Conf-940507--45

BNL-61448

# TEMPERATURE DEPENDENCE OF THE WESTCOTT G-FACTOR FOR NEUTRON CAPTURE AND NEUTRON FISSION REACTIONS IN ENDF/B-VI


Norman E. Holden
High Flux Beam Reactor
Reactor Division
Brookhaven National Laboratory
Upton, New York 11973 USA
(516) 282-5204



## ABSTRACT

The Westcott g-factors, which allow the user to determine reaction rates for nuclear reactions taking place at various temperatures, have been calculated using data from the Evaluated Neutron Nuclear Data library, ENDF-VI. The nuclides chosen have g-factors which are significantly different from unity and result in different reaction rates compared to nuclides whose neutron capture and fission cross sections vary as the reciprocal of the neutron's velocity. Values are presented as a function of temperature up to 400° C.


## I. INTRODUCTION

Reactor neutron capture and fission reaction rates are determined as the product of the neutron flux density and the neutron capture or fission cross section. The standard energy for tabulation of thermal neutron cross sections is that of room temperature of 20.43° C, corresponding to a neutron energy of 0.0253 ev or a neutron velocity of 2200 m/s. Since most reactors do not operate at a temperature of 20° C, there must be some mechanism for converting the cross section, $\sigma_0$, at the tabulated energy to the effective cross section, $\hat{\sigma}$, at the actual temperature of the reactor.

Westcott[1] developed a method for converting $\sigma_0$ to $\hat{\sigma}$ by describing the neutron spectrum as a combination of a Maxwell-Boltzmann speed distribution function which is characterized by a temperature, T, and a component of epithermal energy neutrons, whose neutron flux density distribution is proportional to the reciprocal of the neutron energy, i.e., dE/E. For an isotope whose neutron capture cross section does not vary inversely with the neutron velocity, $\hat{\sigma} = \sigma_0(g+rs)$, where g is the Westcott g-factor, the epithermal index, r, is approximately the fraction of the total neutron density in the epithermal component, and s is a temperature dependent quantity related to the reduced resonance integral.

In the absence of an epithermal component, r = 0, and the g-factor is the ratio of the Maxwellian averaged cross section, $\sigma_t$, to the 2200 m/s cross section, $\sigma_0$.

$$g = \sigma_t/\sigma_0 = (1/v_0\sigma_0)\int (4/\sqrt{\pi})(v/v_t)^3\ \sigma(v)\ \exp(-v/v_t)^2 dv$$

If $\sigma(v)$ varies as 1/v, the Maxwellian cross section is equivalent to the 2200 m/s value and g = 1. For nuclides with resonances in the thermal neutron energy range, g-factors are different from unity and g-factors will be temperature dependent.

## II. DISCUSSION

A number of nuclides in the evaluated neutron data library, ENDF/B-VI, whose neutron capture and fission cross sections are significantly non 1/v, have been analysed to determine their Westcott g-factors as a function of various Maxwellian temperatures from 20° C to 400° C. The resulting g-factor temperature dependence is listed in the accompanying tables for fifty seven neutron capture reactions as well as thirty neutron fission reactions at five

MASTER

## DISCLAIMER

different reactor temperatures.

The g-factors should be unity for those nuclei for which no resonance parameters have been measured. There are six nuclei to which this situation applies, $^{238}$Np, $^{236,237,243}$Pu, and $^{250,251}$Cf. Comparing the 20° C values for these nuclei, the $g_\gamma$ or $g_f$ values are all unity within 0.8 percent, except for the $^{250}$Cf. The values of the g-factor depend upon the location and the strength of the resonance parameters for the nuclides. If there are no resonances near the thermal energy, the g-factor would be close to unity. This can be seen in the values for $^{197}$Au, $^{238}$U, $^{185}$Re, $^{187}$Re, $^{244}$Pu, $^{242}$Cm, $^{244}$Cm, $^{246}$Cm and $^{248}$Cm, where the nearest resonance is at 2 eV to 5 eV, compared to the thermal energies of 0.02 eV to 0.05 eV. Whether the g-factor increases or decreases depends upon whether the closest resonance is at positive or negative energies. When the resonance is a bound level (negative energy), the g-factor will decrease with higher temperatures.

There are three nuclei, $^{237}$U, $^{246,248}$Cm, which have no negative energy resonances, corresponding to bound levels in that nucleus, and have no low lying positive energy resonances. One would expect both capture and fission g-factors to be close to unity for these nuclei and this is indeed the case.

