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# EXTRAPOLATED NEUTRON ACTIVATION CROSS SECTIONS FOR DOSIMETRY TO 44 MeV

by

Lawrence R. Greenwood




## FUSION POWER PROGRAM

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

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September 1978



Results reported in the FPP series of memoranda frequently are preliminary and subject to revision.

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## ABSTRACT

Thirty-one neutron activation cross sections have been extrapolated to 44 MeV for dosimetry applications at high-energy, accelerator-based neutron sources. All cross sections have undergone integral testing in Be(d,n) fields at $E_d$ = 14, 16, and 40 MeV. The integral activities for most of the reactions agree within 10% with calculations based on time-of-flight measurements of the flux spectra. Tests show that at least 25 of the cross sections can be used with the SAND II code to unfold neutron spectra with differential errors of 10-30% in the neutron energy range from 2 to 30 MeV.

## I. Introduction

High-energy, accelerator-based neutron sources are now being used routinely to investigate damage in fusion materials. These sources[1,2] produce a broad neutron spectrum centered around $E_n$ = 14 MeV by stopping a deuteron beam of $E_d$ = 30-40 MeV in a thick beryllium or lithium target. To maximize the neutron fluence, the irradiations are generally conducted close to the target (3-5 mm), where flux and spectral gradients are severe. Accurate, positional neutron dosimetry is thus a necessity if damage rates are to be characterized in terms of damage parameters (DPA, PKA, and gas generation rates) for correlation with measurements in other environments.

Unfortunately, neutron activation cross sections required for dosimetry are very poorly known above 14 MeV, even though the ENDF/B-IV files[3] extend to 20 MeV. However, a few important reactions have been measured to 28 MeV[4,5] and some calculations[6] are available.

Of course, the best approach from a scientific viewpoint would be to measure and/or calculate the required cross sections at high neutron energies. However, time and funding limitations of the fusion materials program require that some effort be made now to extrapolate existing data to higher energies. Integral testing can then be performed in a variety of neutron environments to obtain a reliable set of data for routine dosimetry applications.

Integral testing of the present cross sections shows that most of them are integrally accurate to within 10%.[7,8] When the present cross sections are used with the SAND-II[9] spectral unfolding code, differential spectra may be unfolded with 10-30% accuracy over the neutron energy range from 2 to 30 MeV. Since 90% of the neutron damage in materials in a Be(d,n) spectrum ($E_d$ = 40 MeV) occurs in this neutron energy range, the present level of cross-section accuracy may be barely adequate for the fusion materials program.

It must be emphasized that the cross sections presented in this report are intended for a very specialized integral application and that differential values have very large uncertainties, especially above 30 MeV, where the integral tests are not very sensitive.

## II. Cross-Section Extrapolations

Most neutron activation cross sections currently in use for reactor dosimetry are taken from the ENDF/B-IV Dosimetry File.[10] All of the cross sections for energies below 20 MeV used in the present work come from the ENDF/B-IV files, with the following exceptions. The $^{54}Fe(n,\alpha)\ ^{51}Cr$, $^{45}Sc(n,\alpha)\ ^{42}K$, and $^{238}U(n,2n)^{237}U$ cross sections were taken from the curves in BNL-325.[11] The (n,p) reactions on $^{46}Ti$, $^{47}Ti$, $^{48}Ti$, and $^{59}Co$ as well as the (n,n') reaction on $^{115}In$ came from recent compilations by D. L. Smith, et al (ANL).[12]

Some important reactions have been reported recently by Bayhurst, et al., (LASL)[4] in the 16-28 MeV energy range, as listed in Table I. Some of their data for rare earth materials are not included here since the materials are expensive and probably not suitable for routine dosimetry applications, especially since organic binders may distort the low energy neutron spectrum.[7,8] The $^{58}Ni(n,2n)\ ^{57}Ni$ cross section in ENDF/B-IV[3] is about 40% lower than that reported by LASL.[4] A cross section was thus adopted which smoothly connects the ENDF/B-IV data below 14 MeV with the LASL data above 16 MeV. However, the resulting $^{58}Ni(n,2n)^{57}Ni$ cross section appears to be in error, as will be discussed later.

Calculations have been performed for the $^{59}Co(n,xn)$ reactions by C. Y. Fu[6] (ORNL) up to 30 MeV and the calculations have been normalized to some measurements by Veeser[5] below 24 MeV.

S. Pearlstein (BNL) has developed the THRESH code[13] to predict cross sections from elementary nuclear theory, with parameters derived from the systematics of existing data. This code has been used to guide the extrapolation of the LASL data[4] to threshold and to guide all extrapolations up to 44 MeV. The extrapolated cross sections are listed and plotted as a function of energy in Appendix A.

## III. Competing Reactions in Multi-Isotope Elements

All multi-isotope elements may produce a given nuclide by several different neutron activation reactions. In principle, the total, elemental production cross section should be used in these cases, as is done for $^{89}Zr$, which can be produced by the $^{90}Zr(n,2n)$, $^{91}Zr(n,3n)$, and $^{92}Zr(n,4n)$ reactions.

TABLE I. Cross-Section Reference List for $E_n$ > 20 MeV (reactions not listed have no known measurements)

| Reaction | Reference | Energy Limit, MeV | Comments |
|---|---|---|---|
| $^{27}Al(n,\alpha)^{24}Na$ | 4 | 26 | |
| $^{44}Sc(n,2n)^{44m}Sc$ | 4 | 28 | |
| $Ti(n,x)^{46}Sc$ | 12, 13 | -- | Calculation for $^{47,48}Ti$ |
| $Ti(n,x)^{47}Sc$ | 12, 13 | -- | Calculation for $^{48}Ti$ |
| $Fe(n,x)^{54}Mn$ | 13 | -- | Calculation for $^{56}Fe$ |
| $^{59}Co(n,2n)^{58}Co$ | 5,6 | 30 | Data to 24 MeV; calculation to 30 MeV |
| $^{59}Co(n,3n)^{57}Co$ | 5,6 | 30 | Data to 24 MeV; calculation to 30 MeV |
| $^{58}Ni(n,2n)^{57}Ni$ | 4 | 28 | Data ~40% higher than ENDF/B-IV (ref. 3) |
| $Zr(n,xn)^{89}Zr$ | 4 | 28 | |
| $^{169}Tm(n,2n)^{168}Tm$ | 4 | 28 | |
| $^{169}Tm(n,3n)^{167}Tm$ | 4 | 28 | |
| $^{197}Au(n,2n)^{196}Au$ | 4 | 28 | |
| $^{197}Au(n,3n)^{195}Au$ | 4 | 28 | |
| $^{197}Au(n,4n)^{194}Au$ | 4 | 28 | |
| $^{235}U(n,fission)$ | 14 | 36 | |
| $^{238}U(n,fission)$ | 14 | 36 | |

However, in other cases the contributions from the higher energy reactions are usually not known. Such contributions are very large for the commonly used reactions $^{54}Fe(n,p)^{54}Mn$, $^{46}Ti(n,p)^{46}Sc$, and $^{47}Ti(n,p)^{47}Sc$. In all three cases, higher mass isotopes are more abundant than the isotope which solely contributes at lower energies. In contrast, the $^{58}Ni(n,p)^{58}Co$ and $^{58}Ni(n,2n)^{57}Ni$ reactions have only weak competition from $^{60}Ni$ since $^{58}Ni$ is more abundant than $^{60}Ni$.

The THRESH code[13] was used to calculate the cross sections for the competing reactions $^{47}Ti(n,d + np)^{46}Sc$, $^{48}Ti(n,t + nd + 2np)^{46}Sc$, $^{48}Ti(n,d + np)^{47}Sc$, and $^{56}Fe(n,t + nd + 2np)^{54}Mn$. The respective cross sections were then combined with the values for the $^{46}Ti(n,p)^{46}Sc$, $^{47}Ti(n,p)^{47}Sc$, and $^{54}Fe(n,p)^{54}Mn$ reactions to create total production cross sections. The calculations appear to be too high in the threshold regions, but about right at higher energies, as will be discussed in Section IV.

## IV. Integral Testing

The extrapolated cross-section values (Appendix A) have undergone integral testing in three distinct neutron fields. The results are summarized in Table II. In all cases, neutrons were produced by stopping deuterons in thick beryllium targets. The flux and spectrum were measured using time-of-flight (TOF) spectrometry. Foils were then irradiated in a well-defined geometry where the flux-spectrum is known from the TOF results.

The first test was conducted at the Argonne Tandem Van de Graaff Accelerator at $E_d$ = 14 and 16 MeV.[7] With these deuteron energies, neutrons cannot be produced above 22 MeV; therefore, no cross-section extrapolations were required. The second test was conducted at the Oak Ridge Isochronous Cyclotron at $E_d$ = 40 MeV; at this deuteron energy, the neutron spectrum extends to about 44 MeV.

Table II lists the results of the integral tests as well as the energy ranges for 90% sensitivity for each reaction. As can be seen, the results are quite good for most of the reactions, with average standard deviations of 10-15%.

The following comments and conclusions can be made about the integral tests listed in Table II.

TABLE II. Integral Cross Section Tests. Cross-section errors (%) and the 90% energy sensitivity limits[a] are listed. Relative errors are ±10%, except as noted.

| Reaction | $E_d$ = 14-16 MeV | | $E_d$ = 40 MeV | |
|---|---|---|---|---|
| | 90% limits[a] (MeV) | Error (%) | 90% limits[a] (MeV) | Error (%) |
| $^{45}Sc(n,\gamma)^{46}Sc$[b] | 0.15-11.5 | +3 | $7.6^{-3}$-25.0 | -7 |
| $^{59}Co(n,\gamma)^{60}Co$[b] | 0.21-10.7 | -3 ±15 | $1.6^{-4}$-22.7 | -5 ±10 |
| $^{197}Au(n,\gamma)^{198}Au$[b] | 0.31-9.7 | -3 | $2.5^{-4}$-19.5 | +0 |
| $^{238}U(n,\gamma)^{239}Np$[b] | 0.19-5.7 | -4 | $4.3^{-4}$-4.2 | +8 |
| $^{235}U(n,f)$ | 0.8-13.1 | +7 | 0.6-29.7 | +1 |
| $^{238}U(n,f)$ | 2.0-13.6 | +4 | 5.0-30.8 | -1 |
| $^{115}In(n,n')^{115m}In$ | 1.6-10.9 | -1 | 1.8-23.1 | -3 |
| $Ti(n,p)^{46}Sc$ | 5.1-13.8 | -7 | 9.0-33.0 | -89(+14)[c] |
| $Ti(n,p)^{47}Sc$ | 3.1-13.0 | +2(+12)[c] | 12.0-33.0 | -798(+15)[c] |
| $^{48}Ti(n,p)^{48}Sc$ | 7.1-15.6 | -7 | 9.9-26.6 | +2 |
| $Fe(n,p)^{54}Mn$ | 3.7-12.5 | +6 | 6.0-33.0 | -88(+1)[c] |
| $^{56}Fe(n,p)^{56}Mn$ | 6.4-14.5 | -2 | 8.6-23.5 | -4 |
| $^{59}Co(n,p)^{59}Fe$ | 5.1-14.9 | -8 | 8.1-24.2 | +8 ±15 |
| $^{58}Ni(n,p)^{58}Co$ | 3.5-12.4 | +0 | 4.4-23.4 | +9 |
| $^{60}Ni(n,p)^{60}Co$ | 6.2-13.7 | +14 | 7.9-23.0 | +3 ±6 |
| $^{27}Al(n,\alpha)^{24}Na$ | 7.4-14.6 | +3 | 9.0-21.5 | +0 |
| $^{45}Sc(n,\alpha)^{42}K$ | 6.0-15.5 | -15 | — | — |
| $^{54}Fe(n,\alpha)^{51}Cr$ | 6.4-15.3 | -4 | 9.5-28.0 | -36 |
| $^{59}Co(n,\alpha)^{56}Mn$ | 7.1-15.0 | -4 | 9.3-24.4 | -4 |
| $^{45}Sc(n,2n)^{44m}Sc$ | 12.6-19.0 | -14 | 13.9-27.5 | -1 |
| $^{58}Ni(n,2n)^{57}Ni$ | 13.3-19.4 | +10(-11)[d] | 14.8-28.2 | +14(-30)[d] |
| $^{59}Co(n,2n)^{58}Co$ | 11.5-18.4 | +1 | 12.8-26.6 | -9 |
| $^{59}Co(n,3n)^{57}Co$ | — | — | 22.0-36.0 | -28 ±15 |
| $Zr(n,2n)^{89}Zr$ | 12.6-19.2 | +13 | 14.1-28.1 | -4 |
| $^{93}Nb(n,2n)^{92m}Nb$ | 9.9-16.8 | +7 | 11.2-22.0 | +6 |
| $^{169}Tm(n,2n)^{168}Tm$ | — | — | 10.4-23.3 | +7 |
| $^{169}Tm(n,3n)^{167}Tm$ | — | — | 17.9-30.6 | -9 |
| $^{197}Au(n,2n)^{196}Au$ | 9.3-16.2 | -9 | 10.7-23.5 | -1 |
| $^{197}Au(n,3n)^{195}Au$ | — | — | 18.0-29.4 | +2 ±6 |
| $^{197}Au(n,4n)^{194}Au$ | — | — | 27.2-39.8 | +1 ±11 |
| $^{238}U(n,2n)^{237}U$ | 7.2-13.0 | +4 | 7.7-16.4 | -11 |

[a] 90% of the activation integral is contained in this energy range. The notation $7.6^{-3}$ means $7.6 \times 10^{-3}$.

[b] $(n,\gamma)$ ratios have a ±15% uncertainty since no TOF data exists below 0.8-2 MeV.

[c] The value in parentheses includes the THRESH calculations for higher mass isotopes.

[d] The value in parentheses is for the ENDF/B-IV cross section.

(1) The $(n,\gamma)$ calculations are uncertain by 10-15% since the TOF data do not extend below 0.8-2.0 MeV and were extrapolated to best fit the data.

(2) The multi-isotope THRESH calculations on iron and titanium are unimportant at $E_d$ = 14-16 MeV, but they are essential at $E_d$ = 40 MeV and appear to be accurate.

(3) The $^{58}Ni(n,2n)^{57}Ni$ cross section is uncertain in the 16-20 MeV region. The LASL data[4] and ENDF/B-IV[3] data disagree by about 40%.

(4) The $^{45}Sc(n,\alpha)^{42}K$ and $^{54}Fe(n,\alpha)^{51}Cr$ cross sections have significant errors, especially at higher energies. This is not surprising since the values were taken from the suggested curves in BNL-325.[11]

(5) The cross sections for $^{45}Sc(n,2n)^{44m}Sc$, $Zr(n,2n)^{89}Zr$, and $^{197}Au(n,2n)^{196}Au$ appear to have 10-15% errors in the threshold region, although the higher energy tests are more accurate.

(6) The $^{59}Co(n,3n)^{57}Co$ calculations appear to be too low; however, the accuracy of this test is somewhat worse than the others due to our relatively poor counting statistics ($\sim$ 15%).

## V. Conclusions

The results of the integral tests presented in Table II indicate that most of the extrapolated cross sections are reasonably accurate ($\sim$ 10-15% in an integral sense) and that they will provide the level of accuracy (10-30% for 2-30 MeV neutron energies) required for flux-spectral dosimetry during fusion materials irradiations. However, the agreement indicated in Table II does not mean that the differential cross sections are accurate, especially above 30 MeV. First of all, it must be emphasized that the tests are integral tests and that much larger differential errors are implied. Secondly, many of our extrapolations have not really been tested because they fall outside the 90% sensitivity limits. For example, at $E_d$ = 40 MeV less than 5% of the $^{58}Co$ activity from the $^{58}Ni(n,p)$ reaction is produced above $E_n$ = 23 MeV. Hence, a very large error in the cross section above 30 MeV would make little, if any, difference in the calculated integral. Furthermore, many reactions are being tested in the neutron energy ranges where they are

the best known, since the average neutron energy in the $E_d$ = 40 MeV test is about 14 MeV. Finally, only two of the reactions are sensitive to the neutron energy region above 30 MeV, where the TOF data have the largest uncertainties.

