LA-5221

162

An Evaluation of the
Radiative-Capture Cross Section
for Tungsten

Los Alamos
scientific laboratory

of the University of California

LOS ALAMOS, NEW MEXICO 87544

UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America. Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy ~~\$6.00~~; Microfiche \$0.95

\$4.00

LA-5221

UC-34

ISSUED: May 1973

An Evaluation of the Radiative-Capture Cross Section for Tungsten

by

J. J. Devaney

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

AN EVALUATION OF THE RADIATIVE-CAPTURE CROSS SECTION FOR TUNGSTEN

by

J. J. Devaney

ABSTRACT

An evaluation of the smooth neutron radiative-capture cross section for tungsten and its isotopes between 0.006 and 20 MeV is presented. Included are multiple-reaction corrections to the data which lower the cross section appreciably, especially above 1 MeV. The results are available in ENDF/B format.

I. INTRODUCTION

This paper, an interim report on the evaluation of tungsten neutron cross sections, gives the smooth radiative-capture cross sections from about 0.006 to 20 MeV. We have continued the conservative philosophy of the first paper in this series (De72a); that is, the expected fluctuations at low energy have not been displayed because they could not be substantiated from author to author nor from isotope to isotope. This remark is perhaps borderline for normal tungsten between 0.04 and 0.1 MeV (see Fig. 1 at the end of the report) where several authors (G161, Fr70, Ba69) partially agree on some fluctuation; however, this agreement is not substantiated by comparison of the abundance-weighted isotopic sum with natural tungsten, and it is even contradicted by others (e.g. Po67). We do find significant differences between the isotopic cross-sections, supported both by data and theory, with a reversal in relative magnitude of the isotopes at about 0.2 MeV. This reversal is caused by the differing onset and importance of inelastic-scattering competition. Beyond 3.4 MeV, we cannot justify any isotopic differences, so only the natural element is offered (See Fig. 16). The cross section above about 7 MeV is expected to result largely from direct and collective (semidirect) processes (C165, Br64, Gu66, Lo68, Be68, Be71, Lo70, Ve67, Be70, La59, Lo69, but see also Da64 and Sp69 who would permit higher statistical contributions). In our evaluation, we have weighted experiment according to the stated error, point scatter, comparisons

with other data, age, consistency, extensiveness, and general theoretical expectations. Wherever we could determine the sample size, we made multiple reaction corrections (Dr71, De72b, De73). However, without known sample sizes and the consequent amount of the multiple reaction correction needed, we are forced to regard some of the data above 1 MeV as only upper bounds to the true cross sections. These data are so indicated in the figures by downward directed arrows.

II. RESULTS

We present the smooth capture cross sections in a series of graphs, (Figs. 1-16), together with experimental points as corrected for multiple reactions (De73) and for revised standard cross sections where appropriate. We have put error bars on only a few representative points for clarity. References to experiment are given on each graph. Above 3.4 MeV, the curve for ^{186}W (Fig. 16) is our best estimate for all isotopes. Above 1 MeV, all even isotopes are given by ^{186}W , Fig. 15. The smooth cross sections are also given in tabular form in Appendix A, (ENDF/B format - Dr70).

The smooth curve through the data was generated from weighted cross-section averages over variable energy intervals. Intervals and numbers of experimental points were varied widely as appropriate to an optimum description of the smooth curves. Initial analyses were readjusted within errors so that the abundance-weighted isotopic sums matched the normal element to within experimental error.

^{180}W [abundance 0.135% (Ni 58)] and other isotopes (0.005%) were combined with ^{182}W (26.41%) for an effective abundance of 26.55%, and ^{183}W was taken as 14.40%, ^{184}W as 30.64%, and ^{186}W as 28.41% (Ni 58). The atomic weight of natural tungsten is 183.85.

III. DISCUSSION

A. 0.1- to 3.4-MeV Neutron Energy.

Comparison of our curves for W and ^{186}W , (Fig. 6 vs Fig. 10), shows that $\sigma_{n\gamma} (^{186}\text{W})$ crosses from below to above $\sigma_{n\gamma}(\text{W})$ at about 0.23 MeV. Interpreting this effect to be the more successful competition of inelastic scattering of the lighter isotopes, especially the odd isotope, ^{183}W , we have constructed the curves of Figs. 7-9 and 11-14. Onset of inelastic scattering is appreciable above the first level of the target, which is 0.1001 MeV for ^{182}W (Wa66), 0.0465 MeV for ^{183}W (Ar66), 0.1112 MeV for ^{184}W (Ma66), and 0.1225 MeV for ^{186}W (Gov 66). The (n, n') reaction, which also contributes below the first excited level of the target, is expected to be negligible within the accuracy of our estimates of the effect of inelastic scattering on the capture cross section, (See Ref. 14 of De73 for further discussion.) We used identities of the form

$$\sigma_{n\gamma} = \sigma_{\text{FCN}} \frac{\sigma_{n\gamma}}{\sigma_{\text{cnn}} + \sigma_{\text{nn}'} + \sigma_{n\gamma}} \quad (1)$$

to estimate the competition of inelastic scattering.