There are nine nuclei. $^{230}$Th, $^{234,236,238}$U, $^{242,244}$Pu, $^{242,244}$Cm, and $^{252}$Cf for which there are no bound levels or positive energy resonances close to zero energy. Again, one would expect the g-factors for the two resonances to be close to unity in each of these cases. This is the case, although there is a difference between the $g_\gamma$ and the $g_f$ values for $^{242}$Pu and $^{244}$Cm. In the first case, there are no fission widths for the bound or first four positive energy resonances, so the $g_f$ value is much closer to unity than the $g_\gamma$ value. In the second case, most of the fission cross section comes from the bound level and the $g_f$ value is less than unity, while the capture cross section comes primarily from the positive energy resonances and the $g_\gamma$ value is slightly larger than unity.

There are two nuclei, $^{232}$U, and $^{238}$Pu, for which there are bound levels close to zero energy but no positive energy resonances below one or two electron volts. One would expect g-factors significantly less than unity for these nuclei and the $g_\gamma$ and $g_f$ values are about 0.97 and 0.96.

## III. TEMPERATURE DEPENDENCE

The changes in $g_f$ and $g_\gamma$ for $^{233,235}$U and $^{239,241}$Pu at the various temperatures indicate that some of the earlier calculations of the thermal energy parameters of the fissile nuclei, which assumed a single $g_f$ and $g_\gamma$ for the maxwellian cross section measurements in various reactors, might have problems. A perennial concern in those calculations has been the much lower 220 m/s fission cross sections for $^{235}$U which were derived from the maxwellian measurement reaction rates compared to the direct 2200 m/s cross section measurements. If the lower $g_f$ value at the higher temperatures were utilized, the resulting equivalent 2200 m/s fission cross section might have been larger.

The uncertainties of g-factors have been analysed by Westcott[2] for $^{233}$U, $^{235}$U, $^{239}$Pu, and $^{241}$Pu at room temperatures. The uncertainties varied from 0.1 to 0.3 percent. These are basically standard nuclides for which there are much data in the literature at room temperatures. In the case of the various nuclides studied here, the data are much less extensive. The uncertainty could be as much as an order of magnitude larger for these nuclides.

## REFERENCES

[1]C.H. Westcott, J. Nucl. Energy 2, 59 (1955).

[2]C.H. Westcott, Chalk River Nuclear Laboratory Report, AECL-3255 (April 1969).

*This research was carried out under the auspices of the US Department of Energy Contract No. DE-AC02-76CH00016.

