	1.33, IT 0.059
		Ni <sup>60</sup> (n,p)Co <sup>60</sup>	5.26 y	1.33, 1.17
		Ni <sup>60</sup> (n,2n)Ni <sup>59</sup>	8 x 10 <sup>4</sup> y	
Ni <sup>61</sup>	1.19%	Ni <sup>61</sup> (n,p)Co <sup>61</sup>	1.65 h	0.068
Ni <sup>62</sup>	3.56%	Ni <sup>62</sup> (n,p)Co <sup>62m</sup>	1.9 m	
		Ni <sup>62</sup> (n,p)Co <sup>62</sup>	13.9 m	1.17, 1.47, 1.74, 2.03
		Ni <sup>62</sup> (n,α)Fe <sup>59</sup>	45 d	1.10, 1.29, 0.19

NICKEL

TABLE I-Ni (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ni <sup>64</sup>	1.08%	Ni <sup>64</sup> (n,p)Co <sup>64m</sup>	2 m	
		Ni <sup>64</sup> (n,p)Co <sup>64</sup>	7.8 m	
		Ni <sup>64</sup> (n,α)Fe <sup>61</sup>	6.0 m	0.29
		Ni <sup>64</sup> (n,2n)Ni <sup>63</sup>	92 y	

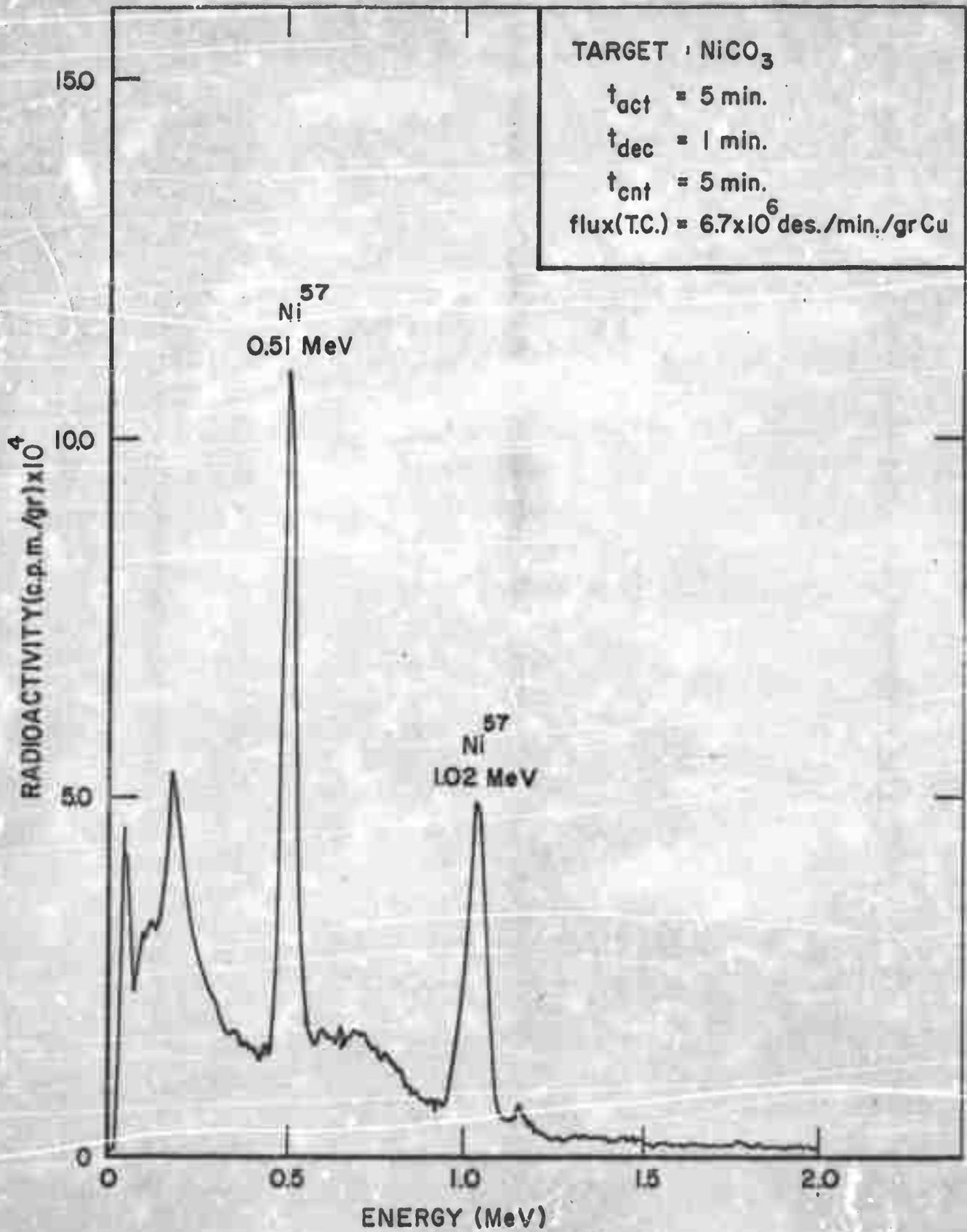


FIGURE I-Ni

## NICKEL

TABLE II-Ni

## PEAKS OBSERVED IN FIGURE I-Ni

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ni	0.51	Ni <sup>58</sup> (n, 2n) Ni <sup>57</sup>	36 h	
	1.02	Ni <sup>58</sup> (n, 2n) Ni <sup>57</sup>	36 h	0.51 Mev coincidence sum peak

TABLE III-Ni

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.51	5 m	1 m	5 m	320	0.52

TABLE IV-Ni

## POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for nickel from any other element.

For other positron emitting radioisotopes than Ni<sup>67</sup>, see Section I, Appendix II.

NIOBIUM

NIOBIUM

TABLE I-Nb

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Nb <sup>93</sup>	100%	Nb <sup>93</sup> (n,p)Zr <sup>93</sup>	9.5 x 10 <sup>5</sup> y	0.029
		Nb <sup>93</sup> (n,α)Y <sup>90m</sup>	3.2 h	0.20, 2.3, IT 0.48
		↓		
		Nb <sup>93</sup> (n,α)Y <sup>90</sup>	64.2 h	1.75
		Nb <sup>93</sup> (n,n')Nb <sup>93m</sup>	3.7 y	IT 0.029
Nb <sup>93</sup> (n,2n)Nb <sup>92</sup>		10.1 d	0.93, 0.89, 1.82	

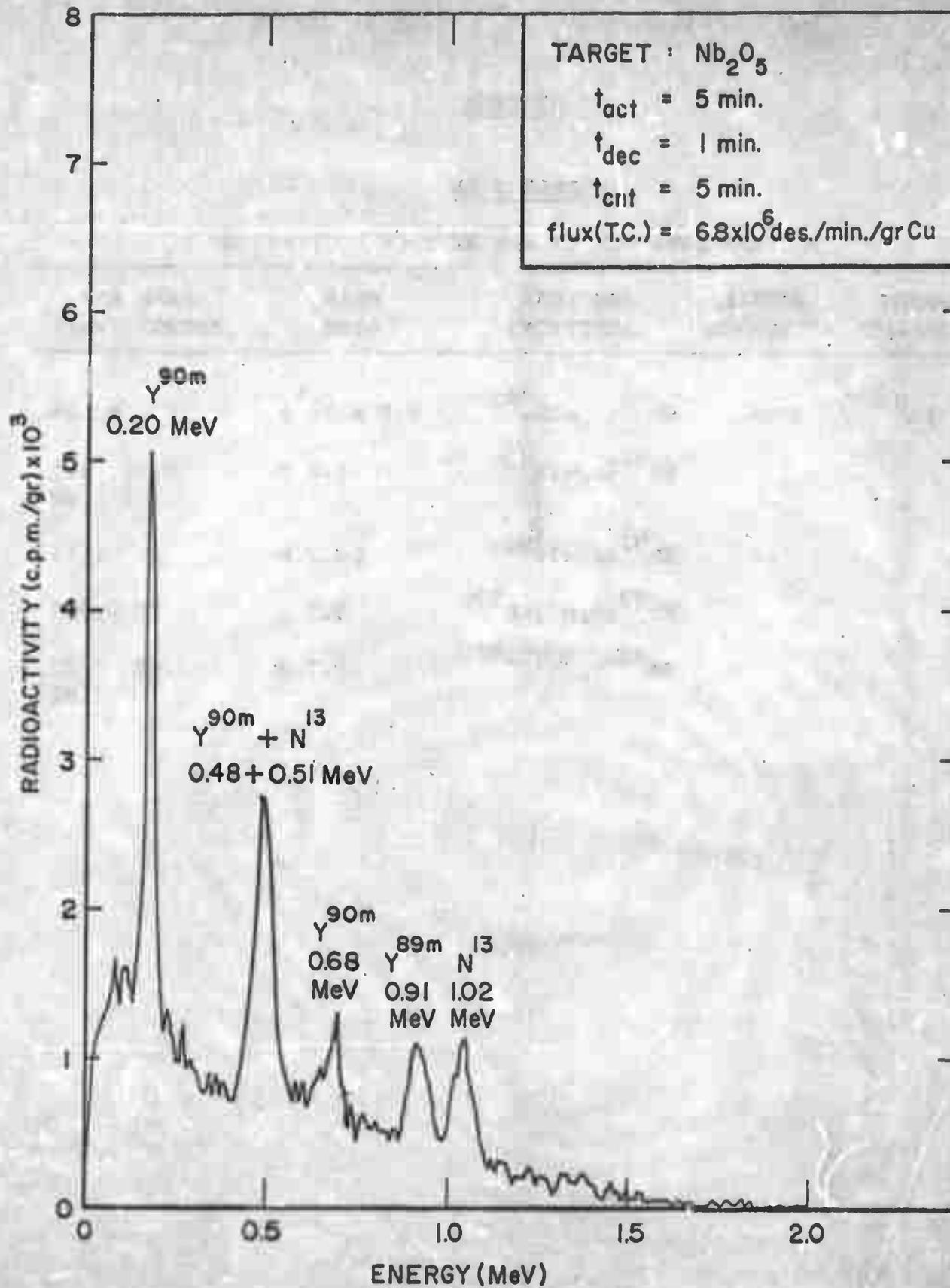


FIGURE I-Nb

TABLE II-Nb

PEAKS OBSERVED IN FIGURE I-Nb

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Nb	0.20	$Nb^{93}(n, \alpha)Y^{90m}$	3.2 h	
	0.48 + 0.51	$Nb^{93}(n, \alpha)Y^{90m}$	3.2 h	
	0.68	$Nb^{93}(n, \alpha)Y^{90m}$	3.2 h	0.48 + 0.20 sum peak
	0.91	$Nb^{93}(n, n' \alpha)Y^{89m}$	16 s	

TABLE III-Nb

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT(mg)
0.20	5 m	1 m	5 m	7	18

TABLE IV-Nb

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.20	Zirconium	$Zr^{90}(n, p)Y^{90m}$	

NITROGENTABLE I-N

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
$N^{14}$	99.63%	$N^{14}(n,p)C^{14}$	5730 y	
		$N^{14}(n,2n)N^{13}$	9.96 m	$\beta^+$
$N^{15}$	0.37%	$N^{15}(n,p)C^{15}$	2.25 s	5.30
		$N^{15}(n,\alpha)B^{12}$	0.020 s	4.4

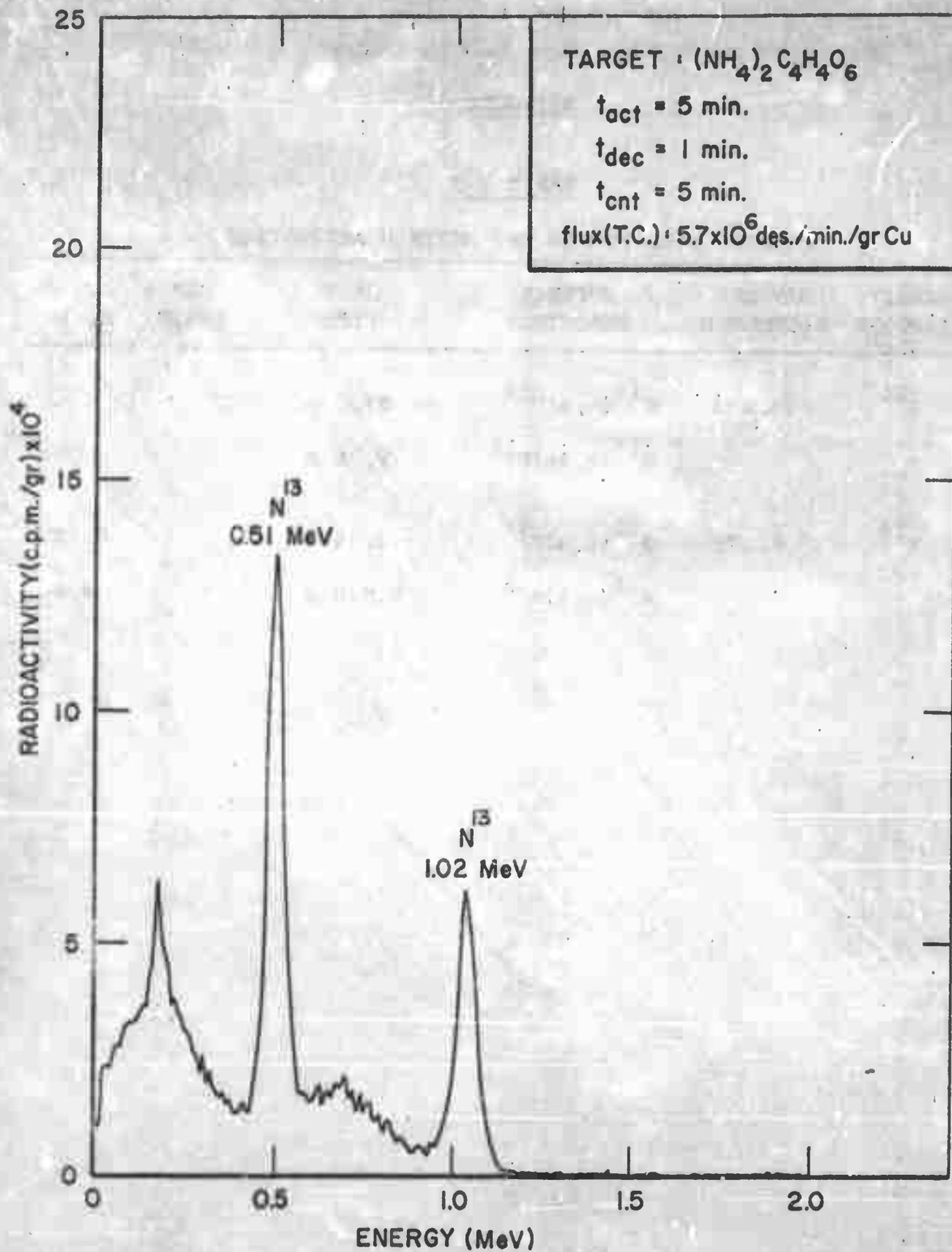


FIGURE I-N

TABLE II-N

## PEAKS OBSERVED IN FIGURE I-N

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-N	0.51	$N^{14}(n, 2n)N^{13}$	9.96 m	
	1.02	$N^{14}(n, 2n)N^{13}$	9.96 m	0.51 Mev coincidence sum peak

TABLE III-N

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.51	5 m	1 m	5 m	350	0.47

NOTE: When organic compounds, or water solutions are used, the blank activity due to the  $C^{13}(p, n)N^{13}$  and  $O^{16}(p, \alpha)N^{13}$  have to be taken in account. The activity depends respectively from the (C)/(H) and (O)/(H) ratio.

NITROGEN

TABLE IV-N

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.51	Copper	$\text{Cu}^{63} (n, 2n) \text{Cu}^{62}$	(1)
	Samarium	$\text{Sm}^{144} (n, 2n) \text{Sm}^{143}$	(1)

$\text{Cu}^{62}$  and  $\text{Sm}^{143}$  have a half life respectively of 9.9 m and 9 m, making their identification from  $\text{N}^{13}$  very difficult.

For other positron emitting radioisotopes than  $\text{N}^{13}$ , see Section I, Appendix II.

PALLADIUM

PALLADIUM

TABLE I-Pd

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Pd <sup>102</sup>	0.96%	Pd <sup>102</sup> (n,p)Rh <sup>102m</sup>	2.9 y	β+
		Pd <sup>102</sup> (n,p)Rh <sup>102</sup>	206 d	0.47, 0.51, 0.42, 2.06, β+
		Pd <sup>102</sup> (n,2n)Pd <sup>101</sup>	8.5 h	0.024, 0.296, 0.590, 0.269, 1.31, β+
Pd <sup>104</sup>	10.97	Pd <sup>104</sup> (n,p)Rh <sup>104m</sup>	4.4 m	0.051, IT 0.077
		Pd <sup>104</sup> (n,p)Rh <sup>104</sup>	42 s	0.56, 1.24
		Pd <sup>104</sup> (n,2n)Pd <sup>103</sup>	17 d	0.040, 0.052, 0.36
Pd <sup>105</sup>	22.23%	Pd <sup>105</sup> (n,p)Rh <sup>105m</sup>	30 s	IT 0.130
		Pd <sup>105</sup> (n,p)Rh <sup>105</sup>	36 h	0.31, 0.32
		Pd <sup>105</sup> (n,n')Pd <sup>105m</sup>	37μs	0.32, IT 0.18
Pd <sup>106</sup>	27.33%	Pd <sup>106</sup> (n,p)Rh <sup>106m</sup>	2.2 h	0.51, 0.22, 1.22
		Pd <sup>106</sup> (n,p)Rh <sup>106</sup>	30 s	0.51, 0.62, 0.7, 3.4

PALLADIUM

TABLE I-Pd (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$\text{Pd}^{106} (n, \alpha) \text{Ru}^{103}$	40 d	0.040, 0.50, 0.05, 0.61
		$\text{Pd}^{106} (n, 2n) \text{Pd}^{105m}$	37 $\mu$ s	0.32, IT 0.18
$\text{Pd}^{108}$	26.71%	$\text{Pd}^{108} (n, p) \text{Rh}^{108}$	17 s	0.43, 0.62, 0.51, 1.52
		$\text{Pd}^{108} (n, \alpha) \text{Ru}^{105}$	4.43 h	0.72, 0.21, 1.7
		$\text{Pd}^{108} (n, 2n) \text{Pd}^{107m}$	22 s	IT 0.22
		$\text{Pd}^{108} (n, 2n) \text{Pd}^{107}$	$7 \times 10^6$ y	
$\text{Pd}^{110}$	11.81%	$\text{Pd}^{110} (n, p) \text{Rh}^{110}$	5 s	0.38
		$\text{Pd}^{110} (n, \alpha) \text{Ru}^{107}$	4.2 m	0.19, 0.37, 1.3
		$\text{Pd}^{110} (n, 2n) \text{Pd}^{109m}$	4.8 m	IT 0.18
		$\text{Pd}^{110} (n, 2n) \text{Pd}^{109}$	13.5 h	0.088