$\sigma_{\text{FCN}} = \sigma_{\text{cnn}} + \sigma_{\text{nn}'} + \sigma_{n\gamma}$ is the compound-nucleus-formation cross section; σ_{cnn} is the compound elastic cross section; and $\sigma_{\text{nn}'}$ is the total inelastic scattering. These parameters were taken from experiment, extrapolated from experiment, and estimated from optical-model calculations. The results were then revised to fit σ_T (De72a), as well as the known experimental $\sigma_{n\gamma}$ self-consistently for W and ^{186}W plus ^{182}W , ^{183}W , and ^{184}W only up to 0.1 MeV. All cross sections were further adjusted within errors so that the abundance-weighted isotopic sum gave the normal tungsten cross section to well within experimental error. In the above, we used the inelastic scattering data of Lister et al. (La67 and Gol66) for ^{182}W , ^{184}W , and ^{186}W . ^{183}W inelastic scattering was

estimated on the basis of the Artina level scheme (Ar66). It might be noted that this procedure gave cross sections differing by about a factor of 2 from the high-energy capture data of Kononov et al. (Ko66), which data we argue are justifiably rejected because of the equal disagreement of Kononov et al. not only with our above described extrapolation above 0.1 MeV, but also with the ^{186}W weighted average curve at 0.1 - 0.17 MeV (see Fig. 10). Their data also disagree with the W curve (see Fig. 6).

Reliable data for ^{182}W , ^{183}W , and ^{184}W end at 0.1 MeV. We do carry the evaluations for ^{182}W and ^{184}W distinct from ^{186}W to about 1 MeV according to the foregoing prescription in order to account for the natural vs ^{186}W cross-section difference. Beyond 1 MeV, we expect a gradual equivalence in cross section for the even isotopes, but, perhaps more importantly, we have already extrapolated 0.9 MeV above any datum. Consequently, we blend ^{182}W and ^{184}W into ^{186}W at about 1 MeV. However we keep ^{183}W distinct to higher energy. Accordingly, $\sigma_{n\gamma} ^{183}\text{W}$ is predicted to be smaller than for the even isotopes until about 3.4 MeV, where lack of data forces us to one curve for all isotopes. Convergence of the $\sigma_{n\gamma}$ curves is somewhat expected since one believes that isotopic differences tend to disappear at high energy, especially for the dominant collective giant-resonance part.

B. 3.4- to 20-MeV Neutron Energy.

As noted above, we offer one curve for all isotopes in this range (Fig. 16). We have data at 3-4 MeV for ^{186}W and at 14.1 MeV for $A = 181$ and 197 (Dr71). We know that the compound-nucleus process dominates at low energy and the direct and giant-resonance collective processes dominate at the middle energies (Cl65, Br64, Be68, Be70, Be71, Lo68, Lo69, Lo70, Gu66, Ve67, and La59, but see also Da64 and Sp69). Therefore, for the lower energies in this range, we take as a guide the work of Lane and Lynn (theory-La59), Schmittroth for ^{197}Au (theory-Sc72), Barry et al. for ^{238}U (expt.-Ba64), and Bergqvist et al. for ^{58}Fe (expt. and theory-Be68). From 7-15 MeV we are guided by Coulomb unfolded (p, γ) cross sections ($^{142}\text{Ce}(p, \gamma)$ ^{143}Pr , Da64 and Ve66; $^{100}\text{Mo}(p, \gamma)$ ^{101}Tc , Da68; $^{82}\text{Se}(p, \gamma)$ ^{83}Br , Da68; $^{130}\text{Te}(p, \gamma)$ ^{131}I , Da64; $^{209}\text{Bi}(p, \gamma)$ ^{210}Po , Da64; $^{59}\text{Co}(p, \gamma)$ ^{60}Ni , Dr72; $^{60}\text{Ni}(p, \gamma)$ ^{61}Cu , Dr72; and $^{64}\text{Zn}(p, \gamma)$ ^{65}Ga , Dr72); and by (n, γ) cross sections

on elements other than tungsten ($^{206}\text{Pb}(n,\gamma)^{207}\text{Pb}$, Be70; $^{58}\text{Ni}(n,\gamma)^{59}\text{Ni}$, Be68; $^{40}\text{Ca}(n,\gamma)^{41}\text{Ca}$, Be72a; $^{208}\text{Pb}(n,\gamma)^{209}\text{Pb}$, Be72b; $^{165}\text{Ho}(n,\gamma)^{166}\text{Ho}$, Mc73; and $^{238}\text{U}(n,\gamma)^{239}\text{U}$, Mc73). We unfold the coulomb penetration from the proton reactions using the code PENET kindly supplied by P. G. Young (Yo72).

