MASTER

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HIGH RESOLUTION NEUTRON TOTAL
CROSS SECTION MEASUREMENTS WITH
THE (A) ORNL LINAC AND (B) THE
COLUMBIA UNIVERSITY'S NEVIS
SYNCHROCYCLOTRON AND (C) WITH
B.N.L.HFBR.

Progress Report
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ABSTRACT

The research work conducted under the ERDA contract FY-76-S-02-2439*000 involved the measurement, analysis and interpretation of high resolution neutron total and partial cross sections in the neutron energy range of few eV to few hundred keV. Some of these measurements (V, Mn, Co) were performed with the Columbia University's neutron velocity selector and the measurements on separated isotopes of iron, copper, zinc and yttrium were performed with the Oak Ridge electron linear accelerator. By using area and R-matrix shape analysis, the data were analyzed to extract the values of resonance parameters such as resonance energies (E_0), neutron widths (Γ_n), capture widths (Γ_γ), ℓ -assignment and the average values of these parameters. The systematics of these results were also investigated in detail. The complete results of the measurements of total cross sections in the following nuclei: ^{209}Bi , Cu (natural), ^{63}Cu , ^{65}Cu , ^{54}Fe and ^{56}Fe have been published in the scientific journals (reprints attached). The analysis of the total cross section data on Mn, V, Co has been completed and a paper will be submitted for publication. The analysis of the data on ^{57}Fe , ^{58}Fe and isotopes of zinc are in the various stages of completion. The total capture cross section results on ^{63}Cu and ^{65}Cu were completed and have been submitted for publication. The results on ^{55}Mn are being completed. A collaborative research work on (n, γ) capture studies with Brookhaven scientists on the separated isotopes of ^{168}Er was completed and published in Phys. Rev. and the results on ^{170}Er are in the process of being completed.

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I. INTRODUCTION

This technical progress report describes the collaborative research work carried out with the various scientific groups during the contract year (1976-77) on the high resolution measurements of neutron total and capture cross sections in certain nuclei of interest to the development of atomic energy. The first part deals with the work associated with the Columbia University's Nevis Synchrocyclotron Accelerator. Here the main effort was directed towards completing the analysis and interpretation of the earlier measurements in nuclei: Bi, Ta, natural copper, natural zinc, V, Mn and Co.

In the second part of the report the high resolution neutron total cross section measurements in separated isotopes of iron, copper and zinc and total capture cross sections in manganese with the Oak Ridge electron linear accelerator facility are described and in the third part collaborative efforts on the neutron capture γ -ray spectroscopy with the Brookhaven fast chopper group is described.

During this period sufficient effort was also spent in converting and modifying various computer programs of data transfer, area and shape analysis from the IBM to the UNIVAC 1110 computer for the analysis of resonance parameters such as LSFIT code for capture area analysis, peak fit program for spectral analysis etc. We have now these programs available at Albany to be used with our UNIVAC computer

The detailed accomplishment of the research work follows.

II. COLLABORATIVE PROGRAM WITH COLUMBIA UNIVERSITY

J.B. Garg (SUNYA), M.S. Pandey (SUNYA), U.N. Singh,
G. Hacken and J. Rainwater (Columbia University).

The high resolution neutron total cross section measurements made with the Nevis Synchrocyclotron over the last many years were analyzed using area analysis with Doppler broadening for resonances with narrow widths and using a multilevel R-matrix formalism for broad resonances. The information on the resonance energies, neutron widths and J^π assignments were made from this analysis. The values of average level spacing and strength function for $\ell=0$ and $\ell=1$ neutron scattering were determined. These informations are needed for the evaluation of the optical model potential parameters, as well as for the design of atomic reactors. These measurements were made in the energy range of few eV to about 500 keV.

II(a) Neutron Resonance Spectroscopy ²⁰⁹Bi
J.B. Garg (SUNYA), U.N. Singh, J. Rainwater,
H.I. Liou and G. Hacken (Columbia University)

This paper has been published in the Phys. Rev. 136, 124(1976).
 (6 copies of reprints are enclosed here).

II(b) Neutron Resonance Spectroscopy In Natural Copper-I
M.S. Pandey and J.B. Garg (SUNYA)

This paper has been published in Nucl. Science and Engineering 60, 399 (1976). (6 copies of reprints are enclosed here).

II(c) Neutron Resonance Spectroscopy in ¹⁸¹Ta
J.B. Garg (SUNYA), G. Hacken, J. Rainwater,
U.N. Singh (Columbia University)

The total cross section measurements in the natural

sample of ^{181}Ta taken many years ago from few eV to 2 keV has been analyzed for the resonance parameters using an area analysis. From these results the value of average spacing $\langle D \rangle_{l=0} = (4.22 \pm 0.13)$ eV and the value for the s-wave strength function $S_0 = (1.74 \pm 0.15) \times 10^{-4}$ has been obtained. These results will be published in scientific journal in the near future.

II(d) Neutron Resonance Spectroscopy: V, Mn and Co
J.B. Garg (SUNYA) and J. Rainwater (Columbia University)

High resolution total neutron cross section measurements in natural vanadium, manganese and cobalt used as structural materials in nuclear reactors, were made in the energy range of few eV to few hundred keV with the Columbia University's Nevis neutron velocity spectrometer using a 200 meter flight path and a nominal resolution of .5ns/meter. These cross section data were analyzed with a R-matrix code and the resonance parameters have been obtained. From these results the values of s-wave strength function and mean level spacings for separate spins were determined. These results were then used to obtain parameters of the optical model potentials and the value of σ -the spin cut-off factor in the level density formula. The resonance parameters are listed in tables I, II and III and the average properties of these parameters are listed in table IV to IX. The R-matrix theoretical fit to the measured total neutron cross section is shown in the figures 1, 2 and 3 and the calculated values of s-wave strength function has been compared with the experimental values of this quantity in the mass range

of $35 < A < 70$ for the optical model parameters given in table IX, is shown in figure 4.

III. COLLABORATIVE RESEARCH WORK AT OAK RIDGE NATIONAL LAB.

J.B. Garg, M.S. Pandey (SUNYA), J.A. Harvey, W.M. Good
R.L. Macklin and J. Halpern (ORNL).

The measurement of neutron total and capture cross section in nuclei provide valuable data for reactor design, nucleosynthesis of elements, and for a better understanding of the neutron interaction with nuclei. The later information is obtained via investigation of the level resonance parameters and their statistical averages such as the level spacing for given angular momentum and spin, Γ_n and Γ_γ and strength function. The systematics of resonance levels such as spin and parity and their dependence on strength function, level density etc., are also important. The capture cross section measurements are complimentary to the measurements of neutron total cross sections.

These measurements in certain nuclei are equally important for their application in the reactor design. The measurements in the separated isotopes of iron, copper and zinc were undertaken for these reasons with the ORELA neutron facility which has one of the highest resolutions for making such measurements up to few hundred keV neutron energy.

III(a) High Resolution Neutron Total Cross Section In $^{63}_{29}\text{Cu}$ and $^{65}_{29}\text{Cu}$

M.S. Pandey and J.B. Garg (SUNYA) and J.A. Harvey(ORNL)-I

This paper has been accepted for publication in the Physical Review and will be published in the January issue.