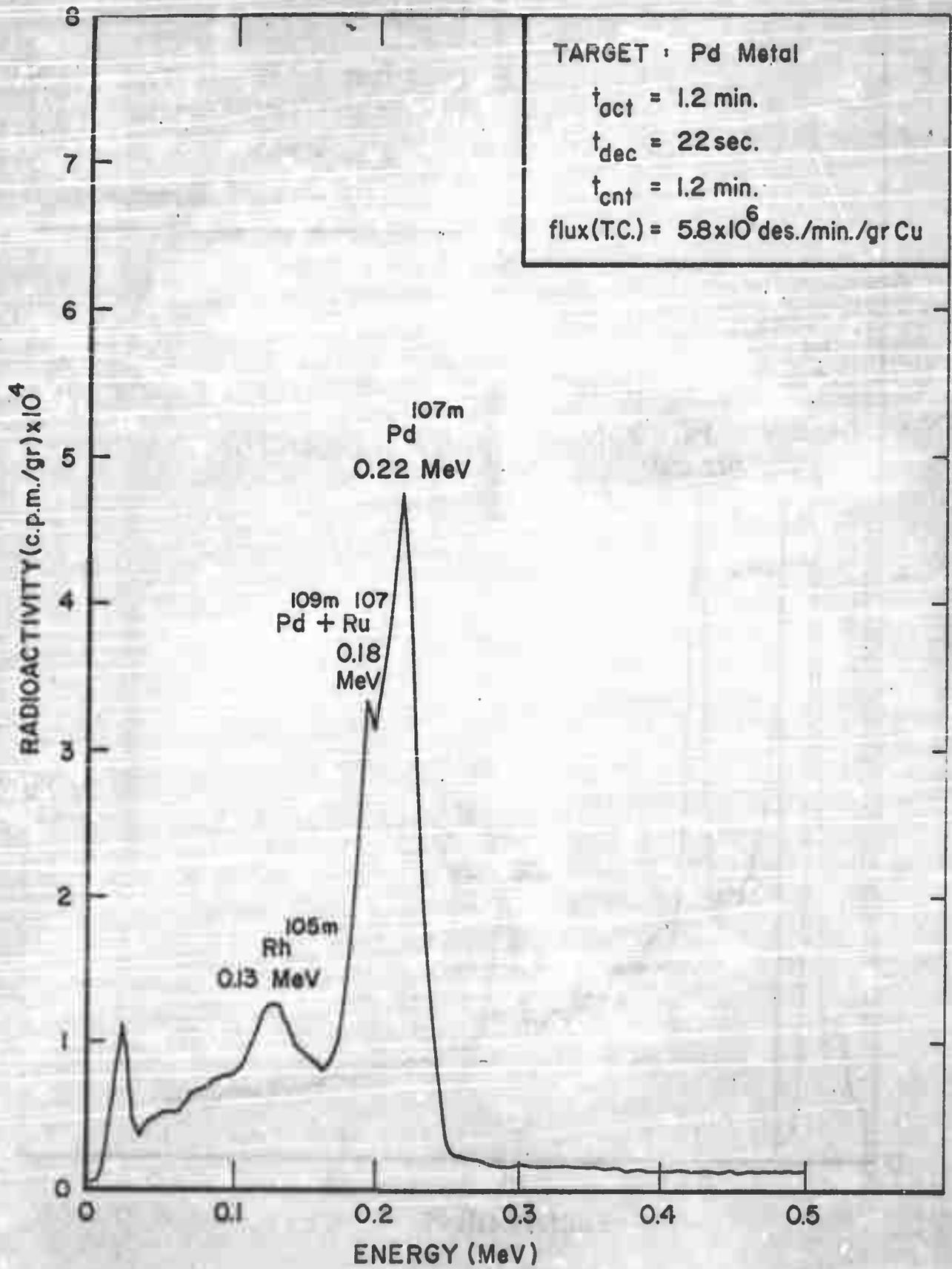


FIGURE I-Pd

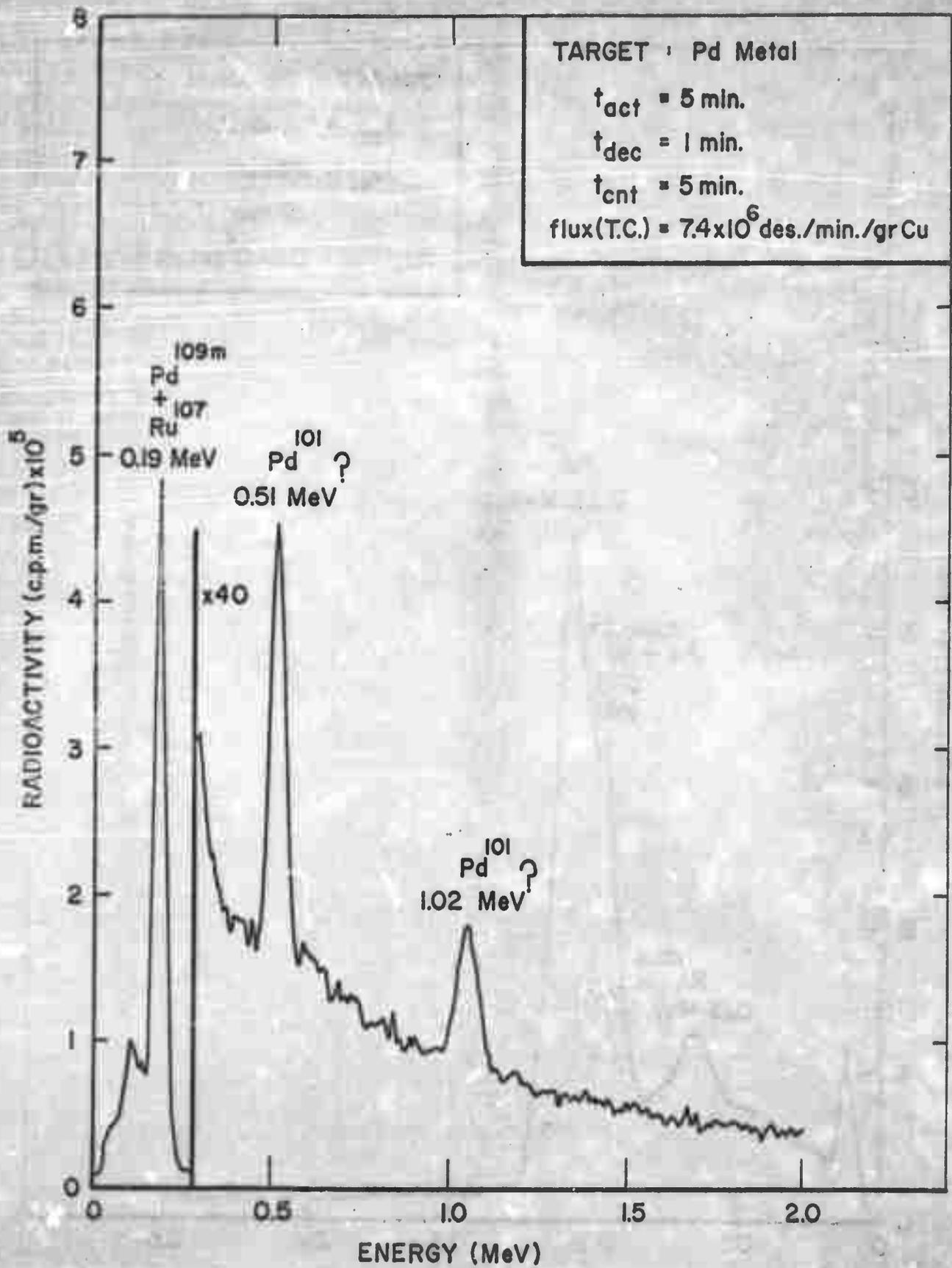


FIGURE II-Pd

TABLE II-Pd

PEAKS OBSERVED IN FIGURE I-Pd and II-Pd

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Pd	0.13	$\text{Pd}^{105} (n, p) \text{Rh}^{105m}$	30 s	
	0.18 + 0.19	$\text{Pd}^{110} (n, 2n) \text{Pd}^{109m}$	4.8 m	
		$\text{Pd}^{110} (n, \alpha) \text{Ru}^{107}$	4.2 m	
II-Pd	0.22	$\text{Pd}^{108} (n, 2n) \text{Pd}^{107m}$	22 s	
	0.13	$\text{Pd}^{105} (n, p) \text{Rh}^{105m}$	30 s	
		0.18 + 0.19	$\text{Pd}^{110} (n, 2n) \text{Pd}^{109m}$	4.8 m
			$\text{Pd}^{110} (n, \alpha) \text{Ru}^{107}$	4.2 m
	0.51	$\text{Pd}^{102} (n, 2n) \text{Pd}^{101}$	8.5 h	probable
1.02	$\text{Pd}^{102} (n, 2n) \text{Pd}^{101}$	8.5 h	0.51 Mev coincidence sum peak	

(1) The major activity at 0.19 Mev is due to  $\text{Ru}^{107}$  and  $\text{Pd}^{109m}$ .

NOTE:  $\text{Rh}^{110}$  ( $T_{1/2} = 5$  sec) not detected for 15 sec irradiation, 5 sec decay and 15 sec counting time.

TABLE III-Pd

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{act}$	$T_{dec}$	$T_{cnt}$	COUNTS/mg/ $T_{cnt}$	DETECTION LIMIT (mg)
0.18+0.19+0.22	1.2 m	22 s	1.2 m	308	0.54
0.18+0.19	5 m	1 m	5 m	732	0.40

PALLADIUM

TABLE IV-Pd

POSSIBLE INTERFERING REACTIONS

---

No detectable interference could be derived for palladium from any other element.

PHOSPHORUSTABLE I-P

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
$P^{31}$	100%	$P^{31}(n,p)Si^{31}$	2.62 h	1.27
		$P^{31}(n,\alpha)Al^{28}$	2.30 m	1.78
		$P^{31}(n,2n)P^{30}$	2.5 m	2.24, $\beta^+$

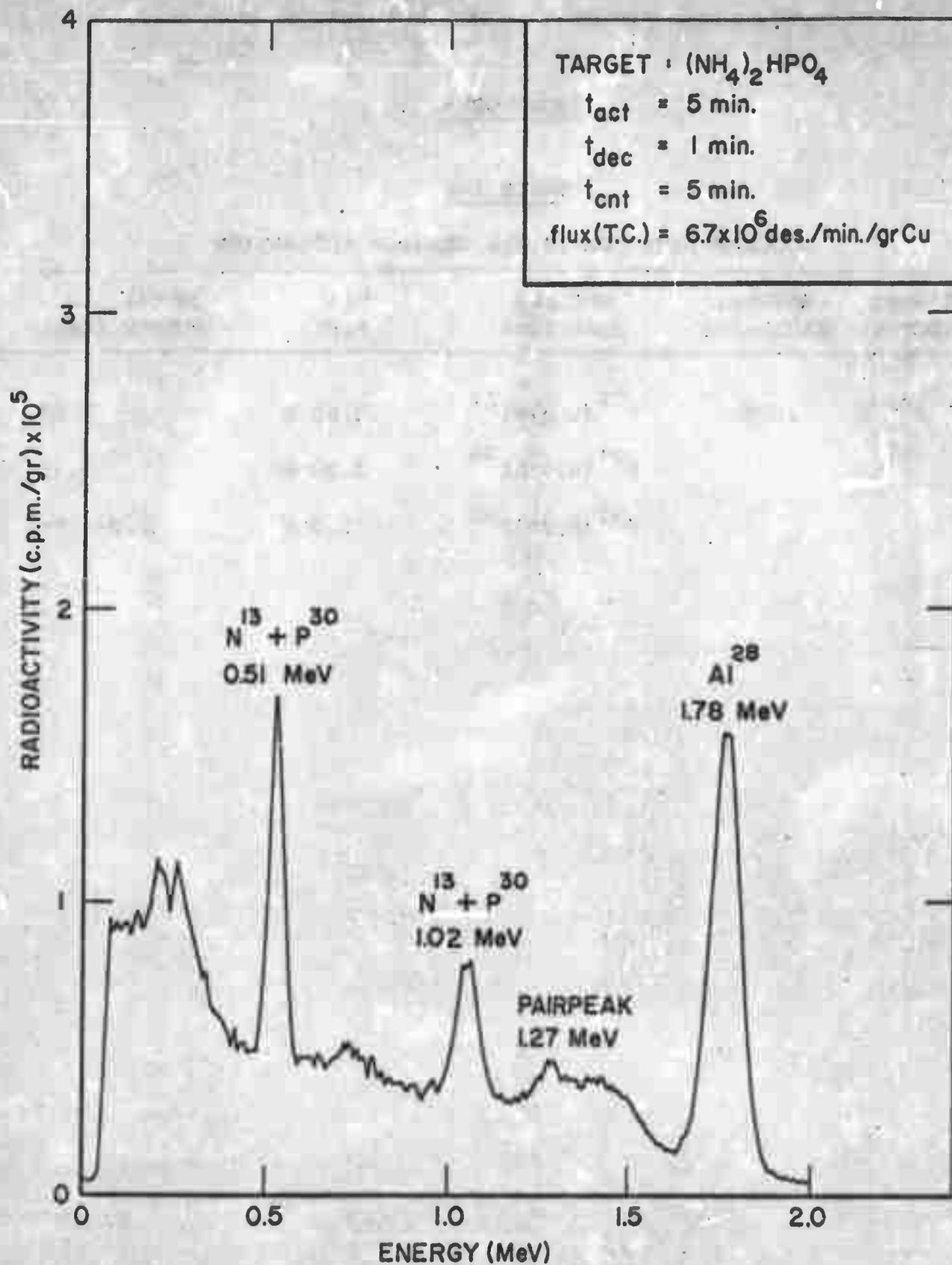


FIGURE I-P

TABLE II-P

## PEAKS OBSERVED IN FIGURE I-P

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-P	0.51	$P^{31}(n, 2n)P^{30}$	2.5 m	
	1.02	$P^{31}(n, 2n)P^{30}$	2.5 m	0.51 Mev coincidence sum peak
	1.78	$P^{31}(n, \alpha)Al^{28}$	2.30m	

TABLE III-P

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT(mg)
0.51	5 m	1 m	5 m	179 (1)	0.92
1.78	5 m	1 m	5 m	1360	0.04

(1) The contribution of nitrogen, present in  $(NH_4)_2HPO_4$ , to the 0.51 Mev photopeak is equal to 315 counts. This value has been subtracted from the  $N^{13} + P^{30}$  activity.

PHOSPHORUS

TABLE IV-P

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
1.78	Silicon	$\text{Si}^{28}(\text{n},\text{p})\text{Al}^{28}$	
	Aluminum	$\text{Al}^{27}(\text{n},\gamma)\text{Al}^{28}$	

For other positron emitting radioisotopes besides  $\text{P}^{30}$ , see Section I, Appendix II.

POTASSIUM

TABLE I-K

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
$K^{39}$	93.10%	$K^{39} (n,p)Ar^{39}$	270 y	
		$K^{39} (n,\alpha)Cl^{36}$	$3 \times 10^5$ y	
		$K^{39} (n,2n)K^{38m}$	0.95 s	$\beta^+$
		$K^{39} (n,2n)K^{38}$	7.7 m	2.2, $\beta^+$
$K^{41}$	6.88%	$K^{41} (n,p)Ar^{41}$	1.83 h	1.29
		$K^{41} (n,\alpha)Cl^{38m}$	0.74 s	IT 0.66
		$K^{41} (n,\alpha)Cl^{38}$	37.3 m	2.2, 1.6

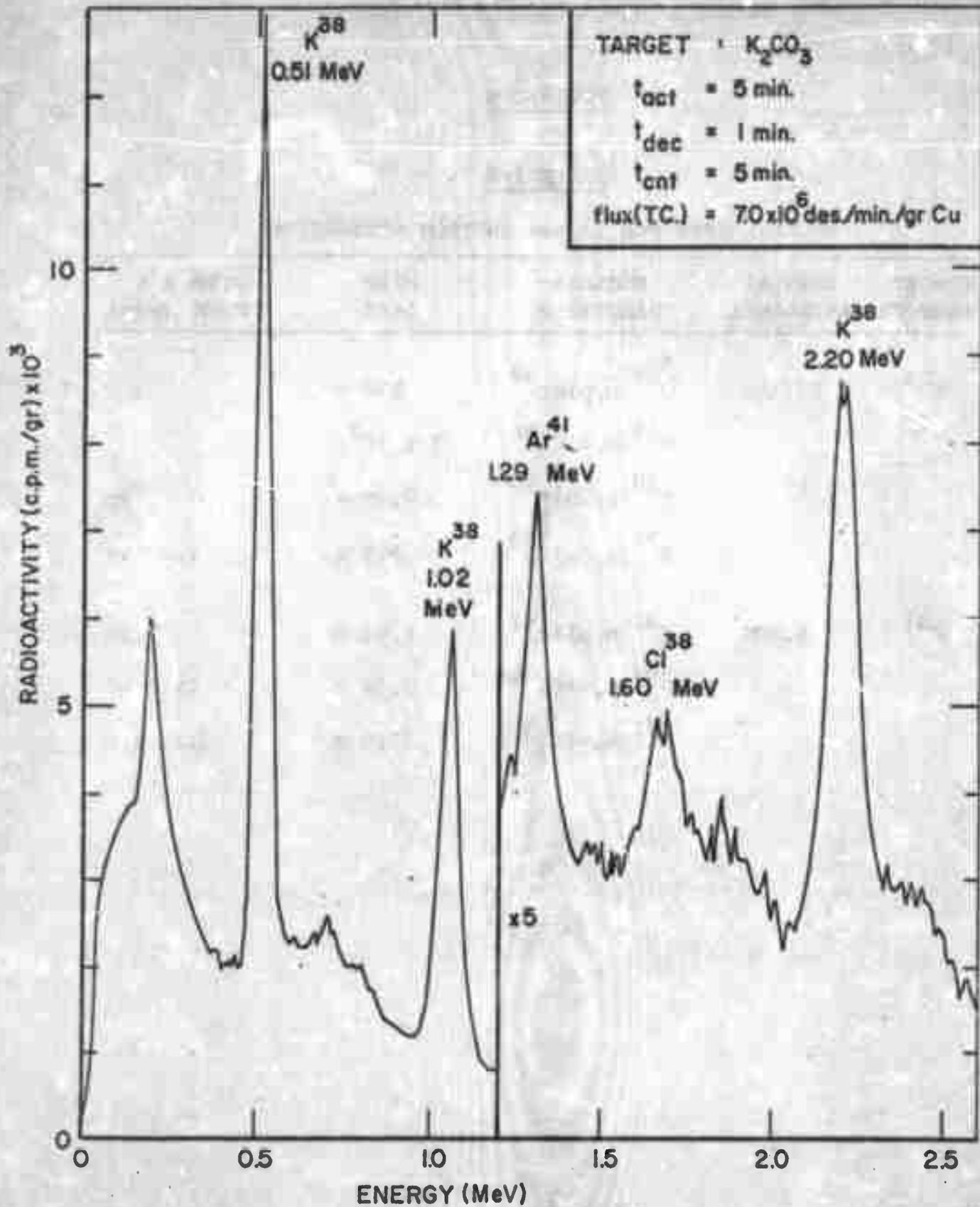


FIGURE I-K

POTASSIUM

TABLE II-K

PEAKS OBSERVED IN FIGURE I-K

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-K	0.51	$K^{39}(n,2n)K^{38}$	7.7 m	
	1.02	$K^{39}(n,2n)K^{38}$	7.7 m	0.51 Mev coincidence sum peak
	1.29	$K^{41}(n,p)Ar^{41}$	1.83h	
	1.6	$K^{41}(n,\alpha)Cl^{38}$	37.3 m	
	2.2	$K^{41}(n,\alpha)Cl^{38}$ $K^{39}(n,2n)K^{38}$	37.3 m 7.7 m	

TABLE III-K

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.51	5 m	1 m	5 m	48	3.4

TABLE IV-K

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for potassium from any other element.

For other positron emitting radioisotopes than  $K^{38}$ , see Section I. Appendix II.

PRASEODYMIUM

PRASEODYMIUM

TABLE I-Pr

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
$\text{Pr}^{141}$	100%	$\text{Pr}^{141} (n,p)\text{Ce}^{141}$	32.5 d	0.145
		$\text{Pr}^{141} (n,2n)\text{Pr}^{140}$	3.4 m	1.6, 1.9, 0.3, $\beta^+$

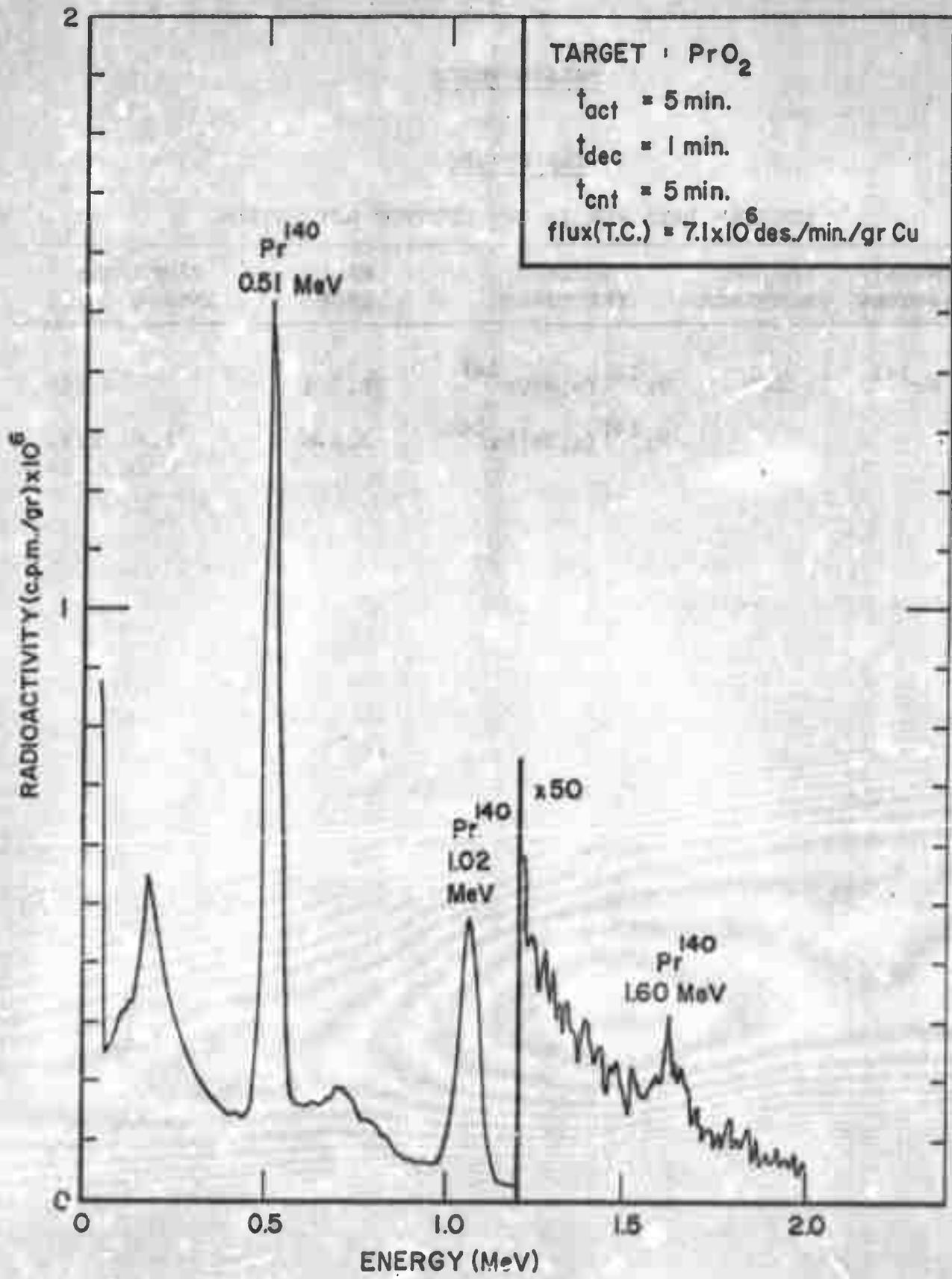


FIGURE I-Pr

TABLE II-Pr

PEAKS OBSERVED IN FIGURE I-Pr

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Pr	0.51	$\text{Pr}^{141} (n, 2n) \text{Pr}^{140}$	3.4 m	
	1.02	$\text{Pr}^{141} (n, 2n) \text{Pr}^{140}$	3.4 m	0.51 Mev coincidence sum peak
	1.60	$\text{Pr}^{141} (n, 2n) \text{Pr}^{140}$	3.4 m	

TABLE III-Pr

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT(mg)
0.51	5 m	1 m	5 m	5400	0.03

TABLE IV-Pr

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for praseodymium from any other element.

For other positrons emitting radioisotopes than  $\text{Pr}^{140}$ , see Section I, Appendix II.

RUBIDIUMTABLE I-Rb

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Rb <sup>85</sup>	72.15%	Rb <sup>85</sup> (n,p)Kr <sup>85m</sup>	4.4 h	0.15, IT 0.31
		Rb <sup>85</sup> (n,p)Kr <sup>85</sup>	10.76 y	0.52
		Rb <sup>85</sup> (n,α)Br <sup>82m</sup>	6.1 m	0.78, 1.48, IT 0.046
		Rb <sup>85</sup> (n,α)Br <sup>82</sup>	35.3 h	0.78, 0.55, 0.62, 0.70, 1.48
		Rb <sup>85</sup> (n,2n)Rb <sup>84m</sup>	20 m	0.24, 0.48, IT 0.46, 0.22
		Rb <sup>85</sup> (n,2n)Rb <sup>84</sup>	33 d	0.88, 1.01, 1.90, β+
		Rb <sup>87</sup>	27.85%	Rb <sup>87</sup> (n,p)Kr <sup>87</sup>
Rb <sup>87</sup> (n,α)Br <sup>84m</sup>	6 m	0.88, 1.46,		
Rb <sup>87</sup> (n,α)Br <sup>84</sup>	32 m	0.88, 2.1, 1.9, 0.27, 3.9		
Rb <sup>87</sup> (n,2n)Rb <sup>86m</sup>	1 m	IT 0.56		
Rb <sup>87</sup> (n,2n)Rb <sup>86</sup>	18.7 d	1.08		

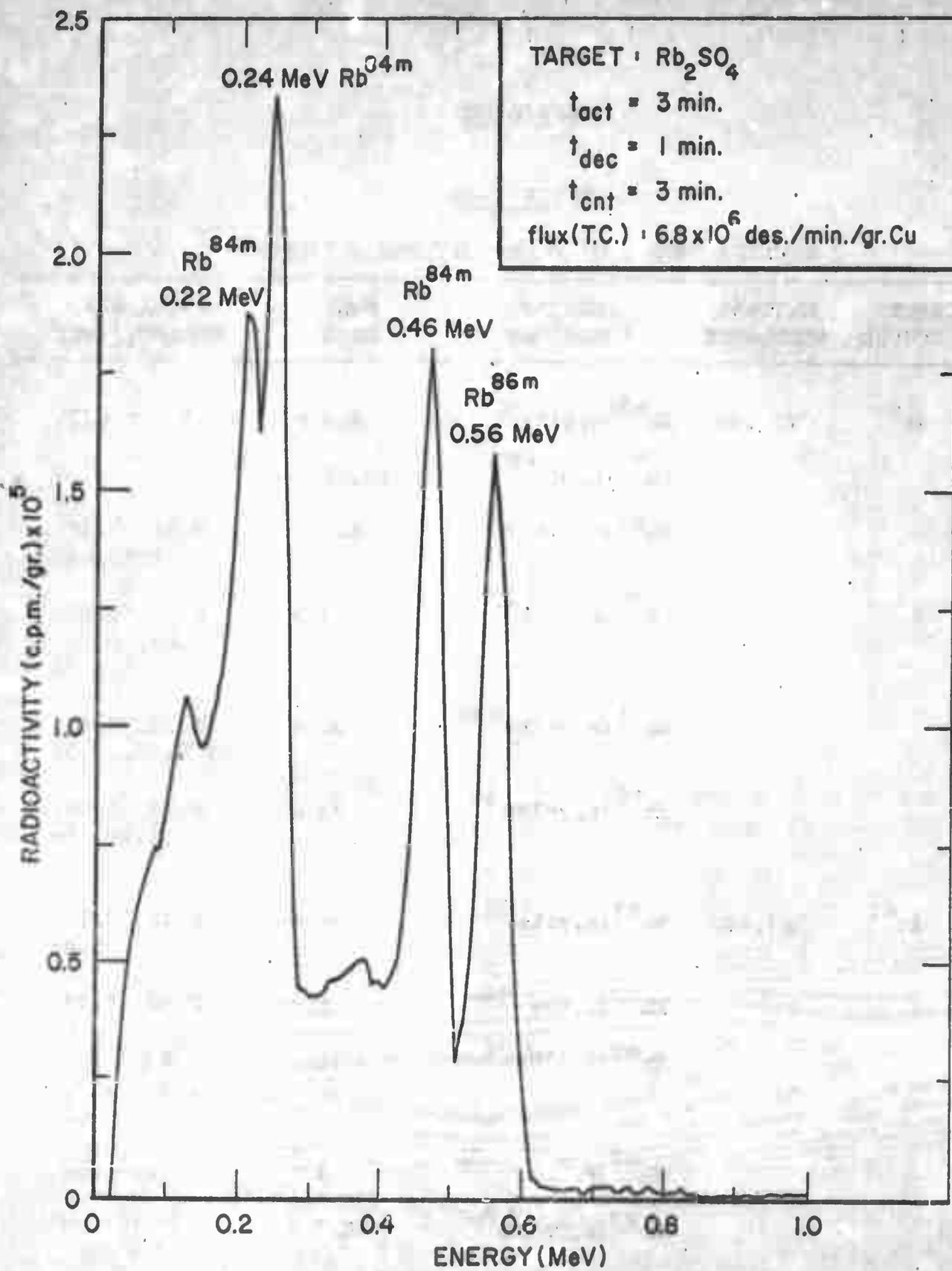


FIGURE I-Rb

TABLE II-Rb

## PEAKS OBSERVED IN FIGURE I-Rb

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Rb	0.22	Rb <sup>85</sup> (n, 2n) Rb <sup>84m</sup>	20 m	
	0.24	Rb <sup>85</sup> (n, 2n) Rb <sup>84m</sup>	20 m	
	0.46	Rb <sup>85</sup> (n, 2n) Rb <sup>84m</sup>	20 m	
	0.56	Rb <sup>87</sup> (n, 2n) Rb <sup>86m</sup>	1 m	

NOTE: An irradiation and counting time of 5 minutes will change the ratio of the 0.46 Mev to 0.56 Mev photopeak.