In estimating the trend of $\sigma_{n,\gamma}$ above 15 MeV we have been guided by Gutfreund and Rakavy (Gu66) and by Longo and Saparetti (Lo68).

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the help of D. M. Drake, P. G. Young, D. R. Harris, and R. J. LaBauve. We are grateful for private communications of data from D. Drake, D. McDaniels, and P. G. Young; from the National Neutron Cross Section Center, Brookhaven National Laboratory by M. Goldberg; and from the Livermore Experimental Cross Section Information Library (refer to the University of California report series, UCRL-50400), Lawrence Livermore Laboratory, by R. J. Howerton. We are also pleased to acknowledge drafting and clerical help from B. Powell, D. McClellan, and N. Whittemore, as well as a critical reading by D. G. Foster, Jr.

REFERENCES

- Ar66. A. Artna, Nucl. Data B1-1-37 (1966).
- Ba64. J. F. Barry, J. Bunce, and P. H. White, J. Nucl. Energy 18, 481 (1964).
- Ba69. Z. M. Bartolome, R. W. Hockenbury, W. R. Moyer, J. R. Tatarczuk, and R. C. Block, "Neutron Radiative Capture and Transmission Measurements of W and Zr Isotopes in the keV Region," Nucl. Sci. Eng. 37, 137 (1969).
- Be58. T. S. Belanova, Soviet Physics-JETP 7, 397 (1958); and At. Energy. (USSR) 8, 549 (1960).
- Be60. T. S. Belanova, Soviet J. At. Energy 8, 462 (1961).
- Be62. I. Bergqvist, "Fast Neutron Radiative Capture Cross Sections in Ag, Ta, W, Au, Hg, and U," Arkiv. Fysik 23, 425 (1962).
- Be65. T. S. Belanova, A. A. Vankov, F. P. Mikhailus, and Yu. Ya. Stavisskii, "Absolute Measurement of the Absorption Cross Sections of Neutrons of 24 keV Energy," Soviet J. At. Energy 19, 858 (1965); or J. Nucl. Energy 20, 411 (1966).
- Be68. I. Bergqvist, B. Lundberg, L. Nilsson, and N. Starfelt, "Radiative Capture in Nickel and Bismuth of Neutrons in the MeV Region," Nucl. Phys. A120, 161 (1968).
- Be70. I. Bergqvist, B. Lundberg, and L. Nilsson "Cross Sections for High-Energy γ -Transitions from MeV Neutron Capture in ^{206}Pb ," Nucl. Phys. A153, 553 (1970).
- Be71. I. Bergqvist, D. Drake, and D. K. McDaniels, "Spectrum of the Reaction $^{208}\text{Pb}(n,\gamma)^{209}\text{Pb}$ and Semidirect Capture Theory," Phys. Rev. Letters 27, 269 (1971).
- Be72a. I. Bergqvist, D. M. Drake, and D. K. McDaniels, "Radiative Capture of Fast Neutrons by ^{40}Ca ," to be published.
- Be72b. I. Bergqvist, D. M. Drake, and D. K. McDaniels, "Radiative Capture of Energetic Neutrons by ^{208}Pb ," Nucl. Phys. A191, 641 (1972).
- Bo58. R. Booth, W. P. Ball, and M. H. MacGregor, "Neutron Activation Cross Sections at 25 keV," Phys. Rev. 112, 226 (1958); includes BNL corrections (p.c. 1971).
- Br64. G. E. Brown, "Direct and Semi-Direct (p, γ) and (n, γ) Reactions," Nucl. Phys. 57, 339 (1964).
- Ch66. A. K. Chaudhary and M. L. Sehgal, Phys. Rev. 152, 1055 (1966).
- Cl65. C. F. Clement, A. M. Lane, and J. R. Rook, "Radiative Capture by Excitation of Collective Vibrations," Nucl. Phys. 66, 273 (1965) and 293 (1965).
- Da64. P. J. Daly and P. F. D. Shaw, "Radiative Proton Capture Cross Sections in Heavy Nuclei," Nucl. Phys. 56, 322 (1964).
- Da68. P. J. Daly, B. M. Seppelt, and P. F. D. Shaw, "Radiative Capture Cross Sections in Medium-Weight and Heavy Nuclei," Nucl. Phys. A119, 673 (1968).
- De72a. J. J. Devaney and D. G. Foster, Jr., "An Evaluation of the Total Cross Section for Tungsten," Los Alamos Scientific Laboratory report LA-4928 (June 1972).
- De72b. J. J. Devaney, "Multiple-Reaction Correction to the Capture Cross Section," Phys. Rev. Lett. 29, 1567 (1972).
- De73. J. J. Devaney, "Multiple-Reaction Correction to Reaction Cross Sections," to be published in Nuclear Science & Engineering.
- Di60. B. C. Diven, J. Terrell, and A. Hemmendinger, "Radiative Capture Cross Sections for Fast Neutrons," Phys. Rev. 120, 556 (1960).
- Di70. M. Diksic, P. Strohal, and G. Petó, "Additional Measurements of the Radiative Capture Cross Sections for 3 MeV Neutrons," Acta Phys. Hung. 28, 257 (1970).
- Dr70. M. K. Drake, "Data Formats and Procedures for the ENDF Neutron Cross Section Library," Brookhaven National Laboratory Report BNL-50274, Vol. 1, (1970).
- Dr71. D. Drake, I. Bergqvist, and D. K. McDaniels, "Dependence of 14 MeV Radiative Neutron Capture on Mass Number," Phys. Lett. 36B 557 (1971).
- Dr72. D. M. Drake, S. L. Whetstone, and I. Halpern, "The Radiative Capture of Fast Protons by Medium Mass Nuclei," Nuclear Physics, to be published.