TABLE I

E_o (keV)	Γ_n (eV)	J
4.148 ± 0.008	498 ± 5	4
6.797 ± 0.06	1237 ± 10	3
→ 11.62 ± 0.06	4826 ± 50	3
15.78 ± 0.02		4
16.21 ± 0.02	333 ± 20	3
16.96 ± 0.03	310 ± 20	3
21.70 ± 0.05	702 ± 50	3
23.39 ± 0.05		4
29.59 ± 0.05	205 ± 20	3
33.51 ± 0.08	26 ± 5	(4)
37.43 ± 0.08	23 ± 5	3
39.58 ± 0.10	616 ± 50	4
42.35 ± 0.12	39 ± 8	3
44.45 ± 0.12	25 ± 5	4
46.58 ± 0.14	26 ± 5	4
48.04 ± 0.15	130 ± 20	3
49.50 ± 0.15	583 ± 50	4
51.88 ± 0.16	136 ± 20	3
52.97 ± 0.17	877 ± 80	3
63.06 ± 0.23	3820 ± 200	3
65.74 ± 0.23		4
68.60 ± 0.25	5217 ± 500	3
73.8 ± 0.27	19 ± 4	4
79.0 ± 0.30	13 ± 3	4
82.8 ± 0.33	1230 ± 120	4
87.6 ± 0.36	2812 ± 300	3
93.2 ± 0.39	87 ± 15	4
94.8 ± 0.4	73 ± 15	3
95.8 ± 0.4		
97.2 ± 0.4		
98.4 ± 0.4		
103.7 ± 0.5		
105.8 ± 0.5		
110.7 ± 0.6	870 ± 80	3
114.5 ± 0.6	1610 ± 100	3
116.1 ± 0.6		
118.7 ± 0.6		
120.6 ± 0.7		
121.6 ± 0.7		
126.0 ± 0.7		
127.0 ± 0.7		
134.7 ± 0.8	4540 ± 400	3
140.6 ± 0.8	3570 ± 300	3
145.5 ± 0.8	2700 ± 300	3
152.5 ± 0.8	4300 ± 300	4
160.0 ± 0.9	10000 ± 1500	3
166.7 ± 0.9	7700 ± 500	3
172.0 ± 1	2600 ± 200	4
177 ± 1	3100 ± 300	3
179 ± 1	3300 ± 300	4
183 ± 1.5	5200 ± 400	

E_o (keV)	Γ_n (eV)	J
188 ± 1.4	7700±300	4
194 ± 1.5	1500±500	3
200 ± 1.5	7400±200	3
211 ± 2.0	1200±200	3

Strong resonances at neutron (lab) energies of 221±2, 232±2, 238±2, 245±2, 251±2, 261±2, 272±2, 278±2, 285±2, 300±3, 306±3, 313±3, 328±3, 336±3, 354±3, 368±3, 393±3, 400±4, 433±4, 450±4, 480±4 keV have also been observed in the experimental data. On account of the somewhat poorer resolution of data at these energies no analysis for the determination of the resonance parameters was attempted.

TABLE II

Mn

E_o (keV)	Γ_n (eV)	J
0.336±.001	22±0.5	2
1.098±.002	15.4±0.5	3
2.370±.003	390±20	3
7.165±0.008	410±20	2
8.13±0.01	6±2	3
8.89±0.01	390±20	3
10.87±0.01	4.5±2	2
17.82±0.02	11.5±1.5	3
17.99±0.02	67±6	2
21.00±0.05	940±50	3
23.63±0.05	410±20	2
25.89±0.05	14±2	3
26.09±0.05	6±1	2
26.48±0.05	135±10	2
27.00±0.05	420±30	3
30.30±0.06	15±3	2
33.65±0.07	20±2	2
35.10±0.08	1820±200	3
35.35±0.08	730±70	2
36.40±0.08	12±1	2
39.80±0.08	22±4	3
41.03±0.10	460±40	3
46.70±0.10	40±10	2
48.40±0.15	43±5	3
51.70±0.15	35±5	3
53.35±0.15	120±20	2
57.45±0.15	520±60	3
58.20±0.16	520±40	2
59.90±0.17	630±60	2
60.40±0.20	105±15	3
62.95±0.21	40±10	2
64.40±0.23	930±150	3
65.65±0.23	100±50	2
66.72±0.25	220±30	3
67.50±0.25	110±50	2
68.40±0.25	55±10	3
70.15±0.25	860±200	2
71.80±0.25	130±50	3
72.80±0.26	170±30	2
74.20±0.27	880±100	3
78.30±0.28	60±10	2
81.63±0.30	400±50	2
82.30±0.32	100±25	3
83.90±0.32	190±20	3
84.90±0.34	880±200	2
85.90±0.35	190±20	3
91.90±0.36	780±300	3

TABLE II (continued)

Mn		
E_o (keV)	Γ_n (eV)	J
96.80 $\pm$ 0.38	600 $\pm$ 200	2
99.10 $\pm$ 0.38	750 $\pm$ 200	3
100.70 $\pm$ 0.40	340 $\pm$ 100	2
102.90 $\pm$ 0.45	140 $\pm$ 40	3
105.4 $\pm$ 0.5	2200 $\pm$ 500	2
108.2 $\pm$ 0.5	350 $\pm$ 50	3
111.1 $\pm$ 0.6	3600 $\pm$ 800	3
114.8 $\pm$ 0.6	160 $\pm$ 50	2
116.9 $\pm$ 0.6	660 $\pm$ 100	3
119.0 $\pm$ 0.6	740 $\pm$ 200	3
124.5 $\pm$ 0.7	900 $\pm$ 200	2
128.1 $\pm$ 0.7	3500 $\pm$ 400	3
130.8 $\pm$ 0.7	80 $\pm$ 20	3
130.9 $\pm$ 0.8	310 $\pm$ 50	2
139.1 $\pm$ 0.8	400 $\pm$ 200	3
143.7 $\pm$ 0.8	650 $\pm$ 200	2
152.9 $\pm$ 0.9	500 $\pm$ 150	3
158.0 $\pm$ 0.9	860 $\pm$ 200	2
161. $\pm$ 1.0	1300 $\pm$ 200	3
169.7 $\pm$ 1.2	1330 $\pm$ 200	2
174.9 $\pm$ 1.2	1810 $\pm$ 300	3
180.5 $\pm$ 1.3	1100 $\pm$ 200	2
182.9 $\pm$ 1.3	1110 $\pm$ 200	2
188.6 $\pm$ 1.4	2350 $\pm$ 400	3
191.9 $\pm$ 1.5	1700 $\pm$ 400	2
196.7 $\pm$ 1.5	570 $\pm$ 100	3

In addition to the resonances listed in Table III the following strong resonances at higher energies 211.2, 225.2, 234. , 240.5, 248.8, 259.3, 274.4, 280.4, 288., 297.4, 308.8, 316.0, 328.5, 339. , 355.9, 361.7, 368., 380.3, 386. , 396.9, 414.5, 421.9, 429.5, 453.6, 475.2, 493. keV have also been observed. In view of the resolution the analysis of these resonances is rather complicated, and the results obtained would be subject to large uncertainties.