Nevertheless, the extrapolated data file should be adequate for the purpose or which it was intended, namely, dosimetry for fusion materials irradiations. The present data can be used with the SAND-II code to unfold neutron spectra with an expected accuracy of 10-30% in the 2-30 MeV region where 90% of materials damage occurs in an $E_d$ = 40 MeV, Be(d,n) spectrum. Furthermore, the desired damage parameters (DPA, PKA, and gas generation rates) will have much smaller errors (10-15%) than the differential flux values since they are integral quantities.

Of course, it is hoped that the data base will continue to improve using both measurements and calculations to reduce the errors. We plan to continue integral testing at other energies, which can help to pinpoint regions where cross sections have the largest uncertainties. The most pressing needs for data are at neutron energies above 28 MeV, where there are virtually no measurements. A relatively small number of measurements coupled with calculations would help enormously in reducing the uncertainties at high energies.

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## APPENDIX A

### Extrapolated Cross Section File

The thirty-one cross sections used in this work are listed in this appendix. A 100-energy-group structure extending to 44 MeV is used. Only a few low energy groups are listed because values for these can be directly obtained from ENDF/B-IV.[3] The cross sections are group averaged, i.e., they rperesent the average value between the energy limits indicated. This format is directly applicable for use with the SAND-II spectral unfolding code.[9] Differential values can be approximated at the mid-energy of a given group. Also included are plots of all of the cross sections listed in the cross reference.

The abbreviated column headings used in the cross-section tables are explained in the following cross reference. A few total cross sections are listed; the values are listed assuming the abundance of the isotope that solely contributes at low neutron energies. This method makes is easier to determine the contributions from higher mass isotopes calculated with the THRESH code.[13] For example, the total cross section for the production of $^{54}$Mn from natural iron can be obtained by multiplying the values listed in the tables under FE254P by 0.058, the abundance of $^{54}$Fe.

## CROSS REFERENCE FOR APPENDIX A

| Short Name | Reaction | Cross Reference Table | Cross Reference Figure | Comments |
|---|---|---|---|---|
| SC45G | $^{45}Sc(n,\gamma)^{46}Sc$ | A-1 | 1 | |
| CO59G | $^{59}Co(n,\gamma)^{60}Co$ | A-1 | 1 | |
| AU197G | $^{197}Au(n,\gamma)^{198}Au$ | A-1 | 1 | |
| U238G | $^{238}U(n,\gamma)^{239}U \rightarrow ^{239}Np$ | A-1 | 1 | |
| U235F | $^{235}U$(n,fission) | A-1 | 7 | |
| FE54P | $^{54}Fe(n,p)^{54}Mn$ | A-2 | 2 | |
| FE254P | $Fe(n,x)^{54}Mn$ | A-2 | 2 | × 0.058 for total |
| FE56P | $^{56}Fe(n,p)^{56}Mn$ | A-2 | 6 | |
| NI58P | $^{58}Ni(n,p)^{58}Co$ | A-2 | 2 | |
| NI60P | $^{60}Ni(n,p)^{60}Co$ | A-2 | 6 | |
| TI46P | $^{46}Ti(n,p)^{46}Sc$ | A-3 | 3 | |
| TI246P | $Ti(n,x)^{46}Sc$ | A-3 | 3 | × 0.0825 for total |
| TI47P | $^{47}Ti(n,p)^{47}Sc$ | A-3 | 3 | |
| TI247P | $Ti(n,x)^{47}Sc$ | A-3 | 3 | × 0.0745 for total |
| TI48P | $^{48}Ti(n,p)^{48}Sc$ | A-3 | 3 | |
| AL27A | $^{27}Al(n,\alpha)^{24}Na$ | A-4 | 4 | |
| SC45A | $^{45}Sc(n,\alpha)^{42}K$ | A-4 | 4 | |
| FE54A | $^{54}Fe(n,\alpha)^{51}Cr$ | A-4 | 4 | |
| CO59A | $^{59}Co(n,\alpha)^{56}Mn$ | A-4 | 4 | |
| CO59P | $^{59}Co(n,p)^{59}Fe$ | A-4 | 6 | |
| SC452 | $^{45}Sc(n,2n)^{44m}Sc$ | A-5 | 5 | |
| NI582 | $^{58}Ni(n,2n)^{57}Ni$ | A-5 | 6 | ENDF/B-IV (Refs. 3,10) |
| NI582B | $^{58}Ni(n,2n)^{57}Ni$ | A-5 | 6 | LASL (Ref. 4) |
| CO592 | $^{59}Co(n,2n)^{58}Co$ | A-5 | 5 | |
| CO593 | $^{59}Co(n,3n)^{57}Co$ | A-5 | 5 | |
| ZR2902 | $Zr(n,x)^{89}Zr$ | A-6 | 8 | × 0.515 for total |
| NB932 | $^{93}Nb(n,2n)^{92m}Nb$ | A-6 | 5 | |
| U2382 | $^{238}U(n,2n)^{237}U$ | A-6 | 8 | |
| IN115N | $^{115}In(n,n')^{115m}In$ | A-6 | 7 | |
| U238F | $^{238}U$(n,fission) | A-6 | 7 | |
| TM1692 | $^{169}Tm(n,2n)^{168}Tm$ | A-7 | 8 | |
| TM1693 | $^{169}Tm(n,3n)^{167}Tm$ | A-7 | 8 | |
| AU1972 | $^{197}Au(n,2n)^{196}Au$ | A-7 | 9 | |
| AU1973 | $^{197}Au(n,3n)^{195}Au$ | A-7 | 9 | |
| AU1974 | $^{197}Au(n,4n)^{194}Au$ | A-7 | 9 | |

TABLE A-1

| ENERGY | GROUP AVERAGED CROSS SECTION, BARNS | | | | |
|---|---|---|---|---|---|
| (MEV) | SC45G | CO59G | AU197G | U238G | U235F |
| 1.000E-09 | 6.374E+01 | 8.999E+01 | 2.370E+02 | 6.502E+00 | 1.485E+03 |
| 1.000E-08 | 2.015E+01 | 2.847E+01 | 7.619E+01 | 2.071E+00 | 4.269E+02 |
| 1.000E-07 | 6.361E+00 | 9.044E+00 | 2.887E+01 | 7.124E-01 | 1.059E+02 |
| 1.000E-06 | 1.956E+00 | 3.010E+00 | 7.855E+02 | 9.748E+01 | 4.185E+01 |
| 1.000E-05 | 6.845E-01 | 1.734E+00 | 7.237E-01 | 7.249E+01 | 4.639E+01 |
| 5.000E-05 | 3.102E-01 | 3.548E+00 | 4.623E+01 | 1.733E+01 | 3.208E+01 |
| 1.000E-04 | 1.764E-01 | 1.915E+01 | 1.465E+01 | 8.102E+00 | 1.719E+01 |
| 5.000E-04 | 1.738E-02 | 2.418E-02 | 1.228E+01 | 3.519E+00 | 1.087E+01 |
| 1.000E-03 | 4.607E-02 | 1.805E-02 | 5.278E+00 | 1.849E+00 | 7.425E+00 |
| 2.000E-03 | 1.029E-01 | 7.636E-02 | 3.053E+00 | 1.346E+00 | 5.090E+00 |
| 4.000E-03 | 8.716E-02 | 2.713E-01 | 2.049E+00 | 9.859E-01 | 4.082E+00 |
| 6.000E-03 | 3.773E-01 | 5.264E-02 | 1.634E+00 | 8.337E-01 | 3.311E+00 |
| 8.000E-03 | 1.993E-01 | 1.090E-01 | 1.364E+00 | 7.300E-01 | 3.074E+00 |
| 1.000E-02 | 6.498E-02 | 4.063E-02 | 8.435E-01 | 5.745E-01 | 2.415E+00 |
| 2.500E-02 | 4.899E-02 | 2.281E-02 | 5.291E-01 | 4.042E-01 | 1.965E+00 |
| 5.000E-02 | 2.272E-02 | 1.079E-02 | 3.999E-01 | 2.838E-01 | 1.815E+00 |
| 7.500E-02 | 2.111E-02 | 1.474E-02 | 3.307E-01 | 2.037E-01 | 1.632E+00 |
| 1.000E-01 | 2.352E-02 | 2.154E-02 | 3.050E-01 | 1.804E-01 | 1.548E+00 |
| 1.250E-01 | 1.938E-02 | 1.971E-02 | 2.912E-01 | 1.649E-01 | 1.490E+00 |
| 1.500E-01 | 1.818E-02 | 1.778E-02 | 2.768E-01 | 1.530E-01 | 1.432E+00 |
| 1.750E-01 | 1.726E-02 | 1.598E-02 | 2.640E-01 | 1.458E-01 | 1.376E+00 |
| 2.000E-01 | 1.636E-02 | 1.468E-02 | 2.494E-01 | 1.372E-01 | 1.332E+00 |
| 2.250E-01 | 1.568E-02 | 1.404E-02 | 2.362E-01 | 1.276E-01 | 1.312E+00 |
| 2.500E-01 | 1.510E-02 | 1.342E-02 | 2.242E-01 | 1.220E-01 | 1.302E+00 |
| 2.750E-01 | 1.456E-02 | 1.278E-02 | 2.132E-01 | 1.174E-01 | 1.292E+00 |
| 3.000E-01 | 1.378E-02 | 1.204E-02 | 1.954E-01 | 1.120E-01 | 1.246E+00 |
| 3.500E-01 | 1.294E-02 | 1.120E-02 | 1.746E-01 | 1.088E-01 | 1.222E+00 |
| 4.000E-01 | 1.210E-02 | 1.030E-02 | 1.585E-01 | 1.075E-01 | 1.205E+00 |
| 4.500E-01 | 1.140E-02 | 9.440E-03 | 1.445E-01 | 1.075E-01 | 1.185E+00 |
| 5.000E-01 | 1.045E-02 | 8.495E-03 | 1.295E-01 | 1.105E-01 | 1.160E+00 |
| 6.000E-01 | 9.290E-03 | 8.003E-03 | 1.112E-01 | 1.154E-01 | 1.142E+00 |
| 7.000E-01 | 8.342E-03 | 8.246E-03 | 1.000E-01 | 1.210E-01 | 1.130E+00 |
| 8.000E-01 | 7.522E-03 | 8.446E-03 | 9.094E-02 | 1.220E-01 | 1.154E+00 |
| 9.000E-01 | 6.850E-03 | 8.290E-03 | 8.694E-02 | 1.208E-01 | 1.194E+00 |
| 1.000E+00 | 5.598E-03 | 7.868E-03 | 8.118E-02 | 1.096E-01 | 1.248E+00 |
| 1.250E+00 | 4.366E-03 | 6.920E-03 | 7.578E-02 | 9.004E-02 | 1.252E+00 |
| 1.500E+00 | 3.488E-03 | 5.478E-03 | 6.884E-02 | 7.052E-02 | 1.256E+00 |
| 1.750E+00 | 2.924E-03 | 4.422E-03 | 6.136E-02 | 5.680E-02 | 1.268E+00 |
| 2.000E+00 | 2.472E-03 | 3.818E-03 | 5.286E-02 | 4.572E-02 | 1.280E+00 |
| 2.250E+00 | 2.172E-03 | 3.482E-03 | 4.506E-02 | 3.792E-02 | 1.280E+00 |
| 2.500E+00 | 1.966E-03 | 3.230E-03 | 3.734E-02 | 3.126E-02 | 1.264E+00 |
| 2.750E+00 | 1.834E-03 | 3.102E-03 | 3.142E-02 | 2.626E-02 | 1.248E+00 |
| 3.000E+00 | 1.696E-03 | 2.900E-03 | 2.414E-02 | 2.048E-02 | 1.210E+00 |
| 3.500E+00 | 1.592E-03 | 2.634E-03 | 1.910E-02 | 1.524E-02 | 1.166E+00 |
| 4.000E+00 | 1.542E-03 | 2.438E-03 | 1.702E-02 | 1.178E-02 | 1.134E+00 |
| 4.500E+00 | 1.512E-03 | 2.312E-03 | 1.582E-02 | 9.342E-03 | 1.106E+00 |
| 5.000E+00 | 1.494E-03 | 2.188E-03 | 1.508E-02 | 7.584E-03 | 1.078E+00 |
| 5.500E+00 | 1.486E-03 | 2.062E-03 | 1.450E-02 | 6.282E-03 | 1.084E+00 |
| 6.000E+00 | 1.480E-03 | 1.982E-03 | 1.410E-02 | 5.288E-03 | 1.254E+00 |
| 6.500E+00 | 1.480E-03 | 1.944E-03 | 1.362E-02 | 4.512E-03 | 1.458E+00 |

TABLE A-1 (cont'd)