- Fr70. M. P. Fricke, W. M. Lopez, S. J. Friesenhahn, A. D. Carlson, and D. G. Costello, "Measurements of Cross Sections for the Radiative Capture of 1-keV to 1 MeV Neutrons by Mo, Rh, Ge, Ta, W, Re, Au, and ^{238}U ," 2nd Intern. Conf. Nuclear Data for Reactors (Helsinki, 1970), Vol. II, p 265.
- Gi61. J. H. Gibbons, R. L. Macklin, P. D. Miller, and J. H. Neiler, "Average Radiative Capture Cross Sections for 7 to 170 keV Neutrons," Phys. Rev. 122, 182 (1961). See also Ma63.
- Gi66. J. H. Gibbons, Conf. Neutron Cross Sections and Technology, Conf-660303, p 404 (Washington, 1966).
- Gol66. M. D. Goldberg et al., "Neutron Cross Sections," Brookhaven National Laboratory report BNL-325, 2nd Ed., Suppl. 2 (1966).
- Gov66. N. B. Gove, Nucl. Data B1-2-1 (1966).
- Gu66. H. Gutfreund and G. Rakavy, "The Direct Capture Mechanism for Intermediate Energy Nucleons," Nucl. Phys. 79, 257 (1966).
- Hu71. R. Hunter, L. Stewart, and T. A. Pitterle, private communication, R. Hunter, 1971.
- Jo59. A. E. Johnsrud, M. G. Silbert, and H. H. Barschall, "Energy Dependence of Fast-Neutron Activation Cross Sections," Phys. Rev. 116, 927 (1959). Renormalized to $\sigma_F^{235\text{U}}$, Hu71.
- Ka63. S. V. Kapchigashev, Yu. P. Popov, and F. L. Shapiro, "Capture Cross Sections in Construction Materials for Neutrons," Soviet J. At. Energy 15, 808 (1963).
- Ko58. V. N. Kononov, Yu. Ya. Stavisskii, and V. A. Tolstikov, "Measurement of the Radiative Capture Cross Section of 25 keV Neutrons," Soviet J. At. Energy 5, 1483 (1958) or J. Nucl. Energy 11, 46 (1959/60).
- Ko66. V. N. Kononov, Yu. Ya. Stavisskii, V. E. Kolesov, A. G. Dovbenko, V. S. Nosterenko, and V. I. Moroka, "Radiative Capture Cross Sections for 30-170 keV Neutrons," Soviet Nucl. Phys. 4, 204 (1967), and Nuclear Data for Reactors, Vol. I, 469 (IAEA, Paris Conf, 1966); also A. G. Dovbenko et al., Conf. Study of Nuclear Structure with Neutrons, Paper 199 (Antwerp, 1965).
- La59. A. M. Lane and J. E. Lynn, "Analysis of Experimental Data on Neutron Capture Reactions," Nucl. Phys. 11, 646 (1959).
- Le58. A. I. Leipunski et al., "Measurements of Radiative Capture Cross Sections for Fast Neutrons," Geneva Conf. Peaceful Uses At. Energy, A/Conf 15, 50 (1958), P/2219. Renormalized, St61.
- Li67. D. Lister, A. B. Smith, and C. Dunford, Phys. Rev. 162, 1077 (1967).
- Lo68. G. Longo and F. Saporetti, "Interference between Collective and Direct Nucleon Radiative Capture," Nuovo Cimento 56B, 264 (1968).
- Lo69. G. Longo and F. Saporetti, "Radiative Capture for Intermediate-Energy Neutrons," Nucl. Phys. A127, 503 (1969).