TABLE III-Rb

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.46	3 m	1 m	3 m	458	0.33
0.56	3 m	1 m	3 m	490	0.29
0.22+0.24	5 m	1 m	5 m	2000	0.11
0.46	5 m	1 m	5 m	1490	0.12
0.56	5 m	1 m	5 m	635	0.21

RUBIDIUM

TABLE IV-Rb

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.56	Strontium	$Sr^{86} (n,p) Rb^{86m}$	

## RUTHENIUM

RUTHENIUM

TABLE I - Ru

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ru <sup>96</sup>	5.51%	Ru <sup>96</sup> (n,α)Mo <sup>93m</sup>	6.9 h	0.69, 1.48, IT 0.26
		↓		
		Ru <sup>96</sup> (n,α)Mo <sup>93</sup>	≈10 <sup>4</sup> y	
		Ru <sup>96</sup> (n,p)Tc <sup>96m</sup>	52 m	IT 0.034
		↓		
		Ru <sup>96</sup> (n,p)Tc <sup>96</sup>	4.3 d	0.77, 0.84, 0.81, 1.12
		Ru <sup>96</sup> (n,2n)Ru <sup>95</sup>	99 m	0.34, 1.1, 0.63, β+
Ru <sup>98</sup>	1.87%	Ru <sup>98</sup> (n,p)Tc <sup>98</sup>	1.5x10 <sup>6</sup> y	0.75, 0.66
		Ru <sup>98</sup> (n,2n)Ru <sup>97</sup>	2.9 d	0.22, 0.11, 0.57
Ru <sup>99</sup>	12.72%	Ru <sup>99</sup> (n,p)Tc <sup>99m</sup>	6.0 h	0.140, IT 0.002, 0.142
		↓		
		Ru <sup>99</sup> (n,p)Tc <sup>99</sup>	2.1x10 <sup>5</sup> y	
Ru <sup>100</sup>	12.62%	Ru <sup>100</sup> (n,p)Tc <sup>100</sup>	17 s	0.54, 0.59
Ru <sup>101</sup>	17.07%	Ru <sup>101</sup> (n,p)Tc <sup>101</sup>	14 m	0.31, 0.54, 0.13, 0.94
Ru <sup>102</sup>	31.61%	Ru <sup>102</sup> (n,α)Mo <sup>99</sup>	66 h	0.140, 0.74, 0.041, 0.78

RUTHENIUM

TABLE I - Ru (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$\text{Ru}^{102}(n,p)\text{Tc}^{102m}$	4.5 m	0.47, 2.0
		$\text{Ru}^{102}(n,p)\text{Tc}^{102}$	5 s	
$\text{Ru}^{104}$	18.58%	$\text{Ru}^{104}(n,\alpha)\text{Mo}^{101}$	14.6m	1.02, 0.59, 2.08, 0.08, 1.66
		$\text{Ru}^{104}(n,p)\text{Tc}^{104}$	18 m	0.31, 4.8
		$\text{Ru}^{104}(n,2n)\text{Ru}^{103}$	40 d	0.040, 0.50, 0.05, 0.61

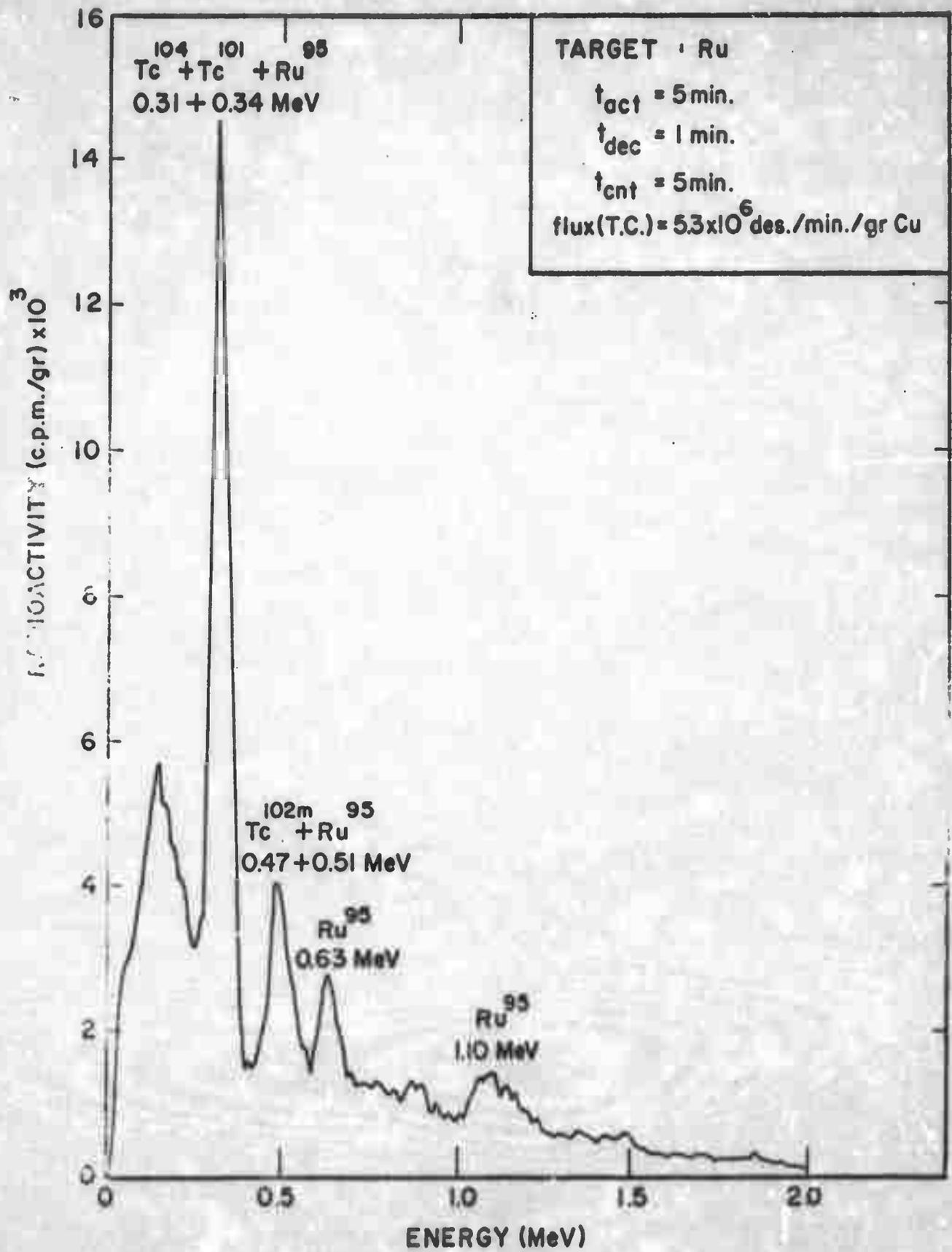


FIGURE I-Ru

TABLE II-Ru

## PEAKS OBSERVED IN FIGURE I-Ru

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ru	0.31 + 0.34	$\text{Ru}^{101}(n,p)\text{Tc}^{101}$	14 m	
		$\text{Ru}^{104}(n,p)\text{Tc}^{104}$	18 m	
		$\text{Ru}^{96}(n,2n)\text{Ru}^{95}$	99 m	
	0.47 + 0.51	$\text{Ru}^{102}(n,p)\text{Tc}^{102m}$	4.5 m	
		$\text{Ru}^{96}(n,2n)\text{Ru}^{95}$	99 m	
	0.63	$\text{Ru}^{96}(n,2n)\text{Ru}^{95}$	99 m	
	1.1	$\text{Ru}^{96}(n,2n)\text{Ru}^{95}$	99 m	

TABLE III-Ru

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{\text{act}}$	$T_{\text{dec}}$	$T_{\text{cnt}}$	COUNTS/ mg/ $T_{\text{cnt}}$	DETECTION LIMIT, mg
0.31	5 m	1 m	5 m	77	1.4

TABLE IV-Ru

## POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for ruthenium from any other element.

SAMARIUM

SAMARIUM

TABLE I-Sm

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Sm <sup>144</sup>	3.09%	Sm <sup>144</sup> (n, p) Pm <sup>144</sup>	365 d	0.70, 0.62, 0.48
		Sm <sup>144</sup> (n, α) Nd <sup>141m</sup>	64 s	IT 0.76
		Sm <sup>144</sup> (n, α) Nd <sup>141</sup>	2.5 h	1.15, 1.30, β+
		Sm <sup>144</sup> (n, 2n) Sm <sup>143m</sup>	1.0 m	IT 0.75
		Sm <sup>144</sup> (n, 2n) Sm <sup>143</sup>	9.0 m	β+
Sm <sup>147</sup>	14.97%	Sm <sup>147</sup> (n, p) Pm <sup>147</sup>	2.7 y	0.12
		Sm <sup>147</sup> (n, 2n) Sm <sup>146</sup>	1.2 x 10 <sup>8</sup> y	
Sm <sup>148</sup>	11.24%	Sm <sup>148</sup> (n, p) Pm <sup>148m</sup>	41 d	0.08, 1.0, IT 0.06
		Sm <sup>148</sup> (n, p) Pm <sup>148</sup>	5.4 d	0.55, 0.91, 1.46
Sm <sup>149</sup>	13.83%	Sm <sup>149</sup> (n, p) Pm <sup>149</sup>	53 h	0.28, 0.85
Sm <sup>150</sup>	7.44%	Sm <sup>150</sup> (n, p) Pm <sup>150</sup>	2.7 h	0.33, 1.17, 1.33, 0.83, 1.75, 0.41, 3.1
		Sm <sup>150</sup> (n, α) Nd <sup>147</sup>	11.1 d	0.091, 0.53, 0.12, 0.69

SAMARIUM

TABLE I-Sm (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
$\text{Sm}^{152}$	26.72%	$\text{Sm}^{152} (n,p) \text{Pm}^{152}$	6 m	0.12, 0.24, 1.0
		$\text{Sm}^{152} (n,\alpha) \text{Nd}^{149}$	1.8 h	0.21, 0.27, 0.11, 0.65
		$\text{Sm}^{152} (n,2n) \text{Sm}^{151}$	90 y	0.022
$\text{Sm}^{154}$	22.71%	$\text{Sm}^{154} (n,p) \text{Pm}^{154}$	2.5 m	
		$\text{Sm}^{154} (n,\alpha) \text{Nd}^{151}$	12 m	0.12, 0.26, 0.030, 2.2
		$\text{Sm}^{154} (n,2n) \text{Sm}^{153}$	47 h	0.103, 0.07, 0.02, 0.64

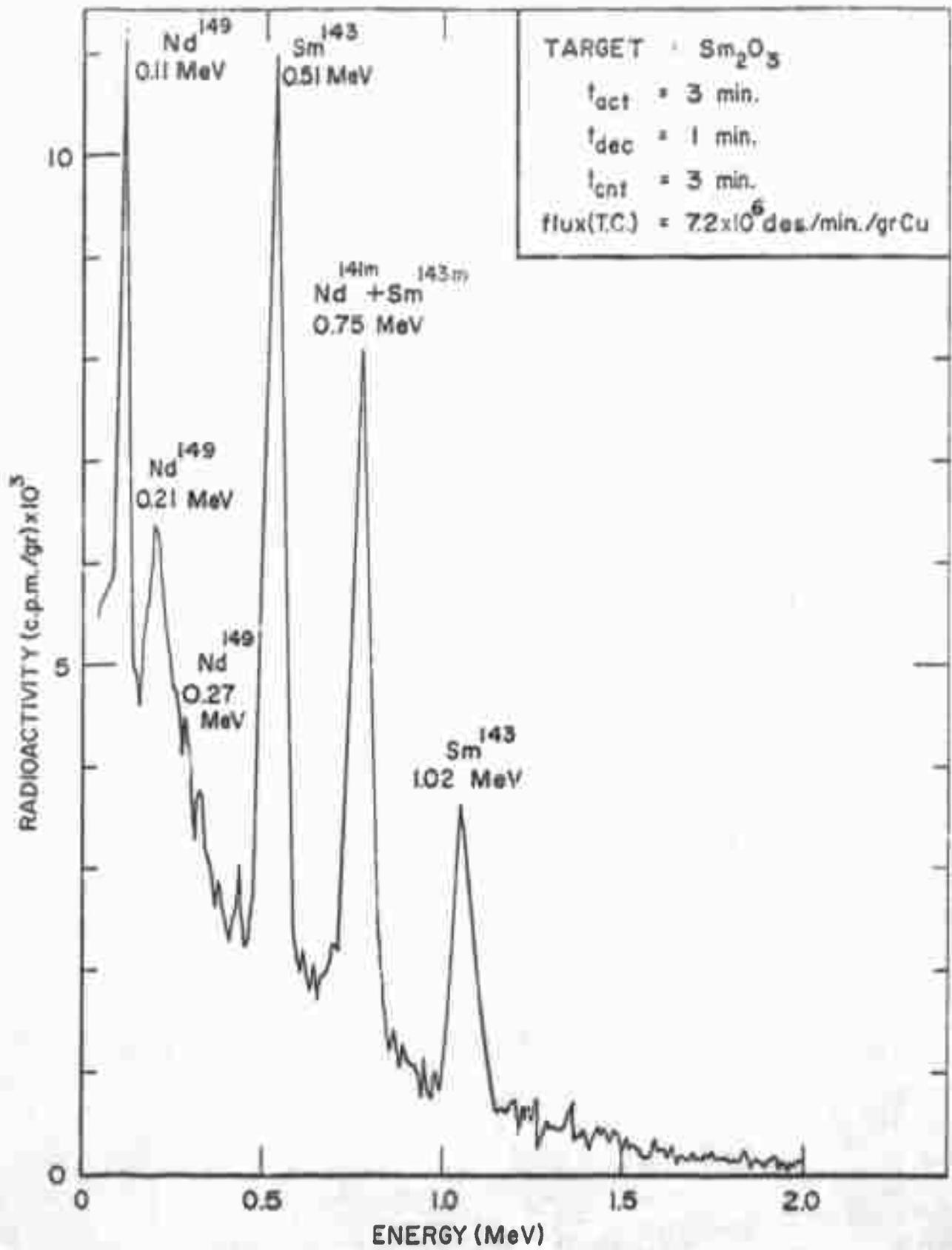


FIGURE I-Sm

TABLE II-Sm

## PEAKS OBSERVED IN FIGURE I-Sm

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Sm	0.11	$\text{Sm}^{152} (n, \alpha) \text{Nd}^{149}$	1.8 h	
	0.21	$\text{Sm}^{152} (n, \alpha) \text{Nd}^{149}$	1.8 h	
	0.27	$\text{Sm}^{152} (n, \alpha) \text{Nd}^{149}$	1.8 h	
	0.51	$\text{Sm}^{144} (n, 2n) \text{Sm}^{143}$	9 m	
	0.75	$\text{Sm}^{144} (n, \alpha) \text{Nd}^{141m}$	64 s	
		$\text{Sm}^{144} (n, 2n) \text{Sm}^{143m}$	1 m	
	1.02	$\text{Sm}^{144} (n, 2n) \text{Sm}^{143}$	9 m	0.51 Mev coincidence sum peak

TABLE III-Sm

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT(mg)
0.75	3 m	1 m	3 m	43	2.3
0.51	5 m	1 m	5 m	80	2.1
0.75	5 m	1 m	5 m	51	2.2

SAMARIUM

TABLE IV-Sm

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.75	Cerium	$Ce^{140} (n, 2n) Ce^{139m}$	(1)
	Neodymium	$Nd^{142} (n, 2n) Nd^{141m}$	(1)
	Neodymium	$Nd^{142} (n, \alpha) Ce^{139m}$	
0.51	Nitrogen	$N^{14} (n, 2n) N^{13}$	(2)
	Copper	$Cu^{63} (n, 2n) Cu^{62}$	(2)

(1)  $Ce^{139m}$  and  $Nd^{141m}$  have a half life respectively of 55 sec and 64 sec, making their identification from  $Sm^{143m}$  very difficult.

(2)  $N^{13}$  and  $Cu^{62}$  have a half life respectively of 9.96 and 9.9 min, making their identification from  $Sm^{143}$  very difficult for other positron emitting radioisotopes, see Section I, Appendix II.

## SELENIUM

SELENIUMTABLE I-Se<sub>1</sub>

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (MeV)
Se <sup>74</sup>	0.87%	Se <sup>74</sup> (n,p) As <sup>74m</sup>	8 s	IT 0.28
		Se <sup>74</sup> (n,p) As <sup>74</sup>	18 d	0.60, 0.64, 2.52, β <sup>+</sup>
		Se <sup>74</sup> (n,α) Ge <sup>71m</sup>	0.020 s	0.175, IT 0.023
		Se <sup>74</sup> (n,α) Ge <sup>71</sup>	11 d	
		Se <sup>74</sup> (n,2n) Se <sup>73m</sup>	44 m	0.88, 0.25, 0.58, β <sup>+</sup>
		Se <sup>74</sup> (n,2n) Se <sup>73</sup>	7.1 h	0.36, 0.066, β <sup>+</sup>
Se <sup>76</sup>	9.02%	Se <sup>76</sup> (n,p) As <sup>76</sup>	26.5 h	0.56, 1.21, 0.66, 0.64, 2.66
		Se <sup>76</sup> (n,α) Ge <sup>73m</sup>	0.53 s	IT 0.054
		Se <sup>76</sup> (n,2n) Se <sup>75</sup>	120 d	0.265, 0.136, 0.280, 0.024, 0.58
Se <sup>77</sup>	7.58%	Se <sup>77</sup> (n,p) As <sup>77m</sup>	116 μs	IT 0.21
		Se <sup>77</sup> (n,p) As <sup>77</sup>	39 h	0.24, 0.52, 0.086, 0.160
		Se <sup>77</sup> (n,n') Se <sup>77m</sup>	18 s	IT 0.16

## SELENIUM

TABLE I-Se (cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
$\text{Se}^{78}$	23.52%	$\text{Se}^{78} (n, p) \text{As}^{78m}$	6 m	IT 0.50
		$\text{Se}^{78} (n, p) \text{As}^{78}$	91 m	0.62, 0.70, 1.31, 0.08, 2.68
		$\text{Se}^{78} (n, \alpha) \text{Ge}^{75m}$	49 s	IT 0.14
		$\text{Se}^{78} (n, \alpha) \text{Ge}^{75}$	82 m	0.27, 0.07, 0.63
		$\text{Se}^{78} (n, 2n) \text{Se}^{77m}$	18 s	IT 0.16
		$\text{Se}^{80}$	49.82%	$\text{Se}^{80} (n, p) \text{As}^{80}$
$\text{Se}^{80} (n, \alpha) \text{Ge}^{77m}$	54 s			0.159, IT 0.16
$\text{Se}^{80} (n, \alpha) \text{Ge}^{77}$	11 h			0.22, 0.27, 0.04, 2.3
$\text{Se}^{80} (n, 2n) \text{Se}^{79m}$	3.9 m			IT 0.096
$\text{Se}^{80} (n, 2n) \text{Se}^{79}$	$7 \times 10^4$ y			
$\text{Se}^{82}$	9.19%			$\text{Se}^{82} (n, 2n) \text{Se}^{81m}$
		$\text{Se}^{82} (n, 2n) \text{Se}^{81}$	18 m	0.28