| ENERGY | GROUP AVERAGED CROSS SECTION, BARNS | | | | |
|---|---|---|---|---|---|
| (MEV) | SC45G | CO59G | AU197G | U238G | U235F |
| 7.000E+00 | 1.490E-03 | 1.906E-03 | 1.324E-02 | 3.892E-03 | 1.622E+00 |
| 7.500E+00 | 1.498E-03 | 1.868E-03 | 1.286E-02 | 3.390E-03 | 1.724E+00 |
| 8.000E+00 | 1.512E-03 | 1.832E-03 | 1.254E-02 | 2.978E-03 | 1.778E+00 |
| 8.500E+00 | 1.542E-03 | 1.794E-03 | 1.224E-02 | 2.642E-03 | 1.800E+00 |
| 9.000E+00 | 1.568E-03 | 1.756E-03 | 1.198E-02 | 2.354E-03 | 1.796E+00 |
| 9.500E+00 | 1.592E-03 | 1.718E-03 | 1.172E-02 | 2.108E-03 | 1.778E+00 |
| 1.000E+01 | 1.618E-03 | 1.688E-03 | 1.148E-02 | 1.902E-03 | 1.754E+00 |
| 1.050E+01 | 1.638E-03 | 1.662E-03 | 1.126E-02 | 1.724E-03 | 1.728E+00 |
| 1.100E+01 | 1.662E-03 | 1.638E-03 | 1.104E-02 | 1.570E-03 | 1.720E+00 |
| 1.150E+01 | 1.682E-03 | 1.612E-03 | 1.084E-02 | 1.432E-03 | 1.740E+00 |
| 1.200E+01 | 1.704E-03 | 1.588E-03 | 1.066E-02 | 1.314E-03 | 1.812E+00 |
| 1.250E+01 | 1.724E-03 | 1.562E-03 | 1.050E-02 | 1.210E-03 | 1.918E+00 |
| 1.300E+01 | 1.744E-03 | 1.538E-03 | 1.034E-02 | 1.120E-03 | 2.030E+00 |
| 1.350E+01 | 1.764E-03 | 1.512E-03 | 1.016E-02 | 1.038E-03 | 2.116E+00 |
| 1.400E+01 | 1.784E-03 | 1.500E-03 | 1.001E-02 | 9.644E-04 | 2.180E+00 |
| 1.450E+01 | 1.800E-03 | 1.500E-03 | 9.868E-03 | 8.984E-04 | 2.220E+00 |
| 1.500E+01 | 1.812E-03 | 1.500E-03 | 9.734E-03 | 8.384E-04 | 2.236E+00 |
| 1.550E+01 | 1.822E-03 | 1.500E-03 | 9.604E-03 | 7.844E-04 | 2.234E+00 |
| 1.600E+01 | 1.832E-03 | 1.500E-03 | 9.480E-03 | 7.354E-04 | 2.220E+00 |
| 1.650E+01 | 1.842E-03 | 1.500E-03 | 9.364E-03 | 6.908E-04 | 2.198E+00 |
| 1.700E+01 | 1.852E-03 | 1.500E-03 | 9.250E-03 | 6.502E-04 | 2.166E+00 |
| 1.750E+01 | 1.860E-03 | 1.500E-03 | 9.140E-03 | 6.130E-04 | 2.134E+00 |
| 1.800E+01 | 1.870E-03 | 1.500E-03 | 9.030E-03 | 6.000E-04 | 2.120E+00 |
| 1.850E+01 | 1.880E-03 | 1.500E-03 | 8.900E-03 | 5.700E-04 | 2.110E+00 |
| 1.900E+01 | 1.890E-03 | 1.500E-03 | 8.810E-03 | 5.400E-04 | 2.100E+00 |
| 1.950E+01 | 1.900E-03 | 1.500E-03 | 8.700E-03 | 5.100E-04 | 2.120E+00 |
| 2.000E+01 | 1.900E-03 | 1.500E-03 | 8.600E-03 | 4.800E-04 | 2.150E+00 |
| 2.100E+01 | 1.900E-03 | 1.500E-03 | 8.370E-03 | 4.100E-04 | 2.350E+00 |
| 2.200E+01 | 1.900E-03 | 1.500E-03 | 8.150E-03 | 3.600E-04 | 2.650E+00 |
| 2.300E+01 | 1.900E-03 | 1.500E-03 | 7.930E-03 | 3.250E-04 | 2.850E+00 |
| 2.400E+01 | 1.900E-03 | 1.500E-03 | 7.710E-03 | 2.950E-04 | 2.900E+00 |
| 2.500E+01 | 1.900E-03 | 1.500E-03 | 7.490E-03 | 2.650E-04 | 2.900E+00 |
| 2.600E+01 | 1.900E-03 | 1.500E-03 | 7.270E-03 | 2.400E-04 | 2.900E+00 |
| 2.700E+01 | 1.900E-03 | 1.500E-03 | 7.050E-03 | 2.200E-04 | 2.900E+00 |
| 2.800E+01 | 1.900E-03 | 1.500E-03 | 6.830E-03 | 1.980E-04 | 2.900E+00 |
| 2.900E+01 | 1.900E-03 | 1.500E-03 | 6.610E-03 | 1.750E-04 | 2.900E+00 |
| 3.000E+01 | 1.900E-03 | 1.500E-03 | 6.390E-03 | 1.580E-04 | 2.900E+00 |
| 3.100E+01 | 1.900E-03 | 1.500E-03 | 6.200E-03 | 1.480E-04 | 2.900E+00 |
| 3.200E+01 | 1.900E-03 | 1.500E-03 | 6.000E-03 | 1.400E-04 | 2.900E+00 |
| 3.300E+01 | 1.900E-03 | 1.500E-03 | 5.800E-03 | 1.300E-04 | 2.900E+00 |
| 3.400E+01 | 1.900E-03 | 1.500E-03 | 5.600E-03 | 1.200E-04 | 2.900E+00 |
| 3.500E+01 | 1.900E-03 | 1.500E-03 | 5.400E-03 | 1.100E-04 | 2.900E+00 |
| 3.600E+01 | 1.900E-03 | 1.500E-03 | 5.200E-03 | 1.000E-04 | 2.900E+00 |
| 3.700E+01 | 1.900E-03 | 1.500E-03 | 5.000E-03 | 9.000E-05 | 2.900E+00 |
| 3.800E+01 | 1.900E-03 | 1.500E-03 | 4.800E-03 | 8.000E-05 | 2.900E+00 |
| 3.900E+01 | 1.900E-03 | 1.500E-03 | 4.600E-03 | 7.500E-05 | 2.900E+00 |
| 4.000E+01 | 1.900E-03 | 1.500E-03 | 4.400E-03 | 7.000E-05 | 2.900E+00 |
| 4.100E+01 | 1.900E-03 | 1.500E-03 | 4.300E-03 | 6.700E-05 | 2.900E+00 |
| 4.200E+01 | 1.900E-03 | 1.500E-03 | 4.200E-03 | 6.400E-05 | 2.900E+00 |
| 4.300E+01 | 1.900E-03 | 1.500E-03 | 4.100E-03 | 6.200E-05 | 2.900E+00 |
| 4.400E+01 | | | | | |

TABLE A-2

| ENERGY | GROUP AVERAGED CROSS SECTION, BARNS | | | | |
|---|---|---|---|---|---|
| (MEV) | FE54P | FE254P | FE56P | NI58P | NI60P |
| 2.750E-01 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3.000E-01 | 0.0 | 0.0 | 0.0 | 3.430E-08 | 0.0 |
| 3.500E-01 | 0.0 | 0.0 | 0.0 | 2.350E-07 | 0.0 |
| 4.000E-01 | 0.0 | 0.0 | 0.0 | 8.500E-07 | 0.0 |
| 4.500E-01 | 0.0 | 0.0 | 0.0 | 2.150E-06 | 0.0 |
| 5.000E-01 | 0.0 | 0.0 | 0.0 | 7.500E-06 | 0.0 |
| 6.000E-01 | 0.0 | 0.0 | 0.0 | 3.300E-05 | 0.0 |
| 7.000E-01 | 0.0 | 0.0 | 0.0 | 1.394E-04 | 0.0 |
| 8.000E-01 | 0.0 | 0.0 | 0.0 | 3.098E-04 | 0.0 |
| 9.000E-01 | 0.0 | 0.0 | 0.0 | 6.701E-04 | 0.0 |
| 1.000E+00 | 0.0 | 0.0 | 0.0 | 2.953E-03 | 0.0 |
| 1.250E+00 | 1.385E-04 | 1.385E-04 | 0.0 | 9.501E-03 | 0.0 |
| 1.500E+00 | 2.345E-03 | 2.345E-03 | 0.0 | 1.837E-02 | 0.0 |
| 1.750E+00 | 7.613E-03 | 7.613E-03 | 0.0 | 3.211E-02 | 0.0 |
| 2.000E+00 | 2.454E-02 | 2.454E-02 | 0.0 | 4.919E-02 | 0.0 |
| 2.250E+00 | 5.235E-02 | 5.235E-02 | 0.0 | 9.324E-02 | 1.258E-05 |
| 2.500E+00 | 8.719E-02 | 8.719E-02 | 0.0 | 1.199E-01 | 1.159E-04 |
| 2.750E+00 | 1.154E-01 | 1.154E-01 | 2.200E-08 | 1.684E-01 | 2.294E-04 |
| 3.000E+00 | 1.698E-01 | 1.698E-01 | 2.878E-07 | 2.220E-01 | 4.092E-04 |
| 3.500E+00 | 2.544E-01 | 2.544E-01 | 2.738E-06 | 3.183E-01 | 6.454E-04 |
| 4.000E+00 | 2.929E-01 | 2.929E-01 | 5.370E-05 | 3.870E-01 | 8.818E-04 |
| 4.500E+00 | 3.681E-01 | 3.681E-01 | 5.464E-04 | 4.231E-01 | 2.900E-03 |
| 5.000E+00 | 4.319E-01 | 4.319E-01 | 3.026E-03 | 4.868E-01 | 9.896E-03 |
| 5.500E+00 | 5.109E-01 | 5.109E-01 | 9.406E-03 | 5.890E-01 | 2.320E-02 |
| 6.000E+00 | 5.370E-01 | 5.370E-01 | 1.726E-02 | 6.172E-01 | 3.820E-02 |
| 6.500E+00 | 5.637E-01 | 5.637E-01 | 2.556E-02 | 6.300E-01 | 5.400E-02 |
| 7.000E+00 | 5.807E-01 | 5.807E-01 | 3.340E-02 | 6.430E-01 | 7.100E-02 |
| 7.500E+00 | 5.885E-01 | 5.885E-01 | 4.060E-02 | 6.525E-01 | 8.650E-02 |
| 8.000E+00 | 5.897E-01 | 5.897E-01 | 4.720E-02 | 6.587E-01 | 1.055E-01 |
| 8.500E+00 | 5.870E-01 | 5.870E-01 | 5.354E-02 | 6.610E-01 | 1.260E-01 |
| 9.000E+00 | 5.790E-01 | 5.790E-01 | 6.000E-02 | 6.607E-01 | 1.420E-01 |
| 9.500E+00 | 5.697E-01 | 5.697E-01 | 6.694E-02 | 6.547E-01 | 1.550E-01 |
| 1.000E+01 | 5.565E-01 | 5.565E-01 | 7.464E-02 | 6.457E-01 | 1.630E-01 |
| 1.050E+01 | 5.394E-01 | 5.394E-01 | 8.290E-02 | 6.291E-01 | 1.650E-01 |
| 1.100E+01 | 5.210E-01 | 5.210E-01 | 9.140E-02 | 6.061E-01 | 1.604E-01 |
| 1.150E+01 | 5.013E-01 | 5.013E-01 | 9.928E-02 | 5.740E-01 | 1.520E-01 |
| 1.200E+01 | 4.796E-01 | 4.796E-01 | 1.060E-01 | 5.360E-01 | 1.440E-01 |
| 1.250E+01 | 4.556E-01 | 4.556E-01 | 1.110E-01 | 4.951E-01 | 1.410E-01 |
| 1.300E+01 | 4.227E-01 | 4.227E-01 | 1.136E-01 | 4.475E-01 | 1.370E-01 |
| 1.350E+01 | 3.842E-01 | 3.842E-01 | 1.126E-01 | 4.021E-01 | 1.320E-01 |
| 1.400E+01 | 3.430E-01 | 3.430E-01 | 1.090E-01 | 3.630E-01 | 1.254E-01 |
| 1.450E+01 | 3.055E-01 | 3.058E-01 | 1.026E-01 | 3.302E-01 | 1.154E-01 |
| 1.500E+01 | 2.735E-01 | 3.052E-01 | 9.504E-02 | 3.006E-01 | 1.050E-01 |
| 1.550E+01 | 2.446E-01 | 3.337E-01 | 8.624E-02 | 2.748E-01 | 9.650E-02 |
| 1.600E+01 | 2.204E-01 | 3.562E-01 | 7.900E-02 | 2.522E-01 | 8.950E-02 |
| 1.650E+01 | 2.006E-01 | 3.727E-01 | 7.270E-02 | 2.337E-01 | 8.350E-02 |
| 1.700E+01 | 1.832E-01 | 3.970E-01 | 6.636E-02 | 2.185E-01 | 7.850E-02 |
| 1.750E+01 | 1.697E-01 | 4.290E-01 | 6.120E-02 | 2.065E-01 | 7.400E-02 |
| 1.800E+01 | 1.598E-01 | 4.662E-01 | 5.510E-02 | 1.979E-01 | 7.100E-02 |
| 1.850E+01 | 1.519E-01 | 5.087E-01 | 5.200E-02 | 1.923E-01 | 6.700E-02 |

TABLE A-2 (cont'd)

| ENERGY | GROUP AVERAGED CROSS SECTION, BARNS | | | | |
|---|---|---|---|---|---|
| (MEV) | FE54P | FE254P | FE56P | NI58P | NI60P |
| 1.900E+01 | 1.460E-01 | 5.505E-01 | 4.920E-02 | 1.899E-01 | 6.300E-02 |
| 1.950E+01 | 1.421E-01 | 5.915E-01 | 4.600E-02 | 1.890E-01 | 5.900E-02 |
| 2.000E+01 | 1.355E-01 | 6.390E-01 | 4.300E-02 | 1.795E-01 | 5.400E-02 |
| 2.100E+01 | 1.250E-01 | 6.860E-01 | 3.750E-02 | 1.650E-01 | 4.800E-02 |
| 2.200E+01 | 1.150E-01 | 7.245E-01 | 3.300E-02 | 1.550E-01 | 4.200E-02 |
| 2.300E+01 | 1.075E-01 | 7.695E-01 | 2.950E-02 | 1.450E-01 | 3.600E-02 |
| 2.400E+01 | 1.015E-01 | 8.335E-01 | 2.650E-02 | 1.350E-01 | 3.200E-02 |
| 2.500E+01 | 9.500E-02 | 9.235E-01 | 2.300E-02 | 1.250E-01 | 2.800E-02 |
| 2.600E+01 | 8.900E-02 | 1.040E+00 | 2.000E-02 | 1.150E-01 | 2.400E-02 |
| 2.700E+01 | 8.300E-02 | 1.177E+00 | 1.800E-02 | 1.075E-01 | 2.100E-02 |
| 2.800E+01 | 7.700E-02 | 1.316E+00 | 1.600E-02 | 1.025E-01 | 1.800E-02 |
| 2.900E+01 | 7.100E-02 | 1.440E+00 | 1.400E-02 | 9.750E-02 | 1.600E-02 |
| 3.000E+01 | 6.567E-02 | 1.515E+00 | 1.200E-02 | 9.337E-02 | 1.400E-02 |
| 3.100E+01 | 6.100E-02 | 1.548E+00 | 1.150E-02 | 9.012E-02 | 1.300E-02 |
| 3.200E+01 | 5.633E-02 | 1.582E+00 | 1.100E-02 | 8.687E-02 | 1.200E-02 |
| 3.300E+01 | 5.167E-02 | 1.616E+00 | 1.050E-02 | 8.362E-02 | 1.100E-02 |
| 3.400E+01 | 4.700E-02 | 1.649E+00 | 1.000E-02 | 7.875E-02 | 1.000E-02 |
| 3.500E+01 | 4.233E-02 | 1.683E+00 | 9.500E-03 | 7.225E-02 | 9.500E-03 |
| 3.600E+01 | 3.875E-02 | 1.706E+00 | 9.000E-03 | 6.575E-02 | 9.000E-03 |
| 3.700E+01 | 3.625E-02 | 1.719E+00 | 8.500E-03 | 5.925E-02 | 8.500E-03 |
| 3.800E+01 | 3.375E-02 | 1.731E+00 | 8.000E-03 | 5.450E-02 | 8.000E-03 |
| 3.900E+01 | 3.125E-02 | 1.744E+00 | 7.500E-03 | 5.150E-02 | 7.500E-03 |
| 4.000E+01 | 2.875E-02 | 1.756E+00 | 7.000E-03 | 4.850E-02 | 7.000E-03 |
| 4.100E+01 | 2.625E-02 | 1.769E+00 | 6.000E-03 | 4.550E-02 | 6.700E-03 |
| 4.200E+01 | 2.375E-02 | 1.781E+00 | 5.000E-03 | 4.250E-02 | 6.400E-03 |
| 4.300E+01 | 2.125E-02 | 1.794E+00 | 4.500E-03 | 3.950E-02 | 6.200E-03 |
| 4.400E+01 | | | | | |

