AAEC/TM619



XA04N0900

# AUSTRALIAN ATOMIC ENERGY COMMISSION RESEARCH ESTABLISHMENT LUCAS HEIGHTS 

IHERMAL CAPTURE CROSS SECTIONS AND RESONANCE INTEGRALS FOR THE AAEC FISSION PRODUCT LIBRARY
by

## E. CLAYTON

# THERMAL CAPTURE CROSS SECTIONS AND RESONANCE INTEGRALS <br> FOR THE AAEC FISSION PRODUCT LIBRARY 

by
E. CLAYTON


#### Abstract

Thermal capture cross sections and resonance integrals, which provide a summary of the data available on the AAEC fission product library are tabulated. A brief outline is given of the methods used to adjust the calculated cross sections to recommended experimental values. Order of magnitude estimates for unknown cross sections have been included.


The following descriptors have been selected from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA-INIS-12 (INIS: Manual for Indexing) and IAEA-INIS-13 (INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

BREIT -WIGNER FORMULA; CAPTURE; CROSS SECTIONS; DATA; FISSION PRODUCTS; MILLI EV RANGE; RESONANCE; RESONANCE INTEGRALS; TABLES; THERMAL NEUTRONS
Page

1. INTRODUCTION ..... 1
2. THERMAL CAPTURE CROSS SECTIONS ..... 1
3. THE CAPTURE RESONANCE INTEGRALS ..... 2
4. CONCLUSION ..... 3
5. ACKNOWLEDGEMENTS ..... 4
6. REFERENCES ..... 4TABLE 1 - Cross Sections and Resonance Integrals (Barns)

Cross section information for many of the fission products is relatively scanty. The calculations performed here provide a short surmary, in the form of thermal capture cross sections and resonance integrals, of the data available on the AAEC fission product point and group cross section library (Bertram et al. 1971). Where experimental measurements are available the cross sections have been adjusted to give agreement. For many nuclides information is not available and the calculated cross sections from which the values reported here have been derived, may be taken only as an order of magnitude estimate providing a basis for future evaluation and theoretical work.
2. THERMAL CAPTURE CROSS SECTIONS

The calculations were made using the code GUNYA (Ferguson 1969) which assumes that neutron cross sections may be calculated from single level BreitWigner resolved and statistical resonance parameters.

If resolved parameters are given the capture cross section is given by

$$
\begin{aligned}
& \sigma_{n, \gamma}(E)=\sum_{i} \frac{\sigma_{O i} \Gamma_{\gamma i}}{\Gamma_{i}\left(1+x_{i}^{2}\right)} \\
&=4 \pi g_{J} \Gamma_{n i} / k^{2} \Gamma_{i} \\
& \sigma_{o i}=\text { radiation width for level } i \\
& \Gamma_{\gamma i}=\text { neutron width for level } i \\
& \Gamma_{n i}=\text { total width for level } i \\
& \Gamma_{i}=2\left(E_{i}-\text { E)/ } \Gamma_{i}\right. \\
& x_{i} \text { neutron energy }=0.0253 \text { eV for thermal neutrons } \\
& E=\text { the resonance energy for level } i \\
& E_{i}=\text { spin statistical factor } \\
& g_{J}=\text { neutron wave number } \\
& k
\end{aligned}
$$

For nuclides without resolved parameters the statistical parameters of Musgrove (1970) were used in GUNYA for a 'picket fence model' calculation. The theory of this method, in which the cross section is that resulting from an infinite sequence of equally spaced resonances is given by Ferguson (1969).

The accuracy of this model has been investigated extensively by Musgrove (1968) and comparisons of experimental and calculated cross sections have been made by Cook and Wall (1968).