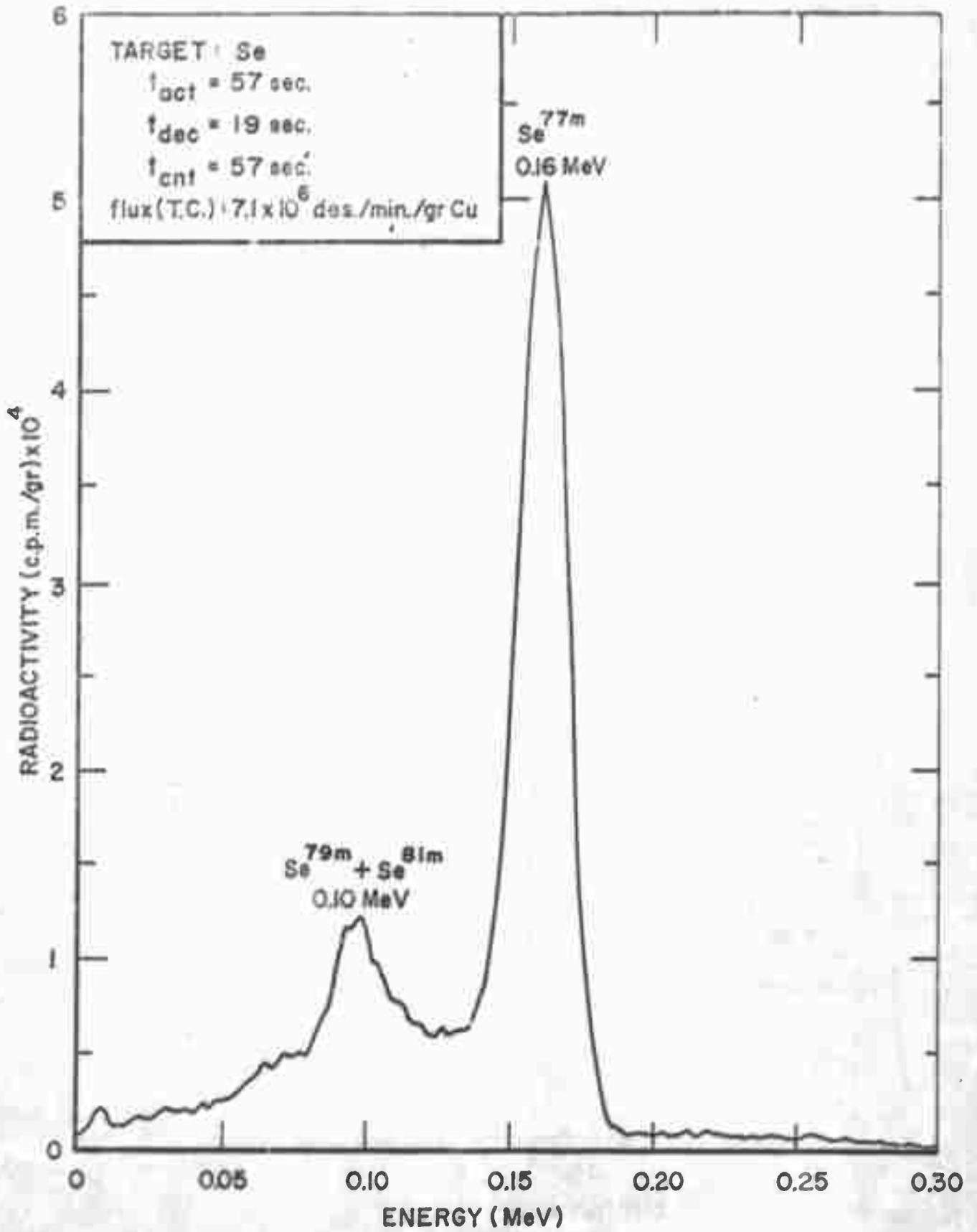


FIGURE I-Se

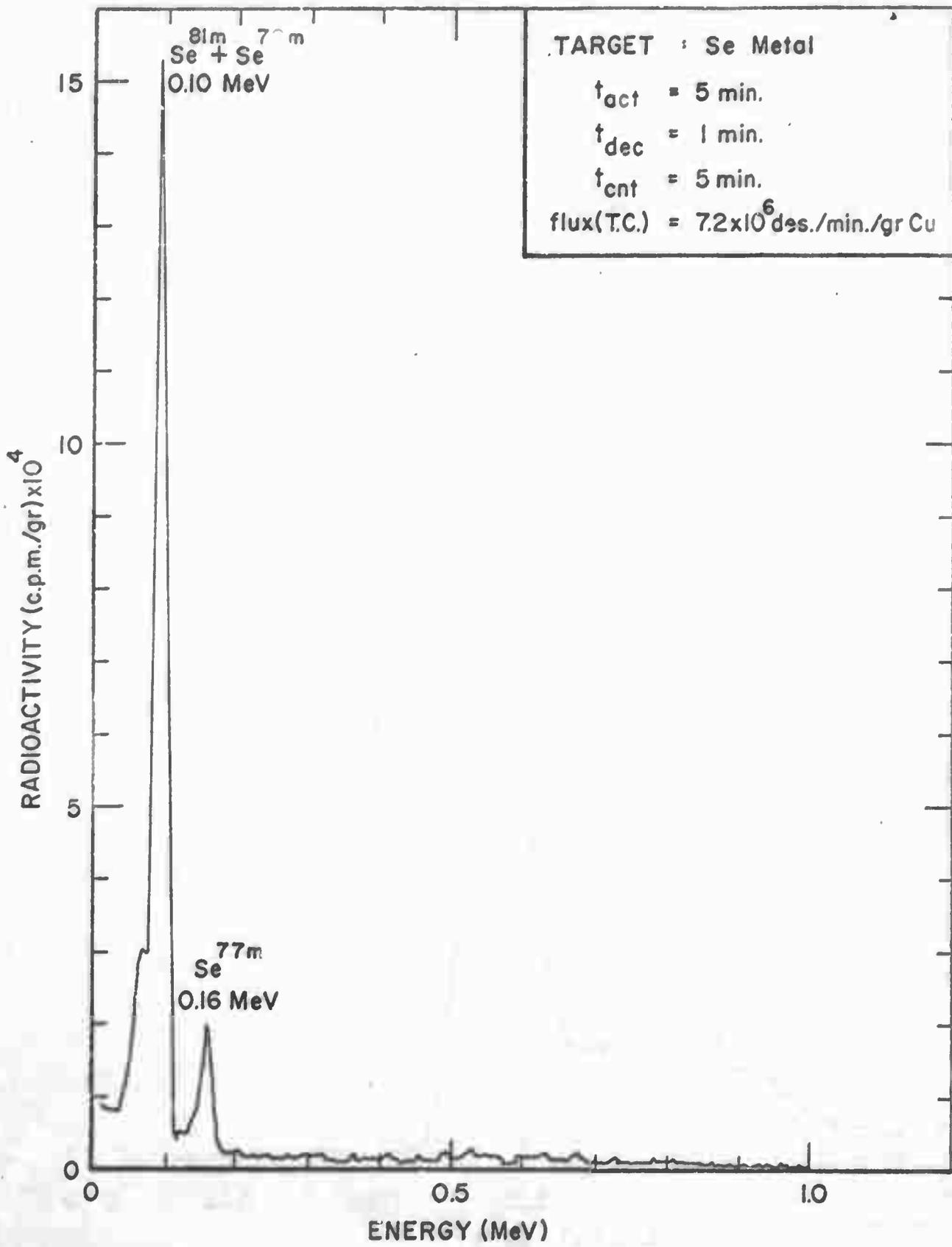


FIGURE II-Se

TABLE II-Se

PEAKS OBSERVED IN FIGURES I-Se and II-Se

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Se	0.10	$\text{Se}^{80}(n, 2n)\text{Se}^{79m}$	3.9 m	(1)
		$\text{Se}^{82}(n, 2n)\text{Se}^{81m}$	57 m	
	0.16	$\text{Se}^{77}(n, n')\text{Se}^{77m}$	18 s	
		$\text{Se}^{78}(n, 2n)\text{Se}^{77m}$	18 s	
II-Se	0.10	$\text{Se}^{80}(n, 2n)\text{Se}^{79m}$	3.9 m	
		$\text{Se}^{82}(n, 2n)\text{Se}^{81m}$	57 m	
	0.16	$\text{Se}^{77}(n, n')\text{Se}^{77m}$	18 s	
		$\text{Se}^{78}(n, 2n)\text{Se}^{77m}$	18 s	

(1) The decay curve made on the photopeak at 0.16 Mev does not show an activity due to  $\text{Ge}^{77m}$  ( $T_{1/2} = 54$  sec) produced by the  $\text{Se}^{80}(n, \alpha)\text{Ge}^{77m}$  reaction.

NOTE:  $\text{As}^{74m}$  ( $T_{1/2} = 8$  sec) not detected for 24 sec irradiation, 8 sec decay and 24 sec counting time.

TABLE III-Se

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{act}$	$T_{dec}$	$T_{cnt}$	COUNTS/mg/ $T_{cnt}$	DETECTION LIMIT (mg)
0.16	57 s	19 s	57 s	261	0.44
0.16	5 m	1 m	5 m	56	1.7
0.10	5 m	1 m	5 m	496	0.24

**SELENIUM**

**TABLE IV-Se**

**POSSIBLE INTERFERING REACTIONS**

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No detectable interference could be derived for selenium from any other element.

SILICONTABLE I - Si

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Si <sup>28</sup>	92.21%	Si <sup>28</sup> (n,p) Al <sup>28</sup>	2.30m	1.78
		Si <sup>28</sup> (n,2n) Si <sup>27</sup>	4.2 s	0.84, 1.01 β+
Si <sup>29</sup>	4.70%	Si <sup>29</sup> (n,p) Al <sup>29</sup>	6.6 m	1.28, 2.43
Si <sup>30</sup>	3.09%	Si <sup>30</sup> (n,p) Al <sup>30</sup>	3.3 s	2.26, 3.52
		Si <sup>30</sup> (n,α) Mg <sup>27</sup>	9.5 m	0.84, 1.01

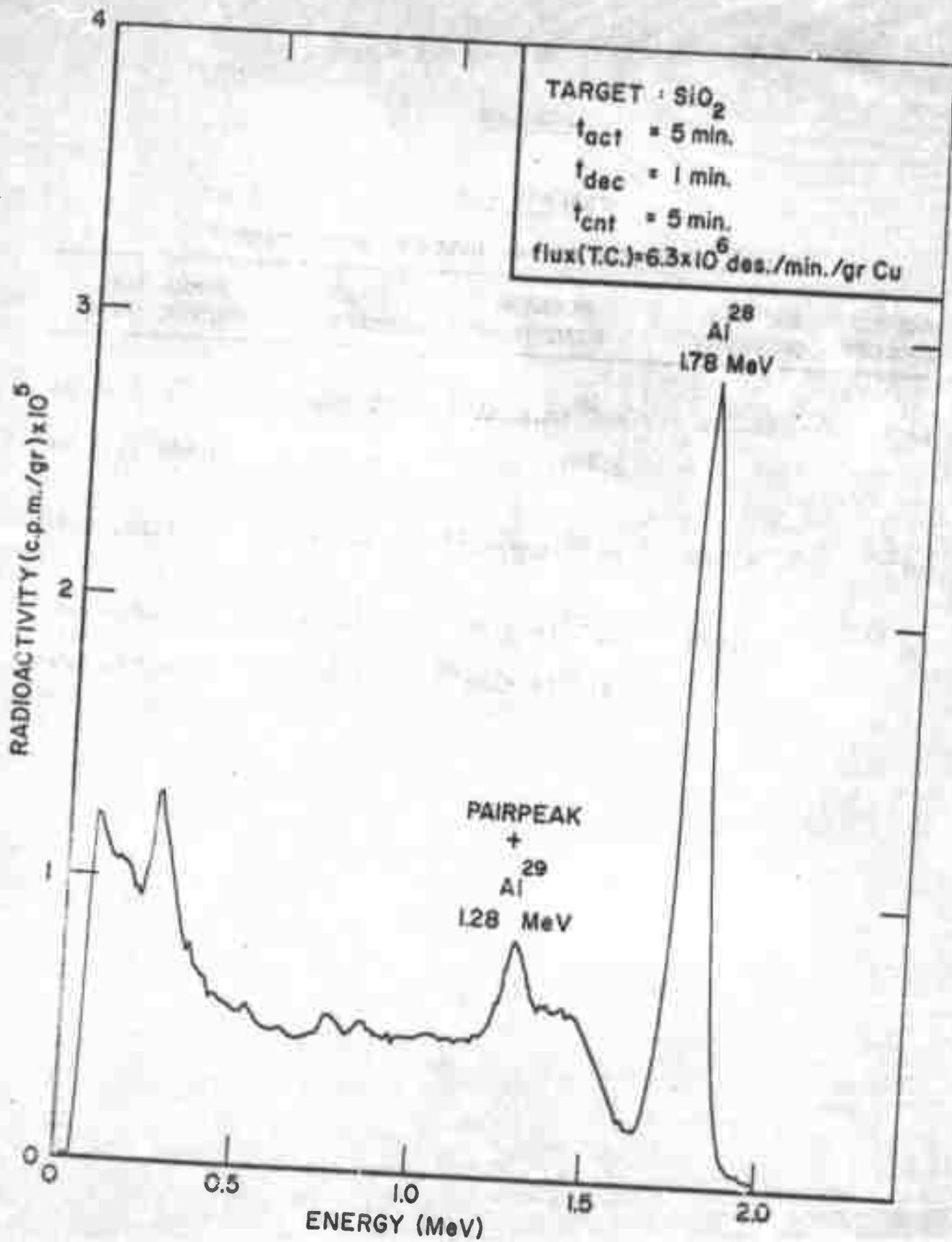


FIGURE I-S1

TABLE II-Si

## PEAKS OBSERVED IN FIGURE I-Si

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Si	1.28	$\text{Si}^{29}(\text{n,p})\text{Al}^{29}$	6.6 m	(1)
	1.78	$\text{Si}^{28}(\text{n,p})\text{Al}^{28}$	2.30m	

- (1) The photopeak at 1.27 Mev is a combination of the pair peak from 1.78 Mev and the photopeak due to  $\text{Al}^{29}$ . In this case, the largest contribution is from the  $\text{Al}^{29}$  isotope. This can be seen by comparing the spectra obtained from phosphorus and silicon. In the case of phosphorus, the 1.27 Mev photopeak is smaller than in the case for silicon.

NOTE:  $\text{Al}^{30}$  ( $T_{1/2} = 3.3$  sec) and  $\text{Si}^{27}$  ( $T_{1/2} = 4.2$  sec) not detected for 13 sec irradiation, 4 sec decay and 13 sec counting time.

TABLE III-Si

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{\text{act}}$	$T_{\text{dec}}$	$T_{\text{cnt}}$	COUNTS/mg/ $T_{\text{cnt}}$	DETECTION LIMIT (mg)
1.78	5 m	1 m	5 m	2360	0.07

## SILICON

TABLE IV-Si

## POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
1.78	Phosphorus	$P^{31}(n, \alpha)Al^{28}$	
	Aluminum	$Al^{27}(n, \gamma)Al^{28}$	

SILVERTABLE I - Ag

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ag <sup>107</sup>	51.82%	Ag <sup>107</sup> (n,p) Pd <sup>107m</sup>	22 s	IT 0.22
		Ag <sup>107</sup> (n,p) Pd <sup>107</sup>	7 x 10 <sup>6</sup> y	
		Ag <sup>107</sup> (n,α) Rh <sup>104m</sup>	4.4 m	0.051, IT 0.077
		Ag <sup>107</sup> (n,α) Rh <sup>104</sup>	42 s	0.56, 1.24
		Ag <sup>107</sup> (n,2n) Ag <sup>106m</sup>	8.3 d	0.51, 2.63
		Ag <sup>107</sup> (n,2n) Ag <sup>106</sup>	24 m	0.51, β+
		Ag <sup>107</sup> (n,n') Ag <sup>107m</sup>	44 s	IT 0.093
Ag <sup>109</sup>	48.18%	Ag <sup>109</sup> (n,p) Pd <sup>109m</sup>	4.8 m	IT 0.18
		Ag <sup>109</sup> (n,p) Pd <sup>109</sup>	13.5 h	0.088
		Ag <sup>109</sup> (n,α) Rh <sup>106m</sup>	2.2 h	0.51, 0.22, 1.22
		Ag <sup>109</sup> (n,α) Rh <sup>106</sup>	30 s	0.51, 0.62, 0.7, 3.4
		Ag <sup>109</sup> (n,2n) Ag <sup>108m</sup>	7.5 y	0.72, 0.62, 0.43
		Ag <sup>109</sup> (n,2n) Ag <sup>108</sup>	2.4 m	0.63, β+
		Ag <sup>109</sup> (n,n') Ag <sup>109m</sup>	40 s	IT 0.088

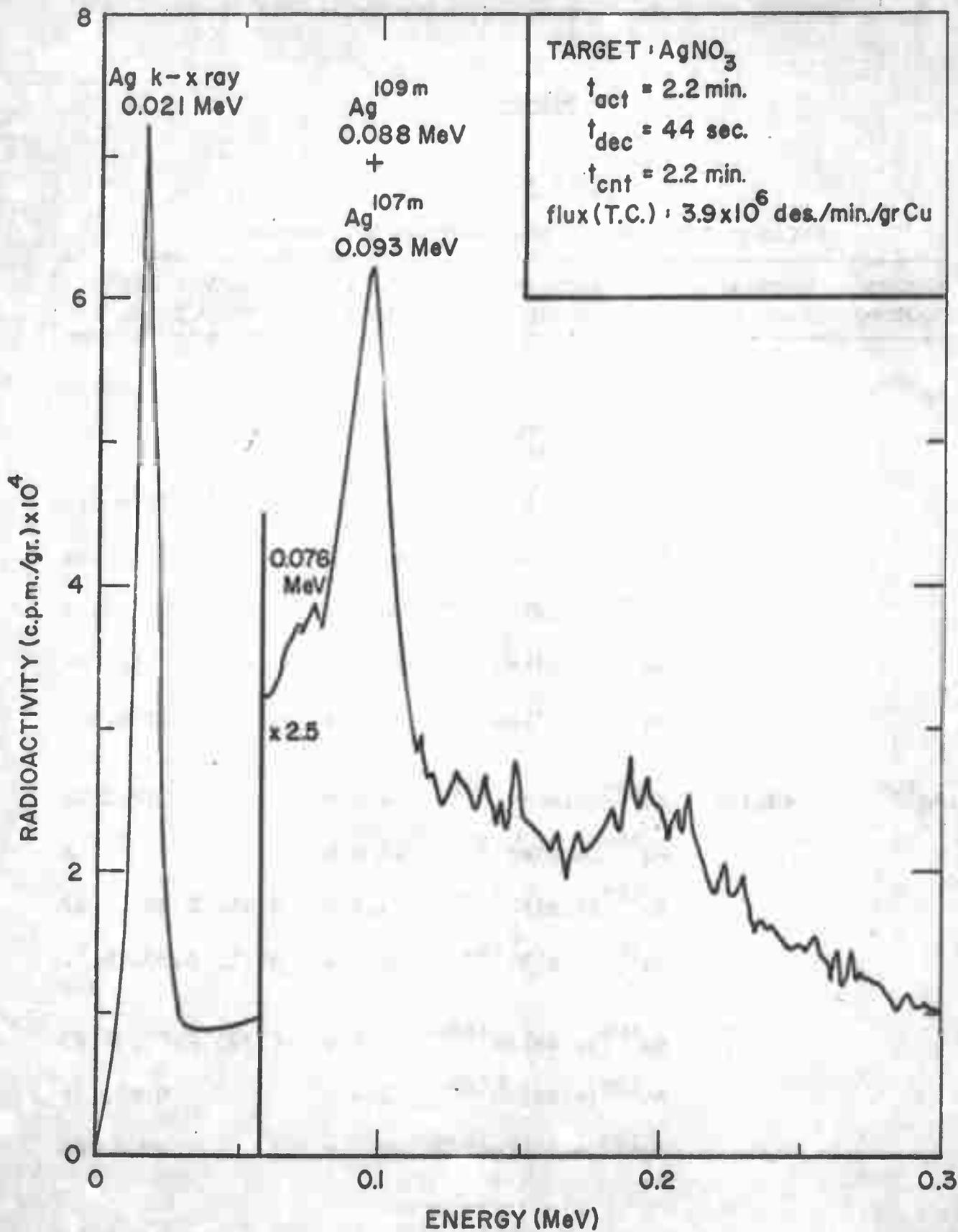


FIGURE I-Ag

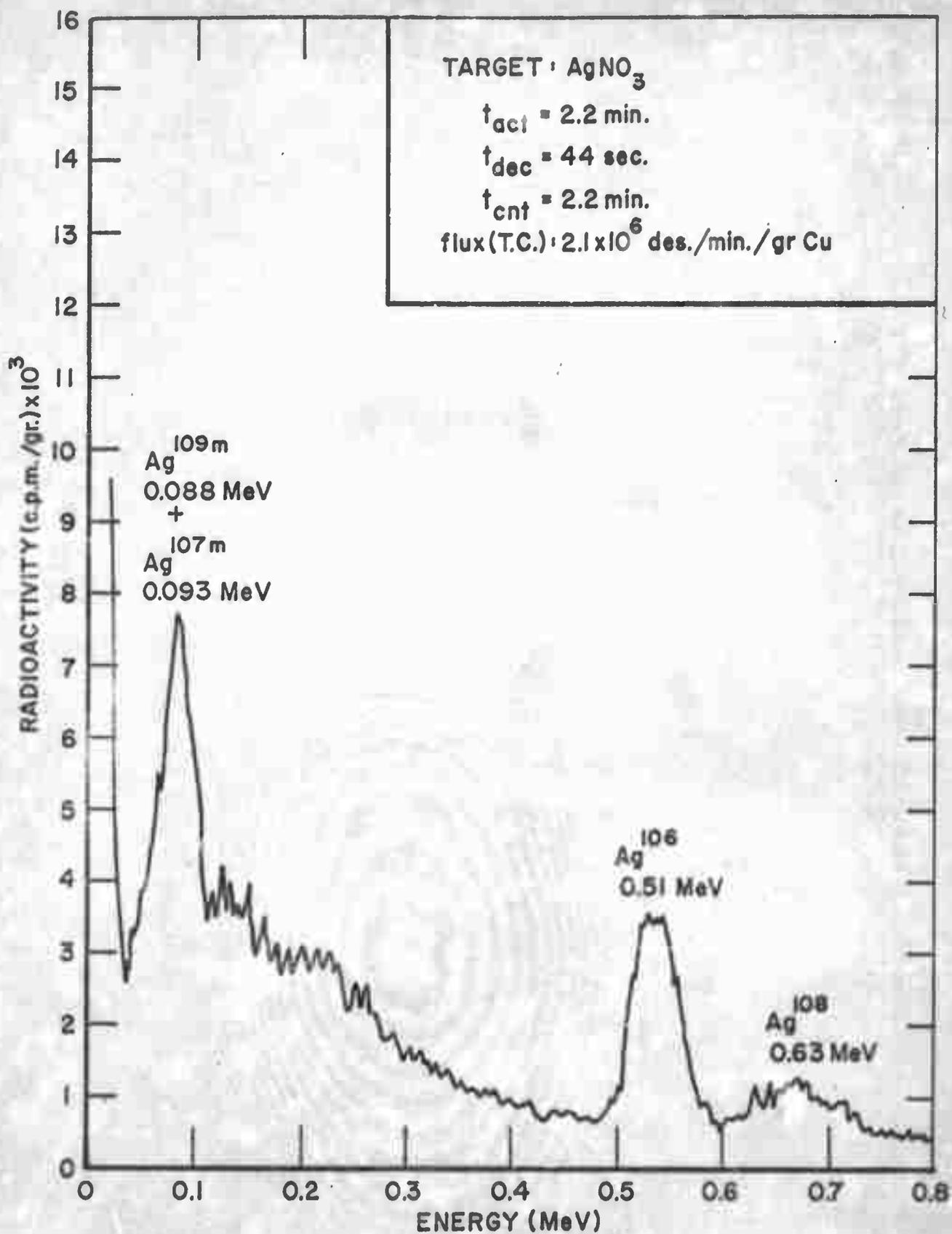


FIGURE II-Ag

TABLE II-Ag

PEAKS OBSERVED IN FIGURES I-Ag and II-Ag

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ag	0.021			k-x ray Ag
	0.093	$\text{Ag}^{107}(n,n')\text{Ag}^{107m}$	44 s	
	0.088	$\text{Ag}^{109}(n,n')\text{Ag}^{109m}$	40 s	(1)
II-Ag	0.51	$\text{Ag}^{107}(n,2n)\text{Ag}^{106}$	24 m	(2)
	0.63	$\text{Ag}^{109}(n,2n)\text{Ag}^{108}$	2.4m	

(1) The actual energy observed is 0.076 Mev because of the relatively high activity due to the 0.093 Mev peak. Contribution from the  $(\text{Ag}^{109}(n,p)\text{Pd}^{109})$  reaction is negligible and can be seen from the study of the decay curve of the 0.093 + 0.088 Mev  $\gamma$  energy peak combined.