TABLE A-3

| ENERGY | GROUP AVERAGED CROSS SECTION, BARNS | | | | |
|---|---|---|---|---|---|
| (MEV) | TI46P | TI246P | TI47P | TI247P | TI48P |
| 4.500E-01 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5.000E-01 | 0.0 | 0.0 | 3.577E-10 | 3.577E-10 | 0.0 |
| 6.000E-01 | 0.0 | 0.0 | 1.819E-07 | 1.819E-07 | 0.0 |
| 7.000E-01 | 0.0 | 0.0 | 1.519E-06 | 1.519E-06 | 0.0 |
| 8.000E-01 | 0.0 | 0.0 | 1.390E-05 | 1.390E-05 | 0.0 |
| 9.000E-01 | 0.0 | 0.0 | 8.564E-05 | 8.564E-05 | 0.0 |
| 1.000E+00 | 0.0 | 0.0 | 1.377E-03 | 1.377E-03 | 0.0 |
| 1.250E+00 | 0.0 | 0.0 | 3.396E-03 | 3.396E-03 | 0.0 |
| 1.500E+00 | 5.143E-06 | 5.143E-06 | 5.236E-03 | 5.236E-03 | 0.0 |
| 1.750E+00 | 4.375E-05 | 4.375E-05 | 1.383E-02 | 1.383E-02 | 0.0 |
| 2.000E+00 | 8.839E-05 | 8.839E-05 | 2.553E-02 | 2.553E-02 | 0.0 |
| 2.250E+00 | 1.330E-04 | 1.330E-04 | 3.233E-02 | 3.233E-02 | 0.0 |
| 2.500E+00 | 1.777E-04 | 1.777E-04 | 3.097E-02 | 3.097E-02 | 0.0 |
| 2.750E+00 | 2.829E-04 | 2.829E-04 | 3.348E-02 | 3.348E-02 | 0.0 |
| 3.000E+00 | 2.432E-03 | 2.432E-03 | 4.584E-02 | 4.584E-02 | 8.878E-07 |
| 3.500E+00 | 1.275E-02 | 1.275E-02 | 6.004E-02 | 6.004E-02 | 8.056E-06 |
| 4.000E+00 | 3.166E-02 | 3.166E-02 | 6.915E-02 | 6.915E-02 | 1.645E-05 |
| 4.500E+00 | 5.599E-02 | 5.599E-02 | 7.563E-02 | 7.563E-02 | 4.473E-05 |
| 5.000E+00 | 8.221E-02 | 8.221E-02 | 8.292E-02 | 8.292E-02 | 2.594E-04 |
| 5.500E+00 | 1.078E-01 | 1.078E-01 | 9.059E-02 | 9.059E-02 | 1.068E-03 |
| 6.000E+00 | 1.303E-01 | 1.303E-01 | 9.897E-02 | 9.897E-02 | 2.855E-03 |
| 6.500E+00 | 1.510E-01 | 1.510E-01 | 1.077E-01 | 1.077E-01 | 5.220E-03 |
| 7.000E+00 | 1.716E-01 | 1.716E-01 | 1.148E-01 | 1.148E-01 | 8.230E-03 |
| 7.500E+00 | 1.910E-01 | 1.910E-01 | 1.209E-01 | 1.209E-01 | 1.165E-02 |
| 8.000E+00 | 2.061E-01 | 2.061E-01 | 1.255E-01 | 1.255E-01 | 1.485E-02 |
| 8.500E+00 | 2.209E-01 | 2.209E-01 | 1.280E-01 | 1.280E-01 | 1.820E-02 |
| 9.000E+00 | 2.353E-01 | 2.353E-01 | 1.288E-01 | 1.288E-01 | 2.175E-02 |
| 9.500E+00 | 2.460E-01 | 2.460E-01 | 1.290E-01 | 1.290E-01 | 2.575E-02 |
| 1.000E+01 | 2.556E-01 | 2.556E-01 | 1.290E-01 | 1.290E-01 | 3.000E-02 |
| 1.050E+01 | 2.652E-01 | 2.652E-01 | 1.290E-01 | 1.290E-01 | 3.400E-02 |
| 1.100E+01 | 2.732E-01 | 2.732E-01 | 1.286E-01 | 1.286E-01 | 3.856E-02 |
| 1.150E+01 | 2.782E-01 | 2.782E-01 | 1.280E-01 | 1.298E-01 | 4.368E-02 |
| 1.200E+01 | 2.800E-01 | 2.800E-01 | 1.265E-01 | 1.470E-01 | 4.918E-02 |
| 1.250E+01 | 2.791E-01 | 2.794E-01 | 1.246E-01 | 1.676E-01 | 5.488E-02 |
| 1.300E+01 | 2.744E-01 | 2.774E-01 | 1.216E-01 | 1.863E-01 | 6.023E-02 |
| 1.350E+01 | 2.682E-01 | 2.772E-01 | 1.182E-01 | 2.049E-01 | 6.381E-02 |
| 1.400E+01 | 2.607E-01 | 2.824E-01 | 1.135E-01 | 2.260E-01 | 6.559E-02 |
| 1.450E+01 | 2.516E-01 | 2.902E-01 | 1.085E-01 | 2.544E-01 | 6.579E-02 |
| 1.500E+01 | 2.403E-01 | 3.057E-01 | 1.028E-01 | 2.704E-01 | 6.388E-02 |
| 1.550E+01 | 2.300E-01 | 3.228E-01 | 9.750E-02 | 3.127E-01 | 6.095E-02 |
| 1.600E+01 | 2.200E-01 | 3.335E-01 | 9.178E-02 | 3.964E-01 | 5.738E-02 |
| 1.650E+01 | 2.100E-01 | 3.376E-01 | 8.621E-02 | 5.141E-01 | 5.318E-02 |
| 1.700E+01 | 2.002E-01 | 3.348E-01 | 8.071E-02 | 6.433E-01 | 4.931E-02 |
| 1.750E+01 | 1.922E-01 | 3.415E-01 | 7.610E-02 | 7.498E-01 | 4.606E-02 |
| 1.800E+01 | 1.847E-01 | 3.562E-01 | 7.205E-02 | 8.497E-01 | 4.395E-02 |
| 1.850E+01 | 1.774E-01 | 3.928E-01 | 6.914E-02 | 9.157E-01 | 4.233E-02 |
| 1.900E+01 | 1.704E-01 | 4.317E-01 | 6.686E-02 | 9.652E-01 | 4.158E-02 |
| 1.950E+01 | 1.635E-01 | 4.706E-01 | 6.561E-02 | 1.009E+00 | 4.093E-02 |
| 2.000E+01 | 1.550E-01 | 5.300E-01 | 6.300E-02 | 1.084E+00 | 3.880E-02 |
| 2.100E+01 | 1.475E-01 | 6.000E-01 | 5.900E-02 | 1.190E+00 | 3.600E-02 |

TABLE A-3 (cont'd)

| ENERGY | GROUP AVERAGED CROSS SECTION, BARNS | | | | |
|---|---|---|---|---|---|
| (MEV) | TI46P | TI246P | TI47P | TI247P | TI48P |
| 2.200E+01 | 1.350E-01 | 6.550E-01 | 5.500E-02 | 1.285E+00 | 3.400E-02 |
| 2.300E+01 | 1.200E-01 | 7.000E-01 | 5.150E-02 | 1.425E+00 | 3.200E-02 |
| 2.400E+01 | 1.110E-01 | 7.400E-01 | 4.800E-02 | 1.570E+00 | 3.000E-02 |
| 2.500E+01 | 1.020E-01 | 7.800E-01 | 4.400E-02 | 1.665E+00 | 2.800E-02 |
| 2.600E+01 | 9.400E-02 | 8.250E-01 | 4.100E-02 | 1.735E+00 | 2.650E-02 |
| 2.700E+01 | 8.750E-02 | 8.700E-01 | 3.850E-02 | 1.785E+00 | 2.500E-02 |
| 2.800E+01 | 8.050E-02 | 9.100E-01 | 3.550E-02 | 1.830E+00 | 2.350E-02 |
| 2.900E+01 | 7.400E-02 | 9.500E-01 | 3.300E-02 | 1.875E+00 | 2.250E-02 |
| 3.000E+01 | 6.875E-02 | 9.675E-01 | 3.100E-02 | 1.899E+00 | 2.192E-02 |
| 3.100E+01 | 6.425E-02 | 9.625E-01 | 2.900E-02 | 1.897E+00 | 2.175E-02 |
| 3.200E+01 | 5.975E-02 | 9.575E-01 | 2.700E-02 | 1.896E+00 | 2.158E-02 |
| 3.300E+01 | 5.525E-02 | 9.525E-01 | 2.500E-02 | 1.894E+00 | 2.142E-02 |
| 3.400E+01 | 5.075E-02 | 9.475E-01 | 2.300E-02 | 1.892E+00 | 2.125E-02 |
| 3.500E+01 | 4.625E-02 | 9.425E-01 | 2.100E-02 | 1.891E+00 | 2.108E-02 |
| 3.600E+01 | 4.250E-02 | 9.387E-01 | 1.925E-02 | 1.890E+00 | 2.062E-02 |
| 3.700E+01 | 3.950E-02 | 9.362E-01 | 1.775E-02 | 1.890E+00 | 1.987E-02 |
| 3.800E+01 | 3.650E-02 | 9.337E-01 | 1.625E-02 | 1.890E+00 | 1.912E-02 |
| 3.900E+01 | 3.350E-02 | 9.313E-01 | 1.475E-02 | 1.890E+00 | 1.837E-02 |
| 4.000E+01 | 3.075E-02 | 9.288E-01 | 1.350E-02 | 1.887E+00 | 1.775E-02 |
| 4.100E+01 | 2.825E-02 | 9.262E-01 | 1.250E-02 | 1.882E+00 | 1.725E-02 |
| 4.200E+01 | 2.575E-02 | 9.237E-01 | 1.150E-02 | 1.877E+00 | 1.675E-02 |
| 4.300E+01 | 2.325E-02 | 9.212E-01 | 1.050E-02 | 1.872E+00 | 1.625E-02 |
| 4.400E+01 | | | | | |

TABLE A-4

| ENERGY | GROUP AVERAGED CROSS SECTION, BARNS | | | | |
|---|---|---|---|---|---|
| (MEV) | AL27A | SC45A | FE54A | CO59A | CO59P |
| 5.000E-01 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6.000E-01 | 0.0 | 1.250E-05 | 0.0 | 0.0 | 0.0 |
| 7.000E-01 | 0.0 | 3.750E-05 | 0.0 | 0.0 | 0.0 |
| 8.000E-01 | 0.0 | 6.250E-05 | 0.0 | 0.0 | 2.883E-06 |
| 9.000E-01 | 0.0 | 8.750E-05 | 0.0 | 0.0 | 8.649E-06 |
| 1.000E+00 | 0.0 | 1.125E-04 | 0.0 | 0.0 | 1.874E-05 |
| 1.250E+00 | 0.0 | 1.375E-04 | 0.0 | 0.0 | 3.315E-05 |
| 1.500E+00 | 0.0 | 1.625E-04 | 0.0 | 0.0 | 4.757E-05 |
| 1.750E+00 | 0.0 | 1.875E-04 | 0.0 | 0.0 | 6.198E-05 |
| 2.000E+00 | 0.0 | 2.312E-04 | 0.0 | 0.0 | 7.640E-05 |
| 2.250E+00 | 0.0 | 2.937E-04 | 0.0 | 0.0 | 9.081E-05 |
| 2.500E+00 | 0.0 | 3.562E-04 | 0.0 | 0.0 | 1.416E-04 |
| 2.750E+00 | 0.0 | 4.187E-04 | 0.0 | 0.0 | 2.911E-04 |
| 3.000E+00 | 5.904E-23 | 5.125E-04 | 0.0 | 0.0 | 8.912E-04 |
| 3.500E+00 | 8.935E-14 | 6.375E-04 | 0.0 | 0.0 | 2.426E-03 |
| 4.000E+00 | 4.123E-09 | 9.250E-04 | 2.500E-04 | 0.0 | 4.683E-03 |
| 4.500E+00 | 1.325E-06 | 1.375E-03 | 7.500E-04 | 0.0 | 8.222E-03 |
| 5.000E+00 | 5.184E-05 | 1.825E-03 | 3.050E-03 | 2.000E-04 | 1.069E-02 |
| 5.500E+00 | 6.386E-04 | 2.275E-03 | 7.150E-03 | 7.000E-04 | 1.223E-02 |
| 6.000E+00 | 3.654E-03 | 3.562E-03 | 1.115E-02 | 1.500E-03 | 1.475E-02 |
| 6.500E+00 | 1.094E-02 | 5.687E-03 | 1.505E-02 | 2.750E-03 | 1.825E-02 |
| 7.000E+00 | 2.144E-02 | 7.812E-03 | 2.000E-02 | 4.370E-03 | 2.100E-02 |
| 7.500E+00 | 3.424E-02 | 9.937E-03 | 2.600E-02 | 6.320E-03 | 2.300E-02 |
| 8.000E+00 | 4.868E-02 | 1.187E-02 | 3.250E-02 | 8.650E-03 | 2.525E-02 |
| 8.500E+00 | 6.338E-02 | 1.362E-02 | 3.950E-02 | 1.100E-02 | 2.775E-02 |
| 9.000E+00 | 7.614E-02 | 1.537E-02 | 4.625E-02 | 1.300E-02 | 3.025E-02 |
| 9.500E+00 | 8.664E-02 | 1.712E-02 | 5.275E-02 | 1.484E-02 | 3.275E-02 |
| 1.000E+01 | 9.540E-02 | 2.025E-02 | 5.775E-02 | 1.666E-02 | 3.550E-02 |
| 1.050E+01 | 1.036E-01 | 2.475E-02 | 6.125E-02 | 1.850E-02 | 3.850E-02 |
| 1.100E+01 | 1.112E-01 | 2.925E-02 | 6.475E-02 | 2.034E-02 | 4.150E-02 |
| 1.150E+01 | 1.182E-01 | 3.375E-02 | 6.825E-02 | 2.240E-02 | 4.450E-02 |
| 1.200E+01 | 1.240E-01 | 3.950E-02 | 7.275E-02 | 2.498E-02 | 4.800E-02 |
| 1.250E+01 | 1.274E-01 | 4.650E-02 | 7.825E-02 | 2.698E-02 | 5.200E-02 |
| 1.300E+01 | 1.284E-01 | 5.100E-02 | 8.375E-02 | 2.828E-02 | 5.600E-02 |
| 1.350E+01 | 1.264E-01 | 5.300E-02 | 8.925E-02 | 2.902E-02 | 6.000E-02 |
| 1.400E+01 | 1.220E-01 | 5.350E-02 | 9.300E-02 | 2.904E-02 | 6.200E-02 |
| 1.450E+01 | 1.162E-01 | 5.250E-02 | 9.500E-02 | 2.844E-02 | 6.200E-02 |
| 1.500E+01 | 1.092E-01 | 4.900E-02 | 9.700E-02 | 2.720E-02 | 6.200E-02 |
| 1.550E+01 | 1.011E-01 | 4.300E-02 | 9.900E-02 | 2.560E-02 | 6.200E-02 |
| 1.600E+01 | 9.270E-02 | 3.750E-02 | 9.700E-02 | 2.390E-02 | 6.037E-02 |
| 1.650E+01 | 8.390E-02 | 3.250E-02 | 9.100E-02 | 2.210E-02 | 5.712E-02 |
| 1.700E+01 | 7.530E-02 | 2.950E-02 | 8.475E-02 | 2.000E-02 | 5.387E-02 |
| 1.750E+01 | 6.740E-02 | 2.850E-02 | 7.825E-02 | 1.776E-02 | 5.062E-02 |
| 1.800E+01 | 5.670E-02 | 2.750E-02 | 7.300E-02 | 1.480E-02 | 4.750E-02 |
| 1.850E+01 | 5.100E-02 | 2.650E-02 | 6.900E-02 | 1.340E-02 | 4.450E-02 |
| 1.900E+01 | 4.400E-02 | 2.550E-02 | 6.525E-02 | 1.200E-02 | 4.150E-02 |
| 1.950E+01 | 4.000E-02 | 2.450E-02 | 6.175E-02 | 1.130E-02 | 3.850E-02 |
| 2.000E+01 | 3.600E-02 | 2.300E-02 | 5.800E-02 | 1.050E-02 | 3.500E-02 |
| 2.100E+01 | 2.800E-02 | 2.100E-02 | 5.450E-02 | 9.000E-03 | 3.100E-02 |
| 2.200E+01 | 2.300E-02 | 1.900E-02 | 5.250E-02 | 7.800E-03 | 2.725E-02 |