If experimental results were available the calculated cross sections were adjusted to give agreement with these results. This adjustment is necessary as one does not have sufficient knowledge of the resonance parameters to determine the cross section accurately. For example, the effect of negative energy resonances can only be estimated because theoretical knowledge of these states is limited. For nuclides with resolved resonance parameters the adjustment is by the insertion of a negative energy resonance with parameters calculated to remove the discrepancy. Where no resolved data is available, the alignment of the picket fence has been changed by shifting the position of the first positive energy resonance. Both methods of adjustment are considered in detail by Ferguson (1969). As the 'picket fence model' is an approximate calculation the values even after adjustment will not give exact agreement with experimental values. For nuclides without an experimentally measured cross section the values calculated can only be taken as an order of magnitude estimate.
3. THE CAPTURE RESONANCE INTEGRALS

The resonance integral is defined by

$$
\begin{equation*}
I=\int_{E_{c}}^{\infty} \sigma_{n, \gamma} \text { (E) } \frac{d E}{E} \tag{2}
\end{equation*}
$$

$\mathrm{E}_{\mathrm{C}}$ is a lower limit for the integral and is normally set at 0.5 eV though this will vary with the experimental conditions.

The data prepared for the AAEC fission product library is divided into three regions, 0.001 eV to $5 \mathrm{keV}, 5 \mathrm{keV}$ to 100 keV and 100 keV to 15 MeV . (Bertram et al. 1971). This data has been used to calculate the capture resonance integral by defining $I$ as

$$
\begin{equation*}
I=\sum_{i} \sigma_{i} \Delta u_{i} \tag{3}
\end{equation*}
$$

where $\sigma_{i}$ is the group averaged cross section and $\Delta u_{i}$ is the lethargy width of the ith group. The group averaging is over a $1 / E$ flux and the sum runs from 0.5 eV to 15 MeV .

In Table 1 , values of the calculated thermal cross sections and resonance integrals have been set out, together with the values given in other compilations. The resonance integrals are in good agreement with other compilations.

For the nuclides marked * in Table 1 the calculated resonance integrals differed by more than two standard deviations from the experimental values
given by Walker (1969). These differences are due to the statistical fluctuations pointed out by Musgrove (1968). Accordingly the calculated cross sections have been adjusted to force agreement with the experimental values. For ${ }^{148} \mathrm{Pm}$ and ${ }^{148 \mathrm{~m}} \mathrm{Pm}$ the values given by Robinson (private communication on fission product data for WIMS library 1969) were used for comparison purposes.

For this adjustment the group cross section data was used and the point cross section library was subsequently modified. The procedure followed was to insert an appropriate artificial resonance to give the correct group cross sections. The resonance position was taken as

$$
\begin{equation*}
E_{r}=\left(4.09 \times 10^{6} g_{J} \bar{\Gamma} / \Delta R\right)^{2 / 3} \tag{4}
\end{equation*}
$$

where the assumption $\bar{\Gamma} \simeq \bar{\Gamma}_{\gamma}$ has been made and $\Delta R$ is the discrepancy between the experimental and calculated resonance integrals.

For the group in which this resonance fell, the capture cross section $\sigma_{i}$ was adjusted to give

$$
\begin{equation*}
\sigma_{c}=\sigma_{i}+\frac{\Delta R}{\Delta u_{i}} \tag{5}
\end{equation*}
$$

For each group a maximum permissible cross section may be defined by

$$
\begin{equation*}
\sigma_{0}=4 \pi g_{J} \frac{\bar{\Gamma}_{n} \bar{\Gamma}_{\gamma}}{\mathrm{k}^{2} \bar{\Gamma}_{\Gamma}} \tag{6}
\end{equation*}
$$

where $\mathrm{k}^{2}$ is the wave number for the group mid-energy. After the group cross section was calculated from (5) this is compared to $\sigma_{o}$ of (6). If $\sigma_{c}$ is larger than $\sigma_{0}$ the group nearest $E_{r}$ defined by (4) satisfying $\sigma_{C}<\sigma_{o}$ was chosen.