(2) The sum peak at 1.02 Mev is not shown, in this figure.

TABLE III-Ag

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT(mg)
0.093+0.088	2.2 m	44 s	2.2 m	146	2.2
0.021	2.2 m	44 s	2.2 m	316	0.40
0.51	5 m	1 m	5 m	2127	0.08

NOTE: The observation of the k-x ray is very much dependent upon sample shape and should only be used analytically where sample size and shape is controlled.

SILVER

TABLE IV-Ag

POSSIBLE INTERFERING REACTIONS

---

No detectable interference could be derived for silver from any other element.

SODIUMTABLE I - Na

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Na <sup>23</sup>	100%	Na <sup>23</sup> (n,p)Ne <sup>23</sup>	38s	0.44 1.65
		Na <sup>23</sup> (n, $\alpha$ )F <sup>20</sup>	11s	1.63
		Na <sup>23</sup> (n,2n)Na <sup>22</sup>	2.58y	1.28 $\beta^+$

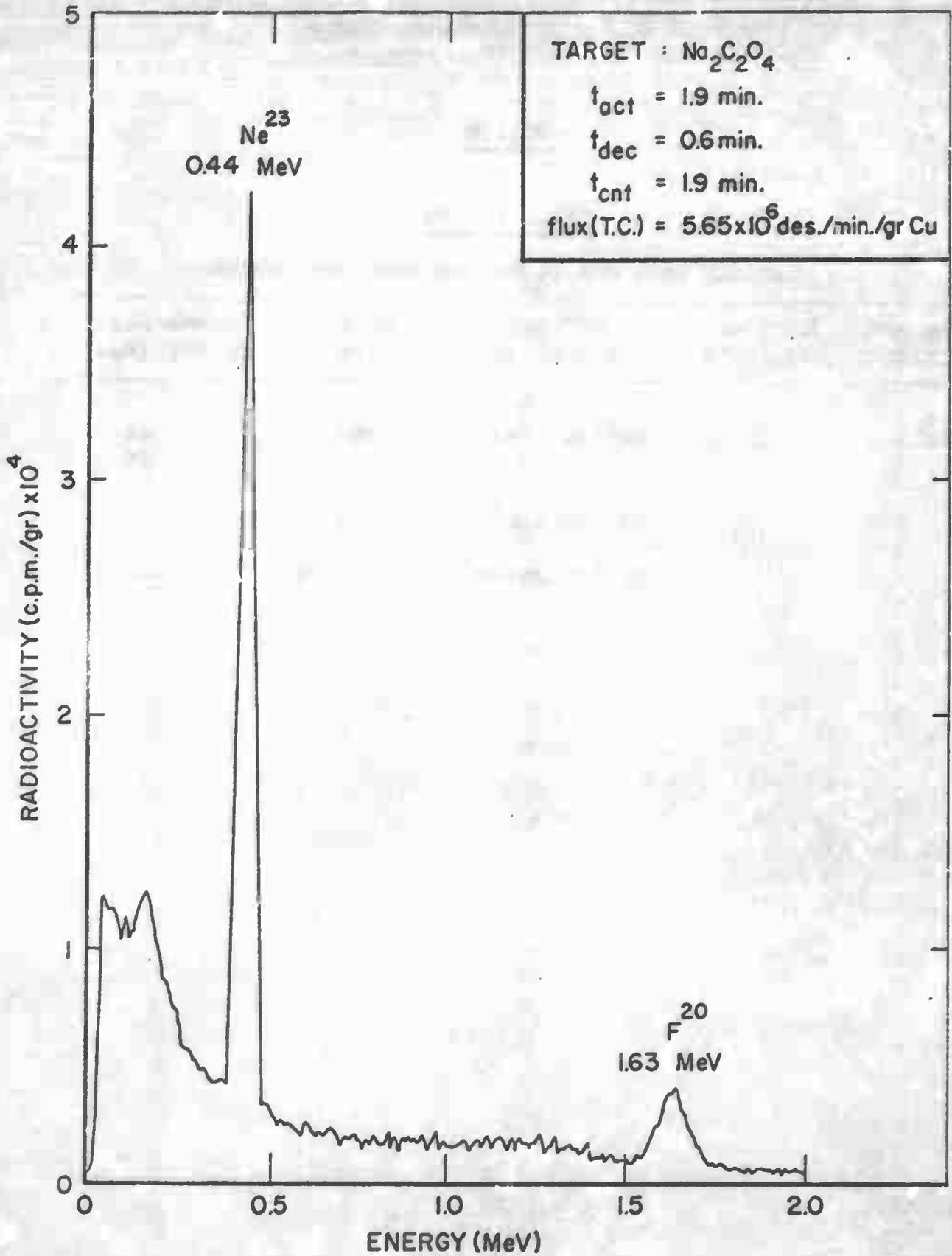


FIGURE I-Na

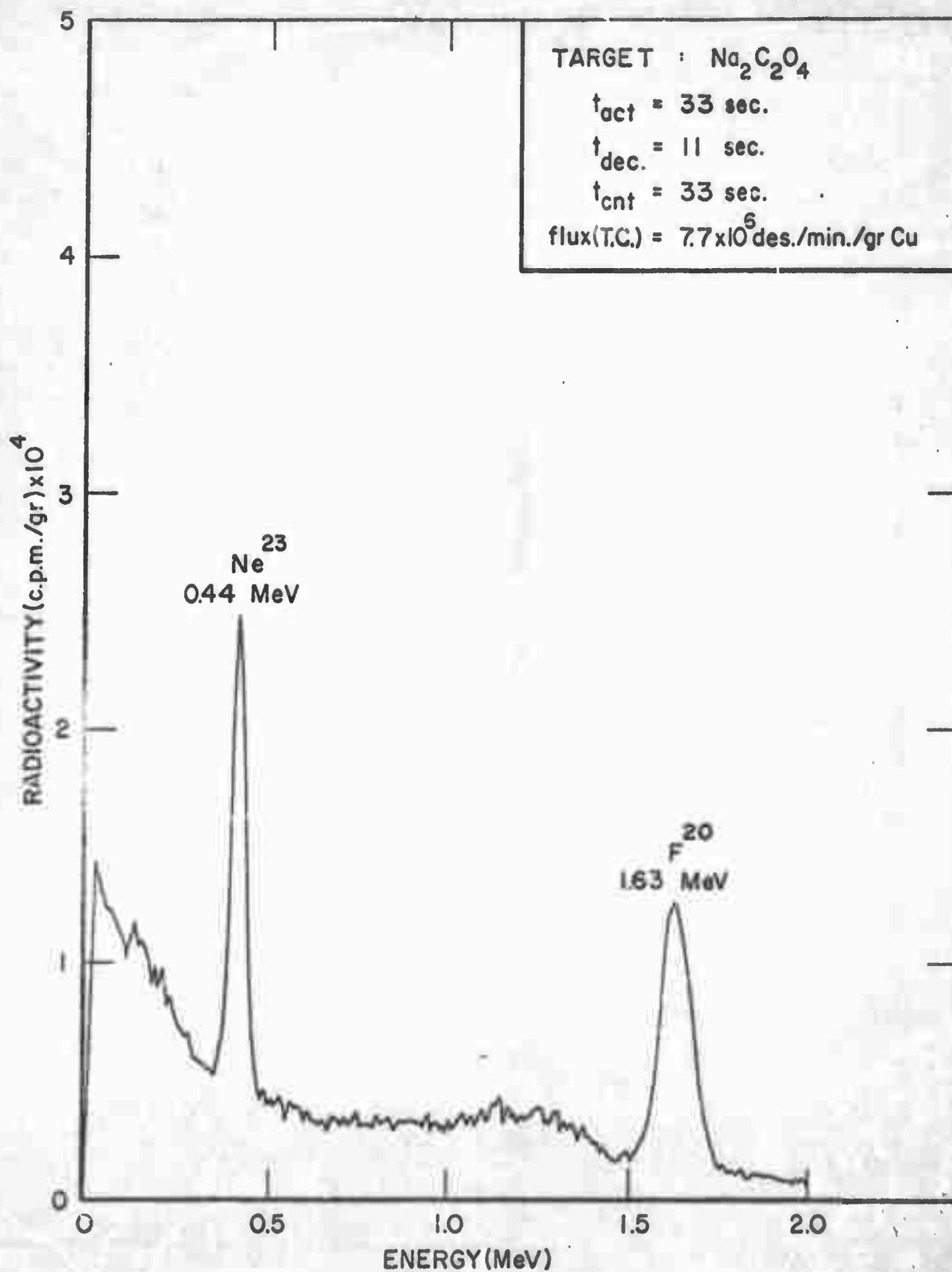


FIGURE II-Na

TABLE II-Na

PEAKS OBSERVED IN FIGURE I-Na and II-Na

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Na	0.44	$\text{Na}^{23}(n,p)\text{Ne}^{23}$	38 s	
and II-Na	1.63	$\text{Na}^{23}(n,\alpha)\text{F}^{20}$	11 s	

TABLE III-Na

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT(mg)
0.44	1.9 m	38 s	1.9 m	200	0.37
0.44	33 s	11 s	33 s	75	0.50
1.63	33 s	11 s	33 s	93	0.25

TABLE IV-Na

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.44	Magnesium	$\text{Mg}^{26}(n,\alpha)\text{Ne}^{23}$	

## STRONTIUM

STRONTIUM

TABLE I - Sr

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Sr <sup>84</sup>	0.56%	Sr <sup>84</sup> (n,p)Rb <sup>84m</sup>	20 m	0.24, IT 0.22, 0.46
		↓		
		Sr <sup>84</sup> (n,p)Rb <sup>84</sup>	33 d	0.88, 1.01, 1.90, β+
		Sr <sup>84</sup> (n,α)Kr <sup>81m</sup>	13 s	IT 0.19
		↓		
		Sr <sup>84</sup> (n,α)Kr <sup>81</sup>	2.1 x 10 <sup>5</sup> y	
		Sr <sup>84</sup> (n,2n)Sr <sup>83</sup>	33 h	0.755, 0.385, 0.040, β+
Sr <sup>86</sup>	9.86%	Sr <sup>86</sup> (n,p)Rb <sup>86m</sup>	1 m	IT 0.56
		↓		
		Sr <sup>86</sup> (n,p)Rb <sup>86</sup>	18.7 d	1.08
		Sr <sup>86</sup> (n,α)Kr <sup>83m</sup>	1.86h	0.009, IT 0.032
		Sr <sup>86</sup> (n,2n)Sr <sup>85m</sup>	70 m	0.23, IT 0.008, 0.23
		Sr <sup>86</sup> (n,2n)Sr <sup>85</sup>	64 d	0.514
Sr <sup>87</sup>	7.02%	Sr <sup>87</sup> (n,n')Sr <sup>87m</sup>	2.8 h	IT 0.39
Sr <sup>88</sup>	82.56%	Sr <sup>88</sup> (n,p)Rb <sup>88</sup>	18 m	1.85, 0.91, 2.7, 1.39, 4.9
		Sr <sup>88</sup> (n,α)Kr <sup>85m</sup>	4.4 h	0.15, IT 0.31
		↓		
		Sr <sup>88</sup> (n,α)Kr <sup>85</sup>	10.76y	0.52
		Sr <sup>88</sup> (n,2n)Sr <sup>87m</sup>	2.8 h	IT 0.39

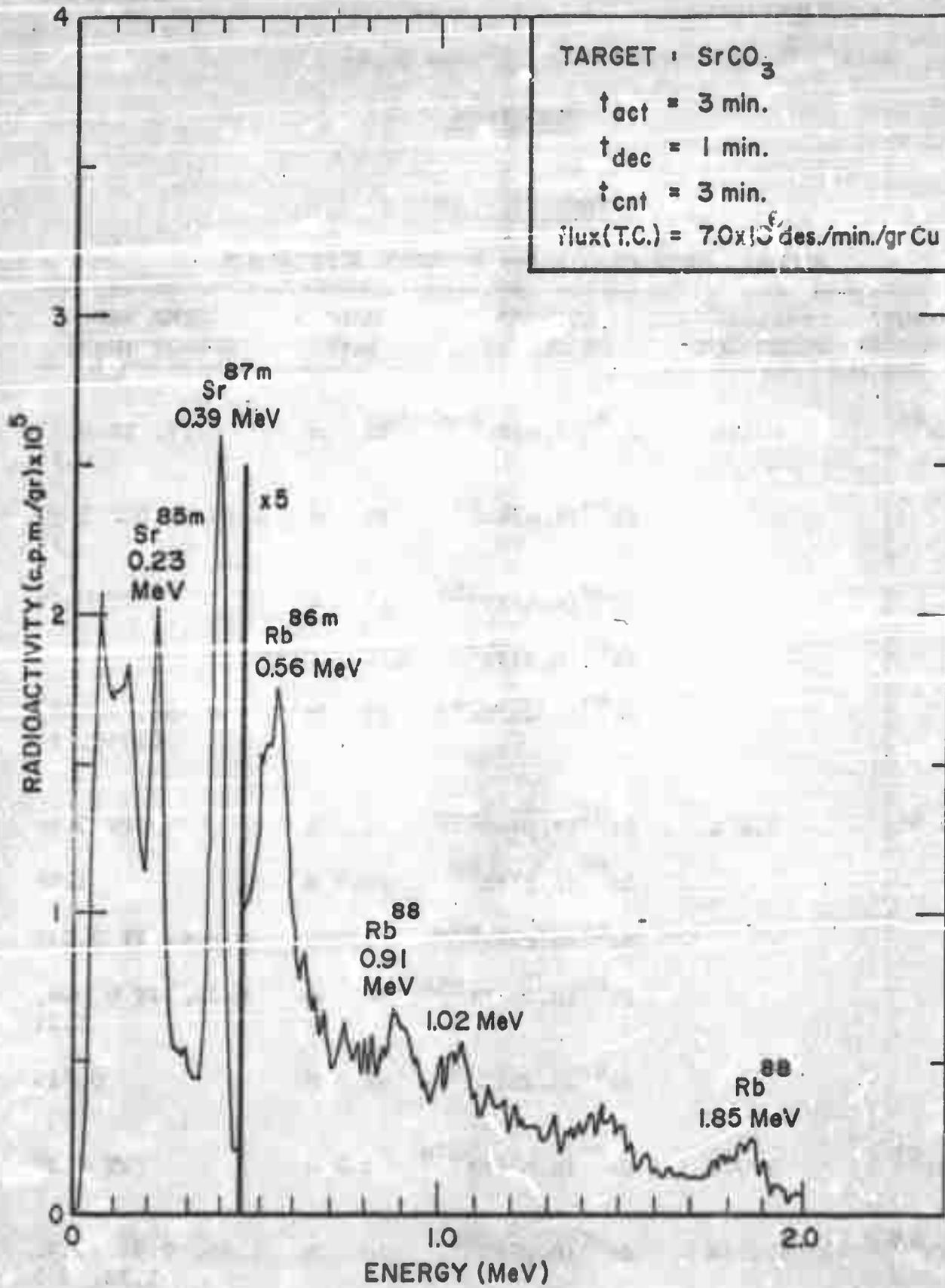


FIGURE I-Sr

TABLE II-Sr

## PEAKS OBSERVED IN FIGURE I-Sr

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Sr	0.23	$\text{Sr}^{86} (n, 2n) \text{Sr}^{85m}$	70 m	(1)
	0.39	$\text{Sr}^{88} (n, 2n) \text{Sr}^{87m}$	2.8h	
		$\text{Sr}^{87} (n, n') \text{Sr}^{87m}$	2.8h	
	0.51 + 0.56	$\text{Sr}^{86} (n, p) \text{Rb}^{86m}$	1 m	(2)
	0.91	$\text{Sr}^{88} (n, p) \text{Rb}^{88}$	18 m	
	1.85	$\text{Sr}^{88} (n, p) \text{Rb}^{88}$	18 m	

(1) By following the decay of the 0.23 Mev photopeak, no contribution, due to  $\text{Rb}^{84m}$  ( $T_{1/2} = 20$  min), has been found.

(2) Photopeak at 0.56 Mev is a combination of the activity at 0.56 Mev from  $\text{Rb}^{86m}$  and the activity at 0.51 Mev from the  $\text{N}^{13}$  of the vial.

NOTE:  $\text{Kr}^{81m}$  ( $T_{1/2} = 13$  sec) not detected for 39 sec irradiation, 13 sec decay and 39 sec counting time.

TABLE III-Sr

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T act	T dec	T cnt	COUNTS/mg/T cnt	DETECTION LIMIT (mg)
0.23	5 m	1 m	5 m	63	1.8
0.39	5 m	1 m	5 m	198	0.80

NOTE: The determination of Sr, using the 0.56 Mev photopeak, is not reliable because of the activity at 0.51 Mev due to  $\text{N}^{13}$  produced in the vial.

STRONTIUM

TABLE IV-Sr

POSSIBLE INTERFERING REACTIONS

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No detectable interference could be derived for strontium from any other element.

## TANTALUM

TANTALUMTABLE I - Ta

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (MeV)	
Ta <sup>180</sup>	0.0123%	Ta <sup>180</sup> (n,p) Hf <sup>180m</sup>	5.5 h	0.093, 0.44, IT 0.058, -0.50	
		Ta <sup>180</sup> (n,α) Lu <sup>177m</sup>	155 d	0.055, 0.47, IT 0.12	
		↓			
		Ta <sup>180</sup> (n,α) Lu <sup>177</sup>	6.8 d	0.208, 0.113, 0.07, 0.32	
		Ta <sup>180</sup> (n,2n) Ta <sup>179</sup>	~1.6 y		
		Ta <sup>180</sup> (n,n') Ta <sup>180m</sup>	8.1 h	0.093, 0.102	
Ta <sup>181</sup>	99.988%	Ta <sup>181</sup> (n,p) Hf <sup>181</sup>	45 d	0.48, 0.006, 0.70	
		Ta <sup>181</sup> (n,α) Lu <sup>178m</sup>	30 m	0.089, 0.093, 0.43	
		↓			
		Ta <sup>181</sup> (n,α) Lu <sup>178</sup>	5 m	0.33, 0.089, 0.093, 0.43	
		Ta <sup>181</sup> (n,2n) Ta <sup>180m</sup>	8.1 h	0.093, 0.102	
		Ta <sup>181</sup> (n,n') Ta <sup>181m</sup>	20 μs		
		Ta <sup>181</sup> (n,n') Ta <sup>181m</sup>	7 μs	IT 0.006	

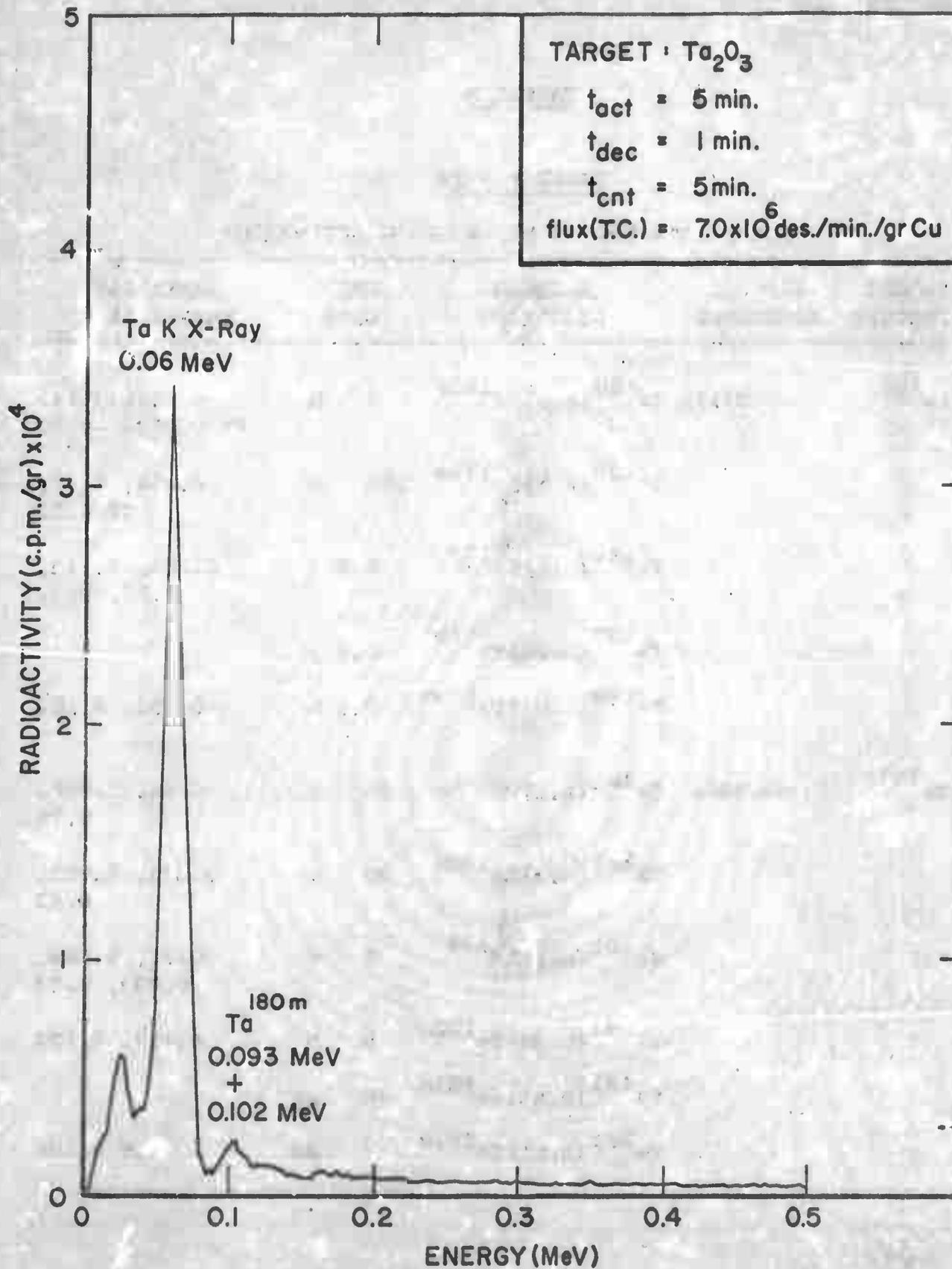


FIGURE I-Ta

## TANTALUM

TABLE II-Ta

## PEAKS OBSERVED IN FIGURE I-Ta

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ta	0.06			Ta x-ray
	0.093	$Ta^{180}(n,n')Ta^{180m}$	8.1 h	
	0.102	$Ta^{181}(n,2n)Ta^{180m}$	8.1 h	

TABLE III-Ta

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT(mg)
0.06	5 m	1 m	5 m	165	0.48

TABLE IV-Ta

## POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for tantalum from any other element.

TERBIUM

TERBIUM

TABLE I - Tb

NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Tb <sup>159</sup>	100%	Tb <sup>159</sup> (n, p) Gd <sup>159</sup>	18 h	0.058, 0.36
		Tb <sup>159</sup> (n, α) Eu <sup>156</sup>	15.2d	0.089, 1.23, 0.20, 2.19
		Tb <sup>159</sup> (n, 2n) Tb <sup>158m</sup>	11 s	IT 0.111
		Tb <sup>159</sup> (n, 2n) Tb <sup>158</sup>	150 y	0.08, 1.19