TABLE A-4 (cont'd)

| ENERGY | GROUP AVERAGED CROSS SECTION, BARNS | | | | |
|---|---|---|---|---|---|
| (MEV) | AL27A | SC45A | FE54A | CO59A | CO59P |
| 2.300E+01 | 1.800E-02 | 1.700E-02 | 5.100E-02 | 6.900E-03 | 2.375E-02 |
| 2.400E+01 | 1.440E-02 | 1.587E-02 | 5.000E-02 | 6.400E-03 | 2.075E-02 |
| 2.500E+01 | 1.140E-02 | 1.562E-02 | 5.000E-02 | 6.100E-03 | 1.825E-02 |
| 2.600E+01 | 9.100E-03 | 1.537E-02 | 5.000E-02 | 5.900E-03 | 1.625E-02 |
| 2.700E+01 | 7.400E-03 | 1.512E-02 | 4.950E-02 | 5.750E-03 | 1.475E-02 |
| 2.800E+01 | 5.900E-03 | 1.500E-02 | 4.900E-02 | 5.650E-03 | 1.325E-02 |
| 2.900E+01 | 4.800E-03 | 1.500E-02 | 4.900E-02 | 5.550E-03 | 1.175E-02 |
| 3.000E+01 | 3.600E-03 | 1.500E-02 | 4.900E-02 | 5.450E-03 | 1.068E-02 |
| 3.100E+01 | 3.400E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 1.004E-02 |
| 3.200E+01 | 3.000E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 9.393E-03 |
| 3.300E+01 | 2.800E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 8.750E-03 |
| 3.400E+01 | 2.600E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 8.107E-03 |
| 3.500E+01 | 2.400E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 7.464E-03 |
| 3.600E+01 | 2.200E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 6.821E-03 |
| 3.700E+01 | 2.100E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 6.179E-03 |
| 3.800E+01 | 2.000E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 5.536E-03 |
| 3.900E+01 | 2.000E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 4.893E-03 |
| 4.000E+01 | 2.000E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 4.250E-03 |
| 4.100E+01 | 2.000E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 3.607E-03 |
| 4.200E+01 | 2.000E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 2.964E-03 |
| 4.300E+01 | 2.000E-03 | 1.500E-02 | 4.900E-02 | 5.400E-03 | 2.321E-03 |
| 4.400E+01 | | | | | |

TABLE A-5

| ENERGY | GROUP AVERAGED CROSS SECTION, BARNS | | | | |
|---|---|---|---|---|---|
| (MEV) | SC452 | NI582 | NI582B | C0592 | C0593 |
| 1.000E+01 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1.050E+01 | 0.0 | 0.0 | 0.0 | 7.202E-03 | 0.0 |
| 1.100E+01 | 0.0 | 0.0 | 0.0 | 8.500E-02 | 0.0 |
| 1.150E+01 | 0.0 | 0.0 | 0.0 | 2.150E-01 | 0.0 |
| 1.200E+01 | 1.012E-02 | 2.230E-05 | 1.784E-05 | 3.400E-01 | 0.0 |
| 1.250E+01 | 3.457E-02 | 1.136E-03 | 1.136E-03 | 4.500E-01 | 0.0 |
| 1.300E+01 | 6.310E-02 | 8.525E-03 | 8.525E-03 | 5.400E-01 | 0.0 |
| 1.350E+01 | 8.900E-02 | 1.950E-02 | 1.950E-02 | 6.100E-01 | 0.0 |
| 1.400E+01 | 1.050E-01 | 2.737E-02 | 2.900E-02 | 6.570E-01 | 0.0 |
| 1.450E+01 | 1.190E-01 | 3.412E-02 | 3.900E-02 | 6.920E-01 | 0.0 |
| 1.500E+01 | 1.312E-01 | 3.962E-02 | 4.800E-02 | 7.200E-01 | 0.0 |
| 1.550E+01 | 1.417E-01 | 4.387E-02 | 5.600E-02 | 7.400E-01 | 0.0 |
| 1.600E+01 | 1.497E-01 | 4.725E-02 | 6.250E-02 | 7.570E-01 | 0.0 |
| 1.650E+01 | 1.552E-01 | 4.975E-02 | 6.750E-02 | 7.720E-01 | 0.0 |
| 1.700E+01 | 1.587E-01 | 5.187E-02 | 7.125E-02 | 7.850E-01 | 0.0 |
| 1.750E+01 | 1.602E-01 | 5.362E-02 | 7.375E-02 | 7.950E-01 | 0.0 |
| 1.800E+01 | 1.607E-01 | 5.500E-02 | 7.700E-02 | 8.000E-01 | 0.0 |
| 1.850E+01 | 1.602E-01 | 5.600E-02 | 8.100E-02 | 8.020E-01 | 0.0 |
| 1.900E+01 | 1.597E-01 | 5.662E-02 | 8.525E-02 | 8.050E-01 | 0.0 |
| 1.950E+01 | 1.592E-01 | 5.687E-02 | 8.975E-02 | 7.750E-01 | 0.0 |
| 2.000E+01 | 1.555E-01 | 5.700E-02 | 9.450E-02 | 7.500E-01 | 1.000E-02 |
| 2.100E+01 | 1.500E-01 | 5.700E-02 | 9.950E-02 | 7.000E-01 | 4.000E-02 |
| 2.200E+01 | 1.440E-01 | 5.700E-02 | 1.010E-01 | 6.500E-01 | 8.000E-02 |
| 2.300E+01 | 1.350E-01 | 5.700E-02 | 9.750E-02 | 5.900E-01 | 1.200E-01 |
| 2.400E+01 | 1.250E-01 | 5.500E-02 | 9.100E-02 | 5.200E-01 | 1.550E-01 |
| 2.500E+01 | 1.155E-01 | 4.900E-02 | 8.350E-02 | 4.600E-01 | 1.850E-01 |
| 2.600E+01 | 1.065E-01 | 4.050E-02 | 7.600E-02 | 4.000E-01 | 2.100E-01 |
| 2.700E+01 | 9.750E-02 | 3.150E-02 | 7.000E-02 | 3.600E-01 | 2.300E-01 |
| 2.800E+01 | 8.850E-02 | 2.400E-02 | 6.600E-02 | 3.200E-01 | 2.450E-01 |
| 2.900E+01 | 7.950E-02 | 1.775E-02 | 6.200E-02 | 2.900E-01 | 2.550E-01 |
| 3.000E+01 | 7.112E-02 | 1.312E-02 | 5.400E-02 | 2.700E-01 | 2.625E-01 |
| 3.100E+01 | 6.337E-02 | 1.038E-02 | 4.200E-02 | 2.500E-01 | 2.675E-01 |
| 3.200E+01 | 5.562E-02 | 7.625E-03 | 3.000E-02 | 2.300E-01 | 2.725E-01 |
| 3.300E+01 | 4.787E-02 | 4.875E-03 | 1.800E-02 | 2.200E-01 | 2.775E-01 |
| 3.400E+01 | 4.112E-02 | 3.187E-03 | 1.087E-02 | 2.100E-01 | 2.750E-01 |
| 3.500E+01 | 3.537E-02 | 2.562E-03 | 8.625E-03 | 2.000E-01 | 2.650E-01 |
| 3.600E+01 | 2.963E-02 | 1.938E-03 | 6.375E-03 | 1.950E-01 | 2.550E-01 |
| 3.700E+01 | 2.388E-02 | 1.312E-03 | 4.125E-03 | 1.870E-01 | 2.450E-01 |
| 3.800E+01 | 2.008E-02 | 9.333E-04 | 2.792E-03 | 1.800E-01 | 2.350E-01 |
| 3.900E+01 | 1.825E-02 | 8.000E-04 | 2.375E-03 | 1.700E-01 | 2.250E-01 |
| 4.000E+01 | 1.642E-02 | 6.667E-04 | 1.958E-03 | 1.600E-01 | 2.125E-01 |
| 4.100E+01 | 1.458E-02 | 5.333E-04 | 1.542E-03 | 1.550E-01 | 1.975E-01 |
| 4.200E+01 | 1.275E-02 | 4.000E-04 | 1.125E-03 | 1.500E-01 | 1.825E-01 |
| 4.300E+01 | 1.092E-02 | 2.667E-04 | 7.083E-04 | 1.450E-01 | 1.675E-01 |
| 4.400E+01 | | | | | |

TABLE A-6

| ENERGY | GROUP AVERAGED CROSS SECTION, BARNS | | | | |
|---|---|---|---|---|---|
| (MEV) | ZR2902 | NB932 | U2382 | IN115N | U238F |
| 6.000E-03 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 8.000E-03 | 0.0 | 0.0 | 0.0 | 0.0 | 3.263E-05 |
| 1.000E-02 | 0.0 | 0.0 | 0.0 | 0.0 | 8.700E-05 |
| 2.500E-02 | 0.0 | 0.0 | 0.0 | 0.0 | 5.880E-05 |
| 5.000E-02 | 0.0 | 0.0 | 0.0 | 0.0 | 4.000E-05 |
| 7.500E-02 | 0.0 | 0.0 | 0.0 | 0.0 | 4.000E-05 |
| 1.000E-01 | 0.0 | 0.0 | 0.0 | 0.0 | 4.192E-05 |
| 1.250E-01 | 0.0 | 0.0 | 0.0 | 0.0 | 4.562E-05 |
| 1.500E-01 | 0.0 | 0.0 | 0.0 | 0.0 | 4.940E-05 |
| 1.750E-01 | 0.0 | 0.0 | 0.0 | 0.0 | 5.300E-05 |
| 2.000E-01 | 0.0 | 0.0 | 0.0 | 0.0 | 5.690E-05 |
| 2.250E-01 | 0.0 | 0.0 | 0.0 | 0.0 | 6.066E-05 |
| 2.500E-01 | 0.0 | 0.0 | 0.0 | 0.0 | 6.430E-05 |
| 2.750E-01 | 0.0 | 0.0 | 0.0 | 0.0 | 6.804E-05 |
| 3.000E-01 | 0.0 | 0.0 | 0.0 | 1.011E-05 | 8.352E-05 |
| 3.500E-01 | 0.0 | 0.0 | 0.0 | 8.262E-04 | 1.084E-04 |
| 4.000E-01 | 0.0 | 0.0 | 0.0 | 1.779E-03 | 1.500E-04 |
| 4.500E-01 | 0.0 | 0.0 | 0.0 | 2.320E-03 | 2.060E-04 |
| 5.000E-01 | 0.0 | 0.0 | 0.0 | 3.628E-03 | 5.018E-04 |
| 6.000E-01 | 0.0 | 0.0 | 0.0 | 1.114E-02 | 1.285E-03 |
| 7.000E-01 | 0.0 | 0.0 | 0.0 | 2.145E-02 | 2.096E-03 |
| 8.000E-01 | 0.0 | 0.0 | 0.0 | 3.732E-02 | 6.368E-03 |
| 9.000E-01 | 0.0 | 0.0 | 0.0 | 5.660E-02 | 1.448E-02 |
| 1.000E+00 | 0.0 | 0.0 | 0.0 | 8.214E-02 | 3.014E-02 |
| 1.250E+00 | 0.0 | 0.0 | 0.0 | 1.396E-01 | 1.391E-01 |
| 1.500E+00 | 0.0 | 0.0 | 0.0 | 1.893E-01 | 3.910E-01 |
| 1.750E+00 | 0.0 | 0.0 | 0.0 | 2.279E-01 | 5.006E-01 |
| 2.000E+00 | 0.0 | 0.0 | 0.0 | 2.844E-01 | 5.442E-01 |
| 2.250E+00 | 0.0 | 0.0 | 0.0 | 3.199E-01 | 5.518E-01 |
| 2.500E+00 | 0.0 | 0.0 | 0.0 | 3.341E-01 | 5.524E-01 |
| 2.750E+00 | 0.0 | 0.0 | 0.0 | 3.354E-01 | 5.464E-01 |
| 3.000E+00 | 0.0 | 0.0 | 0.0 | 3.317E-01 | 5.468E-01 |
| 3.500E+00 | 0.0 | 0.0 | 0.0 | 3.252E-01 | 5.604E-01 |
| 4.000E+00 | 0.0 | 0.0 | 0.0 | 3.116E-01 | 5.648E-01 |
| 4.500E+00 | 0.0 | 0.0 | 0.0 | 3.151E-01 | 5.590E-01 |
| 5.000E+00 | 0.0 | 0.0 | 0.0 | 3.270E-01 | 5.600E-01 |
| 5.500E+00 | 0.0 | 0.0 | 0.0 | 3.367E-01 | 6.038E-01 |
| 6.000E+00 | 0.0 | 0.0 | 2.651E-02 | 3.378E-01 | 7.446E-01 |
| 6.500E+00 | 0.0 | 0.0 | 2.680E-01 | 3.200E-01 | 8.850E-01 |
| 7.000E+00 | 0.0 | 0.0 | 7.912E-01 | 2.989E-01 | 9.576E-01 |
| 7.500E+00 | 0.0 | 0.0 | 1.117E+00 | 2.960E-01 | 9.840E-01 |
| 8.000E+00 | 0.0 | 0.0 | 1.294E+00 | 2.947E-01 | 9.956E-01 |
| 8.500E+00 | 0.0 | 6.400E-04 | 1.420E+00 | 2.849E-01 | 9.964E-01 |
| 9.000E+00 | 0.0 | 3.000E-02 | 1.500E+00 | 2.698E-01 | 9.870E-01 |
| 9.500E+00 | 0.0 | 8.400E-02 | 1.537E+00 | 2.546E-01 | 9.776E-01 |
| 1.000E+01 | 0.0 | 1.540E-01 | 1.546E+00 | 2.358E-01 | 9.760E-01 |
| 1.050E+01 | 0.0 | 2.360E-01 | 1.549E+00 | 2.084E-01 | 9.800E-01 |
| 1.100E+01 | 0.0 | 3.160E-01 | 1.550E+00 | 1.814E-01 | 9.850E-01 |
| 1.150E+01 | 0.0 | 3.780E-01 | 1.518E+00 | 1.549E-01 | 9.910E-01 |
| 1.200E+01 | 6.000E-02 | 4.240E-01 | 1.410E+00 | 1.283E-01 | 1.007E+00 |