For the nuclides ${ }^{85} \mathrm{Rb},{ }^{100} \mathrm{Mo},{ }^{100} \mathrm{Ru},{ }^{102} \mathrm{Ru},{ }^{106} \mathrm{Pd},{ }^{128} \mathrm{Xe},{ }^{143} \mathrm{Pr},{ }^{150} \mathrm{Sm}$ and ${ }^{156} \mathrm{Gd}$, this procedure cannot be followed, as the calculated resonance integrals are larger than the experimental values and consequently $\Delta \mathrm{R}$ is negative. The procedure followed in these cases was the time honoured eyeball correction. The cross sections were adjusted manually; the method used being the lowering of the resonance group cross sections until agreement with the resonance integral was reached.

The alterations outlined above have been incorporated in the fission product library making it consistent with present evaluations.
4. CONCLUSION

A brief summary of the AAEC Fission Product Library has been given. The two group data given here have been made consistent with other work. The
primary data source used was the compilation of Walker (1969). Data has also been taken from England (1965), Garrison and Roos (1962) and Drake (1966). 5. ACKNOWLEDGEMENTS

I would like to thank Mrs. E.K. Rose who performed the calculations and other members of the Nuclear Data Group, AAEC, for their assistance during the course of this work.
6. REFERENCES

Bertram, W.K., Clayton, E., Cook, J.L., Ferguson, H.D., Musgrove, A.R. and Rose, E.K. (1971) - AAEC/E214.

Cook, J.L. and Wall, A.L. (1968) - Nucl. Sci. Engng. 31, 234.
Drake, M.K. (1966) - Nucleonics 24, 108.
England, T.R. (1965) - WAPD-TM/333.
Ferguson, H.D. (1969) - AAEC/TM520.
Garrison, J.D. and Roos, B.W. (1962) - Nucl. Sci. Engng. 12, 115.
Hughes, D.J. and Schwartz, R.B. (Eds.) (1958) - BNL-325. (2nd Ed.) also Goldberg, M.D., Mughabghab, S.F., Purohit, S.N., Magurno, B.A. and May, V.M. (1966) (Eds.) - BNL-325 (2nd Ed. Supplement No. 2).

Knolls Atomic Power Laboratory (1966) - 'Chart of the Nuclides'.
Mowatt, R.S. (1970) - Can. J. Phys. 48, 1933.
Musgrove, A.R. (1968) - J. Nucl. Energy. 22, 657.
Musgrove, A.R. (1970) - AAEC/E211.
Walker, W.H. (1969) - AECL-3037.

## TABLE 1

## REFERENCE CODE

B

CJP

E

G

K

Hughes and Schwartz (1958) and Goldberg et al. (1966) (recommended values)

Mowatt (1970)
England (1965)
Garrison and Roos (1962)
KAPL (1966)
Thermal capture cross section and group cross sections calculated from recommended resolved resonance parameters in BNL-325. This value of the resonance integral has been obtained by altering the cross sections by the methods given in the text.

For the nuclides ${ }^{98} \mathrm{Mo},{ }^{110} \mathrm{Pd},{ }^{113} \mathrm{Cd},{ }^{115} \mathrm{In},{ }^{115} \mathrm{Sn},{ }^{124} \mathrm{Sn},{ }^{152} \mathrm{Sm}$, ${ }^{156}$ Gd and ${ }^{162}$ Dy adjustment of the thermal capture cross sections has not been possible as the calculated cross section is larger than the experimental value (see Ferguson 1969)