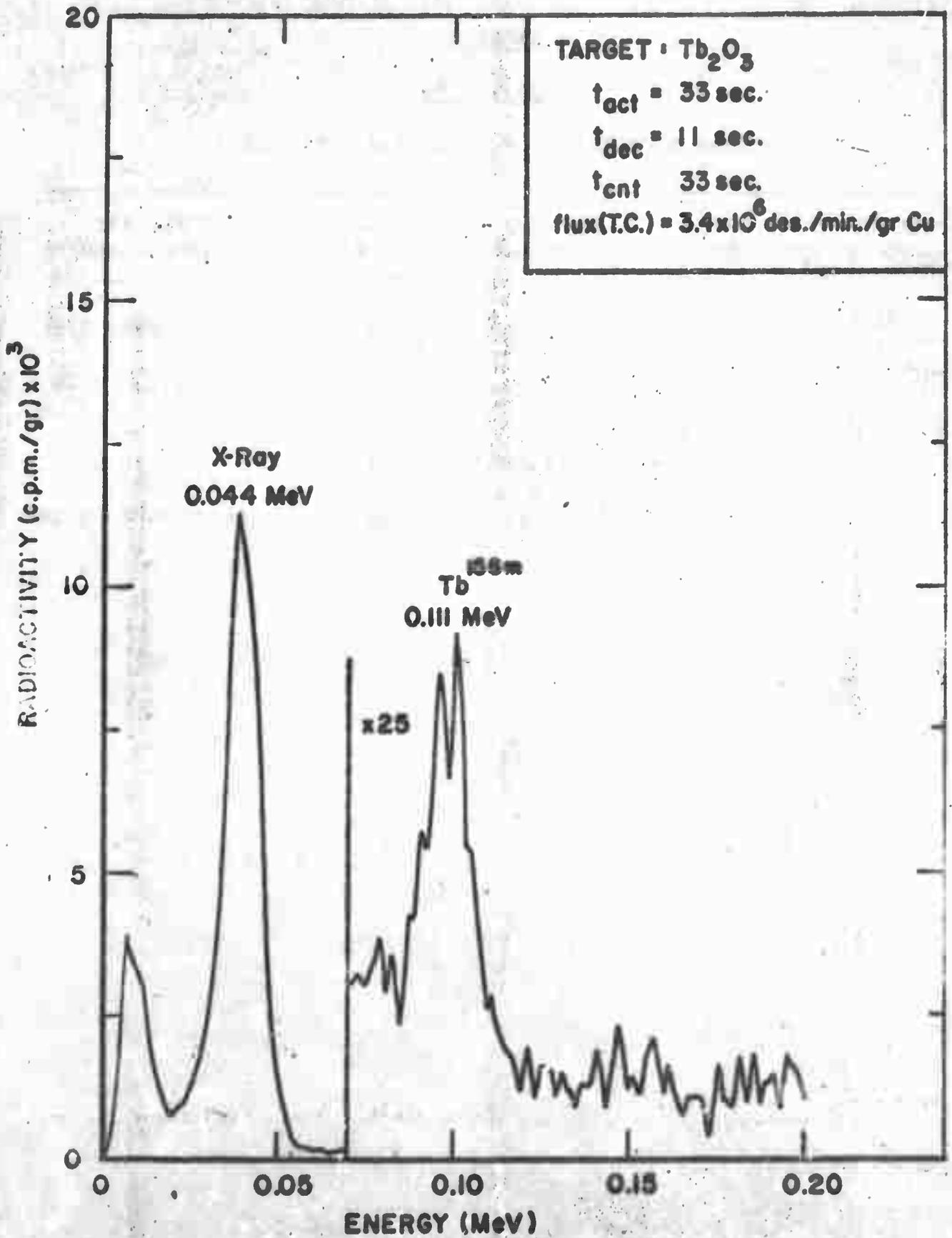


FIGURE I-Tb

## TERBIUM

TABLE II - Tb

## PEAKS OBSERVED IN FIGURE I - Tb

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Tb	0.044			x-rays
	0.111	$Tb^{159} (n, 2n) Tb^{158m}$	11 s	

TABLE III - Tb

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{act}$	$T_{dec}$	$T_{cnt}$	COUNTS/ mg/ $T_{cnt}$	DETECTION LIMIT, mg
0.044	33 s	11 s	33 s	123	0.93

TABLE IV - Tb

## POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for terbium from any other element.

TIN

TABLE I - Sn

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Sn <sup>112</sup>	0.96%	Sn <sup>112</sup> (n,p)In <sup>112m</sup>	0.042s	IT 0.31
		Sn <sup>112</sup> (n,p)In <sup>112m</sup>	21m	IT 0.155
		Sn <sup>112</sup> (n,p)In <sup>112</sup>	14m	0.62, 0.71, β+
		Sn <sup>112</sup> (n,α)Cd <sup>109m</sup>	12μs	IT 0.058
		Sn <sup>112</sup> (n,α)Cd <sup>109</sup>	1.3y	0.088
		Sn <sup>112</sup> (n,2n)Sn <sup>111</sup>	35m	β+
Sn <sup>114</sup>	0.66%	Sn <sup>114</sup> (n,p)In <sup>114m</sup>	2.5 s	IT 0.150
		Sn <sup>114</sup> (n,p)In <sup>114m</sup>	50d	0.72, 0.56, IT 0.191
		Sn <sup>114</sup> (n,p)In <sup>114</sup>	72s	β+
		Sn <sup>114</sup> (n,α)Cd <sup>111m</sup>	49m	0.247, IT 0.15
		Sn <sup>114</sup> (n,2n)Sn <sup>113</sup>	20m	IT 0.079
		Sn <sup>114</sup> (n,2n)Sn <sup>113</sup>	118d	0.255, 0.39
Sn <sup>115</sup>	0.35%	Sn <sup>115</sup> (n,p)In <sup>115m</sup>	4.4h	IT 0.34
		Sn <sup>115</sup> (n,n')Sn <sup>115m</sup>	159μs	0.12, 0.50, IT 0.11
Sn <sup>116</sup>	14.30%	Sn <sup>116</sup> (n,p)In <sup>116m</sup>	2.2 s	IT 0.16
		Sn <sup>116</sup> (n,p)In <sup>116m</sup>	54m	1.29, 1.10

## TIN

TABLE I - Sn (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$\text{Sn}^{116}(\text{n},\text{p})\text{In}^{116}$	14s	1.3
		$\text{Sn}^{116}(\text{n},\alpha)\text{Cd}^{113}$	14y	IT 0.27
		$\text{Sn}^{116}(\text{n},2\text{n})\text{Sn}^{115\text{m}}$	159 $\mu$ s	0.12, 0.50, IT 0.11
$\text{Sn}^{117}$	7.61%	$\text{Sn}^{117}(\text{n},\text{p})\text{In}^{117\text{m}}$	1.9h	0.16, IT 0.31
		$\downarrow$ $\text{Sn}^{117}(\text{n},\text{p})\text{In}^{117}$	45m	0.56, 0.16
		$\text{Sn}^{117}(\text{n},\text{n}')\text{Sn}^{117\text{m}}$	14d	0.161, IT 0.159
$\text{Sn}^{118}$	24.03%	$\text{Sn}^{118}(\text{n},\text{p})\text{In}^{118\text{m}}$	4.4m	1.22, 1.05, 0.2, 2.0
		$\text{Sn}^{118}(\text{n},\text{p})\text{In}^{118}$	5.1s	1.22
		$\text{Sn}^{118}(\text{n},\alpha)\text{Cd}^{115\text{m}}$	43d	0.94, 0.17, 1.56
		$\downarrow$ $\text{Sn}^{118}(\text{n},\alpha)\text{Cd}^{115}$	2.3d	0.52, 0.34
		$\text{Sn}^{118}(\text{n},\text{n}')\text{Sn}^{117\text{m}}$	14d	0.161, IT 0.159
$\text{Sn}^{119}$	8.58%	$\text{Sn}^{119}(\text{n},\text{p})\text{In}^{119\text{m}}$	18m	0.9, IT 0.3
		$\downarrow$ $\text{Sn}^{119}(\text{n},\text{p})\text{In}^{119}$	2.0m	0.82
		$\text{Sn}^{119}(\text{n},\text{n}')\text{Sn}^{119\text{m}}$	250d	0.024, IT 0.065
$\text{Sn}^{120}$	32.85%	$\text{Sn}^{120}(\text{n},\text{p})\text{In}^{120\text{m}}$	3.2s	1.18
		$\downarrow$ $\text{Sn}^{120}(\text{n},\text{p})\text{In}^{120}$	44s	0.73, 1.18
		$\text{Sn}^{120}(\text{n},\alpha)\text{Cd}^{117\text{m}}$	3.2h	0.3, 2.5
		$\downarrow$ $\text{Sn}^{120}(\text{n},\alpha)\text{Cd}^{117}$	2.5h	0.3, 1.6

TABLE I - Sn (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$\text{Sn}^{120} (n, 2n) \text{Sn}^{119}$	250 d	0.024, IT 0.065
$\text{Sn}^{122}$	4.72%	$\text{Sn}^{122} (n, p) \text{In}^{122}$	7.5 s	1.14 1.0
		$\text{Sn}^{122} (n, \alpha) \text{Cd}^{119m}$	2.7 m	
		$\downarrow$ $\text{Sn}^{122} (n, \alpha) \text{Cd}^{119}$	9.5 m	0.82
		$\text{Sn}^{122} (n, 2n) \text{Sn}^{121m}$	$\approx 25$ y	0.037
		$\downarrow$ $\text{Sn}^{122} (n, 2n) \text{Sn}^{121}$	27 y	
$\text{Sn}^{124}$	5.94%	$\text{Sn}^{124} (n, 2n) \text{Sn}^{123m}$	125 d	1.08
		$\downarrow$ $\text{Sn}^{124} (n, 2n) \text{Sn}^{123}$	40 m	0.16

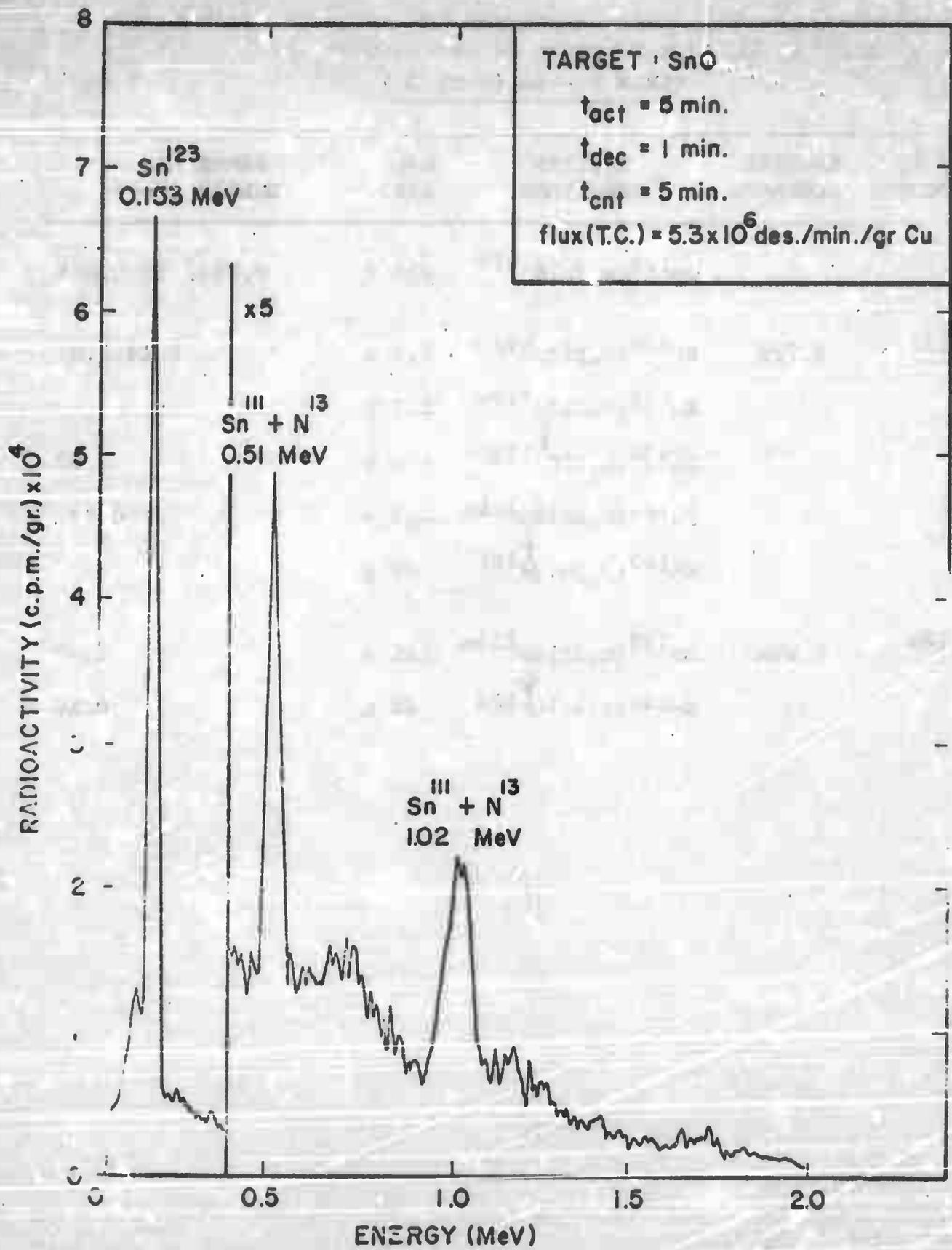


FIGURE I-Sn

TABLE II-Sn

## PEAKS OBSERVED IN FIGURE I-Sn

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Sn	0.153	$\text{Sn}^{122} (n, \gamma) \text{Sn}^{123}$	40 m	
	0.511	$\text{Sn}^{112} (n, 2n) \text{Sn}^{111}$	35 m	

NOTE: An irradiation shorter than five minutes, does not show photopeaks.

TABLE III-Sn

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT, mg
0.153	5 m	1 m	5 m	173	0.69

TABLE IV-Sn

## POSSIBLE INTERFERING REACTIONS

No detectable interferences could be derived for tin from any other element.

TITANIUMTABLE I - Ti

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Ti <sup>46</sup>	7.93%	Ti <sup>46</sup> (n,p) Sc <sup>46m</sup>	20 s	IT 0.14
		Ti <sup>46</sup> (n,p) Sc <sup>46</sup>	84 d	1.12, 0.89
		Ti <sup>46</sup> (n,2n) Ti <sup>45</sup>	3.08h	β+
Ti <sup>47</sup>	7.28%	Ti <sup>47</sup> (n,p) Sc <sup>47</sup>	3.4 d	0.16
Ti <sup>48</sup>	73.94%	Ti <sup>48</sup> (n,p) Sc <sup>48</sup>	44 h	1.31, 1.04, 0.99, 0.17
		Ti <sup>48</sup> (n,α) Ca <sup>45</sup>	165 d	
Ti <sup>49</sup>	5.51%	Ti <sup>49</sup> (n,p) Sc <sup>49</sup>	57.5 m	1.76
Ti <sup>50</sup>	5.34%	Ti <sup>50</sup> (n,p) Sc <sup>50m</sup>	0.35s	IT 0.26
		Ti <sup>50</sup> (n,p) Sc <sup>50</sup>	1.8 m	0.52, 1.56, 1.12
		Ti <sup>50</sup> (n,α) Ca <sup>47</sup>	4.7 d	1.31

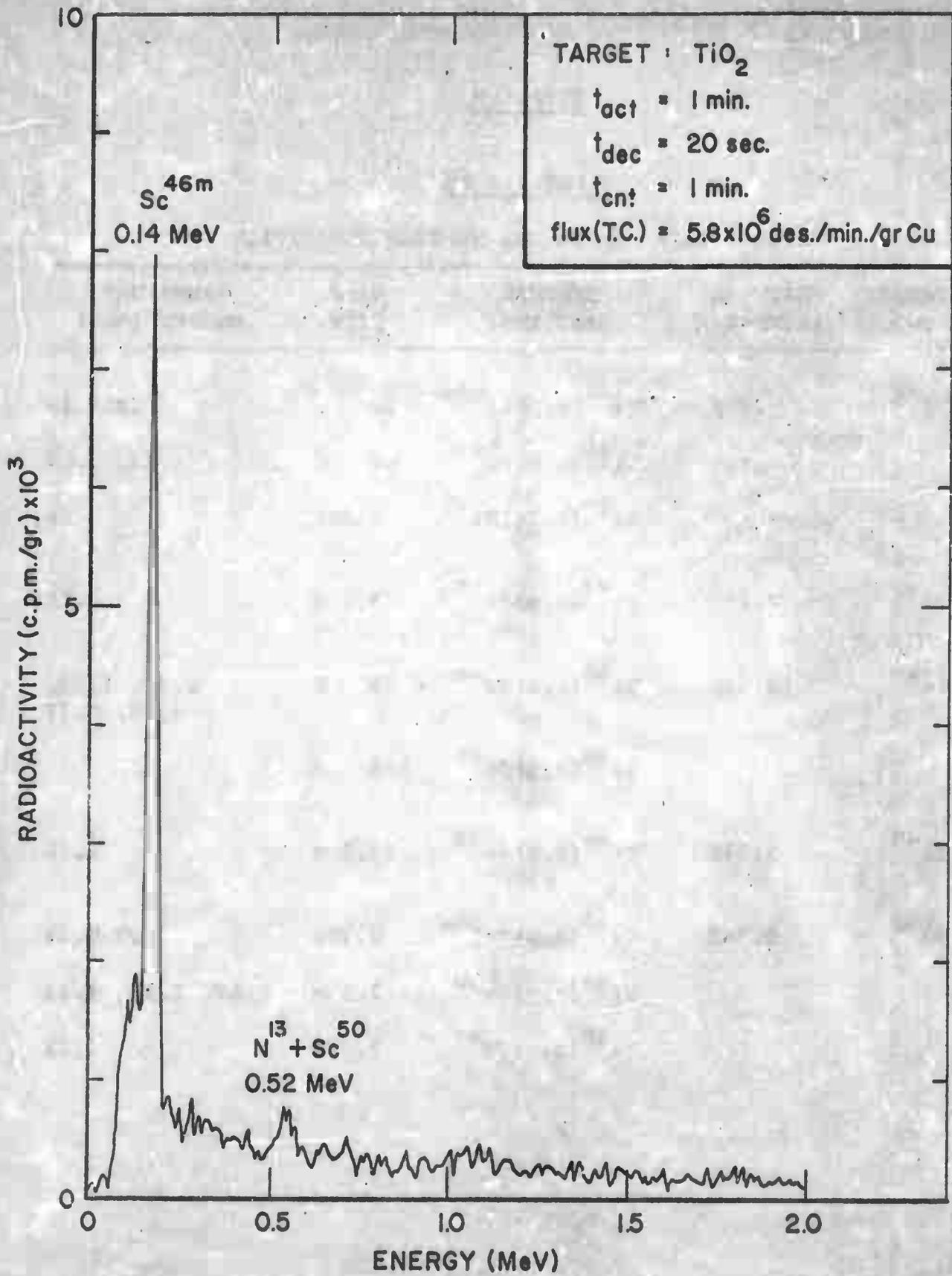


FIGURE I-T1

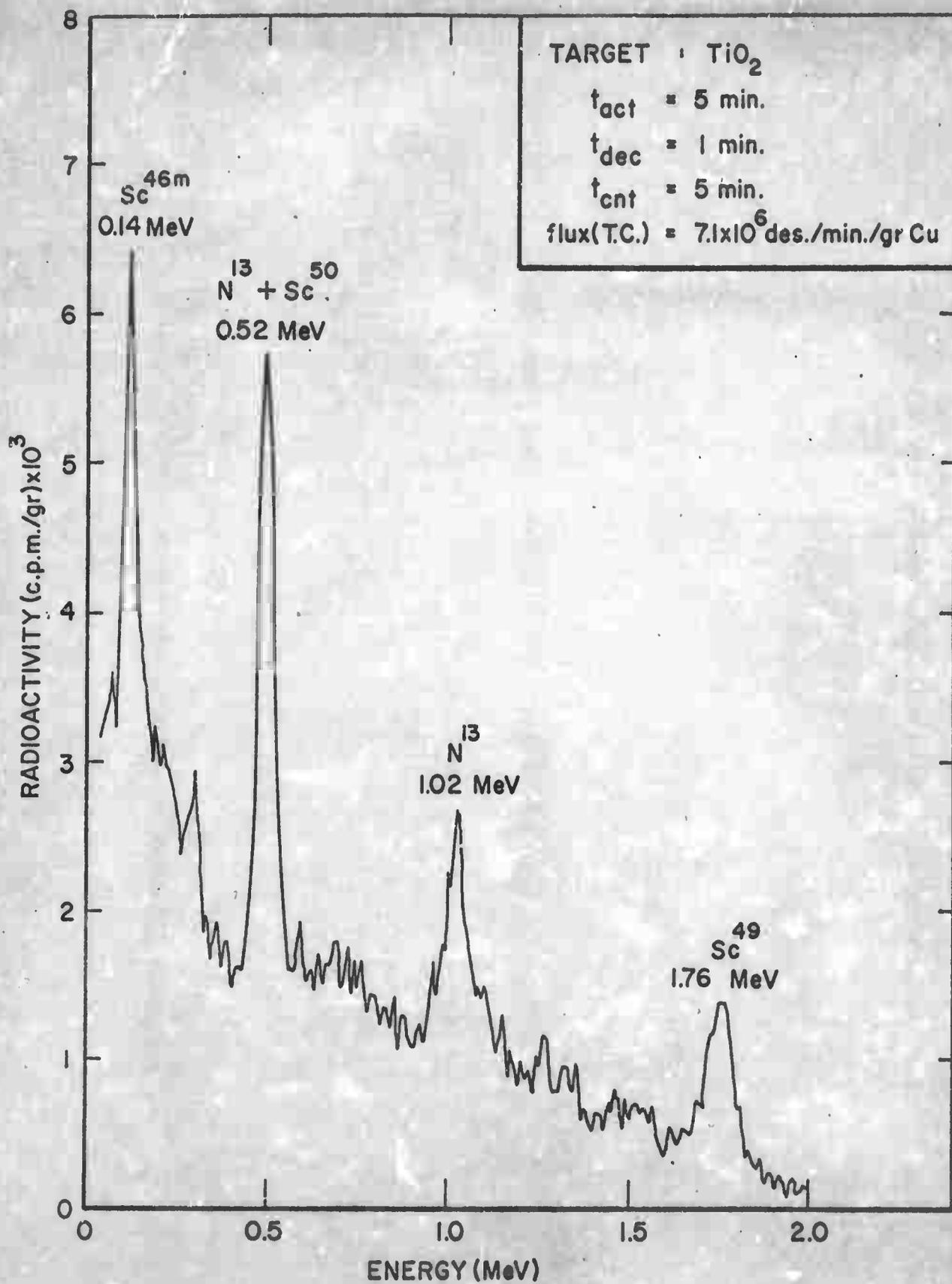


FIGURE II-T1

## TITANIUM

TABLE II-Ti

PEAKS OBSERVED IN FIGURES I-Ti and II-Ti

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Ti	0.14	$Ti^{46}(n,p)Sc^{46m}$	20 s	
	0.52	$Ti^{50}(n,p)Sc^{50}$	1.8 m	
II-Ti	0.14	$Ti^{46}(n,p)Sc^{46m}$	20 s	
	0.52	$Ti^{50}(n,p)Sc^{50}$	1.8 m	
	1.76	$Ti^{49}(n,p)Sc^{49}$	57.5m	

TABLE III-Ti

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.14	1 m	20 s	1 m	17	2.5
0.14	5 m	1 m	5 m	7	18
0.52	5 m	1 m	5 m	9	18
1.76	5 m	1 m	5 m	8	7.1

TABLE IV-Ti

POSSIBLE INTERFERING REACTIONS

No detectable interference could be derived for titanium from any other element.