TABLE A-6 (cont'd)

| ENERGY | GROUP AVERAGED CROSS SECTION, BARNS | | | | |
|---|---|---|---|---|---|
| (MEV) | ZR2902 | NB932 | U2382 | IN115N | U238F |
| 1.250E+01 | 1.850E-01 | 4.550E-01 | 1.255E+00 | 1.021E-01 | 1.034E+00 |
| 1.300E+01 | 3.350E-01 | 4.730E-01 | 1.090E+00 | 7.977E-02 | 1.070E+00 |
| 1.350E+01 | 5.000E-01 | 4.830E-01 | 9.325E-01 | 6.932E-02 | 1.120E+00 |
| 1.400E+01 | 6.400E-01 | 4.890E-01 | 7.675E-01 | 6.433E-02 | 1.174E+00 |
| 1.450E+01 | 7.600E-01 | 4.920E-01 | 6.050E-01 | 6.117E-02 | 1.230E+00 |
| 1.500E+01 | 8.550E-01 | 4.910E-01 | 4.600E-01 | 6.033E-02 | 1.280E+00 |
| 1.550E+01 | 9.250E-01 | 4.890E-01 | 3.200E-01 | 5.967E-02 | 1.306E+00 |
| 1.600E+01 | 9.875E-01 | 4.830E-01 | 2.125E-01 | 5.900E-02 | 1.334E+00 |
| 1.650E+01 | 1.042E+00 | 4.730E-01 | 1.375E-01 | 5.833E-02 | 1.348E+00 |
| 1.700E+01 | 1.090E+00 | 4.630E-01 | 9.000E-02 | 5.767E-02 | 1.338E+00 |
| 1.750E+01 | 1.130E+00 | 4.530E-01 | 7.000E-02 | 5.700E-02 | 1.328E+00 |
| 1.800E+01 | 1.157E+00 | 4.400E-01 | 5.800E-02 | 5.633E-02 | 1.320E+00 |
| 1.850E+01 | 1.172E+00 | 4.240E-01 | 5.400E-02 | 5.567E-02 | 1.320E+00 |
| 1.900E+01 | 1.185E+00 | 4.080E-01 | 5.000E-02 | 5.500E-02 | 1.320E+00 |
| 1.950E+01 | 1.195E+00 | 3.920E-01 | 4.600E-02 | 5.433E-02 | 1.350E+00 |
| 2.000E+01 | 1.200E+00 | 3.470E-01 | 4.200E-02 | 5.335E-02 | 1.390E+00 |
| 2.100E+01 | 1.200E+00 | 2.700E-01 | 3.800E-02 | 5.205E-02 | 1.540E+00 |
| 2.200E+01 | 1.196E+00 | 1.850E-01 | 3.400E-02 | 5.075E-02 | 1.600E+00 |
| 2.300E+01 | 1.185E+00 | 1.125E-01 | 3.000E-02 | 4.945E-02 | 1.800E+00 |
| 2.400E+01 | 1.153E+00 | 6.750E-02 | 2.725E-02 | 4.815E-02 | 1.900E+00 |
| 2.500E+01 | 1.083E+00 | 4.000E-02 | 2.575E-02 | 4.685E-02 | 1.950E+00 |
| 2.600E+01 | 1.001E+00 | 2.350E-02 | 2.425E-02 | 4.555E-02 | 1.950E+00 |
| 2.700E+01 | 9.109E-01 | 1.350E-02 | 2.275E-02 | 4.425E-02 | 1.950E+00 |
| 2.800E+01 | 8.170E-01 | 7.500E-03 | 2.175E-02 | 4.295E-02 | 1.950E+00 |
| 2.900E+01 | 7.256E-01 | 4.000E-03 | 2.125E-02 | 4.165E-02 | 1.950E+00 |
| 3.000E+01 | 6.412E-01 | 2.750E-03 | 2.075E-02 | 4.096E-02 | 1.950E+00 |
| 3.100E+01 | 5.637E-01 | 2.250E-03 | 2.025E-02 | 4.089E-02 | 1.960E+00 |
| 3.200E+01 | 4.863E-01 | 1.750E-03 | 2.000E-02 | 4.082E-02 | 1.980E+00 |
| 3.300E+01 | 4.087E-01 | 1.250E-03 | 2.000E-02 | 4.075E-02 | 1.980E+00 |
| 3.400E+01 | 3.487E-01 | 9.375E-04 | 2.000E-02 | 4.068E-02 | 2.050E+00 |
| 3.500E+01 | 3.062E-01 | 8.125E-04 | 2.000E-02 | 4.061E-02 | 2.150E+00 |
| 3.600E+01 | 2.638E-01 | 6.875E-04 | 2.000E-02 | 4.054E-02 | 2.180E+00 |
| 3.700E+01 | 2.212E-01 | 5.625E-04 | 2.000E-02 | 4.046E-02 | 2.210E+00 |
| 3.800E+01 | 1.892E-01 | 5.000E-04 | 2.000E-02 | 4.039E-02 | 2.210E+00 |
| 3.900E+01 | 1.675E-01 | 5.000E-04 | 2.000E-02 | 4.032E-02 | 2.210E+00 |
| 4.000E+01 | 1.458E-01 | 5.000E-04 | 2.000E-02 | 4.025E-02 | 2.210E+00 |
| 4.100E+01 | 1.242E-01 | 5.000E-04 | 2.000E-02 | 4.018E-02 | 2.210E+00 |
| 4.200E+01 | 1.025E-01 | 5.000E-04 | 2.000E-02 | 4.011E-02 | 2.210E+00 |
| 4.300E+01 | 8.083E-02 | 5.000E-04 | 2.000E-02 | 4.004E-02 | 2.210E+00 |
| 4.400E+01 | | | | | |

TABLE A-7

| ENERGY | GROUP AVERAGED CROSS SECTION, BARNS | | | | |
|---|---|---|---|---|---|
| (MEV) | TM1692 | TM1693 | AU1972 | AU1973 | AU1974 |
| 7.500E+00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 8.000E+00 | 0.0 | 0.0 | 3.200E-02 | 0.0 | 0.0 |
| 8.500E+00 | 2.806E-01 | 0.0 | 1.396E-01 | 0.0 | 0.0 |
| 9.000E+00 | 7.009E-01 | 0.0 | 3.810E-01 | 0.0 | 0.0 |
| 9.500E+00 | 9.223E-01 | 0.0 | 7.330E-01 | 0.0 | 0.0 |
| 1.000E+01 | 1.070E+00 | 0.0 | 1.049E+00 | 0.0 | 0.0 |
| 1.050E+01 | 1.218E+00 | 0.0 | 1.320E+00 | 0.0 | 0.0 |
| 1.100E+01 | 1.366E+00 | 0.0 | 1.540E+00 | 0.0 | 0.0 |
| 1.150E+01 | 1.513E+00 | 0.0 | 1.720E+00 | 0.0 | 0.0 |
| 1.200E+01 | 1.661E+00 | 0.0 | 1.855E+00 | 0.0 | 0.0 |
| 1.250E+01 | 1.809E+00 | 0.0 | 1.955E+00 | 0.0 | 0.0 |
| 1.300E+01 | 1.955E+00 | 0.0 | 2.045E+00 | 0.0 | 0.0 |
| 1.350E+01 | 2.010E+00 | 0.0 | 2.115E+00 | 0.0 | 0.0 |
| 1.400E+01 | 2.015E+00 | 0.0 | 2.145E+00 | 0.0 | 0.0 |
| 1.450E+01 | 2.028E+00 | 0.0 | 2.125E+00 | 0.0 | 0.0 |
| 1.500E+01 | 2.043E+00 | 0.0 | 2.085E+00 | 7.292E-03 | 0.0 |
| 1.550E+01 | 2.057E+00 | 0.0 | 2.060E+00 | 2.188E-02 | 0.0 |
| 1.600E+01 | 2.059E+00 | 5.442E-02 | 2.012E+00 | 5.786E-02 | 0.0 |
| 1.650E+01 | 2.005E+00 | 1.784E-01 | 1.937E+00 | 1.818E-01 | 0.0 |
| 1.700E+01 | 1.911E+00 | 3.107E-01 | 1.850E+00 | 3.205E-01 | 0.0 |
| 1.750E+01 | 1.680E+00 | 4.680E-01 | 1.750E+00 | 4.856E-01 | 0.0 |
| 1.800E+01 | 1.450E+00 | 6.310E-01 | 1.612E+00 | 6.650E-01 | 0.0 |
| 1.850E+01 | 1.279E+00 | 8.062E-01 | 1.437E+00 | 8.550E-01 | 0.0 |
| 1.900E+01 | 1.115E+00 | 9.828E-01 | 1.275E+00 | 1.037E+00 | 0.0 |
| 1.950E+01 | 9.511E-01 | 1.159E+00 | 1.125E+00 | 1.212E+00 | 0.0 |
| 2.000E+01 | 7.962E-01 | 1.306E+00 | 9.250E-01 | 1.425E+00 | 0.0 |
| 2.100E+01 | 6.305E-01 | 1.454E+00 | 7.100E-01 | 1.640E+00 | 0.0 |
| 2.200E+01 | 5.115E-01 | 1.570E+00 | 5.650E-01 | 1.795E+00 | 0.0 |
| 2.300E+01 | 4.468E-01 | 1.622E+00 | 4.750E-01 | 1.890E+00 | 0.0 |
| 2.400E+01 | 4.032E-01 | 1.621E+00 | 4.150E-01 | 1.920E+00 | 1.383E-02 |
| 2.500E+01 | 3.637E-01 | 1.620E+00 | 3.700E-01 | 1.890E+00 | 4.150E-02 |
| 2.600E+01 | 3.336E-01 | 1.574E+00 | 3.450E-01 | 1.790E+00 | 1.254E-01 |
| 2.700E+01 | 3.135E-01 | 1.475E+00 | 3.350E-01 | 1.640E+00 | 2.801E-01 |
| 2.800E+01 | 2.950E-01 | 1.370E+00 | 3.275E-01 | 1.480E+00 | 4.753E-01 |
| 2.900E+01 | 2.783E-01 | 1.257E+00 | 3.225E-01 | 1.250E+00 | 7.250E-01 |
| 3.000E+01 | 2.637E-01 | 1.137E+00 | 3.183E-01 | 9.750E-01 | 9.687E-01 |
| 3.100E+01 | 2.512E-01 | 1.012E+00 | 3.150E-01 | 7.250E-01 | 1.206E+00 |
| 3.200E+01 | 2.387E-01 | 8.875E-01 | 3.117E-01 | 5.300E-01 | 1.444E+00 |
| 3.300E+01 | 2.262E-01 | 7.625E-01 | 3.083E-01 | 3.900E-01 | 1.681E+00 |
| 3.400E+01 | 2.163E-01 | 6.625E-01 | 3.050E-01 | 3.013E-01 | 1.825E+00 |
| 3.500E+01 | 2.087E-01 | 5.875E-01 | 3.017E-01 | 2.638E-01 | 1.875E+00 |
| 3.600E+01 | 2.012E-01 | 5.125E-01 | 3.000E-01 | 2.263E-01 | 1.875E+00 |
| 3.700E+01 | 1.937E-01 | 4.375E-01 | 3.000E-01 | 1.888E-01 | 1.825E+00 |
| 3.800E+01 | 1.883E-01 | 3.833E-01 | 3.000E-01 | 1.683E-01 | 1.750E+00 |
| 3.900E+01 | 1.850E-01 | 3.500E-01 | 3.000E-01 | 1.650E-01 | 1.650E+00 |
| 4.000E+01 | 1.817E-01 | 3.167E-01 | 3.000E-01 | 1.617E-01 | 1.500E+00 |
| 4.100E+01 | 1.783E-01 | 2.833E-01 | 3.000E-01 | 1.583E-01 | 1.300E+00 |
| 4.200E+01 | 1.750E-01 | 2.500E-01 | 3.000E-01 | 1.550E-01 | 1.100E+00 |
| 4.300E+01 | 1.717E-01 | 2.167E-01 | 3.000E-01 | 1.517E-01 | 9.000E-01 |
| 4.400E+01 | | | | | |

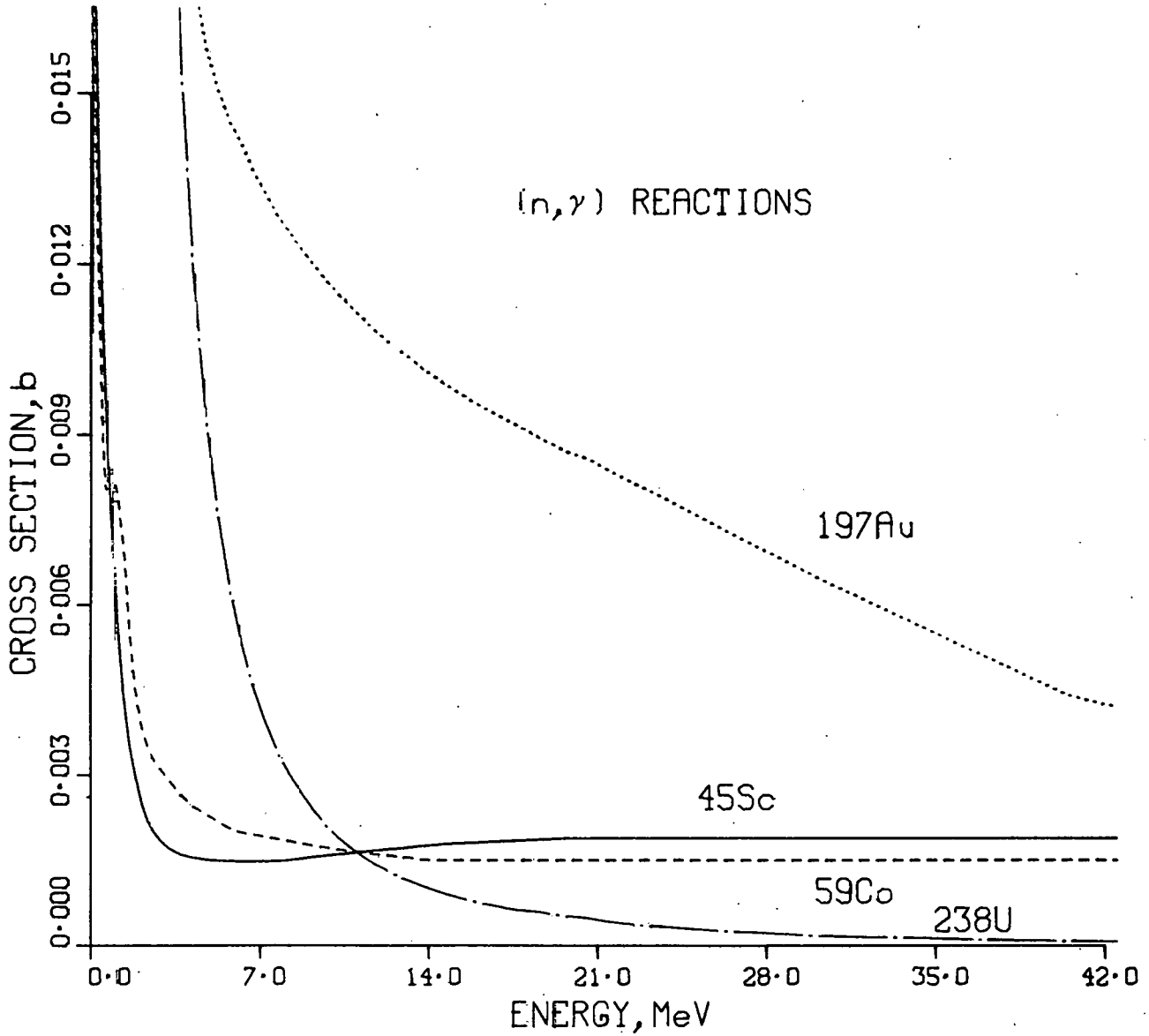


Figure 1. The high energy regions of various (n,γ) cross sections are emphasized. The low energy regions can be found in Refs. 3, 10 and 11.