TABLE 1
Capture Cross Sections and Resonance Integrals

| Nuclide | $\begin{array}{r} 0.0253 \mathrm{eV} \mathrm{Ca} \\ \text { Sect } \\ \text { Bar } \\ \text { Calculated } \end{array}$ | are Cross <br> Evaluated | Resonance Integral <br> Barns <br> Calculated |
| :---: | :---: | :---: | :---: |
| ${ }^{72} \mathrm{Zn}$ | 0.059 | - | 0.07 |
| ${ }^{72} \mathrm{Ga}$ | 4.25 | - | 25.7 |
| ${ }^{72} \mathrm{Ge}^{\dagger}$ | 0.98 | 0.98 (E) | 0.55 |
| ${ }^{73} \mathrm{Ge}$ | 13.69 | 14.0 (E) | 34.1 |
| ${ }^{74} \mathrm{Ge}$ | 0.434 | 0.45 (B) | 0.36 |
| ${ }^{76} \mathrm{Ge}^{\dagger}$ | 0.159 | 0.16 (W) | 0.18 |
| ${ }^{77} \mathrm{Ge}$ | 1.48 | - | 7.01 |
| ${ }^{75} \mathrm{As}^{+}$ | 4.30 | 4.3 (E) | 60.53 |
| ${ }^{76} \mathrm{As}$ | 60.8 | - | 216.1 |
| ${ }^{77}$ As | 12.69 | - | 68.25 |
| ${ }^{76} \mathrm{Se}^{\dagger}$ | 85.1 | 85.0 (K) | 42.08 |
| ${ }^{77} \mathrm{Se}^{\dagger}$ | 42.05 | 42.0 (E) | 28.89 |
| ${ }^{78} \mathrm{Se}^{\dagger}$ | 0.401 | 0.41 (K) | 7.09 |
| ${ }^{79} \mathrm{Se}$ | 39.28 | 40.0 (E) | 55.48 |
| ${ }^{80} \mathrm{Se}^{\dagger}$ | 0.575 | 0.58 (W) | 1.000 |
| ${ }^{81} \mathrm{Br}^{\dagger}$ | 3.00 | 3.10 (B) | 59.61 |
| ${ }^{82} \mathrm{Br}$ | 18.09 | - | 90.46 |
| ${ }^{82} \mathrm{Kr}^{\dagger}$ | 25.02 | 25.0 (W) | 191.5 |
| ${ }^{83}{ }_{\mathbf{K r}}{ }^{+}$ | 200.3 | 200.0 (W) | 217.3 |
| ${ }^{84} \mathrm{Kr}^{\dagger}$ | 0.097 | 0.1 (W) | 3.60 |
| ${ }^{8}{ }^{5} \mathrm{Kr}$ | 7.944 | 8.0 (W) | 8.16 |
| ${ }^{86} \mathrm{Kr}$ | 0.999 | 1.0 (W) | 0.48 |
| ${ }^{85} \mathrm{Rb}^{\dagger}$ | 0.421 | 0.42 (W) | 7.00 * |
| ${ }^{86} \mathrm{Rb}$ | 4.92 | - | 43.6 |
| ${ }^{87} \mathrm{Rb}^{\dagger}$ | 0.121 | 0.12 (W) | 2.47 |

TABLE 1 (Cont'd)