Westcott G-Factor for (N,Gamma) Reactions

| Nuclide | 20° C | 100° C | 200° C | 300° C | 400° C |
|---|---|---|---|---|---|
| $^{103}Rh$ | 1.0246 | 1.0435 | 1.0685 | 1.0953 | 1.1240 |
| $^{113}Cd$ | 1.3324 | 1.6155 | 1.9838 | 2.3165 | 2.5873 |
| $^{115}In$ | 1.0205 | 1.0360 | 1.0564 | 1.0779 | 1.1006 |
| $^{135}Xe$ | 1.1613 | 1.2243 | 1.2497 | 1.2368 | 1.2022 |
| $^{148}Pm$ | 1.4758 | 1.9072 | 2.4781 | 2.9906 | 3.4011 |
| $^{149}Sm$ | 1.7090 | 2.0320 | 2.2853 | 2.4033 | 2.4305 |
| $^{151}Sm$ | 0.9291 | 0.8550 | 0.7784 | 0.7153 | 0.6624 |
| $^{151}Eu$ | 0.9014 | 0.8307 | 0.7717 | 0.7440 | 0.7463 |
| $^{152}Eu$ | 0.9272 | 0.8562 | 0.7819 | 0.7198 | 0.6671 |
| $^{153}Eu$ | 0.9741 | 0.9523 | 0.9276 | 0.9055 | 0.8856 |
| $^{154}Eu$ | 1.2278 | 1.4201 | 1.6744 | 1.9131 | 2.1169 |
| $^{155}Eu$ | 1.0573 | 1.1057 | 1.1778 | 1.2726 | 1.4078 |
| $^{155}Gd$ | 0.8443 | 0.7845 | 0.7115 | 0.6453 | 0.5872 |
| $^{157}Gd$ | 0.8521 | 0.7983 | 0.7288 | 0.6640 | 0.6060 |
| $^{164}Dy$ | 0.9880 | 0.9779 | 0.9656 | 0.9537 | 0.9422 |
| $^{175}Lu$ | 0.9771 | 0.9572 | 0.9351 | 0.9156 | 0.8983 |
| $^{176}Lu$ | 1.7458 | 2.3441 | 3.0451 | 3.5959 | 3.9807 |
| $^{177}Hf$ | 1.0217 | 1.0382 | 1.0601 | 1.0836 | 1.1091 |
| $^{182}Ta$ | 1.6385 | 2.1545 | 2.7700 | 3.2648 | 3.6196 |
| $^{185}Re$ | 1.0066 | 1.0105 | 1.0156 | 1.0209 | 1.0265 |
| $^{187}Re$ | 0.9962 | 0.9915 | 0.9858 | 0.9802 | 0.9747 |
| $^{197}Au$ | 1.0066 | 1.0106 | 1.0156 | 1.0207 | 1.0259 |
| $^{230}Th$ | 1.0076 | 1.0125 | 1.0193 | 1.0271 | 1.0359 |
| $^{231}Pa$ | 0.9960 | 0.9963 | 1.0307 | 1.1325 | 1.3240 |
| $^{233}Pa$ | 0.9812 | 0.9614 | 0.9419 | 0.9269 | 0.9156 |
| $^{232}U$ | 0.9738 | 0.9504 | 0.9232 | 0.8981 | 0.8748 |
| $^{233}U$ | 1.0269 | 1.0495 | 1.0790 | 1.1056 | 1.1272 |
| $^{234}U$ | 0.9920 | 0.9839 | 0.9741 | 0.9646 | 0.9553 |
| $^{235}U$ | 0.9832 | 0.9692 | 0.9588 | 0.9551 | 0.9558 |
| $^{236}U$ | 1.0040 | 1.0059 | 1.0082 | 1.0106 | 1.0131 |
| $^{237}U$ | 0.9901 | 0.9809 | 0.9699 | 0.9591 | 0.9486 |
| $^{238}U$ | 1.0040 | 1.0057 | 1.0079 | 1.0100 | 1.0122 |
| $^{237}Np$ | 0.9926 | 0.9865 | 0.9845 | 0.9960 | 1.0317 |
| $^{238}Np$ | 0.9927 | 0.9851 | 0.9760 | 0.9672 | 0.9588 |
| $^{236}Pu$ | 0.9919 | 0.9838 | 0.9740 | 0.9644 | 0.9551 |
| $^{237}Pu$ | 1.0012 | 1.0012 | 1.0012 | 1.0012 | 1.0012 |
| $^{238}Pu$ | 0.9586 | 0.9219 | 0.8803 | 0.8428 | 0.8086 |
| $^{239}Pu$ | 1.1449 | 1.3044 | 1.6067 | 2.0214 | 2.5134 |
| $^{240}Pu$ | 1.0294 | 1.0524 | 1.0834 | 1.1170 | 1.1543 |
| $^{241}Pu$ | 1.0198 | 1.0401 | 1.1084 | 1.2116 | 1.3316 |
| $^{242}Pu$ | 1.0115 | 1.0194 | 1.0295 | 1.0400 | 1.0507 |
| $^{243}Pu$ | 0.9935 | 0.9865 | 0.9781 | 0.9701 | 0.9624 |
| $^{244}Pu$ | 0.9992 | 0.9970 | 0.9942 | 0.9915 | 0.9887 |
| $^{241}Am$ | 1.0018 | 1.0164 | 1.0919 | 1.2436 | 1.4634 |
| $^{242m}Am$ | 1.1085 | 1.1857 | 1.2717 | 1.3416 | 1.3944 |
| $^{243}Am$ | 1.0153 | 1.0267 | 1.0427 | 1.0618 | 1.0852 |
| $^{242}Cm$ | 0.9943 | 0.9880 | 0.9803 | 0.9728 | 0.9654 |
| $^{243}Cm$ | 1.0065 | 1.0103 | 1.0155 | 1.0211 | 1.0272 |
| $^{244}Cm$ | 1.0012 | 1.0006 | 0.9999 | 0.9994 | 0.9991 |
| $^{245}Cm$ | 0.9495 | 0.9076 | 0.8601 | 0.8174 | 0.7790 |
| $^{246}Cm$ | 1.0072 | 1.0117 | 1.0172 | 1.0229 | 1.0286 |
| $^{247}Cm$ | 1.0270 | 1.0484 | 1.0782 | 1.1121 | 1.1523 |
| $^{248}Cm$ | 1.0038 | 1.0055 | 1.0076 | 1.0097 | 1.0110 |
| $^{249}Cf$ | 0.9741 | 0.9504 | 0.9266 | 0.9092 | 0.8989 |
| $^{250}Cf$ | 1.0150 | 1.0246 | 1.0389 | 1.0594 | 1.0970 |
| $^{251}Cf$ | 0.9951 | 0.9891 | 0.9821 | 0.9761 | 0.9717 |
| $^{252}Cf$ | 0.9922 | 0.9844 | 0.9748 | 0.9655 | 0.9564 |