- Lo70. G. Longo and F. Saporetti, "Different Contributions of Direct and Collective Capture in (p, γ) and (n, γ) Reactions," Nuovo Cimento 67A, 356 (1970).
- Ly59. W. S. Lyon and R. L. Macklin, Phys. Rev. 114, 1619 (1959). Renormalized, Gol66.
- Ma57. R. L. Macklin, N. H. Lazar, and W. S. Lyon, "Neutron Activation Cross Sections with Sb-Be Neutrons," Phys. Rev. 107, 504 (1957).
- Ma63. R. L. Macklin, J. H. Gibbons, and T. Inada, "Neutron Capture Cross Sections Near 30 keV" Nucl. Phys. 43, 353 (1963).
- Ma66. M. J. Martin, Nucl. Data B1-1-63 (1966).
- Ma67. R. L. Macklin and J. H. Gibbons, "Capture-Cross-Sections Studies for 30-220-keV Neutrons Using a New Technique," Phys. Rev. 159, 1007 (1967).
- Mc73. D. K. McDaniels, private communication, 1972.
- Mi62. J. A. Miskel, K. V. Marsh, M. Lindner, and R. J. Nagle, "Neutron Activation Cross Sections," Phys. Rev. 128, 2717 (1962). Renormalized $\sigma_F^{235\text{U}}$, Hu71.
- Na71. R. J. Nagle, J. H. Landrum, and M. Lindner, "Neutron Capture Cross Sections in the MeV Range," 3rd. Conf. Neutron Cross Sections and Technology, Conf-710301, Vol. I, p 259 (Oak Ridge, 1971).
- Ni58. A. O. Nier recommendation in K. Way et al., Nuclear Data Sheets, Appendix 2, National Research Council (1958).
- Pa58. M. V. Pasechnik et al., "Fast Neutron Scattering and Capture by Atomic Nuclei," Geneva Conf. Peaceful Uses At. Energy, A/Conf 15, 18 (1958), P/2030; also Yu. V. Gofman and M. V. Pasechnik, USSR Conf. Low Energy Nuclear Reactions, p 15 (1957). Renormalized, Gol66.
- Pe58. J. L. Perkin, L. P. O'Connor, and R. F. Coleman, "Radiative Capture Cross Sections for 14.5 MeV Neutrons," Proc. Phys. Soc. (Lond.) 72, 505 (1958).
- Po67. W. P. Ponitz, D. Kompe, K. H. Beckerts, and H. O. Menlove, in the sequence of papers: D. Kompe, "Capture Cross Section Measurements," Nucl. Phys. A133, 513 (1969), H. O. Menlove and W. P. Ponitz, Nucl. Sci. Eng. 33, 24 (1968), and the Karlsruhe reports KFK-454, KFK-455, KFK-635.
- Sc72. F. A. Schmittroth, Trans. Am. Nucl. Soc. 15, 464 (1972) and "Theoretical Calculations of Fast Neutron Capture Cross Sections," Hanford Engineering Laboratory report HEDL-TME-71-106, (1971).
- Sp69. D. Sperber, "Statistical Theory of (n, γ) and (p, γ) Excitation Functions," Phys. Rev. 184, 1201 (1969).
- St60. Yu. Ya. Stavisskii and V. A. Tolstikov, "Cross Sections for the Radiative Capture of Fast Neutrons by the isotopes ^{51}V , ^{93}Nb , ^{186}W , and ^{210}Po ," Soviet J. At. Energy 9, 942 (1961), or J. Nucl. Energy 16, 496 (1962). Renormalized to $\sigma_F^{235\text{U}}$, Hu71.
- St61. Yu. Ya. Stavisskii and A. B. Shaper,