TABLE III

E_o (keV)	Γ_n (eV)	$\Delta\Gamma_n$ (eV)	J
-0.10 $\pm$	3.09		3
.132 $\pm$	5.15 $\pm .3$		4
2.48 ± 0.004	3.5 ± 1		(3)
4.318 ± 0.004	117 ± 6		4
5.02 ± 0.02	675 ± 30		3
6.38 ± 0.01	2.3 $\pm .3$		(4)
8.05 ± 0.01	36 ± 2		3
8.74 ± 0.01	2.7 $\pm .5$		(4)
9.68 ± 0.01	3.3 $\pm .7$		(3)
10.70 ± 0.01	65 ± 3		4
11.85 ± 0.02	2.6 $\pm .5$		(3)
13.28 ± 0.02	22 ± 2		3
15.64 ± 0.02	74 ± 3		3
16.92 ± 0.03	161 ± 5		4
18.64 ± 0.03	5 ± 1		(3)
19.13 ± 0.03	3.3 $\pm .6$		(4)
19.70 ± 0.03	5 ± 1		(3)
21.96 ± 0.04	840 ± 50		3
22.51 ± 0.04	229 ± 25		4
24.46 ± 0.04	428 ± 40		3
25.15 ± 0.04	189 ± 20		4
25.90 ± 0.05	30 ± 3		4
27.35 ± 0.05	173 ± 18		4
29.37 ± 0.05	20 ± 4		(3)
30.11 ± 0.06	335 ± 20		4
31.41 ± 0.06	145 ± 15		3
32.77 ± 0.07	155 ± 15		3
33.03 ± 0.07	41 ± 4		4
34.93 ± 0.07	303 ± 25		4
36.74 ± 0.08	32 ± 3		3
37.05 ± 0.08	4.6 ± 1		(3)
39.38 ± 0.08	14 ± 3		(4)
40.27 ± 0.09	33 ± 8		(3)
40.73 ± 0.09	4 ± 1		(3)
41.53 ± 0.09	49 ± 10		4
42.88 ± 0.09	5 ± 3		(4)

E_o (keV)	Γ_n (eV)	$\Delta\Gamma_n$ (eV)	J
43.61 ± 0.1	7 ± 3		3
45.21 ± 0.1	316 ± 25		3
46.00 ± 0.1	292 ± 25		4
47.21 ± 0.1	80 ± 20		3
49.50 ± 0.12	48 ± 5		(4)
50.43 ± 0.12	120 ± 15		3
51.47 ± 0.12	513 ± 40		4
53.07 ± 0.14	120 ± 15		3
53.99 ± 0.14	365 ± 30		4
56.45 ± 0.16	204 ± 10		3
57.75 ± 0.16	46 ± 4		(4)
59.20 ± 0.18	250 ± 20		4
59.95 ± 0.18	187 ± 15		3
61.30 ± 0.20	147 ± 15		4
62.33 ± 0.20	30 ± 3		3
63.0 ± 0.20	150 ± 30		3
63.72 ± 0.20	90 ± 20		3
64.20 ± 0.20	54 ± 10		4
65.08 ± 0.25	49 ± 10		3
66.24 ± 0.25	135 ± 20		4
67.40 ± 0.25	62 ± 10		3
68.64 ± 0.25	50 ± 10		3
70.25 ± 0.30	221 ± 25		4
72.03 ± 0.30	383 ± 40		3
72.65 ± 0.30	225 ± 25		4
73.70 ± 0.30	52 ± 10		3
74.75 ± 0.30	98 ± 15		4
75.90 ± 0.32	98 ± 15		3
77.15 ± 0.32	397 ± 40		3
79.62 ± 0.35	269 ± 25		4
81.65 ± 0.35	374 ± 40		3
83.22 ± 0.35	161 ± 20		3
84.40 ± 0.35	329 ± 35		4
86.60 ± 0.40	14 ± 4		4
88.80 ± 0.40	1277 ± 125		4

<u>E₀ (keV)</u>	<u>Γ_n (eV)</u>	<u>ΔΓ_n (eV)</u>	<u>J</u>
93.05 ± 0.40	2178		4
95.07 ± 0.40	1028		3
98.20 ± 0.40	448		4
98.40 ± 0.40	2614		4
100.50 ± 0.45	604		3
101.70 ± 0.45	760		4
103.90 ± 0.45	537		3
105.30 ± 0.50	155		3
106.40 ± 0.50	776		4
109.20 ± 0.50	629		3
110.20 ± 0.50	395		4
111.0 ± 0.55	238		
113.2 ± 0.55	641		3
114.9 ± 0.55	1050		4
117.6 ± 0.55	1225		3
119.3 ± 0.60	1480		4
124.3 ± 0.60	756		3
126.2 ± 0.60	1100		3
130.5 ± 0.65	1462		4

TABLE IV

The relative contribution to the thermal neutron capture cross section and the resonance absorption integral from the first few resonances.

E_v (keV)	J	Γ_n (eV)	Γ_γ (ev) (assumed)	(σ_n, σ) (barns)	I_γ (barns)
0.336	2	26.5	.46	10.12	7.080
7.166	2	483.	.46	0.09	.016
23.690	2	460	.46	0.004	.002
1.098	3	18.5	.46	0.51	0.916
2.370	3	470.	.46	1.88	0.201
8.890	3	465.	.46	0.07	0.014
-2.830	2	318.	.46	0.60	

Total = 13.274 8.33

(1/v) contribution to $I_\gamma \rightarrow 5.99$

I_γ (total) = 14.32

TABLE V

Relative contribution to the thermal neutron capture cross sections from the first three resonances with the following parameters

E_0 (keV)	J	Γ_n (eV)	Γ_γ (eV)	$(\sigma_{n\gamma})$ (barns)	I_γ (barns)
4.148	4	498±5	2.2	2.30	.2305
6.797	3	1237±10	2.2	1.29	.088
11.620	3	4826±50	2.2	1.27	.030

$$(\sigma_{n\gamma})_{\text{Total}} = 4.86 \quad .415$$

$$I_\gamma(1/v) = 0.45(\sigma_{n\gamma}) = 2.19$$

$$I_\gamma(\text{Total}) = 2.605$$

TABLE VI

Relative contribution to the thermal neutron capture cross section and to the resonance absorption integral from the following resonances

E_o (keV)	J	Γ_n (eV)	Γ_γ (eV)	$\sigma_{n\gamma}$ (barns)	I_γ (barns)
0.130	4	5.15	0.42	25.90	58.52
4.318	4	118.9	0.42	0.94	.053
5.021	3	675.0	0.42	0.32	.030
-0.100	3	3.5	0.16	10.04	
				37.20	58.603
(1/v) contribution to $I_\gamma \rightarrow$					16.74
				Total	75.343

TABLE VII

Values of the coefficients A_J and B_J and R' as obtained from the R-matrix analysis of the total neutron cross section data from thermal to 50 keV neutron energy range.