| Nuclide |  |  |  | Resonance Integral <br> Barns <br> Calculated |
| :---: | :---: | :---: | :---: | :---: |
| ${ }^{86} \mathrm{Sr}^{\dagger}$ | 0.999 | 1.0 |  | 3.35 |
| ${ }^{88} \mathrm{Sr}^{\dagger}$ | 0.0054 | 0.0055 |  | 0.05 |
| ${ }^{89} \mathrm{Sr}$ | 0.416 | 0.42 |  | 0.36 |
| ${ }^{90} \mathrm{Sr}$ | 0.796 | 0.8 | (W) | 0.41 |
| ${ }^{91} \mathrm{Sr}$ | 0.148 | - |  | 0.62 |
| ${ }_{89}{ }_{Y}{ }^{\dagger}$ | 1.282 | 1.28 | (B) | 0.68 |
| ${ }^{90} \mathrm{Y}$ | 3.48 | 3.5 | (E) | 2.61 |
| ${ }^{91} \mathrm{Y}$ | 1.054 | 1.07 | (E) | 1.94 |
| ${ }^{93} \mathrm{Y}$ | 0.078 | - |  | 0.99 |
| ${ }^{90} \mathrm{Zr}^{\dagger}$ | 0.099 | 0.10 | (E) | 0.085 |
| ${ }^{11} \mathrm{Zr}^{\dagger}$ | 1.579 | 1.58 | (B) | 7.81 |
| ${ }^{9} 2 \mathrm{Zr}{ }^{\dagger}$ | 0.250 | 0.25 | (B) | 0.297 |
| ${ }^{93} \mathbf{z r}{ }^{\dagger}$ | 1.996 | 2.0 | (W) | 26.0 |
| ${ }^{94} \mathrm{Zr}^{\dagger}$ | 0.075 | 0.076 | (G) | 0.21 |
| ${ }^{95} \mathrm{Zr}$ | 0.49 | - |  | 5.42 |
| ${ }^{96} \mathbf{Z r}{ }^{\dagger}$ | 0.196 | 0.2 | (W) | 5.30 |
| ${ }^{9} 7 \mathrm{Zr}$ | 0.202 | - |  | 1.55 |
| $9^{5} \mathrm{Nb}$ | 1.45 | - |  | 25.1 |
| ${ }_{9}^{5} \mathrm{MO}^{\dagger}$ | 14.52 | 14.5 | (G) | 106.3 |
| $96 \mathrm{Mo}^{+}$ | 1.196 | 1.2 | (E) | 26.11 |
| $97 \mathrm{Mo}{ }^{\dagger}$ | 2.199 | 2.2 | (G) | 15.05 |
| $9^{8} \mathrm{MO}^{+}$ | 0.144 | 0.14 | (W) | $6.698{ }^{*}$ |
| $9^{9} \mathrm{Mo}$ | 1.733 | - |  | 24.8 |
| $100 \mathrm{Mo}{ }^{+}$ | 0.225 | 0.2 | (W) | $4.00{ }^{*}$ |
| ${ }^{9} 9 \mathrm{Tc}^{\dagger}$ | 22.01 | 22.0 | (B) | 197.9 |
| 9 mm TC | 1.62 | - |  | 26.7 |
| ${ }^{100} \mathrm{Ru}$ | 5.49 | 5.8 | (W) | 11.57* |
| ${ }^{101} \mathrm{Ru}^{+}$ | 5.17 | 5.2 | (W) | 79.6 |
| ${ }^{102} \mathrm{Ru}^{+}$ | 1.285 | 1.3 | (W) | 4.266 * |
| $10{ }^{3} \mathrm{Ru}$ | 7.71 |  |  | 66.0 |
| 104 Ru | 0.438 | 0.47 | (B) | 5.43 |
| ${ }^{105} \mathrm{Ru}$ | 0.188 | 0.2 | (E) | 5.10 |
| ${ }^{106} \mathrm{Ru}$ | 0.138 | 0.146 | (B) | 1.28 |

TABLE 1 (Cont'd)


TABLE 1 (Cont'd)