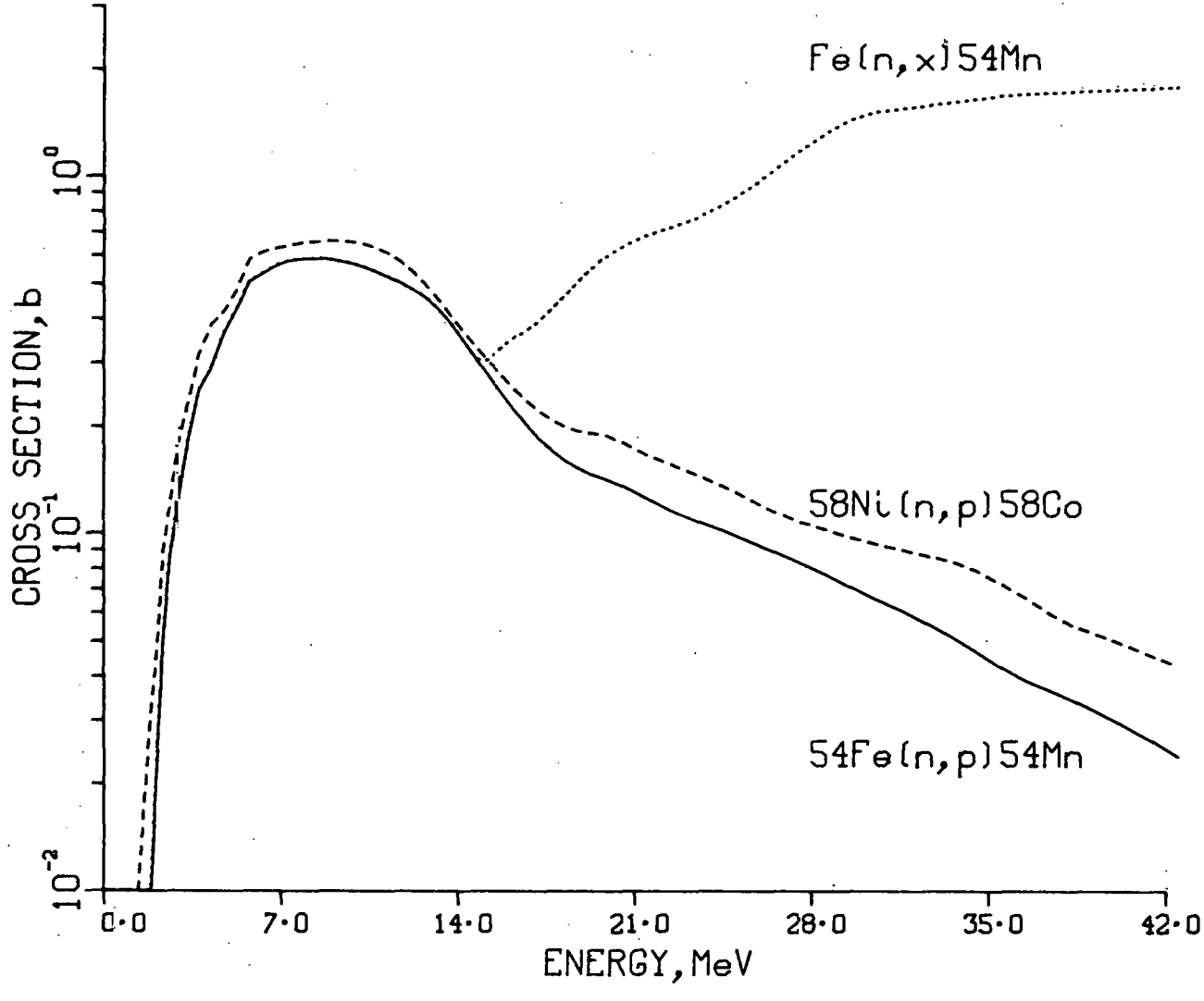


Figure 2. Semi-log plot of (n,p) cross sections for $^{58}Ni$ and $^{54}Fe$. The $Fe(n,x)^{54}Mn$ values include THRESH[13] calculations for $^{56}Fe(n,t + nd + 2np)^{54}Mn$ divided by the abundance of $^{54}Fe$. The total cross section for production of $^{54}Mn$ from natural Fe can thus be obtained by multiplying by 0.058.

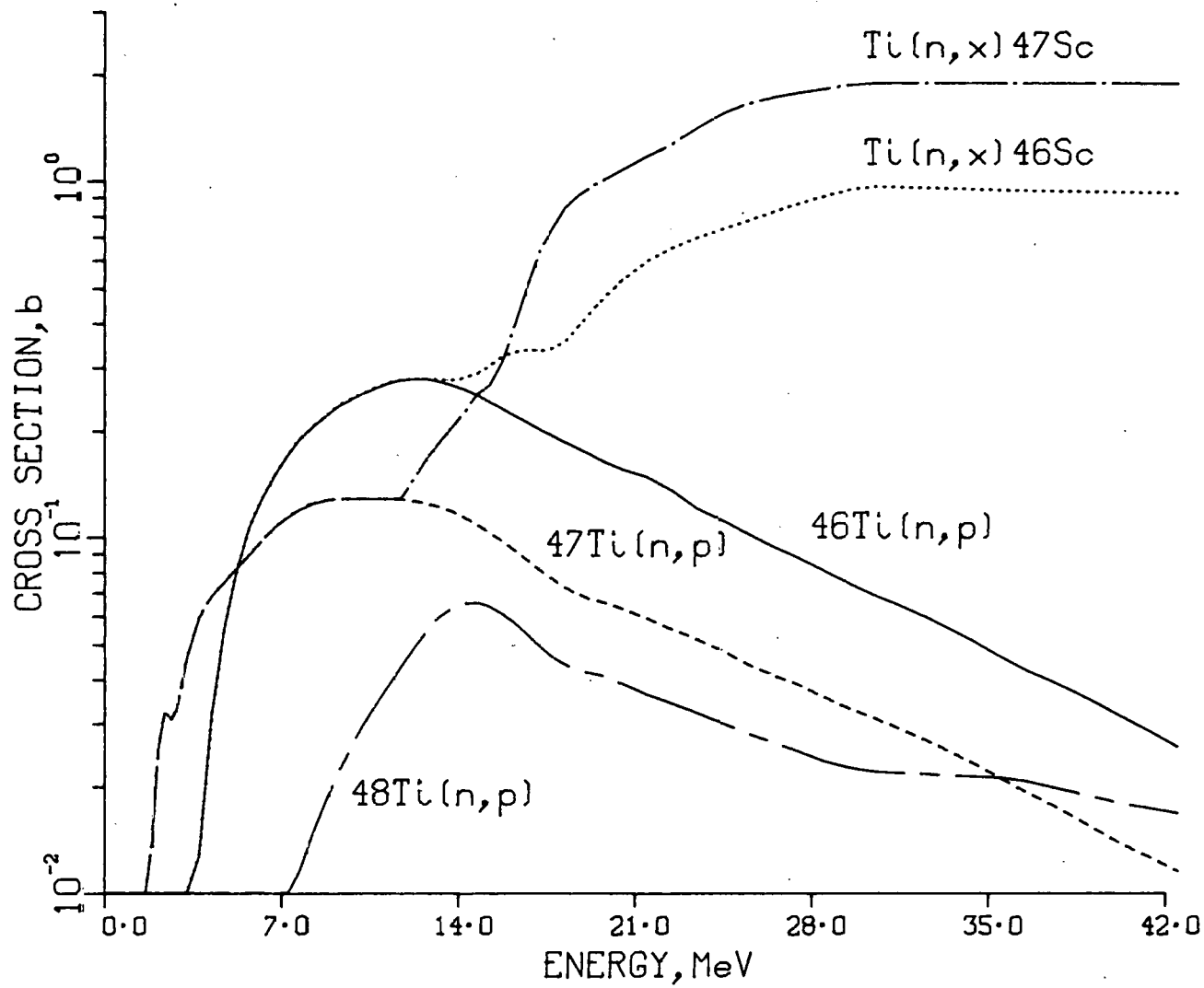


Figure 3. Semi-log plot of (n,p) cross sections for the titanium isotopes (Ref. 12). The Ti(n,x)$^{46}$Sc values include THRESH[13] calculations for $^{47}$Ti(n,d + np + pn)$^{46}$Sc and $^{48}$Ti(n,t + nd + 2np)$^{46}$Sc divided by the abundance of $^{46}$Ti, and the Ti(n,x)$^{47}$Sc divided by the abundance of $^{47}$Ti. Total production cross sections for $^{46}$Sc and $^{47}$Sc can thus be obtained by multiplying by 0.0825 and 0.0745, respectively.

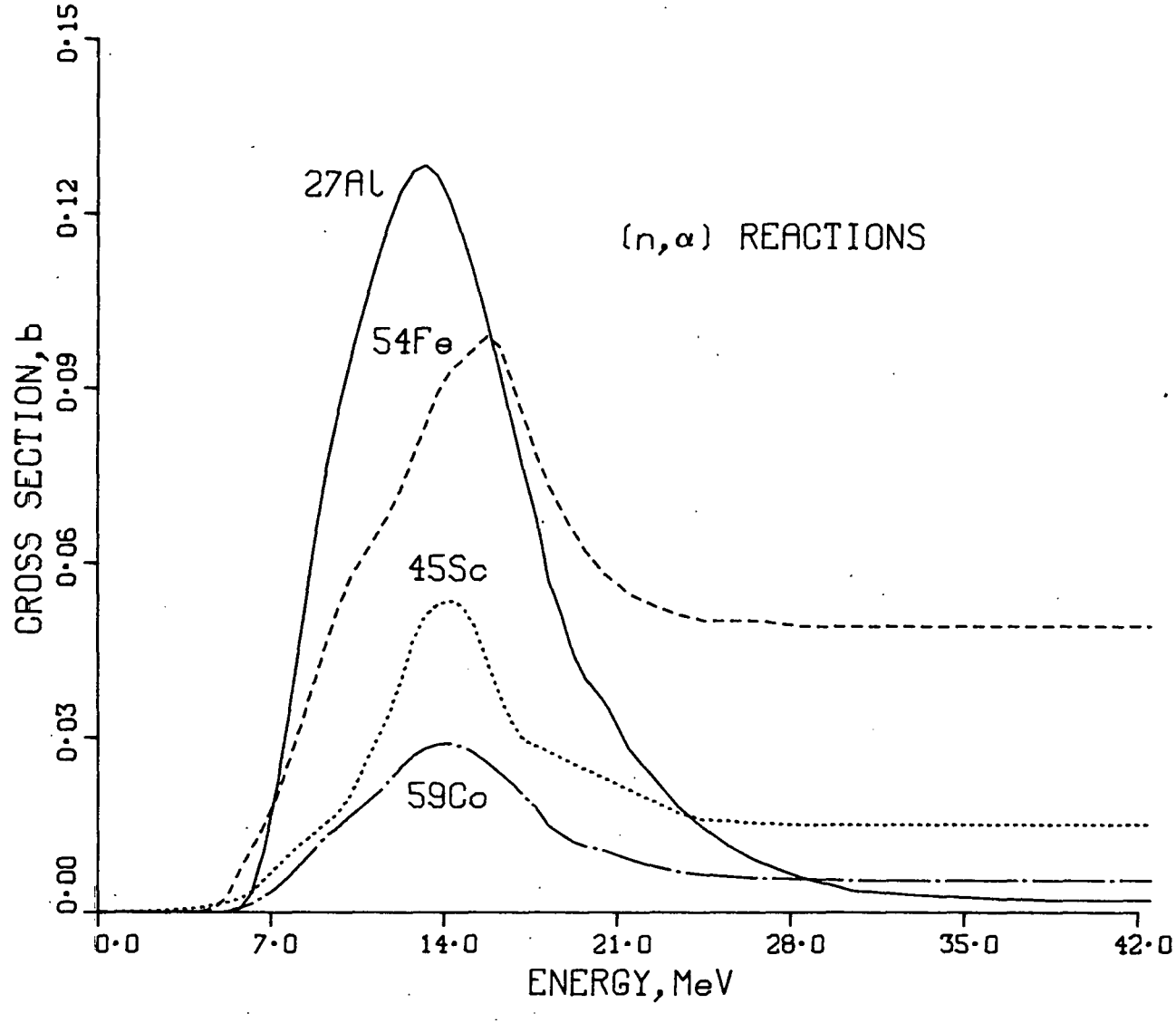


Figure 4. Various (n,α) cross sections are shown. The $^{54}Fe$ and $^{45}Sc$ values below 20 MeV were taken from Ref. 11.

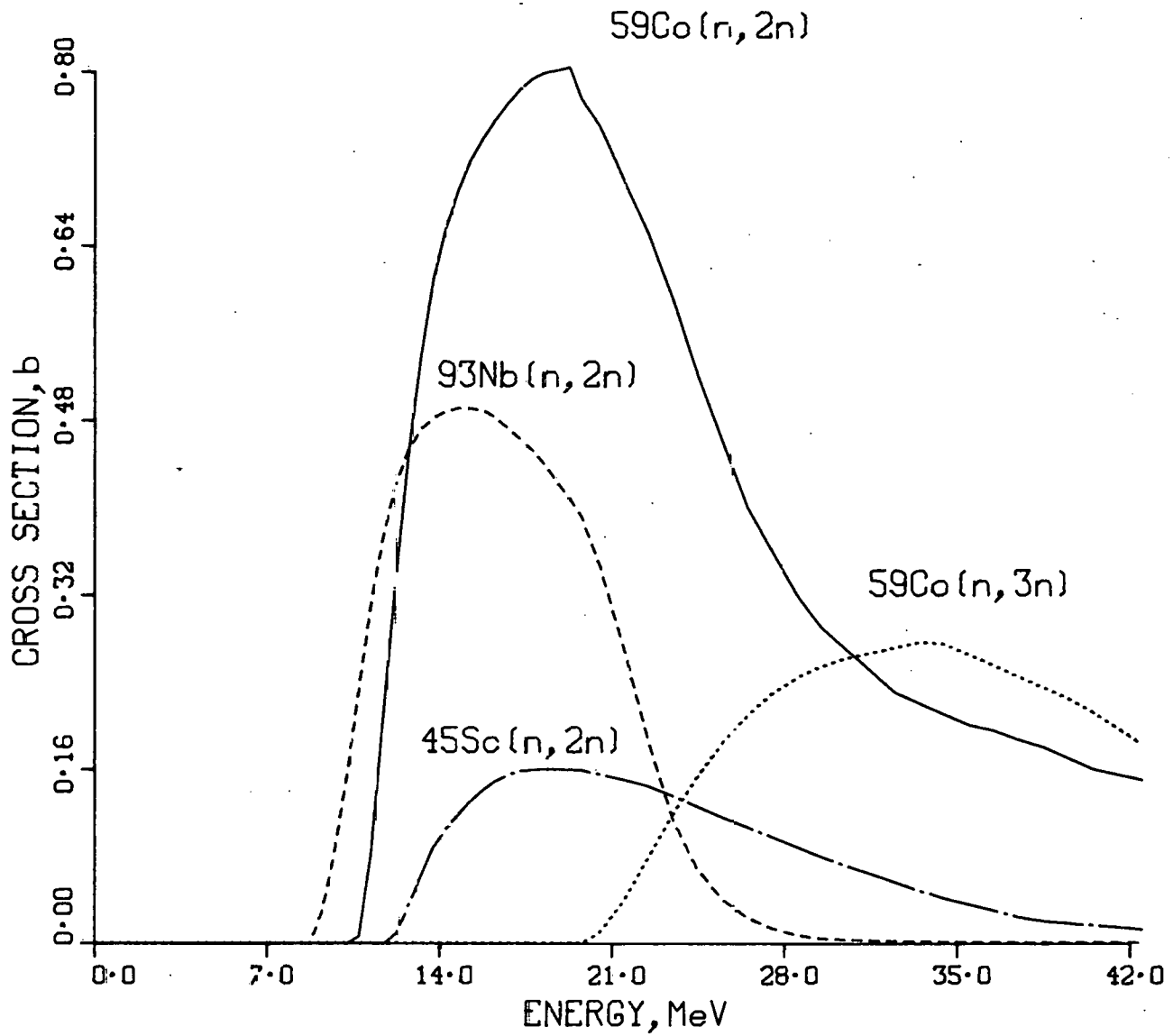


Figure 5. Various (n,xn) cross sections are shown. The $^{59}Co$ values below 30 MeV were taken from measurements in Ref. 5 and calculations in Ref. 6.

