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Neutron and Non-Neutron Nuclear Data for Radiation Dosimetry

Reference: Holden, N.E., **"Neutron and Non-Neutron Nuclear Data for Radiation Dosimetry"**, *Reactor Dosimetry,ASTM STP1398,* John G. Williams, David W. Vehar, Frank H. Ruddy and David M. Gilliam, Eds., American Society for Testing and Materials, West Conshoken, PA,2000.

Abstract: Neutron nuclear data that is used in reactor dosimetry include thermal neutron cross sections and neutron resonance integrals for reactions on a target nucleus. Non-neutron nuclear data used in reactor dosimetry include isotopic compositions of target nuclides and radioactive half-lives, gamma-ray energies and intensities of reaction product nuclides. All of these data are periodically evaluated and recommended values are provided in the Handbook of Chemistry and Physics. The latest recommended values are discussed and they are contrasted with some earlier nuclear data, which were provided with neutron detector foils.

Keywords: Neutron cross section, resonance integral, half-life isotopic composition, gamma-ray energy, gamma-ray intensity

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INTRODUCTION

The published literature provide a large variety of neutron cross section information and non-neutron nuclear data which are periodically evaluated. The recommended values from the evaluation are published in the Chemical Rubber Company's Handbook of Chemistry and Physics. In the alternating years, either neutron or non-neutron data are evaluated.

In the odd-numbered years, all pertinent information on the isotopic masses, atomic weights and isotopic composition, radioactive half-lives, alpha particle, beta, proton, positron, isomeric transition energy and branching ratios and (-ray energies and abundances, as well as other nuclear information are reviewed and "best values" are recommended[*1*].

In the even-numbered years, neutron cross sections for

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thermal energy reactions, neutron resonance integrals, neutron scattering lengths, and maxwellian averaged neutron cross sections at an energy of 30 kev for astrophysics applications are reviewed and "best values" are recommended[*2*]. In the year 2000 edition, "fission spectrum averaged neutron cross sections" will be evaluated and included.

There have been a number of problems with the data reported in the catalogues for neutron detector foils. Although potential users are warned that quoted values serve only as a guide, users should be aware, when the data are seriously out of date or when the quoted values have been misinterpreted because of lack of knowledge of the resulting decay scheme. These problems will be discussed.

THERMAL NEUTRON CROSS SECTIONS AND RESONANCE INTEGRALS

The latest evaluation of the thermal neutron cross sections and resonance integrals lead to different values of these parameters compared to values provided with detector foils. The elemental comparisons are listed in Table 1 in the units of 10^{-24} cm^2 (barns) for the specific reactions.

Table 1. Recommended Cross Sections, Resonance Integrals

Nuclide	Old Sigma	Rec. Sigma	Old ResInt	Rec.ResInt
^{23}Na(n,()	0.54 b	0.53 b	0.35 b	0.32 b
^{45}Sc(n,()	26.5 b	27.2 b	11.3 b	12. b
^{55}Mn(n,()	13.2 b	13.3 b	14. b	14.0 b
Fe(n,()			1.58 b	1.4 b
^{59}Co(n,()	37.4 b	37.12 b	77. b	74. b
Cu(n,()	4.5 b	3.8 b	5.6 b	4.1 b
Mo(n,()			25. b	26. b
Ag(n,()			750. b	767. b
In(n,()	170. b	197. b	3243. b	3300. b
Dy(n,()	920. b	950. b		
Lu(n,()			900. b	830. b
Ta(n,()			720. b	650. b
W(n,()			350. b	360. b
^{197}Au(n,()	100. b	98.65 b	1565. b	1550. b

Th(n,()			86. b	85. b
^{235}U(n,f)	575. b	582. b		
^{238}U(n,f)			278. b	277. b
^{239}Pu(n,f)			304. b	300. b

Even when compared with the last edition of the Neutron Cross Section book[*3*] (previously called BNL-325), there have been significant changes in many neutron cross sections. There are additional measured (n,p) and (n,") reactions at thermal neutron energies for a number of elements. In many of these cases, the target nuclide is radioactive, e.g., the 2.3 barn (n,p) cross section and the 0.9 barn (n,") cross section of $7x10^5$ year ^{26}Al, or the 0.047 barn (n,p) cross section and the 0.59 millibarn (n,") cross sections of $3x10^5$ year ^{36}Cl. In both of these cases, there had previously not been any measured data available for either reaction.

For the case of the stable target nuclei, the "-particle production in sulfur at thermal neutron energies is lower, ^{32}S(n,") < 0.5 millibarn compared to 7 millibarn previously and ^{33}S(n,") = 0.12 millibarn compared to 0.19 millibarn before. The neutron destruction cross section for ^{65}Zn is 66 ± 8 barn compared to 250 barn. The neutron capture cross section for ^{64}Ni is lower, 1.6 barn compared to 1.8 barn. The neutron fission cross section for ^{238}Np is 30% larger, while the fission resonance integral is 60% larger. The ^{107}Ag neutron capture cross section is 6% lower, while the ^{115}In(n,() value is 1.5% larger. The neutron capture cross section for ^{237}Np is about 10% lower, while the neutron capture resonance integral for ^{175}Lu is 35% larger.

ISOTOPIC COMPOSITION OF THE ELEMENTS

Changes in the isotopic composition of the elements have an impact on the neutron activation of foils used in radiation dosimetry. The foil that is irradiated usually has a normal composition of the naturally occurring stable isotopes of that element. The reaction rate that is measured will depend on what the natural abundance in the foil is for the stable isotope undergoing the reaction. This is necessary information whether the reaction is for neutron capture, for (n,"), or for the (n,p)reaction.