Vanadium		Manganese		Cobalt	
R = 5.4 fm		R = 5 fm		R = 5.4 fm	
J=3	J=4	J=2	J=3	J=3	J=4
$A_J=0.35$	-0.37	0.23	0.50	-0.16	-0.12
$B_J=0.56 \times 10^{-4}$	0.46×10^{-4}	0.78×10^{-4}	1.2×10^{-10}	0.12×10^{-4}	0.17×10^{-4}
$R' = 3.51 \text{ fm}$		3.85 fm		6.26 fm	
7.39 fm		2.5 fm		6.05 fm	

TABLE VIII
S-Wave Strength Function Values In Units Of 10^{-4}

Nucleus and Spin State	Energy Range		Other Measurements
	²⁹	⁴⁵	
Vanadium	0-100 keV	0-200 keV	
J=4	5.02±1.99	6.54±2.19	8.33 ^(a)
J=3	10.8 ±4.5	9.1 ±2.7	7.38 (a)
J=3,4	7.9 ± 2.1	7.8 ± 1.6	8.10 (a) (4.2±1.0) ^(c)
	⁷⁵	⁹⁰	
Cobalt	0-100 keV	0-130 keV	0-120 keV
J=3	4.99±1.56	4.07±0.86	3.50 (b)
J=4	3.15±0.92	4.86±1.07	3.04 (b)
J=3,4	4.07±0.66	4.47±0.66	3.8±1.6 ^(b) 4.5±1.0 ^(c)
	⁴⁹	⁷³	
Manganese	0-100 keV	0-200 keV	50-210 keV
J=2	4.13±1.22	3.75±0.95	2.80 ^(a)
J=3 c	5.93±1.93	6.0 ±1.5	3.81 (a) 4.5±1.0 ^(c)
J=2,3	5.03± 1.01	4.87± 0.81	(3.3±0.3)(a) 4.08±1.0 ^(b) 0.7

(a) Rohr and Friedland(ref.8) corrected for missed levels.

(b) Morganstern et al (ref. 7).

(c) Seth et al (ref. 28).

TABLE IX

The final optical model parameters used
in the calculations of strength function.

$U = 48 \text{ MeV}$
 Re
 $W = -6.5 \text{ MeV}$
 $r = 1.40$
 Re
 $a = 0.65 \text{ fm}$
 Re
 $V_{so} = -6 \text{ MeV}$
 $r_{lm} = 1.35$
 $a_{lm} = 0.40 \text{ fm}$
 $r_{so} = 1.35$
 $a_{so} = 0.65 \text{ fm}$

Figure 1

Figure 2

Figure 2

Figure 3

Figure 4

III(b) Total Cross Sections in the Separated Isotopes of Zinc
J.B. Garg, S. Jain (SUNYA) and J.A. Harvey (ORNL)

Total neutron cross sections in the isotopes of ^{30}Zn (A=64, 66, 67, 68 and 70) were performed using ORELA facilities. These isotopes were obtained from Oak Ridge Isotope Division and from the Los Alamos Scientific Lab. The isotopes were in the form of powdered oxides with the respective enrichment as given in table I. The samples were packed in a container of polyethylene tubing of dimensions (ID = 2.64 cms and different heights depending upon the amount of material available). Two sets of measurements were made, one emphasizing the high energy region using the NE 110 fast scintillator and one emphasizing the low energy region using a Li-glass scintillator detector. Both these sets of measurements were made at a flight path of 78.2 meters and an electron burst width of 5 ns. The channels of the time-of-flight analyzer were varied from a minimum of 1 ns up to the maximum value of 512 ns depending upon the energy region to be measured. Samples of U^{238} and 3" CH_2 were also used simultaneously for the determination of the background.

The raw data has been stored in the magnetic tapes and has been processed for the determination of σ_T vs E_n values after taking into account the dead time correction, normalization, background subtraction, etc.

The tables II to VI list the energies of resonances and the tentative l-assignment made from the shape of the resonances in the various isotopes. These data are currently being analyzed for extracting the resonance parameters with the

help of area and R-matrix codes at SUNYA.

The values of the average spacings for s- and p-wave resonances for these isotopes are given in the table VII.

III(c) High Resolution Total Neutron Cross Section in ^{54}Fe and ^{56}Fe .

M.S. Pandey, J.B. Garg (SUNYA) and J.A. Harvey and W.M. Good (ORNL).

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III(d) Total Neutron Cross Section in ^{58}Fe

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The total neutron cross section in the separated isotope of ^{58}Fe ($a=73.3\%$) was measured using ORELA facility. The measurements were made at 78.2 m station using NE 110 detector for high energy and ^6Li -glass scintillator for low energy regions.

The atomic percent abundances of various isotopes in the sample are as follows: (58-73.26, 57-1.86, 56-23.74, 54-1.14). Hence the major impurity in the sample is that of isotope of ^{56}Fe (23.74%) and hence in fitting the σ_T vs E_n curves, the proper account of the contribution from the ^{56}Fe resonances had to be taken. The parameters of ^{56}Fe resonances are known from earlier publications¹⁻²⁾. The impurity of ^{54}Fe is only 1% and hence its effect is not important although the contribution of strong resonances of ^{54}Fe was taken into account in the analysis.

The sample, in powder oxide form (Fe_2O_3) weighing 14.10 gms was contained in a polyethylene holder and hence the σ_T were corrected for the oxygen content in the sample and

Table I

Atomic Percentage of Masses in the Separated
Isotopes of Zn used for the Measurement

Mass	Isotopes				
	^{64}Zn	^{66}Zn	^{67}Zn	^{68}Zn	^{70}Zn
64	97.87	0.35	1.66	0.26	5.08
66	1.18	99.35	4.46	0.27	3.71
67	0.21	0.12	89.68	0.19	0.81
68	0.74	0.19	4.15	99.28	4.46
70	<0.05	<0.05	<0.05	<0.1	85.9

Table II

Resonance Energies of ^{64}Zn		Resonance Energies of ^{64}Zn		Resonance Energies of ^{64}Zn	
E_0 (keV)	ℓ	E_0 (keV)	ℓ	E_0 (keV)	ℓ
0.265±0.0004	1	67.69±0.01	1	142.89±0.10	0
0.480±0.0008	1	68.96±0.04	0	145.57±0.10	0
2.556±	0	69.56±0.01	1	148.28±0.10	0
4.158±0.001	0	72.81±0.04	1	150.46±0.10	0
5.201±0.001	1	73.62±0.04	1	151.13±0.08	1
5.966±0.001	1	74.55±0.06	1	151.71±0.10	1
8.412±0.002	1	75.04±0.04	1	155.13±0.12	0
8.795±0.002	1	77.12±0.03	1	157.56±0.20	0
10.78±0.09	0	78.38±0.05	1	159.50±0.20	0
10.838±0.01	1	78.78±0.08	0	160.02±0.04	1
13.100±0.2	0	79.13±0.03	1	161.74±0.10	1
13.96±0.01	1	81.46±0.02	1	164.91±0.10	1
15.30±0.01	0	83.13±0.02	1	166.41±0.02	1
16.99±0.01	1	83.62±0.14	0	168.52±0.07	0
18.432±0.015	1	86.72±0.02	1	169.26±0.07	1
20.145±0.016	1	87.41±0.09	0	170.70±0.20	0
21.360±0.08	0	89.61±0.34	0	171.42±0.07	1
22.20±0.01	1	90.27±0.08	1	179.05±0.10	0
22.66±0.04	0	92.68±0.06	1	180.97±0.10	0
26.19±0.02	1	94.88±0.12	0	182.56±0.10	1
28.48±0.01	1	96.34±0.04	1	182.92±0.04	1
28.55±0.01	1	96.62±0.06	0	183.69±0.08	1
29.12±0.04	0	100.22±0.06	1	185.27±0.10	0
29.66±0.07	0	101.83±0.07	1	186.40±0.08	1
30.74±0.08	0	105.74±0.05	1	186.91±0.08	1
32.57±0.20	0	106.54±0.08	1	187.43±0.08	1
35.16±0.02	1	108.16±0.13	0	188.84±0.08	1
35.70±0.02	1	110.02±0.08	1	189.49±0.08	1
36.75±0.02	1	111.72±0.10	0	192.02±0.08	1
39.26±0.04	0	114.16±0.14	0	193.91±0.08	0
39.44±0.03	1	115.35±0.11	1	196.26±0.08	1
39.81±0.02	1	116.86±0.09	1	196.97±0.08	0
41.02±0.05	0	117.59±0.09	1	199.37±0.08	1
43.93±0.03	1	120.47±0.11	0		
44.68±0.01	1	121.57±0.04	1		
46.91±0.02	1	121.84±0.18	0		
47.99±0.08	0	122.51±0.03	1		
50.72±0.10	0	125.13±0.03	1		
52.16±0.10	0	125.69±0.06	1		
53.70±0.04	1	132.72±0.19	0		
54.32±0.07	0	133.66±0.03	1		
60.90±0.03	0	134.49±0.17	0		
61.78±0.06	1	134.98±0.04	1		
62.14±0.03	1	137.28±0.10	1		
64.90±0.01	1	140.35±0.04	1		
65.16±0.03	1	140.89±0.08	0		
58±0.01	1	141.59±0.08	1		
50±0.09	0				