- "Fast-Neutron Radiative Capture Cross Sections in Tungsten and Molybdenum," Sov. Prog. Neut. Phys., p 227 (1961); also ANL-TRANS-168.
- Ve67. E. V. Verdick and J. M. Miller, "Radiative Capture and Neutron Emission in $\text{La}^{139}\alpha$ and Ce^{142}p ," Phys. Rev. 153, 1253 (1967).
- Wa66. K. Way, Nucl. Data B1-1-1 (1966).
- Yo72. P. G. Young, private communication (1972). We are grateful for this timely assistance by Dr. Young.
- Za68. G. G. Zaikin, "Cross Sections for Radiative Capture of Fast Neutrons by Cu^{63} , Cu^{65} , and W^{186} ," Soviet J. At. Energy 25, 1362 (1968). Renormalized σ_p ^{235}U , $\text{Hu}71$.

APPENDIX

ENDF/B-FORMAL LISTING OF TUNGSTEN CROSS SECTIONS

The capture cross section of tungsten and its isotopes from about 0.005 MeV to 20 MeV are listed in ENDF/B format. Holierith descriptive information is omitted here because it is included in the text.

TUNGSTEN SMOOTH RADIATIVE CAPTURE CROSS SECTION					MATERIAL 740	740 1451	7
7.40000+04	1.42213+02	0	0	0		740 3102	46
0.00000+0	0+0.4061+06	0		2	53	740 3102	47
17	2	53	4			740 3102	48
5.8	+03 7.	-01 7.	+03 5.98	-01 9.	+03 5.21	-01 740 3102	49
1.1	+04 4.65	-01 1.5	+04 3.94	-01 1.8	+04 3.54	-01 740 3102	50
2.2	+04 3.17	-01 2.5	+04 2.9	-01 3.	+04 2.67	-01 740 3102	51
3.5	+04 2.45	-01 4.	+04 2.28	-01 5.	+04 2.02	-01 740 3102	52
6.	+04 1.91	-01 7.	+04 1.87	-01 8.	+04 1.815	-01 740 3102	53
9.	+04 1.71	-01 1.	+05 1.55	-01 1.2	+05 1.31	-01 740 3102	54
1.4	+05 1.12	-01 1.6	+05 9.95	-02 1.8	+05 9.12	-02 740 3102	55
2.	+05 8.37	-02 2.4	+05 7.11	-02 2.6	+05 6.67	-02 740 3102	56
3.	+05 6.97	-02 3.4	+05 5.68	-02 4.	+05 5.21	-02 740 3102	57
4.6	+05 4.81	-02 5.0	+05 4.05	-02 6.	+05 4.44	-02 740 3102	58
8.	+05 4.11	-02 1.0	+06 3.92	-02 1.5	+06 3.36	-02 740 3102	59
1.8	+06 3.05	-02 2.0	+06 2.79	-02 2.5	+06 2.06	-02 740 3102	60
3.	+06 1.46	-02 3.4	+06 1.09	-02 5.	+06 2.39	-03 740 3102	61
6.	+06 1.07	-03 6.3	+06 9.1	-04 6.5	+06 8.8	-04 740 3102	62
6.7	+06 8.7	-04 7.0	+06 8.9	-04 8.	+06 1.06	-03 740 3102	63
9.	+06 1.33	-03 1.	+07 1.48	-03 1.1	+07 1.51	-03 740 3102	64
1.2	+07 1.35	-03 1.3	+07 1.22	-03 1.4	+07 1.0	-03 740 3102	65
1.7	+07 4.6	-04 2.0	+07 2.0	-04		740 3102	66