| Nuclide | ```O.0253 eV Capture Cross Section Barns Calculated Evaluated``` |  |  | Resonance Integral <br> Barns Calculated |
| :---: | :---: | :---: | :---: | :---: |
| ${ }^{21}{ }^{1} \mathrm{Sb}^{\dagger}$ | 6.198 | 6.2 | (W) | 205.5 |
| ${ }^{122} \mathrm{Sb}$ | 21.5 | - |  | 159.0 |
| $123 \mathrm{Sb}^{\dagger}$ | 4.19 | 4.2 |  | 125.6 |
| 124 Sb | 6.35 | 6.5 |  | 19.25 |
| ${ }^{125} \mathrm{Sb}$ | 0.97 | - |  | 19.05 |
| ${ }^{126} 5$ b | 5.81 | - |  | 64.5 |
| 1275 | 0.92 | - |  | 14.7 |
| ${ }^{128} \mathrm{Sb}$ | 1.14 | - |  | 15.9 |
| ${ }^{122} \mathrm{Te}^{\dagger}$ | 2.794 | 2.80 |  | 46.87 |
| ${ }^{123}{ }^{3} \mathrm{Te}^{\dagger}$ | 413.3 | 410.0 |  | 5661.0 |
| 123 m Te | 42.89 | - |  | 273.1 |
| $124 \mathrm{Te}{ }^{\dagger}$ | 6.51 | 6.5 |  | 7.94 |
| $125 \mathrm{Te}{ }^{\dagger}$ | 1.558 | 1.56 |  | 17.53 |
| 125 m Te | 11.09 | - |  | 78.85 |
| ${ }^{126}{ }^{\text {T }}{ }^{\dagger}$ | 0.998 | 1.0 |  | 8.18 |
| 127 Te | 2.76 | - |  | 48.2 |
| 127 m Te | 9.40 | - |  | 103.4 |
| ${ }^{128} \mathbf{7 e}$ | 0.214 | 0.22 | (W) | 1.558 |
| ${ }^{129} \mathrm{Te}$ | 0.37 | - |  | 7.41 |
| 129 m Te | 1.111 | - |  | 20.51 |
| ${ }^{130} \mathrm{Te}^{\dagger}$ | 0.260 | 0.26 |  | 0.184 |
| ${ }^{131} \mathrm{Te}$ | 0.04 | - |  | 0.05 |
| $131 \mathrm{~m}_{\mathrm{Te}}$ | 0.11 | - |  | 0.16 |
| ${ }^{132} \mathrm{Te}$ | 0.002 | - |  | 0.007 |
| $127{ }^{\text {¢ }}{ }^{\dagger}$ | 6.191 | 6.2 | (W) | 151.8 |
| $129{ }^{1}{ }^{+}$ | 28.04 | 28.0 | (B) | 25.97 |
| ${ }^{130} \mathrm{I}$ | 16.73 | 18.0 |  | 173.3 |
| ${ }^{131} \mathrm{I}$ | 0.942 | 1.0 |  | 10.0 |
| ${ }^{133} \mathrm{I}$ | 0.003 | - |  | 0.005 |
| ${ }^{135} \mathrm{I}$ | 0.02 | - |  | 0.03 |
| ${ }^{128} \mathrm{Xe}$ | 4.214 | 4.4 | (W) | 110.0 * |
| ${ }^{130} \mathrm{Xe}$ | 4.264 | 4.4 |  | 17.29 |
| ${ }^{131} \mathrm{Xe}^{\dagger}$ | 110.1 | 110.0 |  | 789.9 |

TABLE 1 (Cont'd)