Table III

Resonance Energies of ^{66}Zn

E_0 (keV)	ℓ
0.220±	1
0.320±	1
0.520±	1
2.621±	
4.044±0.001	0
4.385±0.001	1
5.343±0.001	1
6.711±0.002	1
9.176±0.002	1
10.469±0.003	0
14.257±0.011	0
15.652±0.012	1
16.327±0.012	1
17.047±0.012	0
17.263±0.024	1
19.761±	0
20.814±0.009	1
21.015±0.005	1
21.704±0.009	1
24.408±0.018	0
26.693±0.012	1
31.020±0.007	1
34.387±0.01	0
34.92 ±0.01	1
35.97 ±0.01	1
36.86 ±0.01	0
40.37 ±0.01	1
40.57 ±0.01	1
41.84 ±0.01	1
42.72 ±0.02	0
43.65 ±0.01	1
44.98 ±0.01	0
49.80 ±0.01	1
51.52 ±0.01	0
52.68 ±0.02	1
55.10 ±0.02	1
56.79 ±0.02	0
59.59 ±0.02	1
60.52 ±0.02	1
61.04 ±0.02	1
62.91 ±0.02	1
63.41 ±0.02	1
64.82 ±0.07	0
67.43 ±0.02	1
67.99 ±0.1	0
70.05 ±0.04	1
72.05 ±0.04	1
72.58 ±0.04	1
72.99 ±0.04	1
76.82 ±0.1	0

Resonance Energies of ^{66}Zn

E_0 (keV)	ℓ
77.80±0.03	1
78.86±0.03	1
79.31±0.03	0
80.06±0.03	1
84.38±0.03	1
84.52±0.03	0
86.77±0.03	1
88.16±0.03	1
88.65±0.03	1
90.14±0.03	0
90.45±0.03	1
91.44±0.03	0
93.55±0.03	1
94.42±	0
97.11±0.03	0
97.88±0.03	0
99.06±0.06	0
100.29±0.03	0
102.34±0.06	1
103.96±0.04	1
104.72±0.04	1
105.78±0.04	1
108.46±0.04	0
109.71±0.08	1
110.51±0.08	1
111.04±0.04	1
113.73±0.08	1
115.10±0.08	1
117.11±0.04	0
118.66±0.08	1
120.53±0.08	0
121.96±0.08	1
126.04±0.08	1
128.45±0.08	0
130.75±0.05	1
131.24±0.05	1
131.83±0.04	1
132.68±0.04	1
133.75±	0
134.70±0.04	1
135.25±0.04	0
137.44±	0
139.30±0.04	1
139.81±0.04	0
141.55±0.04	1
145.49±	0
147.01±0.04	1
148.19±0.04	1
150.83±0.04	
153.04±	0
154.27±0.08	1

Resonance Energies of ^{66}Zn

E_0 (keV)	ℓ
156.38±0.08	1
158.07±0.06	1
159.19±0.08	0
159.73±0.06	0
161.46±0.08	1
165.60±0.08	0
166.89±0.08	1
167.14±0.08	1
168.57±0.08	0
171.88±0.08	1
173.20±0.12	0
173.83±0.08	1
175.51±0.08	1
177.32±0.08	0
179.56±0.08	1
180.08±0.08	0
181.19±0.08	1
183.59±0.08	1
185.61±0.08	1
187.55±0.10	0
189.02±0.08	1
191.96±0.08	1
193.61±0.08	1
198.77±0.10	0

Table IV

Resonance Energies Of ^{67}Zn			Resonance Energies Of ^{67}Zn			Resonance Energies Of ^{67}Zn		
$E_o \pm$	ΔE	ℓ	$E_o \pm$	ΔE	ℓ	$E_o \pm$	ΔE	ℓ
0.225	0.012	0	12.469	0.008	1	30.032	0.015	1
0.45	0.025	0	12.922	0.051	0	30.224	0.022	1
0.525	0.015	0	12.956	0.026	0	30.456	0.023	0
0.595	0.005	0	13.040	0.009	1	31.129	0.031	0
0.750	0.002	0	13.366	0.026	1	31.824	0.016	1
1.094	0.001	1	13.534	0.026	0	32.123	0.033	0
1.319	0.003	0	14.373	0.019	0	32.601	0.059	0
1.544	0.007	0	14.570	0.020	0	32.811	0.025	0
1.870	0.003	1	14.610	0.010	1	33.520	0.017	1
2.068	0.004	0	14.680	0.020	1	33.685	0.018	1
2.129	0.005	0	15.144	0.074	0	33.905	0.018	1
2.243	0.005	0	16.093	0.024	0	34.011	0.018	1
2.420	0.003	1	16.233	0.012	1	34.496	0.018	0
2.467	0.011	0	16.386	0.012	0	34.641	0.019	1
2.649	0.015	0	16.434	0.096	0	34.880	0.019	1
3.001	0.001	1	17.161	0.020	0	35.308	0.019	1
3.423	0.014	0	17.444	0.013	1	35.449	0.019	1
3.608	0.001	1	17.950	0.028	1	36.207	0.020	0
3.790	0.029	0	18.156	0.056	0	36.314	0.019	0
4.041	0.006	1	18.451	0.028	0	36.501	0.020	1
4.093	0.006	0	18.869	0.020	0	36.749	0.020	1
4.169	0.011	1	19.091	0.015	1	37.060	0.020	1
4.341	0.004	1	19.196	0.030	0	37.611	0.021	1
4.602	0.001	1	19.393	0.015	0	37.704	0.011	1
4.901	0.001	1	19.547	0.031	1	38.175	0.021	1
4.962	0.004	0	19.749	0.032	0	38.462	0.021	1
4.991	0.006	0	20.003	0.016	1	38.708	0.022	0
5.038	0.005	1	21.119	0.013	0	39.45	0.01	1
5.231	0.004	0	21.342	0.018	1	40.05	0.03	1
5.807	0.003	1	21.546	0.032	0	40.365	0.012	1
6.326	0.057	0	21.686	0.009	1	40.584	0.011	1
7.014	0.007	0	22.112	0.018	0	40.700	0.035	1
7.098	0.018	0	22.314	0.018	0	40.969	0.025	1
7.500	0.009	0	22.846	0.015	0	41.134	0.024	0
7.641	0.007	1	23.098	0.020	0	41.655	0.018	0
7.785	0.006	0	23.333	0.025	1	42.128	0.037	0
7.913	0.016	0	23.505	0.026	0	42.429	0.007	1
8.252	0.019	0	24.167	0.005	1	42.603	0.025	0
8.495	0.014	0	24.263	0.021	1	42.709	0.025	0
8.560	0.007	1	24.702	0.027	0	42.973	0.032	1
9.043	0.007	1	25.369	0.086	0	43.219	0.058	
9.149	0.007	1	25.686	0.029	1	43.720	0.032	
9.312	0.008	0	26.176	0.012	0	44.673	0.014	
9.355	0.013	0	26.980	0.025	0	44.975	0.020	
9.934	0.008	0	27.469	0.032	0	45.444	0.076	
10.042	0.002	1	27.715	0.007	1	46.060	0.007	
10.067	0.003	1	28.218	0.047	0	46.568	0.036	
10.419	0.055	1	28.339	0.027	0	47.135	0.051	
10.939	0.011	0	28.770	0.048	0	48.150	0.052	
11.891	0.007	0	28.957	0.014	0	48.300	0.150	
12.205	0.016	0	29.710	0.051	0	49.044	0.013	
						49.291	0.039	
						49.846	0.078	