TUNGSTEN

TABLE I - W

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
$W^{180}$	0.14%	$W^{180}(n,p)Ta^{180m}$	8.1 h	0.093, 0.102
		$W^{180}(n,2n)W^{179m}$	5 m	IT 0.222
		$W^{180}(n,2n)W^{179}$	30 m	0.031
		$W^{180}(n,n')W^{180m}$	0.005 s	0.10, IT 0.22, 0.5
$W^{182}$	26.41%	$W^{182}(n,p)Ta^{182m}$	16 m	0.15, 0.32, IT 0.18, 0.36
		$W^{182}(n,p)Ta^{182}$	115 d	0.10, 1.12, 1.22, 1.19
		$W^{182}(n,\alpha)Hf^{179m}$	19 s	0.217, IT 0.161
		$W^{182}(n,2n)W^{181m}$	14 $\mu$ s	IT 0.37
		$W^{182}(n,2n)W^{181}$	130 d	0.15, 0.14
$W^{183}$	14.40%	$W^{183}(n,p)Ta^{183}$	5.0 d	0.246, 0.354, 0.108, 0.244, 0.041, 0.41
		$W^{183}(n,n')W^{183m}$	5.3 s	0.16, 0.21, IT 0.11
		$W^{183}(n,\alpha)Hf^{180}$	5.5 h	0.093, 0.44, IT 0.058, 0.50
$W^{184}$	30.64%	$W^{184}(n,p)Ta^{184}$	8.7 h	0.40, 0.111, 0.24, 0.91, 0.16, 1.44

TUNGSTEN

TABLE I - W (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
		$W^{184}(n, 2n)W^{183m}$	5.3 s	0.16, 0.21, IT 0.11
		$W^{184}(n, \alpha)Hf^{181}$	45 d	0.48, 0.006, 0.70
$W^{186}$	28.41%	$W^{186}(n, p)Ta^{186}$	10 m	0.20, 0.73, 0.12, 0.11
		$W^{186}(n, 2n)W^{185}$	1.7 m	0.075, 0.175
		$W^{186}(n, 2n)W^{185m}$	74 d	0.125
		$W^{186}(n, \alpha)Hf^{183}$	1.1 h	

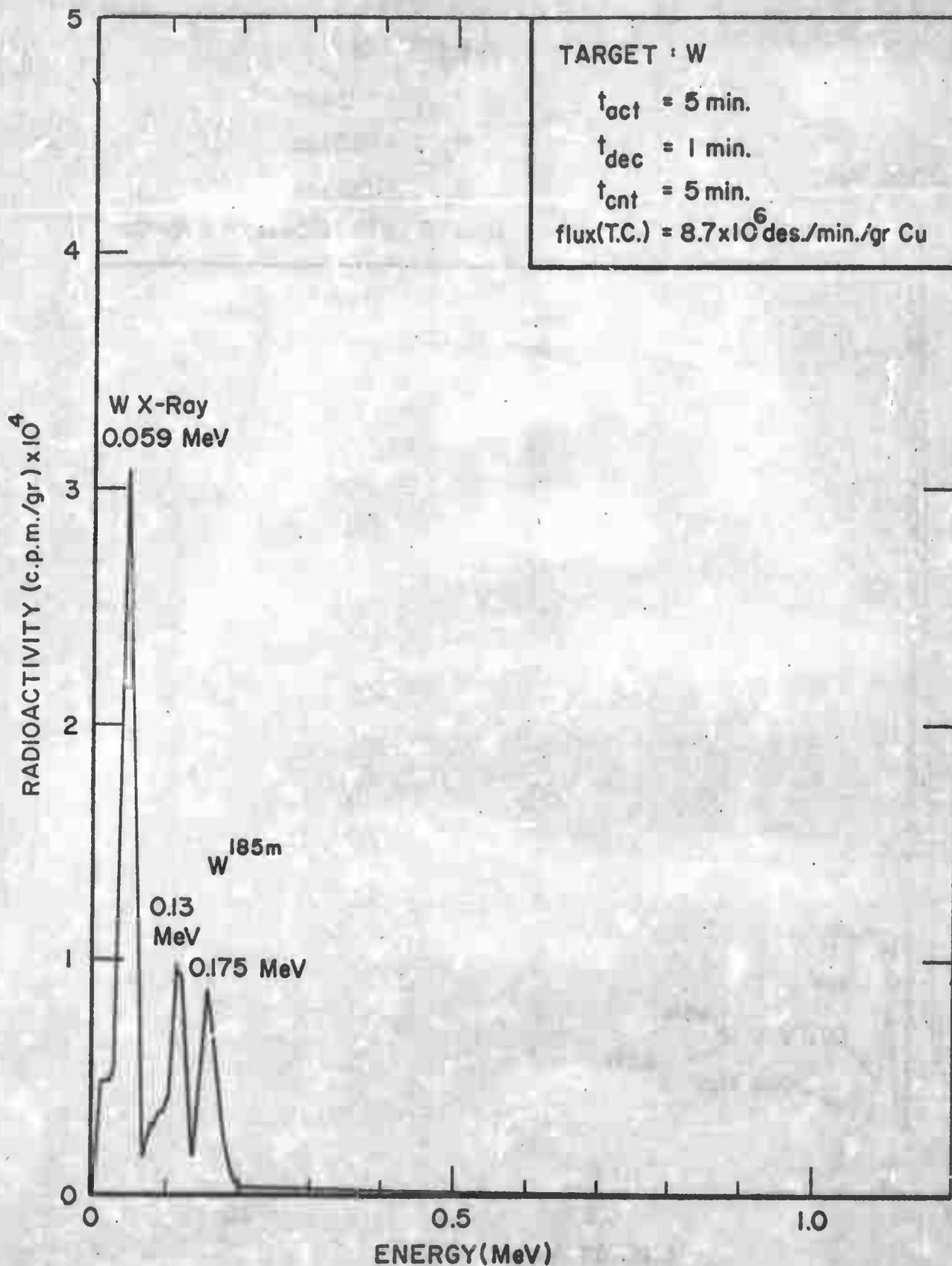


FIGURE I-W

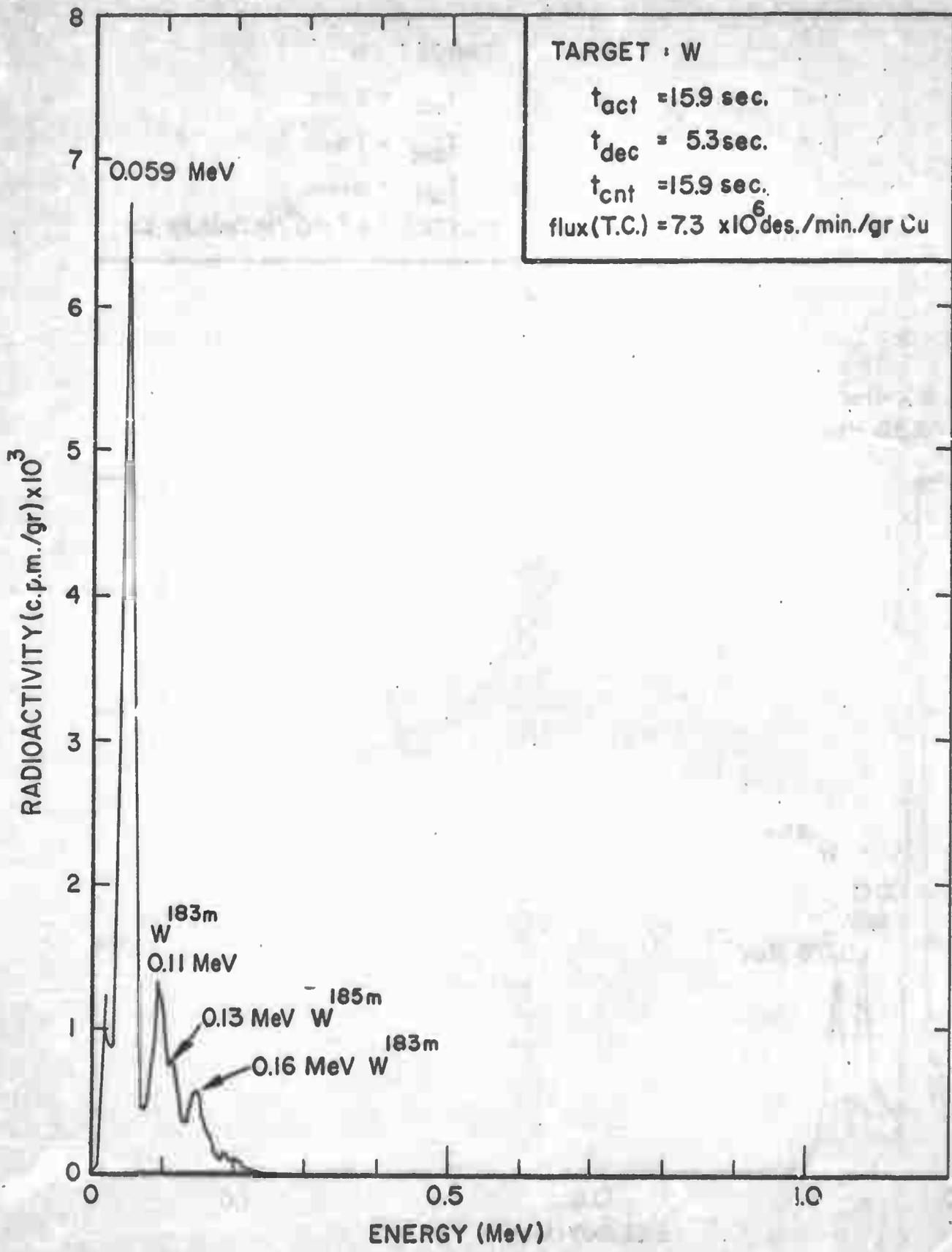


FIGURE II-W

TABLE II-W

## PEAKS OBSERVED IN FIGURES I AND II-W

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-W	0.059			W x-ray (1)
	0.13	$W^{186}(n, 2n)W^{185m}$	1.7 m	(1)
	0.175	$W^{186}(n, 2n)W^{185m}$	1.7 m	
II-W	0.059			W x-ray
	0.11	$W^{184}(n, 2n)W^{183m}$	5.3 s	
	0.13	$W^{186}(n, 2n)W^{185m}$	1.7 m	(1)
	0.16	$W^{183}(n, n')W^{183m}$	5.3 s	
		$W^{184}(n, 2n)W^{183m}$	5.3 s	

(1) Refer, for explanation of photopeaks, to "Applied Gamma Ray Spectrometry" by C. E. Grouthamel.

TUNGSTEN

TABLE III-W

SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T act	T dec	T cnt	COUNTS/mg/T cnt	DETECTION LIMIT (mg)	
					1X	5X
0.059	15.9 s	5.3 s	15.9 s	29	3.0	1.3
0.11+0.13	15.9 s	5.3 s	15.9 s	2.5	15	8.0
0.16	15.9 s	5.3 s	15.9 s	2	27	13
0.059	5 m	1 m	5 m	38	4.2	
0.175	5 m	1 m	5 m	15	9.3	
0.13	5 m	1 m	5 m	12	15	

NOTE: Because of the very short half life of  $W^{183m}$ , five irradiation have been performed, and their spectra accumulated. The seventh column refers to the sensitivities obtained after five irradiations.

TABLE IV-W

POSSIBLE INTERFERING REACTIONS

The possible reactions producing  $W^{183m}$  or  $W^{185m}$  from the element Rhenium or Osmium have not been investigated.

VANADIUMTABLE I - V

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
$V^{50}$	0.24%	$V^{50}(n,\alpha)Sc^{47}$	3.4 d	0.16
		$V^{50}(n,2n)V^{49}$	330 d	
$V^{51}$	99.76%	$V^{51}(n,p)Ti^{51}$	5.8 m	0.32, 0.93, 0.61
		$V^{51}(n,\alpha)Sc^{48}$	44 h	1.31, 1.04, 0.99, 0.17

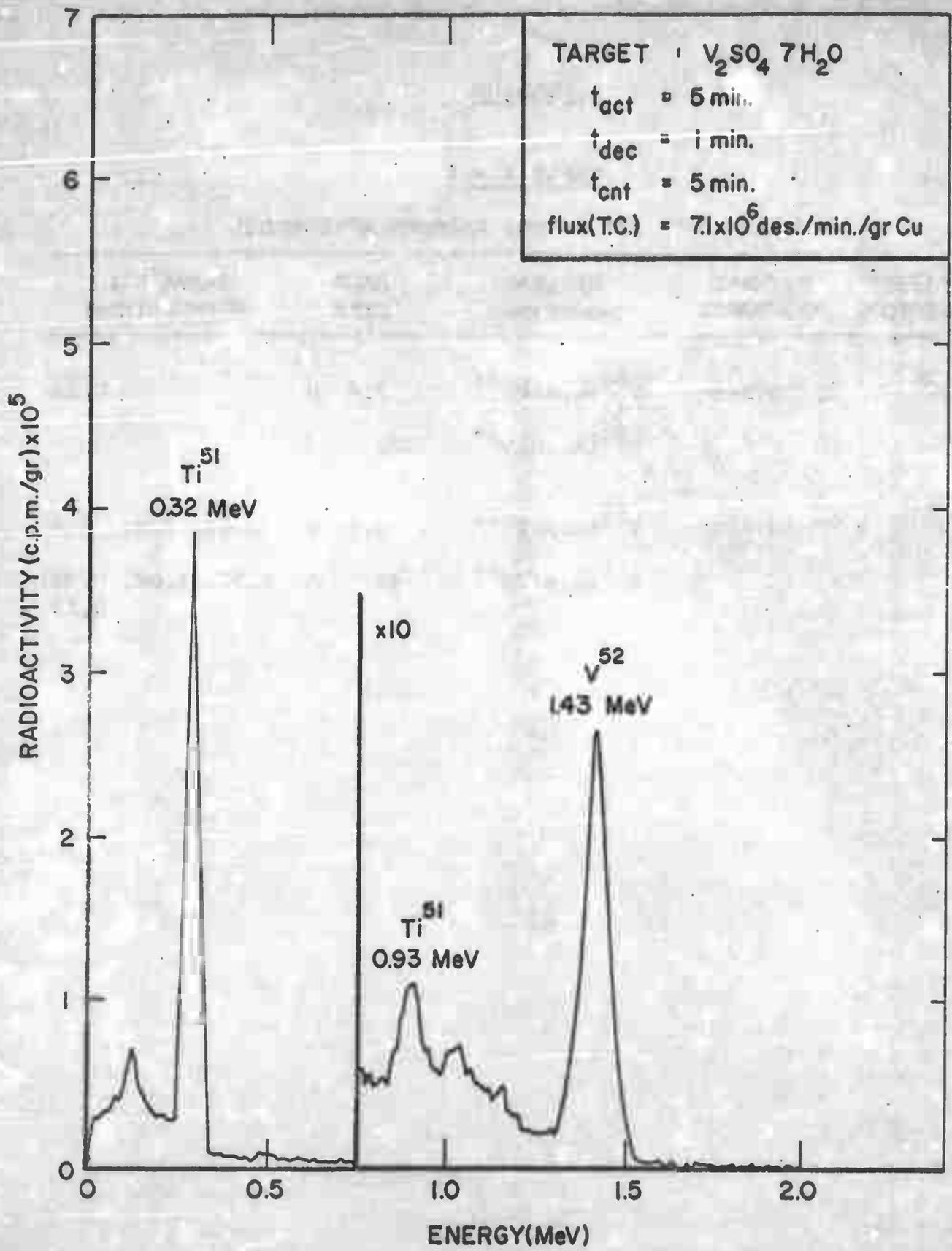


FIGURE I-V

TABLE II-V

## PEAKS OBSERVED IN FIGURE I-V

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-V	0.32	$V^{51}(n,p)Ti^{51}$	5.8 m	
	0.93	$V^{51}(n,p)Ti^{51}$	5.8 m	
	1.43	$V^{51}(n,\gamma)V^{52}$	3.77m	

TABLE III-V

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.32	5 m	1 m	5 m	1150	0.14
1.43	5 m	1 m	5 m	144	0.70

TABLE IV-V

## POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
1.43	Chromium	$Cr^{52}(n,p)V^{52}$	
	Manganese	$Mn^{55}(n,\alpha)V^{52}$	

YTTTRIUMTABLE I - Y

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
$Y^{89}$	100%	$Y^{89}(n,p)Sr^{89}$	50.4 d	
		$Y^{89}(n,\alpha)Rb^{86m}$	1 m	IT 0.56
		$Y^{89}(n,\alpha)Rb^{86}$	18.7 d	1.08
		$Y^{89}(n,2n)Y^{88m}$	300 $\mu$ s	IT 0.39
		$Y^{89}(n,2n)Y^{88m}$	0.014 s	IT 0.24
		$Y^{89}(n,2n)Y^{88}$	108 d	1.83, 0.90, $\beta^+$
		$Y^{89}(n,n')Y^{89m}$	16 s	IT 0.91

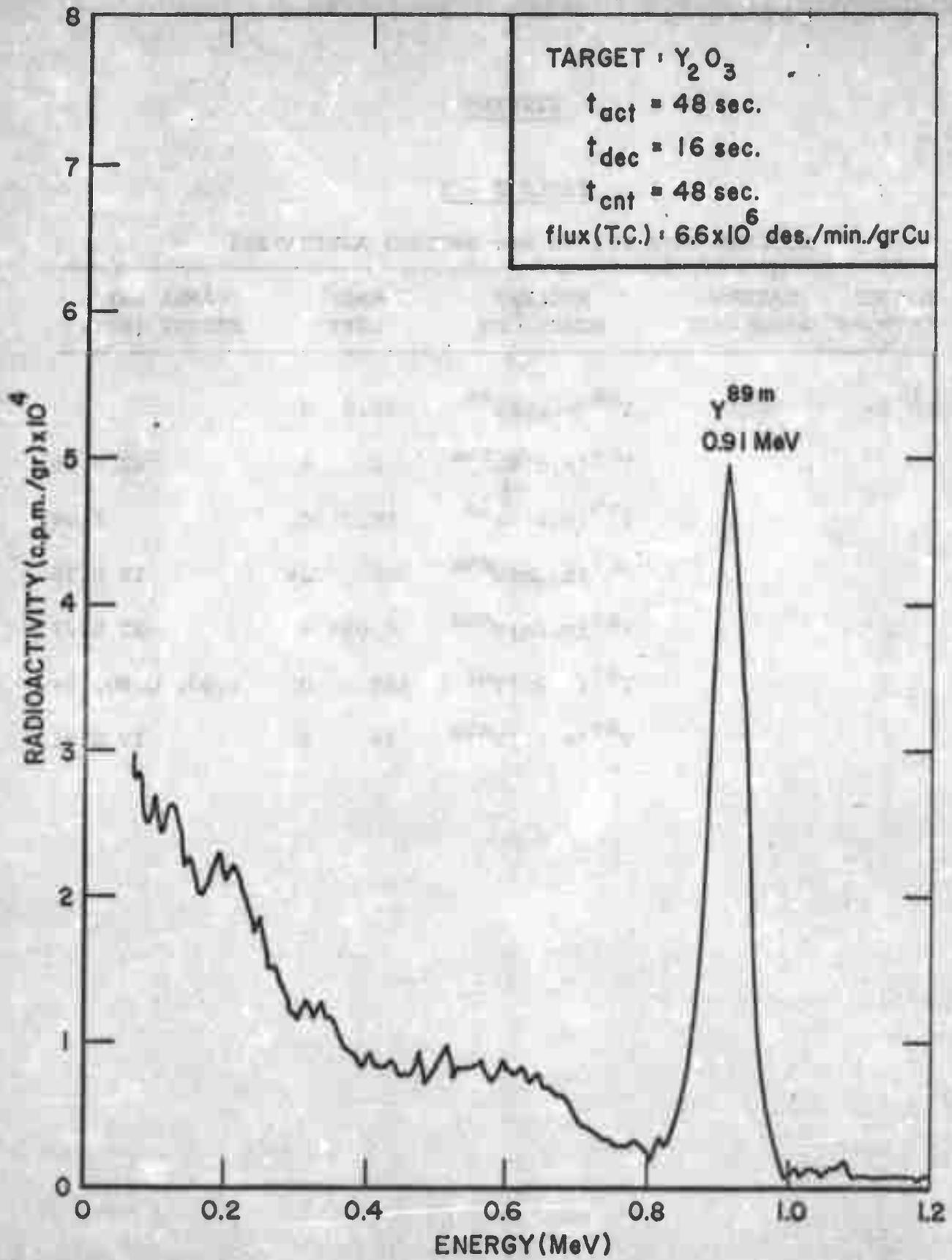


FIGURE I-Y

TABLE II-Y

## PEAKS OBSERVED IN FIGURE I-Y

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Y	0.91	$Y^{89}(n,n')Y^{89m}$	16 s	

NOTE: After a 3 minute irradiation time of Yttrium, the activity due to  $Rb^{86m}$  could not be positively identified because of the rather high activity at 0.51 Mev due to the vial.