TUNGSTEN-182 SMOOTH RADIATIVE CAPTURE CROSS SECTION					MATERIAL 742	742 1451	6
7.41820+04	1.80385+02	0	0	0		742 3102	29
0.00000+0	0+6.19140+06	0		2	51	742 3102	30
17	2	51	4			742 3102	31
4.85	+03 7.	-01 1.	+04 5.83	-01 1.5	+04 4.85	-01 742 3102	32
2.	+04 4.	-01 2.5	+04 3.31	-01 3.	+04 2.8	-01 742 3102	33
3.5	+04 2.46	-01 4.	+04 2.19	-01 4.5	+04 2.0	-01 742 3102	34
5.	+04 1.95	-01 6.	+04 1.915	-01 7.	+04 1.93	-01 742 3102	35
7.5	+04 1.93	-01 8.	+04 1.89	-01 8.5	+04 1.81	-01 742 3102	36
9.	+04 1.715	-01 1.	+05 1.56	-01 1.2	+05 1.233	-01 742 3102	37
1.4	+05 1.16	-01 1.6	+05 1.03	-01 1.8	+05 9.37	-02 742 3102	38
2.	+05 8.64	-02 2.6	+05 6.87	-02 3.	+05 6.1	-02 742 3102	39
3.4	+05 5.6	-02 4.	+05 5.13	-02 5.	+05 4.65	-02 742 3102	40
6.0	+05 4.37	-02 7.	+05 4.23	-02 1.	+06 3.99	-02 742 3102	41
1.5	+06 3.4	-02 1.8	+06 3.12	-02 2.	+06 2.82	-02 742 3102	42
2.5	+06 2.09	-02 3.	+06 1.49	-02 3.4	+06 1.12	-02 742 3102	43
5.	+06 2.39	-03 6.	+06 1.07	-03 6.3	+06 9.1	-04 742 3102	44
6.5	+06 8.8	-04 6.7	+06 8.7	-04 7.0	+06 8.9	-04 742 3102	45
8.	+06 1.06	-03 9.	+06 1.33	-03 1.	+07 1.48	-03 742 3102	46
1.1	+07 1.51	-03 1.2	+07 1.35	-03 1.3	+07 1.22	-03 742 3102	47
1.4	+07 1.0	-03 1.7	+07 4.6	-04 2.	+07 2.0	-04 742 3102	48

TUNGSTEN-183 SMOOTH RADIATIVE CAPTURE CROSS SECTION MATERIAL 743 743 1451 6									
7.41830+04	1.81379+02	0	0					743	3102 27
0.00000+0	0+1.4111+06	0	2					48	743 3102 28
	13 2	48	4						743 3102 29
1.6	+04 7.01 -01 2.	+04 6.34 -01 2.5	+04 5.72 -01 743 3102 30						
3.	+04 5.23 -01 4.	+04 4.45 -01 5.	+04 3.79 -01 743 3102 31						
5.5	+04 3.51 -01 6.	+04 3.32 -01 7.	+04 3.025 -01 743 3102 32						
8.	+04 2.725 -01 9.	+04 2.43 -01 9.5	+04 2.35 -01 743 3102 33						
1.	+05 2.3 -01 1.4	+05 1.535 -01 1.8	+05 1.05 -01 743 3102 34						
2.	+05 8.97 -02 2.2	+05 7.85 -02 2.4	+05 7.15 -02 743 3102 35						
2.6	+05 5.59 -02 3.	+05 5.89 -02 3.4	+05 5.41 -02 743 3102 36						
4.	+05 4.9 -02 5.	+05 4.315 -02 6.	+05 3.95 -02 743 3102 37						
7.	+05 3.71 -02 9.	+05 3.49 -02 1.1	+06 3.31 -02 743 3102 38						
1.5	+06 2.9 -02 1.8	+06 2.61 -02 2.	+06 2.39 -02 743 3102 39						
2.4	+06 1.89 -02 3.	+06 1.28 -02 3.4	+06 9.7 -03 743 3102 40						
5.0	+06 2.39 -03 6.	+06 1.07 -03 6.3	+06 9.1 -04 743 3102 41						
6.5	+06 8.8 -04 6.7	+06 8.7 -04 7.0	+06 8.9 -04 743 3102 42						
8.	+06 1.06 -03 9.	+06 1.33 -03 1.	+07 1.48 -03 743 3102 43						
1.1	+07 1.51 -03 1.2	+07 1.35 -03 1.3	+07 1.22 -03 743 3102 44						
1.4	+07 1.0 -03 1.7	+07 4.6 -04 2.0	+07 2.0 -04 743 3102 45						