| Nuclide | 0.0253 ev Capture CrossSection <br> BarnsCalculated $\quad$ Evaluated |  |  | Resonance Integral <br> Barns Calculated |
| :---: | :---: | :---: | :---: | :---: |
| ${ }^{132} \mathrm{xe}$ | 0.462 | 0.49 | (W) | 2.46 |
| ${ }^{133}{ }^{3} \mathrm{xe}$ | 190.3 | 190.0 | (E) | 52.25 |
| ${ }^{134} \mathrm{xe}{ }^{\dagger}$ | 0.261 | 0.263 | (W) | 4.604 |
| ${ }^{135} \mathrm{xe}{ }^{\dagger}$ | $2.66 \times 10^{6}$ | 2.7 x | $10^{6}(\mathrm{~K})$ | 7262.2 |
| ${ }^{136} \mathrm{xe}$ | 0.199 | 0.2 | (W) | 0.120 |
| ${ }^{13}{ }^{3} \mathrm{Cs}{ }^{+}$ | 29.54 | 29.5 | (W) | 460.3 |
| ${ }^{134} \mathrm{Cs}$ | 133.4 | 134.0 | (E) | 87.97 |
| ${ }^{135} \mathrm{Cs}$ | 8.80 | 8.9 | (W) | 61.99* |
| ${ }^{136} \mathrm{Cs}$ | 1.90 | - |  | 15.55 |
| ${ }^{137} \mathrm{Cs}$ | 0.103 | 0.11 | (W) | 0.414 |
| ${ }^{134} \mathrm{Ba}^{+}$ | 1.945 | 2.0 | (W) | 37.80 |
| ${ }^{136} \mathrm{Ba}^{+}$ | 0.395 | 0.4 | (E) | 17.07 |
| ${ }^{137} \mathrm{Ba}^{+}$ | 5.102 | 5.1 | (E) | 4.916 |
| ${ }^{138} \mathrm{Ba}^{+}$ | 0.351 | 0.35 | (B) | 0.219 |
| ${ }^{140} \mathrm{Ba}$ | 1.586 | 1.6 | (W) | 13.59* |
| ${ }^{139} \mathrm{La}^{+}$ | 9.01 | 9.0 | (W) | 15.63 |
| ${ }^{140} \mathrm{La}$ | 2.51 | 2.7 | (W) | 70.68 |
| ${ }^{140} \mathrm{Ce}$ | 0.589 | 0.6 | (B) | 0.507 |
| ${ }^{141} \mathrm{Ce}$ | 28.81 | 29.0 | (B) | 28.73 |
| $14^{2} \mathrm{Ce}$ | 0.858 | 0.9 | (W) | 1.514 |
| $14^{3} \mathrm{Ce}$ | 5.60 | 6.0 | (E) | 42.66 |
| 144 Ce | 0.936 | 1.0 | (B) | 2.602 |
| ${ }^{141} \mathrm{Pr}{ }^{+}$ | 11.02 | 11.0 | (W) | 17.52 |
| ${ }^{142} \mathrm{Pr}$ | 17.39 | 18.0 | (E) | 143.8 |
| ${ }^{143} \mathrm{Pr}$ | 97.87 | 100.0 | (W) | 190.0* |
| $14^{5} \mathrm{Pr}$ | 18.44 | - |  | 445.1 |
| $14^{2} \mathrm{Nd}$ | 18.64 | 18.7 | (W) | 8.84 |
| ${ }^{14}{ }^{3} \mathrm{Na}^{\dagger}$ | 325.6 | 325.0 | (w) | 64.47 |
| $14^{4} \mathrm{Nd}$ | 3.39 | 3.6 | (W) | 7.64 |
| ${ }^{14} 5^{\text {Nd }}{ }^{\dagger}$ | 44.96 | 45.0 | (w) | 271.3 |
| ${ }^{146} \mathrm{Nd}$ | 1.32 | 1.4 | (W) | 2.36 |
| $147^{7} \mathrm{Nd}$ | 49.32 | - |  | 649.8 |
| ${ }^{148} \mathrm{Nd}$ | 2.355 | 2.5 | (W) | 14.01 * |
| ${ }^{150} \mathrm{Nd}$ | 1.13 | 1.2 | (W) | 2.59 |

TABLE 1 (Cont'd)