Table V

TABLE ()

TABLE ()

TABLE ()

Resonance Energies of ^{68}Zn

Resonance Energies of ^{68}Zn

Resonance Energies of ^{68}Zn

E_0 (keV)	ℓ
0.580	0
2.239±0.0003	1
3.796±0.0008	1
5.045±0.001	0
7.472±0.002	1
8.229±0.002	1
8.580±0.003	1
13.390±	0
16.018±0.011	1
18.394±0.014	1
18.796±	0
20.959±0.005	1
22.832±0.005	1
24.735±0.009	1
26.255±0.009	0
26.515±0.009	0
32.743±0.009	1
33.511±0.009	1
34.724±0.009	0
36.84 ±0.01	1
37.86 ±0.01	1
39.27 ±0.01	1
42.55 ±0.01	0
48.02± 0.02	0
50.58±	0
53.05± 0.01	1
53.90± 0.01	1
56.69± 0.01	1
57.66± 0.02	0
62.34± 0.01	1
62.76± 0.01	1
63.76± 0.01	1
65.87±	0
69.27± 0.02	1
70.90± 0.02	1
71.56± 0.02	0
75.05± 0.02	1
75.65± 0.02	0
76.37± 0.02	1
77.31± 0.02	1
80.76± 0.02	0
82.25± 0.02	1
85.64± 0.02	1
86.68± 0.02	1
87.17± 0.02	0
87.52± 0.02	0
94.12± 0.02	0
96.70± 0.02	0
96.81± 0.02	1
99.33± 0.02	0
102.60± 0.02	1
102.83± 0.02	1

E_0 (keV)	ℓ
105.11± 0.02	0
105.54± 0.02	1
105.81± 0.02	1
109.17± 0.02	1
110.88± 0.02	0
113.35± 0.02	1
117.45± 0.02	1
118.57± 0.02	1
122.60± 0.02	1
123.09± 0.02	1
125.25± 0.02	0
128.45± 0.02	1
130.09± 0.03	1
131.49± 0.03	1
133.16± 0.03	0
136.06± 0.03	1
138.04± 0.03	1
139.68± 0.03	0
140.24± 0.03	1
143.36± 0.03	0
146.22± 0.03	1
149.36± 0.03	1
150.49± 0.03	1
151.71± 0.03	1
153.08± 0.03	1
154.10± 0.03	1
154.92± 0.03	0
154.98± 0.03	1
158.79± 0.03	1
159.37± 0.03	1
159.77± 0.03	1
162.71± 0.03	0
163.87± 0.03	1
166.34± 0.03	1
167.47± 0.03	1
168.92± 0.03	1
170.78± 0.03	1
173.18± 0.03	1
173.96± 0.03	1
174.94± 0.03	0
177.27± 0.03	1
178.44± 0.03	1
179.32± 0.03	1
180.70± 0.03	0
182.12± 0.03	1
184.06± 0.03	1
185.97± 0.03	1
186.37± 0.03	1
187.49± 0.03	0

E_0 (keV)	ℓ
188.03±0.03	1
189.84±0.03	1
190.21±0.03	1
191.96±0.03	0
196.60±0.03	0
197.52±0.03	0

Table VI

Resonance Energies of ^{70}Zn

E_0 (keV)	ℓ
12.071 $\pm$ 0.007	1
12.36 $\pm$ 0.02	0
13.02 $\pm$ 0.01	1
13.37 $\pm$ 0.02	1
17.91 $\pm$ 0.06	0
22.76 $\pm$ 0.01	1
22.95 $\pm$ 0.01	1
31.90 $\pm$ 0.10	0
37.94 $\pm$ 0.02	1
44.28 $\pm$ 0.14	0
48.06 $\pm$ 0.14	1
51.67 $\pm$ 0.10	0
55.52 $\pm$ 0.10	1
56.09 $\pm$ 0.05	1
59.03 $\pm$ 0.02	1
59.77 $\pm$ 0.03	1
61.01 $\pm$ 0.02	1
62.50 $\pm$ 0.02	1
71.14 $\pm$ 0.18	0
78.65 $\pm$ 0.05	0
84.14 $\pm$ 0.02	1
84.70 $\pm$ 0.05	1
84.96 $\pm$ 0.05	1
88.14 $\pm$ 0.08	1
90.26 $\pm$ 0.04	1
91.48 $\pm$ 0.08	1
92.24 $\pm$ 0.14	0
94.40 $\pm$ 0.10	1
98.64 $\pm$ 0.11	1
101.67 $\pm$ 0.12	1
102.99 $\pm$ 0.05	1
106.10 $\pm$ 0.10	0
106.91 $\pm$ 0.08	1
107.38 $\pm$ 0.08	1
113.16 $\pm$ 0.03	1
113.70 $\pm$ 0.08	1
114.49 $\pm$ 0.08	1
120.09 $\pm$ 0.50	0
127.61 $\pm$ 0.09	0
129.72 $\pm$ 0.04	1
130.87 $\pm$ 0.12	1
135.07 $\pm$ 0.10	1
137.33 $\pm$ 0.10	1
138.56 $\pm$ 0.12	0
141.85 $\pm$ 0.10	0
142.91 $\pm$ 0.10	1
145.35 $\pm$ 0.16	0
149.17 $\pm$ 0.14	1
152.61 $\pm$ 0.15	1
163.59 $\pm$ 0.50	0
164.11 $\pm$ 0.11	1
171.25 $\pm$ 0.20	1
173.02 $\pm$ 0.13	1

Resonance Energies of ^{70}Zn (continued)

E_0 (keV)	ℓ
176.35 $\pm$ 0.20	0
181.27 $\pm$ 0.08	1
184.34 $\pm$ 0.28	0
192.05 $\pm$ 0.39	0
194.33 $\pm$ 0.30	1
199.08 $\pm$ 0.13	1

TABLE VII

	Isotopes				
	^{64}Zn	^{66}Zn	^{67}Zn	^{68}Zn	^{70}Zn
$\langle D \rangle_{\ell=0}$	4.10 ± 0.43	4.62 ± 0.52	0.54 ± 0.05	5.81 ± 0.73	10.5 ± 1.6
$\langle D \rangle_{\ell=1}^*$	2.49 ± 0.20	2.42 ± 0.20	0.68 ± 0.06	2.6 ± 0.2	4.75 ± 0.8

*For target nuclei with $I=0^+$, one populates resonances with $J=1/2^+$ only with s-wave neutron capture and resonances with $J=1/2^-$ and $3/2^-$ for capture of $\ell=1$ neutrons. Since the level density is expected to vary approximately as $(2J+1)$, there should be about 3 times more $\ell=1$ resonances than $\ell=0$ resonances in the same energy interval. Our results indicate this ratio to be about 2 indicating missing of some $\ell=1$ resonances.

hydrogen impurity.