TUNGSTEN-184 SMOOTH RADIATIVE CAPTURE CROSS SECTION MATERIAL 744 744 1451 6									
7.41840+04	1.82371+02	0	0					744	3102 30
0.00000+0	0+5.7497+06	0	2					49	744 3102 31
	16 2	49	4						744 3102 32
4.	+03 7.07 -01 6.	+03 5.25 -01 8.	+03 4.08 -01 744 3102 33						
1.	+04 3.29 -01 1.2	+04 3.12 -01 1.5	+04 2.77 -01 744 3102 34						
2.	+04 2.32 -01 2.5	+04 2.06 -01 3.	+04 1.86 -01 744 3102 35						
3.5	+04 1.75 -01 4.	+04 1.72 -01 4.5	+04 1.73 -01 744 3102 36						
6.	+04 1.66 -01 8.	+04 1.54 -01 9.	+04 1.48 -01 744 3102 37						
1.	+05 1.37 -01 1.6	+05 9.04 -02 2.	+05 8.15 -02 744 3102 38						
2.4	+05 6.88 -02 2.6	+05 6.45 -02 3.	+05 5.86 -02 744 3102 39						
3.6	+05 5.46 -02 4.	+05 5.05 -02 5.	+05 4.6 -02 744 3102 40						
6.	+05 4.34 -02 7.	+05 4.3 -02 8.	+05 4.3 -02 744 3102 41						
1.	+06 4.02 -02 1.5	+06 3.4 -02 1.8	+06 3.12 -02 744 3102 42						
2.	+06 2.82 -02 2.5	+06 2.09 -02 3.	+06 1.49 -02 744 3102 43						
3.4	+06 1.12 -02 5.	+06 2.39 -03 6.	+06 1.07 -03 744 3102 44						
6.3	+06 9.1 -04 6.5	+06 8.8 -04 6.7	+06 8.7 -04 744 3102 45						
7.	+06 8.9 -04 8.	+06 1.06 -03 9.	+06 1.33 -03 744 3102 46						
1.	+07 1.48 -03 1.1	+07 1.51 -03 1.2	+07 1.35 -03 744 3102 47						
1.3	+07 1.22 -03 1.4	+07 1.0 -03 1.7	+07 4.6 -04 744 3102 48						
2.0	+07 2.0 -04		744 3102 49						

TUNGSTEN-186 SMOOTH RADIATIVE CAPTURE CROSS SECTION MATERIAL 746 746 1451 6									
7.41860+04	1.84357+02	0	0					746	3102 40
0.00000+0	0 5.46610+06	0	2					46	746 3102 41
	15 2	46	4						746 3102 42
1.4	+03 7. -01 1.8	+03 5.5 -01 2.8	+03 4.5 -01 746 3102 43						
4.5	+03 3.8 -01 6.3	+03 3.4 -01 9.	+03 3.07 -01 746 3102 44						
1.4	+04 2.65 -01 2.	+04 2.32 -01 3.	+04 1.98 -01 746 3102 45						
4.	+04 1.76 -01 5.	+04 1.62 -01 6.	+04 1.59 -01 746 3102 46						
7.5	+04 1.57 -01 8.2	+04 1.49 -01 1.	+05 1.25 -01 746 3102 47						
1.2	+05 1.11 -01 1.6	+05 9.1 -02 2.	+05 7.99 -02 746 3102 48						
2.4	+05 7.25 -02 3.	+05 6.5 -02 4.	+05 5.13 -02 746 3102 49						
5.	+05 5.04 -02 6.	+05 4.8 -02 8.	+05 4.34 -02 746 3102 50						
1.	+06 4.01 -02 1.5	+06 3.4 -02 1.8	+06 3.12 -02 746 3102 51						
2.	+06 2.82 -02 2.5	+06 2.09 -02 3.	+06 1.49 -02 746 3102 52						
3.4	+06 1.12 -02 5.	+06 2.39 -03 6.	+06 1.07 -03 746 3102 53						
6.3	+06 9.1 -04 6.5	+06 8.8 -04 6.7	+06 8.7 -04 746 3102 54						
7.0	+06 8.9 -04 8.	+06 1.06 -03 9.	+06 1.33 -03 746 3102 55						
1.	+07 1.48 -03 1.1	+07 1.51 -03 1.2	+07 1.35 -03 746 3102 56						
1.3	+07 1.22 -03 1.4	+07 1.0 -03 1.7	+07 4.6 -04 746 3102 57						
2.0	+07 2.0 -04		746 3102 58

Fig. 1. Natural tungsten smooth radiative capture cross section.

Fig. 2. Tungsten-182 smooth radiative capture cross section.

Fig. 3. Tungsten-183 smooth radiative capture cross section.

Fig. 4. Tungsten-184 smooth radiative capture cross section.

Fig. 5. Tungsten-186 smooth radiative capture cross section.

Fig. 6. Natural tungsten smooth radiative capture cross section.

Fig. 7. Tungsten-182 smooth radiative capture cross section.

Fig. 8. Tungsten-183 smooth radiative capture cross section.

Fig. 9. Tungsten-184 smooth radiative capture cross section.

Fig. 10. Tungsten-186 smooth radiative capture cross section.

Fig. 11. Natural tungsten radiative capture cross section.

Fig. 12. Tungsten-182 radiative capture cross section.

Fig. 13. Tungsten-183 radiative capture cross section.

Fig. 14. Tungsten-184 radiative capture cross section.

Fig. 15. Tungsten-186 radiative capture cross section.

Fig. 16. Tungsten radiative capture cross section.