For measurements of neutron activation, the minor isotope is often used. Recent measurements for the natural isotopic composition have led to some large changes in the abundance of the minor isotope. Some examples would be ^{30}Si, which changed from 3.12% to 3.091%, ^{36}S which changed from 0.017% to 0.014%, ^{50}Ti, which changed from 5.34% to 5.18%, ^{58}Fe, which changed from 0.31% to 0.282%, ^{64}Ni, which changed from 1.16% to 0.9256%

^{107}Ag, which changed from 48.65% to 48.161%, ^{180}W, which changed from 0.135% to 0.120% and ^{190}Pt, which changed from 0.0127% to 0.014%.

In addition to the changes in the minor isotope abundance values, there have been other changes in recent years in the isotopic composition, which has had an effect for a number of elements used in dosimetry. The latest recommended value of some of the isotopic abundance values along with their uncertainties are compared with some earlier measured values in Table 2, for many stable nuclides used in radiation dosimetry measurements.

Table 2. Recommended Isotopic Abundance Values

Isotope	Older Value	Recommended	Uncertainty
^{24}Mg	78.6 %	78.99 %	0.04 %
^{32}S	95.0 %	94.96 %	0.03 %
^{34}S	4.15 %	4.27 %	0.02 %
^{35}Cl	75.4 %	75.77 %	0.04 %
^{46}Ti	7.95 %	8.25 %	0.03 %
^{47}Ti	7.75 %	7.44 %	0.02 %
^{48}Ti	73.45 %	73.72 %	0.03 %
^{51}V	99.76 %	99.750 %	0.004 %
^{54}Fe	5.8 %	5.845 %	0.035 %
^{56}Fe	91.68 %	91.754 %	0.036 %
^{58}Fe	0.31 %	0.282 %	0.004 %
^{58}Ni	67.76 %	68.0769 %	0.0089 %
^{60}Ni	26.16 %	26.2231 %	0.0077 %
^{63}Cu	69.1 %	69.17 %	0.03 %
^{64}Zn	48.89 %	48.63 %	0.60 %
^{90}Zr	51.46 %	51.45 %	0.40 %
^{98}Mo	23.75 %	24.13 %	0.31 %
^{109}Ag	48.65 %	48.161 %	0.008 %
^{115}In	95.77 %	95.71 %	0.05 %
^{164}Dy	28.1 %	28.19 %	0.37 %

^{175}Lu	97.4 %	97.41 %	0.02 %
^{176}Lu	2.6 %	2.59 %	0.02 %
^{181}Ta	99.9877 %	99.988 %	0.002 %
^{186}W	28.6 %	28.43 %	0.19 %

RADIOACTIVE HALF-LIFE VALUES

The values of the radioactive half-life of the product nucleus in a reaction has a direct impact on the determination of reaction rates. For a given count rate, the reaction rate is proportional to the half-life of the measured product nucleus. There have been a number of changes in the half-lives of the reaction products utilized in reactor dosimetry. The older value of the half-lives of the common reaction products are presented along with the most recently recommended half-life values in Table 3.

Table 3. Radioactive Half-life Values

Nuclide	Old $T_{1/2}$	Rec. $T_{1/2}$	Nuclide	Old $T_{1/2}$	Rec. $T_{1/2}$
^{24}Na	15.06 h	14.96 h	^{28}Al	2.27 m	2.25 m
^{32}P	14.3 d	14.28 d	^{46}Sc	85. d	83.81 d
^{47}Sc	3.43 d	3.349 d	^{48}Sc	44. h	43.7 h
^{54}Mn	310. d	312.1 d	^{56}Mn	2.57 h	2.579 h
^{57}Ni	36. h	35.6 h	^{58}Co	72. d	70.88 d
^{59}Fe	45.1 d	44.51 d	^{60}Co	5.27 y	5.271 y
^{62}Cu	10.1 m	9.67 m	^{64}Cu	12.8 h	12.701 h
^{89}Zr	79.3 h	78.48 h	^{99}Mo	67. h	65.94 h
^{103m}Rh	57. m	56.12 m	^{104}Rh	44. s	42.3 s
^{110m}Ag	24.2 s	24.6 s	^{115m}In	4.5 h	4.486 h
^{116m}In	54. m	54.1 m	^{140}Ba	12.8 d	12.75 d
^{165}Dy	139. m	139.8 m	^{176m}Lu	3.67 h	3.66 h
^{177}Lu	6.8 d	6.75 d	^{182}Ta	111. d	114.43 d
^{187}W	24.1 h	23.9 h	^{198}Au	2.68 d	2.694 d
^{233}Th	23.3 m	22.3 m	^{239}U	23.54 m	23.5 m

Of general interest, there will also be additions into the super-heavy element region of the Table of the Isotopes. There will be at least four nuclides for element Z=112, three nuclides for element Z=114, and one nuclide for element Z=116 and one nuclide for element Z=118 listed with their associated half-life values in the Table for the 2000-2001 edition.

DISCUSSION

Values for many of the parameters that are used in reactor dosimetry have changed over the years. The neutron cross sections of the common target materials, the isotopic compositions of these target materials and the half-lives of the reaction product nuclides that are produced have been reviewed. These changes have been illustrated by a number of examples.

In some of these cases, the change in the cross section and the isotopic abundance have balanced each other out, e.g., the case of the neutron cross section change and the isotopic abundance change for ^{58}Fe. For most of the other illustrations, however, this has not been the case. The resulting change in the reaction rate would be reflected in the change in value of the neutron flux which would be calculated from the dosimetry analysis.

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