TABLE III-Y

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T act	T dec	T cnt	COUNTS/mg/T cnt	DETECTION LIMIT (mg)
0.91	48 s	16 s	48 s	314	0.58

TABLE IV-Y

## POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.91	Zirconium	$Zr^{90}(n,n'p)Y^{89m}$	
	Niobium	$Nb^{93}(n,n'\alpha)Y^{89m}$	

ZINCTABLE I - Zn

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Zn <sup>64</sup>	48.89%	Zn <sup>64</sup> (n,p)Cu <sup>64</sup>	12.9 h	1.34, β <sup>+</sup>
		Zn <sup>64</sup> (n,2n)Zn <sup>63</sup>	38 m	0.67, 0.97, 0.81, 2.9, β <sup>+</sup>
Zn <sup>66</sup>	27.81%	Zn <sup>66</sup> (n,p)Cu <sup>66</sup>	5.1 m	1.04, 0.83
		Zn <sup>66</sup> (n,α)Ni <sup>63</sup>	92 y	
		Zn <sup>66</sup> (n,2n)Zn <sup>65</sup>	245 d	1.12, β <sup>+</sup>
Zn <sup>67</sup>	4.11%	Zn <sup>67</sup> (n,p)Cu <sup>67</sup>	61 h	0.182, 0.090, 0.092
Zn <sup>68</sup>	18.57%	Zn <sup>68</sup> (n,p)Cu <sup>68</sup>	30 s	1.08, 0.81, 1.88, 1.24
		Zn <sup>68</sup> (n,α)Ni <sup>65</sup>	2.56h	1.49, 1.12, 0.37
Zn <sup>70</sup>	0.62%	Zn <sup>70</sup> (n,α)Ni <sup>67</sup>	50 s	0.90, 0.89, 1.26
		Zn <sup>70</sup> (n,2n)Zn <sup>69m</sup>	14 h	IT 0.44
		Zn <sup>70</sup> (n,2n)Zn <sup>69</sup>	55 m	

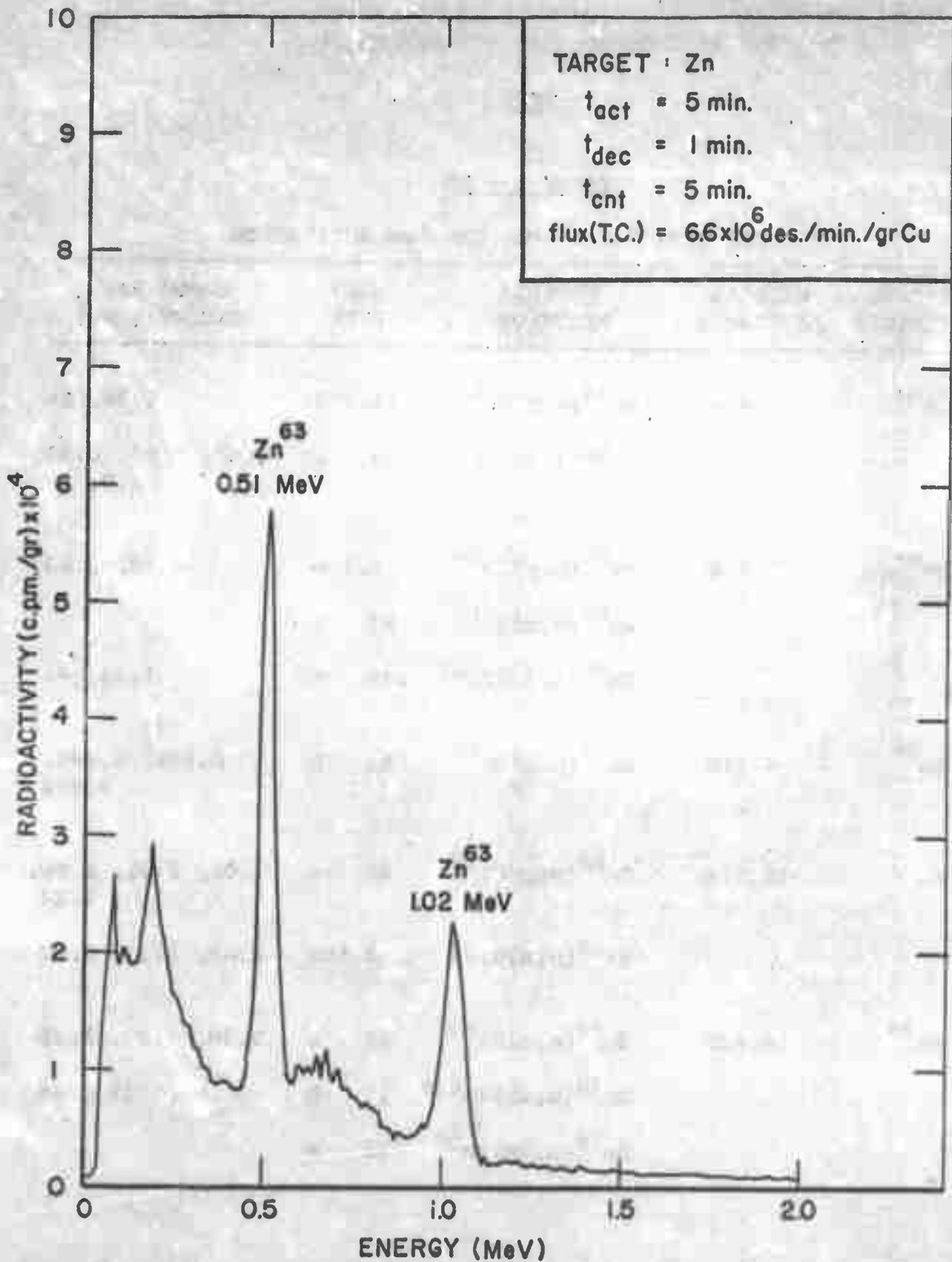


FIGURE I-Zn

TABLE II-Zn

## PEAKS OBSERVED IN FIGURE I-Zn

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Zn	0.51	$Zn^{64}(n, 2n)Zn^{63}$	38 m	
	1.02	$Zn^{64}(n, 2n)Zn^{63}$	38 m	0.51 Mev coincidence sum peak

TABLE III-Zn

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	$T_{act}$	$T_{dec}$	$T_{cnt}$	COUNTS/mg/ $T_{cnt}$	DETECTION LIMIT (mg)
0.51	5 m	1 m	5 m	212	0.77

TABLE IV-Zn

## POSSIBLE INTERFERING REACTIONS

No detectable interference could be noted for zinc from any other element.

For other positron emitting radioisotopes besides  $Zn^{63}$ , see Section I, Appendix II.

ZIRCONIUM

TABLE I - Zr

## NUCLEAR DATA FOR 14 Mev NEUTRON ACTIVATION

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Zr <sup>90</sup>	51.46%	Zr <sup>90</sup> (n,p)Y <sup>90m</sup>	3.2 h	0.20, IT 0.48
		Zr <sup>90</sup> (n,p)Y <sup>90</sup>	64.2 h	1.75
		Zr <sup>90</sup> (n,α)Sr <sup>87m</sup>	2.8 h	IT 0.39
		Zr <sup>90</sup> (n,2n)Zr <sup>89m</sup>	4.2 m	1.5, β+, IT 0.59
		Zr <sup>90</sup> (n,2n)Zr <sup>89</sup>	78.4 h	0.91, 1.7, β+
		Zr <sup>90</sup> (n,n')Zr <sup>90m</sup>	0.8 s	2.18, IT 2.32, 0.14
Zr <sup>91</sup>	11.23%	Zr <sup>91</sup> (n,p)Y <sup>91m</sup>	50 m	IT 0.55
		Zr <sup>91</sup> (n,p)Y <sup>91</sup>	59 d	1.21
		Zr <sup>91</sup> (n,2n)Zr <sup>90m</sup>	0.8 s	2.18, IT 2.32, 0.14
Zr <sup>92</sup>	17.11%	Zr <sup>92</sup> (n,p)Y <sup>92</sup>	3.53h	0.932, 1.39, 0.56, 0.448, 2.4
		Zr <sup>92</sup> (n,α)Sr <sup>89</sup>	50.4 d	
Zr <sup>94</sup>	17.40%	Zr <sup>94</sup> (n,p)Y <sup>94</sup>	20 m	0.92, 0.56, 1.13, 1.65, 3.5
		Zr <sup>94</sup> (n,α)Sr <sup>91</sup>	9.7 h	0.55, 0.65, 1.41
		Zr <sup>94</sup> (n,2n)Zr <sup>93</sup>	9.5 x 10 <sup>5</sup> y	0.029

ZIRCONIUM

TABLE I - Zr (Cont'd.)

TARGET ISOTOPE	NATURAL ABUNDANCE	NUCLEAR REACTIONS	HALF LIFE	GAMMA RAY ENERGY (Mev)
Zr <sup>96</sup>	2.80%	Zr <sup>96</sup> (n,p)Y <sup>96</sup>	2.3 m	0.7, 1.0
		Zr <sup>96</sup> (n,α)Sr <sup>93</sup>	8.3 m	0.6, 0.8, 0.31, 2.1
		Zr <sup>96</sup> (n,2n)Zr <sup>95</sup>	65 d	0.72, 0.76, 0.23, 0.77

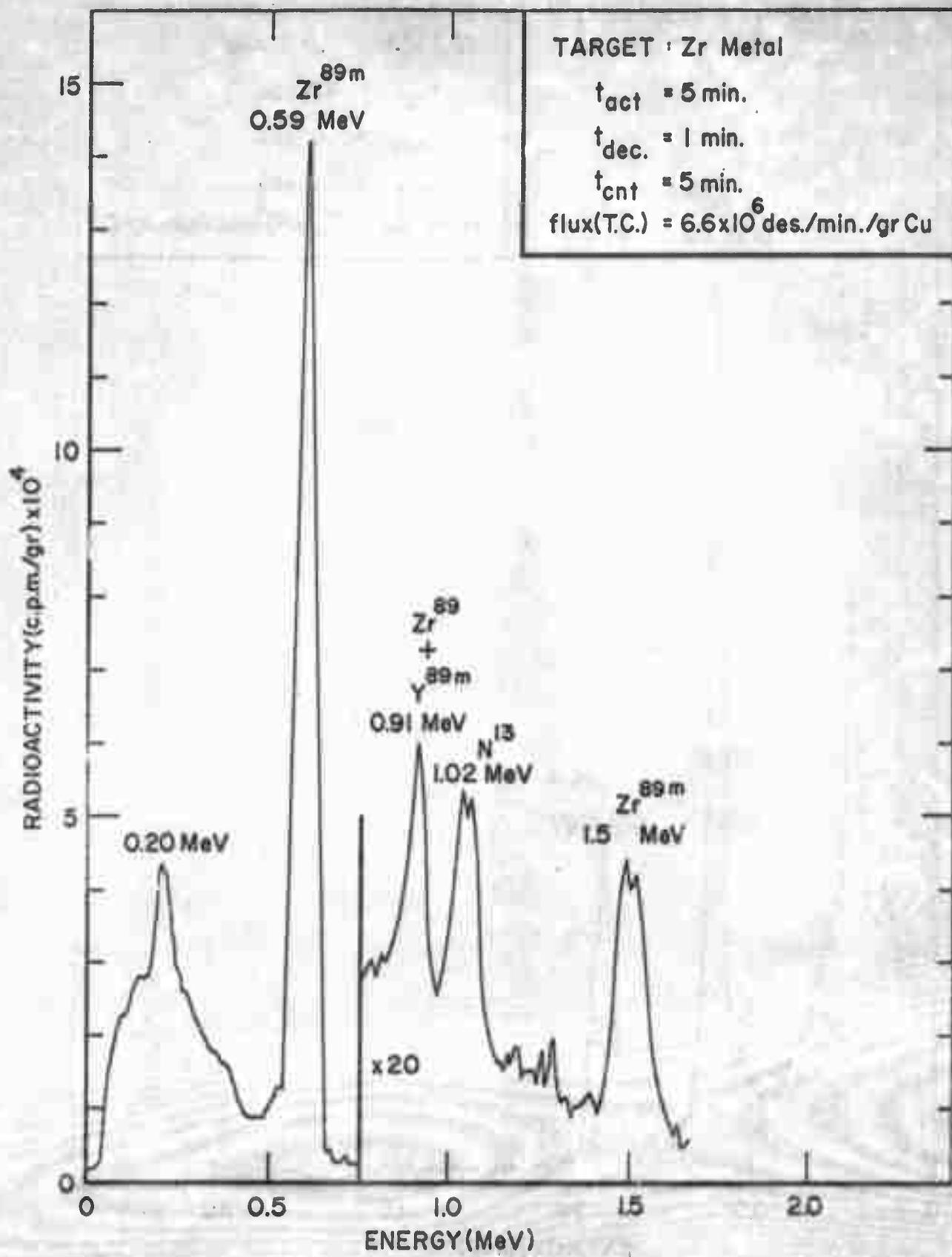


FIGURE I-Zr

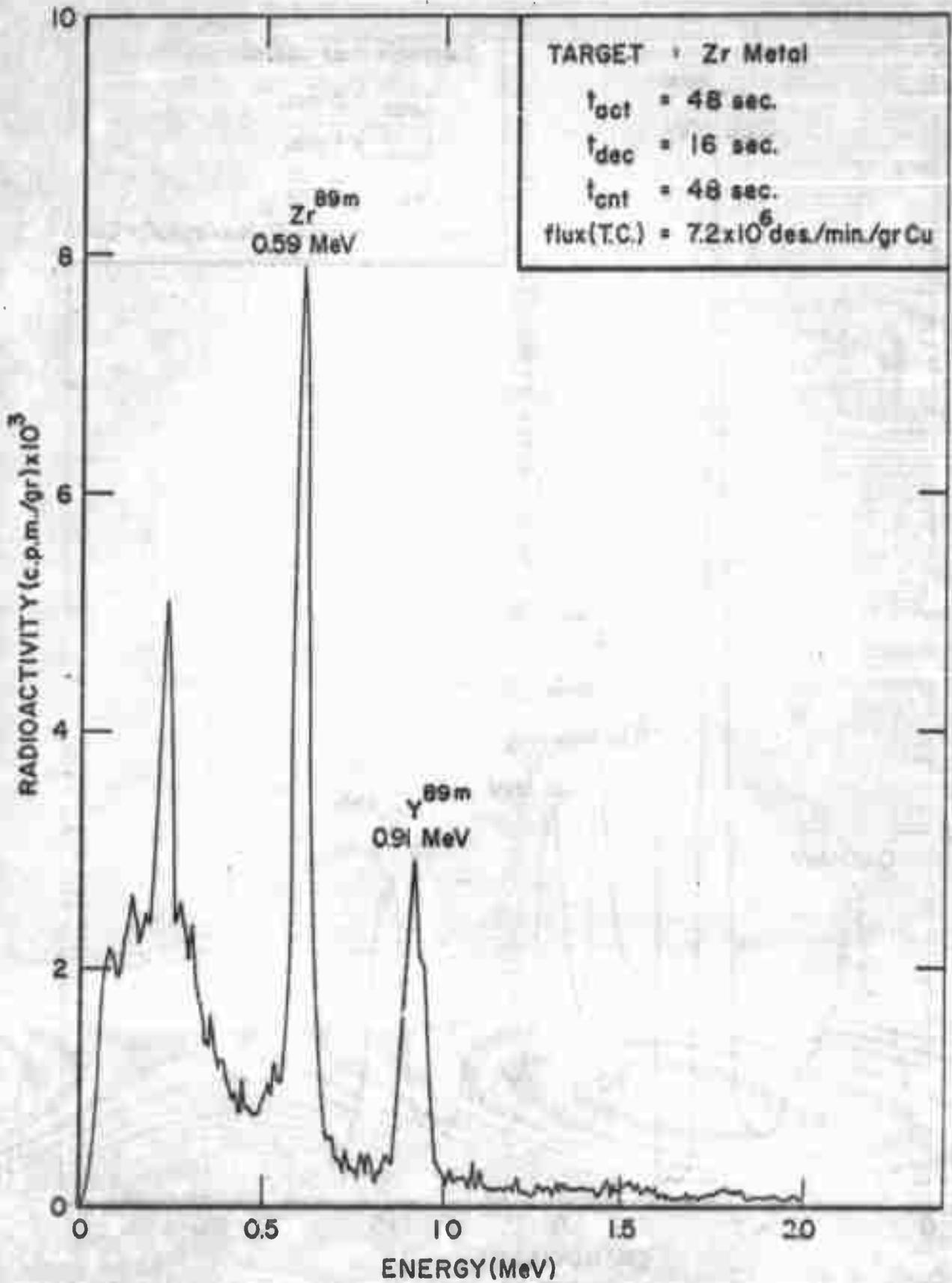


FIGURE II-Zr

TABLE II-Zr

## PEAKS OBSERVED IN FIGURE I-Zr and II-Zr

FIGURE	GAMMA RAY ENERGY (Mev)	NUCLEAR REACTIONS	HALF LIFE	REMARKS
I-Zr	0.20	$Zr^{90}(n,p)Y^{90m}$	3.2 h	Major activity due to backscattering
	0.59	$Zr^{90}(n,2n)Zr^{89m}$	4.2 m	
	0.91	$Zr^{90}(n,n'p)Y^{89n}$	16 s	
		$Zr^{90}(n,2n)Zr^{89}$	18.4 h	
II-Zr	1.5	$Zr^{90}(n,2n)Zr^{89m}$	4.2 m	
	0.59	$Zr^{90}(n,2n)Zr^{89m}$	4.2 m	
	0.91	$Zr^{90}(n,n'p)Y^{89m}$	16 s	

TABLE III-Zr

## SENSITIVITY FOR MAJOR PEAKS

GAMMA RAY ENERGY (Mev)	T <sub>act</sub>	T <sub>dec</sub>	T <sub>cnt</sub>	COUNTS/mg/T <sub>cnt</sub>	DETECTION LIMIT (mg)
0.91	48 s	16 s	48 s	15	2.9
0.59	48 s	16 s	48 s	32	1.5
0.59	5 m	1 m	5 m	645	0.25

NOTE:  $Zr^{90m}$  detectable for 2.4 sec irradiation, 0.8 sec decay and 2.4 sec counting time. The activity is however very low.

ZIRCONIUM

TABLE IV-Zr

POSSIBLE INTERFERING REACTIONS

GAMMA RAY ENERGY (Mev)	ELEMENT	NUCLEAR REACTIONS	REMARKS
0.91	Yttrium	$Y^{89}(n,n')Y^{89m}$	
	Niobium	$Nb^{93}(n,n'\alpha)Y^{89m}$	

## APPENDIX I

### The Texas Convention On The Measurement Of 14 Mev Neutron Fluxes From Accelerators

#### INTRODUCTION

There exists at present no generally accepted method for determining effective fluxes of 14 Mev neutron energies from generators using the  $T(d,n)He^4$  reaction which can be used for fast neutron activation analysis. In order to facilitate inter-laboratory comparisons of fluxes and establish a common bases for the determination of fast neutron fluxes quoted in the Activation Analysis literature the following convention has been adopted.

#### SPECIFICATION

The effective fluxes for sample activations are to be measured by exposing high purity (99.9%) copper discs of 0.25mm thickness and 1 cm and/or 2.5 cm diameter for 1 minute to the neutron flux to be measured. After a minimum cooling time of 1 minute, to permit sample transfer and decay of interfering  $N^{16}$  activity, the positron annihilation radiation emitted by the disc is counted and the disintegration rate of the  $Cu^{62}$  activity determined for the time of the end of the activation. The flux is then given in disintegrations/minute/gram copper and the size of the disc is stated.

## APPENDIX II

### Counting Recommendations For The Measurement Of 14 Mev Neutron Flux From Accelerators

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In the interest of providing a uniform method for assay of copper flux monitors, the following procedure is suggested to provide a standard method of measurement and data analysis which can readily be produced by most experimenters. It is proposed that the activated foils be assayed by quantitative scintillation spectrometry to obtain the disintegration rate for the 9.9 min  $\text{Cu}^{62}$  activity induced in the foil by the  $n,2n$  reaction. If appropriate corrections are applied for irradiation time, decay following irradiation, and the various experimental parameters of the counting arrangement, the result will provide a number which will be proportional to neutron flux.

It is suggested that the copper discs (either 1 or 2.5cm diameter by 0.25 mm thickness) be mounted between two discs of polystyrene or lucite to insure that all positrons emitted in the decay are annihilated in the immediate vicinity of the disc source. The plastic discs should be 3/8" thick (0.95 cm) by either 3 cm or 4.5 cm diameter, depending on which size

copper disc is to be used. The resulting sandwich will provide approximately  $1 \text{ gram/cm}^2$  of plastic on all sides of the copper disc. The source sandwich is to be mounted on the central axis of a 3" diameter by 3" cylindrical NaI detector with the copper disc at a distance of 3 cm from the top surface of the NaI crystal. To accomplish this it will be necessary to determine the distance from the top surface of the detector to the outside surface of the detector can. In present commercial detectors this distance may vary from 2 to 4 mm.

With the source mounted in this manner a pulse-height spectrum of the gamma radiation emitted in the decay of  $\text{Cu}^{62}$  should be obtained. It is assumed that this measurement will be made on a modern multi-channel analyzer incorporating an automatic live-time correction circuit. For the purpose of the decay correction, the mid-point of the counting interval will be used. It will be necessary to consider the difference between real clock time and live time in making the decay correction. To obtain a value which closely approximates the disintegration rate of the sample, the photopeak method outlined in the Gamma-Ray Spectrum Catalogue<sup>5</sup> will be used. An estimate of the contribution to the 0.511 Mev photopeak from the bremsstrahlung should be made. The "photopeak area" is

then obtained by summing the counts in all peak channels. For this purpose the photopeak is defined as a symmetrical shape with the low-energy side of the peak the mirror image of the shape on the high-energy side. The disintegration rate of the source will then be given by the following relationship:

$$N_0 = \frac{N_p}{(P)(\epsilon)(A_q)}$$

where  $N_p$  is the photopeak area in counts/min,  $\epsilon$  is the calculated efficiency for the source detector geometry being used,  $A$  is an absorption correction for the plastic absorber and detector can,  $q$  is the branching ratio for the 0.511 Mev annihilation radiation, and  $P$  is the experimental photopeak efficiency for these conditions. To simplify this procedure the quantity  $(1/P)(\epsilon)(A_q)$  has been calculated for this experiment. To obtain the disintegration rate for the sample at the time of measurement one need only to multiply this factor by the photopeak area. Although some simplifying assumptions have been made in this calculation, the result should be accurate to within  $\pm 5\%$ .

	<u>1 cm diameter disc</u>	<u>5 cm diameter disc</u>
$(1/P)(\epsilon)(A_q)$	8,591	8.703

### APPENDIX III

#### Elements Producing Positron Emitters

Table II lists the elements which, after irradiation with 14 Mev neutrons, produce a 0.51 Mev photopeak as a major peak in the spectrum. This photopeak is due to the annihilation of the positrons.

The radioisotopes producing, in a 5-minute irradiation time, a very low activity are not listed (example  $\text{Cu}^{64}$   $T = 12.8$  hr).

Table II

#### Elements Producing Positron Emitters

Element	Nuclear Reactions	Half Life
Phosphorus	$\text{P}^{31}(n, 2n)\text{P}^{30}$	2.5 m
Praseodymium	$\text{Pr}^{141}(n, 2n)\text{Pr}^{140}$	3.4 m
Bromine	$\text{Br}^{79}(n, 2n)\text{Br}^{78}$	6.5 m
Potassium	$\text{K}^{39}(n, 2n)\text{K}^{38}$	7.7 m
Iron	$\text{Fe}^{54}(n, 2n)\text{Fe}^{53}$	8.5 m
Samarium	$\text{Sm}^{144}(n, 2n)\text{Sm}^{143}$	9.0 m
Nitrogen	$\text{N}^{14}(n, 2n)\text{N}^{13}$	9.96 m
Copper	$\text{Cu}^{63}(n, 2n)\text{Cu}^{62}$	9.9 m
Molybdenum	$\text{Mo}^{92}(n, 2n)\text{Mo}^{91}$	15.5 m
Antimony	$\text{Sb}^{121}(n, 2n)\text{Sb}^{120}$	15.9 m
Silver	$\text{Ag}^{107}(n, 2n)\text{Ag}^{106}$	24 m
Chlorine	$\text{Cl}^{35}(n, 2n)\text{Cl}^{34}$	32.0 m
Zinc	$\text{Zn}^{64}(n, 2n)\text{Zn}^{63}$	38.0 m
Chromium	$\text{Cr}^{50}(n, 2n)\text{Cr}^{49}$	42 m
Gallium	$\text{Ga}^{69}(n, 2n)\text{Ga}^{68}$	68 m
Fluorine	$\text{F}^{19}(n, 2n)\text{F}^{18}$	110 m
Palladium	$\text{Pd}^{102}(n, 2n)\text{Pd}^{101}$	8.5 hr
Nickel	$\text{Ni}^{58}(n, 2n)\text{Ni}^{57}$	36 hr

## APPENDIX IV

### Elements Emitting High Energy Gamma Rays

Oxygen, fluorine and boron are the only elements which produce after 14 Mev neutron activation, radioisotopes emitting gamma photons with energies greater than 4.5 Mev.

For this reason it is possible to detect the produced radioisotopes using a single channel analyzer with a lower discrimination level at 4.5 Mev.

In the above described conditions the following experimental results were obtained.

	Oxygen	Fluorine	Boron
Nuclear reaction	$O^{16}(n,p)N^{16}$	$F^{19}(n,\alpha)N^{16}$	$B^{11}(n,p)Be^{11}$
Half life	7.35 sec	7.35 sec	13.6 sec
Gamma ray energy (Mev)	6.13, 7.12	6.13, 7.12	2.12, 6.8, 4.6, 8.0
Activation time	22 sec	22 sec	40.8 sec
Decay time	7.3 sec	7.3 sec	13.6 sec
Count time	22 sec	22 sec	40.8 sec
Counts/mg/T <sub>cnt</sub>	91	38	29

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