The total and capture cross section measurements in ^{58}Fe isotope has been previously made by Block et al at RPI up to 20 keV and they have observed some weak levels. We have analyzed our data up to 300 keV and the results of the analysis are given in the Table I

Since there is a strong resonance in ^{16}O at the energy of 440 keV with a neutron width of 45 keV, it was not considered reliable to analyze the data above 300 keV neutron energy. Besides the sample was not thick enough to provide good statistics. ($1/n = 26.52$ barns/atm for ^{58}Fe).

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- 1). J.B. Garg, J. Rainwater and W.W. Havens, Jr., Phys. Rev. C3, 2447 (1971).
 2. M.S. Pandey, J.B. Garg, J.A. Harvey and W.M. Good, Proceedings of Conference on Nuclear Cross Sections and Technology, Washington, D.C. 1975 (pages 748-753).

III(e) Total Neutron Cross Section in ^{57}Fe
J.B. Garg, S. Jain (SUNYA) and J.A. Harvey (ORNL)

The total neutron cross section in the separated isotope of ^{57}Fe has been measured using ORELA facilities. The measurements were made at 78.2 meter flight path with the same conditions as was the case for ^{58}Fe .

The total cross section data is currently being analyzed using R-matrix shape analysis to extract resonance parameters.

Table I

Resonance Parameters of ^{58}Fe (Tentative Values)

$\ell=0$ resonances		$\ell=1$ resonances	
E_0 (keV)	Γ_n (keV)	E_0 (keV)	Γ_n (eV)
10.38	0.28	37.6	6
26.057	0.004	129.8	440
43.440	5.50	143.7	10
66.90	0.80	151.8	540
93.0	8.00	159.0	46
120.5	1.44	166.0	121
178.3	2.96	195.6	30
240.5	15.3	201.5	30
265.0	10.7	206.7	63
311.0	3.6	210.3	32
		238.7	190
		247.5	80
		253.0	40
		270.9	88
		282.0	370

III(f) Neutron Capture Cross Section in ^{63}Cu and ^{65}Cu
M.S. Pandey, J.B. Garg (SUNYA), R.L. Macklin
and J. Halpern (ORNL)

This paper has been scheduled to appear in the January issue of the Physical Review.

III(g) Neutron Capture Cross Section in Manganese
J.B. Garg (SUNYA), R. Macklin and J. Halpern (ORNL)

The neutron total capture cross sections of natural manganese has been measured with high resolution between 2.6 keV and 600 keV using a 40 m flight path at the Oak Ridge Electron Linear Accelerator. These cross sections provide valuable information both to the reactor application and to the astrophysicists.

The sample of natural manganese, in the form of a pressed rectangular disc with dimensions: (width 2.56; length 2.62, thickness 0.2 cms weighing 7.765 gms) is placed in the center of a pair of γ -ray detectors. Capture γ -rays were detected by the total energy detector with an efficiency which is independent of the nature of the spectra. A calculated pulse height weighting technique gives a detector response proportional to the total energy of the capture event on the average.

Curves showing measured capture cross sections vs neutron energy (E_n) are shown in the figures 1, 2, and 3. As is evident the resolution of these measurements becomes inadequate to clearly resolve all the resonance after about 100 keV, hence the analysis of the data to extract resonance parameters is performed only up to this energy.

MN-55

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Figure 1

MN-55

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Figure 2

Figure 3

Analysis

The data were analyzed using LSFIT program which provides an estimate of the capture area A_γ for certain values of Γ_n and Γ_γ . For resonances with $\Gamma_n \approx \Gamma_\gamma$ the area is proportional to $g\Gamma_\gamma$. Hence for resonances with large neutron widths the area is calculated for a predetermined value of $g\Gamma_n$ and from this an accurate value of Γ_γ can be determined. For very weak resonances $\Gamma_n \ll \Gamma_\gamma$, Γ_γ is assumed and the program determines a value of $g\Gamma_n$.

As observed in the raw data, some resonances have very large neutron widths. The analysis of these resonances require corrections for multiple scattering and self-shielding which can be made either by incorporating Monte Carlo multiple scattering included in the LSFIT program or by another program known as TACASI. The results of the analysis of the data up to about 30 keV is given in Table I.

IV. Resonance Neutron Capture γ -rays From ^{170}Er J.B. Garg (SUNYA), R.E. Chrien, H.I. Liou, M. Stelts (Brookhaven National Lab.)

γ -rays following neutron capture in the s-wave resonances (with large Γ_n -values) up to 1 keV in ^{170}Er have been measured using the HFBR fast chopper set up. The results were useful in confirming and supplementing the knowledge of excited states in ^{171}Er as obtained from the previous thermal (n, γ), (d,p) and (d,t) experiments. The analysis of these results in the thermal (n, γ) capture is rather complicated by the small impurity of ^{167}Er isotope, which has a $(\sigma_{n\gamma})_{\text{thermal}} = 670$ barns