| Nuclide | 0.0253 eV C Secti Barn Calculated | pture Cross <br> Evaluated | Resonance Integra] <br> Barns Calculated |
| :---: | :---: | :---: | :---: |
| $1{ }^{47} \mathrm{Pm}{ }^{\dagger}$ | 169.9 | 170.0 (W) | $2.178 \times 10^{3}$ |
| ${ }^{148}{ }^{8} \mathrm{Pm}$ | $2.99 \times 10^{3}$ | $3.0 \times 10^{3}$ (W) | $4.398 \times 10^{4}$ |
| $148 \mathrm{~m}_{\mathrm{Pm}}$ | $2.399 \times 10^{4}$ | $2.4 \times 10^{4}$ | $3.199 \times 10^{4}$ |
| $14^{9} \mathrm{Pm}$ | $1.391 \times 10^{3}$ | $1.4 \times 10^{3}$ (W) | 927.7 |
| ${ }^{151} \mathrm{Pm}$ | 173.0 | - | $1.21 \times 10^{3}$ |
| $147{ }^{\text {Sm }}{ }^{\dagger}$ | 54.98 | 58.0 (W) | 566.2 |
| ${ }^{148} \mathrm{Sm}$ | 4.43 | 4.7 (फ) | 18.51 |
| ${ }^{149} \mathrm{Sm}^{+}$ | $4.205 \times 10^{4}$ | $4.2 \times 10^{4}$ (W) | $3.705 \times 10^{3}$ |
| ${ }^{150} \mathrm{Sm}^{+}$ | 101.7 | 102.0 (B) | 257.1* |
| ${ }^{151} \mathrm{Sm}$ | $1.505 \times 10^{4}$ | $1.5 \times 10^{4}(E)$ | $2.178 \times 10^{3}$ |
| ${ }^{152} \mathrm{Sm}$ | 211.1 | 206.0 (W) | $3.24 \times 10^{3}$ |
| ${ }^{153} \mathrm{Sm}$ | 334.5 | - | $1.137 \times 10^{3}$ |
| 154 Sm | 4.71 | 5.0 (W) | 38.21 |
| ${ }^{156} \mathrm{Sm}$ | 17.16 | - | 331.9 |
| ${ }^{153}{ }^{3} u^{\dagger}$ | 450.5 | 450.0 (W) | $1.279 \times 10^{3}$ |
| ${ }^{154} \mathrm{Eu}$ | $1.379 \times 10^{3}$ | $1.5 \times 10^{3}$ (E) | $1.24 \times 10^{3}$ |
| $15^{5} \mathrm{Eu}$ | $4.006 \times 10^{3}$ | $4.04 \times 10^{3}$ (CJP) | $1.223 \times 10^{3}$ |
| ${ }^{156} \mathrm{Eu}$ | 481.7 | - | $1.258 \times 10^{3}$ |
| 157 Eu | 191.0 | - | 826.4 |
| $155 \mathrm{Gd}^{\dagger}$ | $6.105 \times 10^{4}$ | $6.1 \times 10^{4}$ (B) | $1.563 \times 10^{3}$ |
| $156 \mathrm{Gd}^{\dagger}$ | 2.107 | 1.4 (W) | 90.0 * |
| ${ }^{157} \mathrm{Gd}^{\dagger}$ | $2.64 \times 10^{5}$ | $2.64 \times 10^{5}(\mathrm{~W})$ | $3.41 \times 10^{3}$ |
| $158 \mathrm{Gd}{ }^{\dagger}$ | 2.67 | 2.8 (W) | 97.9 |
| 159 Gd | 16.3 | - | 186.7 |
| 160 Gd | 0.723 | 0.768 (B) | 1.445 |
| $159 \mathrm{~Tb}^{+}$ | 22.02 | 22.0 (W) | 376.4 |
| ${ }^{160} \mathrm{~Tb}$ | 494.0 | 525.0 (E) | $1.14 \times 10^{3}$ |
| ${ }^{161} \mathrm{~Tb}$ | 96.6 | - | 655.9 |
| ${ }^{160} \mathrm{Dy}$ | 57.03 | 60.0 (W) | $1.16 \times 10^{3 *}$ |
| ${ }^{161} \mathrm{Dy}^{\dagger}$ | 601.3 | 600.0 (B) | $1.67 \times 10^{3 *}$ |
| ${ }^{162} \mathrm{Dy}^{\dagger}$ | 205.3 | 190.0 (W) | $2.55 \times 10^{3}$ |
| ${ }^{163 \mathrm{Dy}}{ }^{\dagger}$ | 130.1 | 130.0 (W) | $1.65 \times 10^{3}$ |
| ${ }^{164} \mathrm{Dy}{ }^{\dagger}$ | $2.70 \times 10^{3}$ | $2.70 \times 10^{3}(\mathrm{~W})$ | 795.0 |
| ${ }^{165} \mathrm{Ho}^{+}$ | 63.09 | 63.0 (W) | 678.0 |