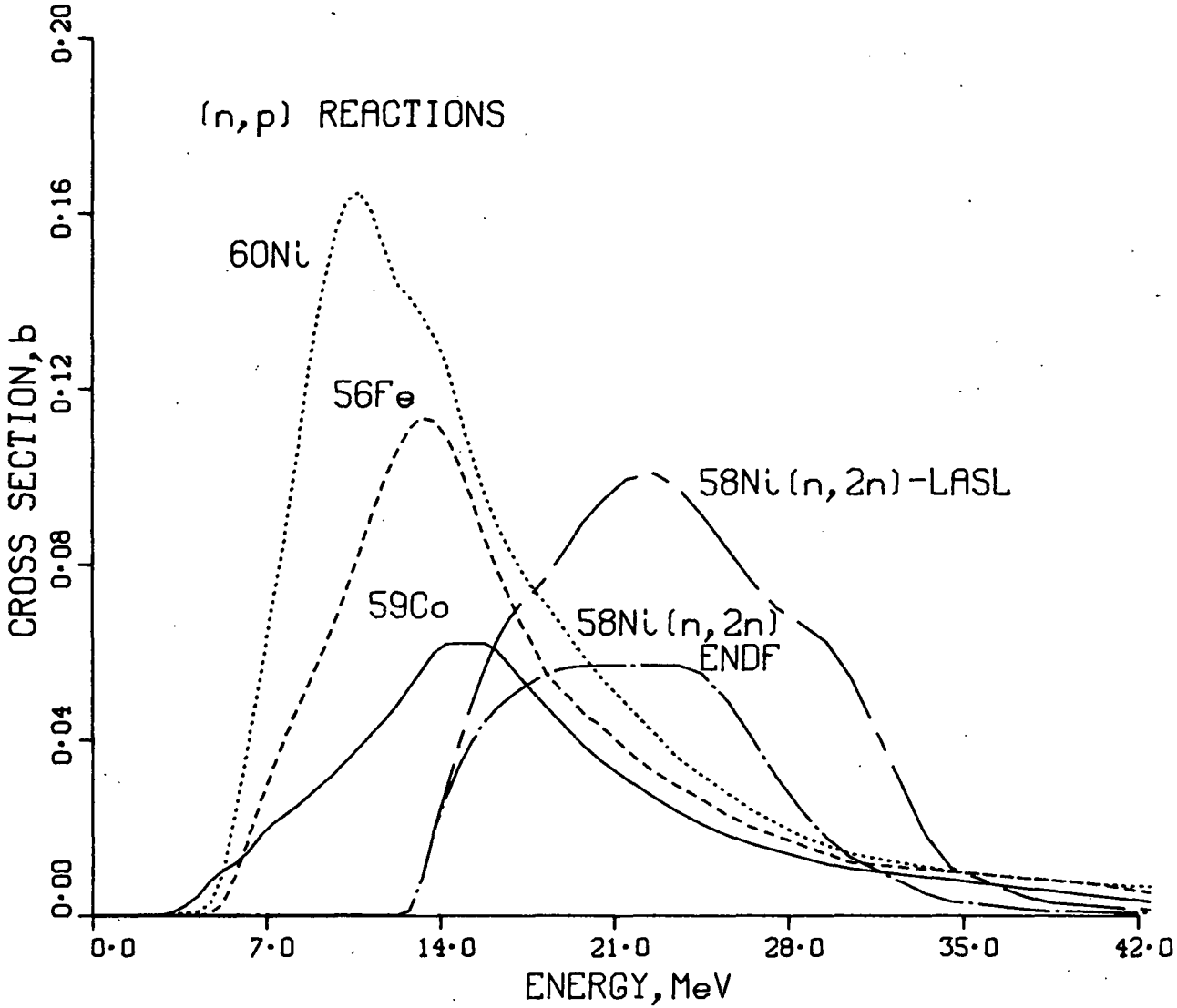


Figure 6. The $^{58}Ni(n,2n)$ and (n,p) cross sections for $^{60}Ni$, $^{56}Fe$, and $^{59}Co$ are shown. The $^{59}Co$ values below 10 MeV are from Ref. 12. The $^{58}Ni$ values labeled ENDF are from Ref. 10 and those labeled LASL are from Ref. 4, extrapolated to fit the ENDF values at low energy.

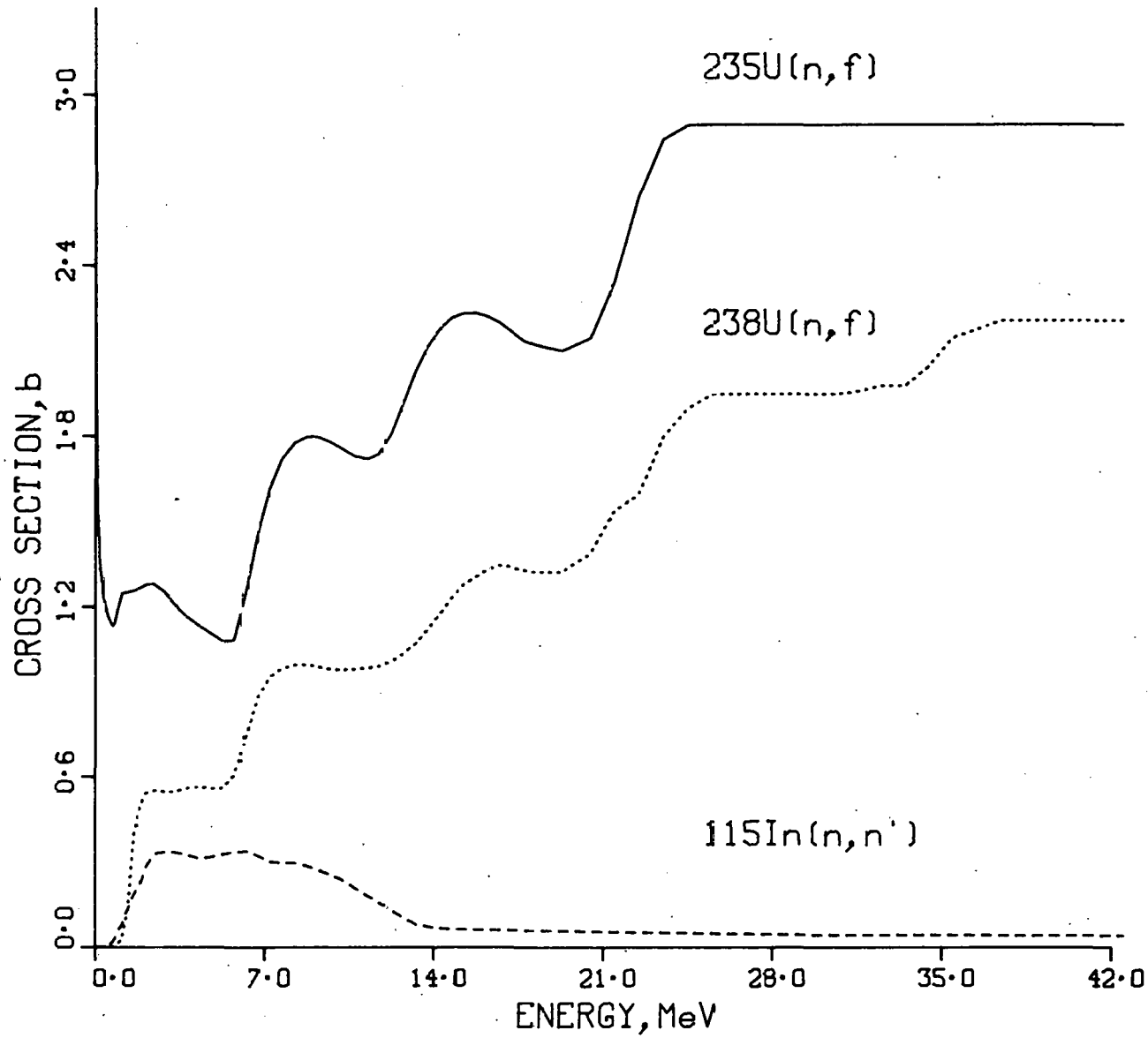


Figure 7. The $^{115}In(n,n')$, $^{235}U(n,f)$ and $^{238}U(n,f)$ cross sections are shown. The $^{115}In$ values below 10 MeV are from Ref. 12 and the fission values between 20 and 36 MeV are from Ref. 14.

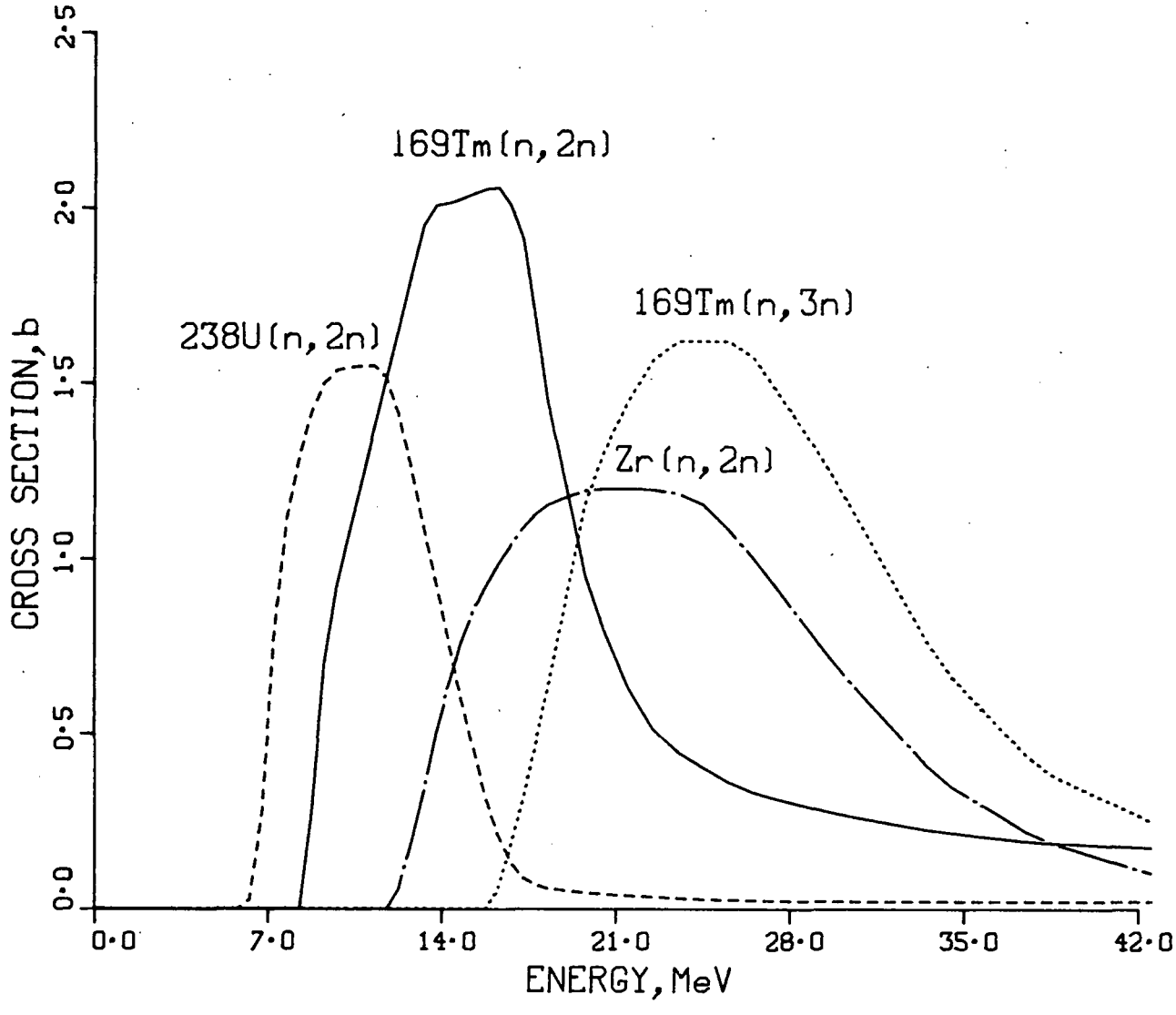


Figure 8. Tm(n,xn) and $^{90}$Zr(n,2n) cross sections are shown from Ref. 4 as well as $^{238}$U(n,2n) values from Ref. 11. The Zr(n,2n) values include small contributions from $^{91}$Zr(n,3n) and $^{92}$Zr(n,4n), based on measurements in Ref. 4. Total $^{89}$Zr production from Zr can be obtained by multiplying by 0.515, the abundance of $^{90}$Zr.

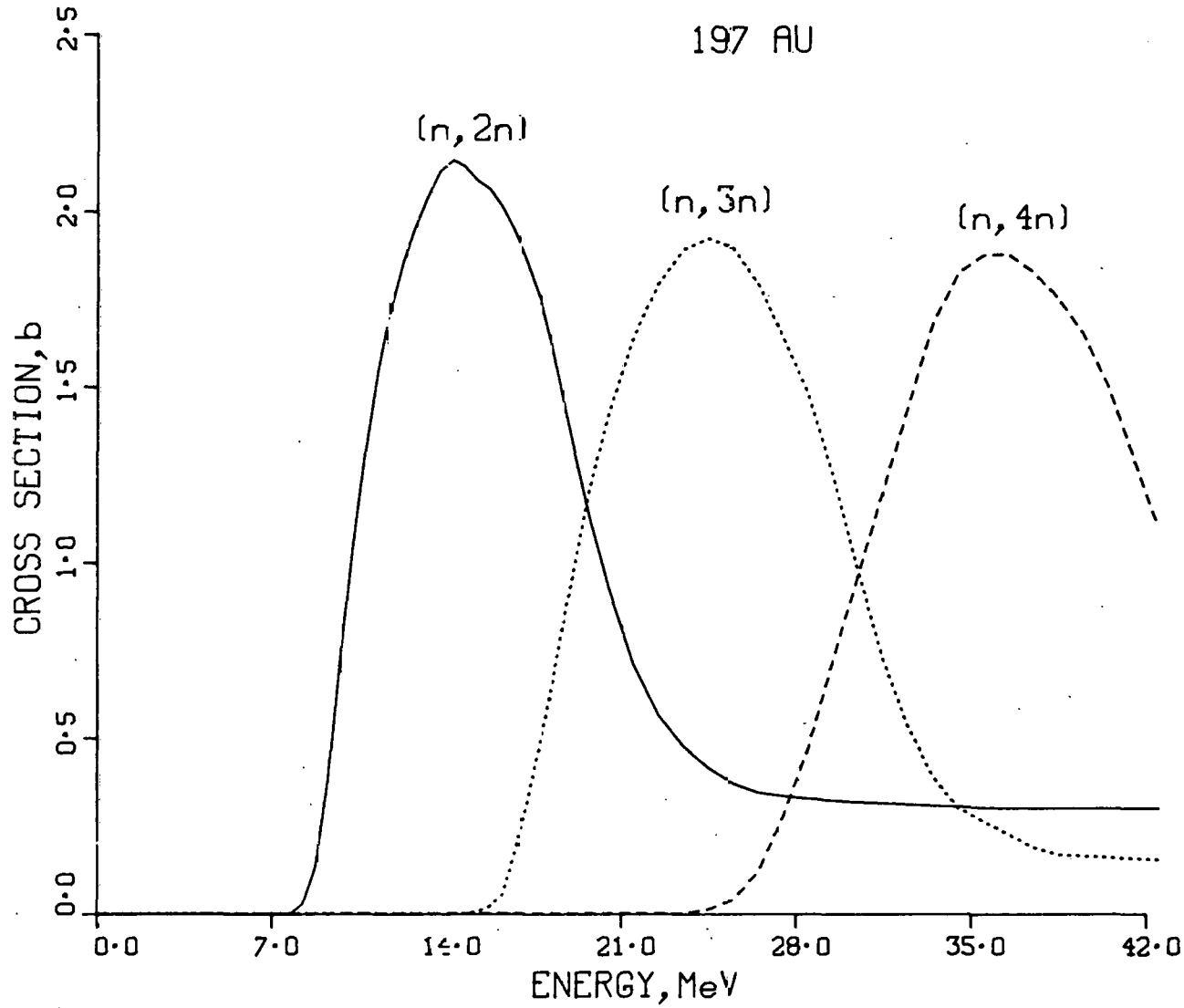


Figure 9. The $^{197}Au(n,xn)$ cross sections are shown. Values below 28 MeV are measurements given in Ref. 4.

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Library, FOM-Institut voor Plasma-Fysica, The Netherlands
Thermonuclear Library, Japan Atomic Energy Research Institute
Library, Kurchatov Institute of Atomic Energy, U.S.S.R.
Library, Laboratorio Gas Ionizata, Italy