TABLE I

 $^{55}\text{Mn}(n,\gamma)$

E_o (keV)	$\frac{g\Gamma_n \Gamma_\gamma}{\Gamma}$ (meV)	$g\Gamma_n$ (eV)	Γ_γ (meV)	k	g
4.000	0.6 ± 0.1	$0.62 \times 10^{-3} \pm 0.68 \times 10^{-4}$	300		.5
4.302	1.9 ± 0.1	$0.192 \times 10^{-2} \pm 0.12 \times 10^{-3}$	300		.5
4.939	111.0 ± 2.8	0.466 ± 0.015	291.5 ± 12.5		.5
6.330	65.2 ± 1.7	$.116 \pm .0053$	300		.5
6.958	3.6 ± 0.5	$.365 \times 10^{-2} \pm .56 \times 10^{-3}$	300		.5
7.158	511.8 ± 7.8	117	820 ± 200	1.0	.41
8.893					
8.814	698.7 ± 22.0	216	846 ± 175	.88	.58
9.789	6.7 ± 0.5	$.702 \times 10^{-2} \pm 0.54 \times 10^{-3}$	300		.5
10.615	18.9 ± 0.7	$.0216 \pm .89 \times 10^{-3}$	300		.5
10.895	66.3 ± 1.9	.5	152.8		.5
11.629	27.3 ± 0.9	$.0333 \pm .14 \times 10^{-2}$	300		.5
12.688	125.2 ± 7.7	$0.557 \pm 0.57 \times 10^{-1}$	323 ± 34.7		.5
14.705	36.5 ± 1.0	$0.048 \pm .0017$	300		.5
14.948	81.6 ± 2.1	$0.179 \pm .01$	300		.5
16.167	105.1 ± 2.5	0.352 ± 0.28	300		.5
17.725	28.4 ± 1.6	$0.35 \times 10^{-1} \pm .24 \times 10^{-2}$	300		.5
17.802	407.3 ± 6.9	6.4	743 ± 16	.64	.58
17.990	207.2 ± 3.8	27.	467 ± 30	.64	.41
18.812	124.0 ± 3.5	$.716 \pm .12$	300		.50
19.127	5.5 ± 0.8	$0.567 \times 10^{-2} \pm .84 \times 10^{-3}$	300		.50
20.225	81.8 ± 2.4	$.18 \pm .011$	300		.50
20.488	1.9 ± 1.0	$.19 \times 10^{-2} \pm .10 \times 10^{-2}$	300		.50
20.824	73.8 ± 2.4	$.145 \pm .93 \times 10^{-2}$	300		.50
20.852	750.9 ± 23.7	500±	762 ± 270	.62	.58
22.327	26.4 ± 1.4	$.32 \times 10^{-1} \pm .2 \times 10^{-2}$	300		.5
22.649	123.1 ± 3.0	$.70 \pm 00$	298.9 ± 8.8		.5
23.658	266.7 ± 10.2	158	405 ± 125	.64	.41
24.416	126.9 ± 3.2	1.0	290.8 ± 8.4		.5
25.713	36.8 ± 2.0	$.488 \times 10^{-1} \pm .36 \times 10^{-2}$	300		.5
25.911	191.2 ± 46.2	1.65 ± 0.50	432.5 ± 135.5		.5
26.460	241.4 ± 6.4	50.	503 ± 50	.88	.5
26.983	682.2 ± 15.3	220.	739 ± 220	1.00	.5
28.255	32.2 ± 2.1	$.041 \pm .0035$	300		.5
28.741	123.8 ± 3.6	$.708 \pm .12$	300		.5

TABLE I (CONTINUED)

E_o (keV)	$\frac{g\Gamma_n \Gamma_\gamma}{\Gamma}$ (meV)	$g\Gamma_n$ (eV)	Γ_γ (meV)	k	g
30.306	207.8±4.9	3.8	432±15	1.0	.5
31.647	72.4±2.6	.113±.64x10 ⁻²	400		.5
31.725	24.9±2.0	.0285±.26x10 ⁻²	400		.5
32.309	92.4±1.9	.172±.66x10 ⁻²	400		.5
32.410	47.2±2.3	.0618±.39x10 ⁻²	400		.5

as compared to the 9 ± 2 barns for ^{170}Er . Hence the spectra obtained at resonances helps to remove this ambiguity. The high energy γ -rays and the relative intensities as observed in these measurements are listed in Table I.

TABLE I

E_Y (keV)	E_X (keV)	$E_n=97.5$ eV $\Gamma_{\gamma\lambda f} \Delta\Gamma_{\gamma\lambda f}$ (meV)	$E_n=284.$ eV $\Gamma_{\gamma\lambda f} \Delta\Gamma_{\gamma\lambda f}$ (meV)	$E_n=496.7$ eV $\Gamma_{\gamma\lambda f} \Delta\Gamma_{\gamma\lambda f}$ (meV)	$E_n=748.8$ eV $\Gamma_{\gamma\lambda f} \Delta\Gamma_{\gamma\lambda f}$ (meV)	$\langle\Gamma_{\gamma\lambda}\rangle$ (meV)
5483.2	198.8	1.10±0.25	3.42±0.62	1.2±0.7	1.4±0.9	1.78
5421.3	260.7	9.45±0.60	3.92±0.62	2.8±1.1	1.8±1.1	4.49
4973.4	708.6	0.32±0.18	<0.1	2.4±1.4	1.0±2.0	0.93
4939.2	742.8	1.60±0.20	2.97±1.68	1.9±1.4	5.1±2.2	2.89
4461.5	1220.5	6.73±0.80	3.20±1.20	0.6±0.6	5.0±1.8	3.88
4308.1	1373.9	1.39±0.17	0.1 ±0.1	<0.2	0.4±0.4	0.54
4185.1	1496.9	0.64±0.08	2.13±0.4	1.0±0.7	0.9±0.7	1.16
4167.3	1514.7	0.77±0.08	1.23±0.4	<0.2	1.1±0.7	0.84
4055.1	1626.9	1.29±0.13	1.0 ±0.5	<0.2	1.8±1.0	1.08
3719.6	1962.4	0.60±0.15	0.34±0.30	0.2±0.2	1.3±0.6	0.61
3706.4	1975.6	0.19±0.15	0.71±0.30	1.62±0.8	3.9±1.2	1.60
3644.8	2037.8	0.88±0.24	0.47±0.30	<0.20	<0.20	0.44
3628.5	2053.5	0.77±0.24	0.75±0.35	1.4±0.8	0.9±0.8	0.96
3618.9	2063.1	0.75±0.24	0.38±0.25	2.4±1.2	1.1±0.8	1.16
3605.9	2076.1	0.85±0.25	0.28±0.20	<0.2	<0.2	0.38
3592.6	2089.4	0.56±0.24	0.37±0.25	<0.2	1.2±0.8	0.58
3577.4	2104.6	3.53±0.35	1.12±0.5	0.8±0.4	0.3±0.2	1.44
3548.0	2134.0	1.98±0.36	1.34±0.45	<0.3	0.3±0.2	0.96
3526.3	2155.7	0.37±0.24	1.68±0.50	<0.3	<0.5	0.62
3482.5	2199.5	0.44±0.12	0.45±0.30	0.95±0.50	1.5±0.7	0.84
3393.2	2288.8	0.44±0.10	0.13±0.13	1.85±0.7	0.9±0.8	0.83
3299	2383.0	0.40±0.15	0.38±0.15	0.96±0.9	<0.8	0.63
3270	2412	0.50±0.15	0.98±0.72	<0.8	<0.8	0.77
3263	2419	0.53±0.15	0.4 ±0.4	<0.8	<0.8	0.61
3246	2436	0.27±0.11	1.3 ±0.7	<0.8	<0.8	0.80
3229	2453	0.22±0.12	<0.4	<0.8	<0.8	
3213	2469	0.50±0.12	0.56±0.4	0.45±0.9	<0.8	0.40
3199	2483	0.44±0.12	0.7 ±0.6	1.42±0.8	1.5±0.8	1.0
3188	2494	0.36±0.12	<0.4	1.8± 0.9	0.3±0.8	0.63
3172	2510	0.70±0.15	1.9 ±0.6	<0.9	<0.8	0.97
3163	2519	0.35±0.20	1.4 ±0.7	2.7± 0.9	0.4±0.8	1.21
3135	2547	0.36±0.20	1.2 ±0.5	1.1± 0.9	1.6±0.8	1.06
3110	2572	0.08±0.08	0.9 ±0.3	4.3± 1.0	1.1±0.8	1.60

Contract Requirement

The principal investigator has fully complied with the proposed research plans outlined in his proposal. He has spent about 30% of his time on this project during the academic year and 100% time for the two summer months. He would continue to devote 30% of his time during the remainder of the current term. A second year graduate student has spent 50% of her time for the entire year on this research. In addition a computer programmer has spent about 25% of the time during the year on this research.

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