Wescott G-Factor for (N,Fission) Reactions

| Nuclide | 20° C | 100° C | 200° C | 300° C | 400° C |
|---|---|---|---|---|---|
| $^{231}Pa$ | 1.0167 | 1.0351 | 1.0944 | 1.2308 | 1.4795 |
| $^{232}U$ | 0.9785 | 0.9591 | 0.9365 | 0.9156 | 0.8963 |
| $^{233}U$ | 0.9973 | 0.9959 | 0.9954 | 0.9963 | 0.9979 |
| $^{234}U$ | 0.9904 | 0.9810 | 0.9695 | 0.9584 | 0.9476 |
| $^{235}U$ | 0.9817 | 0.9657 | 0.9504 | 0.9398 | 0.9326 |
| $^{236}U$ | 1.0055 | 1.0086 | 1.0125 | 1.0165 | 1.0131 |
| $^{237}U$ | 0.9901 | 0.9811 | 0.9701 | 0.9594 | 0.9490 |
| $^{237}Np$ | 0.9858 | 0.9716 | 0.9558 | 0.9439 | 0.9382 |
| $^{238}Np$ | 0.9925 | 0.9848 | 0.9754 | 0.9664 | 0.9577 |
| $^{236}Pu$ | 0.9919 | 0.9838 | 0.9740 | 0.9644 | 0.9551 |
| $^{237}Pu$ | 1.0011 | 1.0012 | 1.0012 | 1.0012 | 1.0012 |
| $^{238}Pu$ | 0.9588 | 0.9222 | 0.8807 | 0.8433 | 0.8093 |
| $^{239}Pu$ | 1.0553 | 1.1214 | 1.2591 | 1.4581 | 1.7008 |
| $^{240}Pu$ | 1.0261 | 1.0464 | 1.0737 | 1.1034 | 1.1362 |
| $^{241}Pu$ | 1.0539 | 1.1074 | 1.2088 | 1.3124 | 1.4275 |
| $^{242}Pu$ | 1.0021 | 1.0023 | 1.0025 | 1.0028 | 1.0030 |
| $^{243}Pu$ | 0.9935 | 0.9865 | 0.9781 | 0.9700 | 0.9624 |
| $^{241}Am$ | 1.0146 | 1.0455 | 1.1563 | 1.3638 | 1.6552 |
| $^{242m}Am$ | 1.1025 | 1.1756 | 1.2571 | 1.3235 | 1.3740 |
| $^{243}Am$ | 1.0136 | 1.0242 | 1.0418 | 1.0688 | 1.1093 |
| $^{242}Cm$ | 0.9938 | 0.9872 | 0.9791 | 0.9711 | 0.9634 |
| $^{243}Cm$ | 1.0074 | 1.0119 | 1.0180 | 1.0245 | 1.0315 |
| $^{244}Cm$ | 0.9905 | 0.9811 | 0.9698 | 0.9589 | 0.9485 |
| $^{245}Cm$ | 0.9552 | 0.9180 | 0.8761 | 0.8387 | 0.8055 |
| $^{246}Cm$ | 1.0077 | 1.0125 | 1.0186 | 1.0247 | 1.0309 |
| $^{247}Cm$ | 1.0296 | 1.0533 | 1.0859 | 1.1230 | 1.1666 |
| $^{248}Cm$ | 1.0036 | 1.0052 | 1.0071 | 1.0091 | 1.0119 |
| $^{249}Cf$ | 0.9805 | 0.9623 | 0.9454 | 0.9353 | 0.9330 |
| $^{251}Cf$ | 0.9993 | 0.9961 | 0.9932 | 0.9920 | 0.9934 |
| $^{252}Cf$ | 0.9924 | 0.9847 | 0.9754 | 0.9663 | 0.9573 |