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Neutron-Capture Yields for Gamma-Ray Spectroscopy

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Abstract. Energies and yields for the gamma rays produced by the capture of thermal neutrons with most isotopes with Z ≤ 30 and a few heavier elements have been compiled and evaluated. Many of the adopted yields are better than those in previous compilations. Existing capture gamma-ray measurements for several elements are poor, and better measurements are needed.

INTRODUCTION

Good values for the yields and energies of the gamma rays emitted following the capture of thermal neutrons are required for many applications. Gamma rays made by cosmic-ray-produced neutrons are used to determine planetary elemental abundances (1, 2). Similar measurements are done down boreholes using neutron sources and generators (3). Many other studies, such as neutron and photon transport calculations, also require high-quality data for neutron-capture gamma rays.

There have been several compilations performed for gamma rays from thermal-neutron-capture reactions. One (2) was completed in the mid-1970s for analysis of planetary gamma rays. Another was completed in about 1980 (4), but it evaluated fewer sources than were used by (2). Another compilation (5) was only completed for isotopes with A≥45 using data in *Nuclear Data Sheets*. A similar compilation, on-line at the Brookhaven National Laboratory's National Nuclear Data Center, is like (5) for A≥45 but uses (4) for A≤44. There are new measured gamma-ray yields for many elements since the last compilation that should be considered. Currently, there is no adequate compilation for thermal-neutron capture gamma-ray data for elements with A≤44.

NEW COMPILATION AND EVALUATIONS

We have compiled data from the published literature and evaluated the energies and yields of gamma rays from thermal-neutron capture reactions for isotopes of elements with atomic number (Z) up to and including 30 (Zn), plus several other heavier isotopes (e.g., Ge, Sm, Gd, and W). In Table 1, we list our adopted energies and yields, compare our yields for important gamma rays with older yields (2,4), and give our data sources using the short versions used by nuclear data centers, the "Nuclear Science References" keynumbers (last 2 digits of year, first 2 letters of author's last name, and 2 more digits).

TABLE 1. Comparisons of our elemental neutron-capture yields (per 100 captures) for major γ rays with those from two earlier compilations (2,4) and the references adopted, using the short "Nuclear Science References keynumbers."

Target	Energy (keV)	Yield (Ours)	Yield (2)	Yield (4)	Data Sources
^{9}Be	6809.9	65.5	--	63.75	86Ke14
^{14}N	5269.2	29.9	31.1	29.73	97Ju02
^{19}F	583.6	37.9	--	13.02	96Ra04
^{23}Na	6395.3	19.9	20.	22.18	83Hu11, 83Ti02
^{24}Mg	3916.9	49.2	48.	48.62	92Wa06 (ref. 6)
^{27}Al	7724.0	26.8	30.	27.43	82Sc14
^{28}Si	4934.0	62.2	61.	62.69	92Ra19
^{28}Si	3539.0	66.5	66.	68.00	"
^{31}P	3900.0	17.8	--	15.96	89Mi16
^{32}S	5420.6	56.6	55.	59.08	85Ra15
^{35}Cl	6110.8	20.6	21.	20.00	96Co16
^{35}Cl	1951.1	19.5	20.	21.72	"
^{35}Cl	1164.9	27.3	--	19.93	"
^{40}Ar	4744.4	53.8	--	55.00	70Ha56, 67Ly05
^{39}K	770.3	40.9	58.	51.48	84Vo01
^{40}Ca	6419.6	41.9	40.	38.89	90En08
^{40}Ca	1942.7	82.3	80.	72.55	67Gr16
^{45}Sc	227.8	28.3	--	52.27	82Ti02
^{48}Ti	6760.1	44.0	40.	24.17	83Ru08
^{48}Ti	1381.8	81.2	82.	69.08	"
^{51}V	6517.3	16.3	--	17.83	91Mi08
^{53}Cr	8884.8	24.5	24.	26.97	89Ho15
^{55}Mn	7243.4	11.4	10.	12.13	75Co05 (*0.93)
^{54}Fe	9297.8	3.3	3.4	4.15	72Ko15 (*0.97)
^{56}Fe	7645.6	23.2	22.	24.13	80Ve05
^{56}Fe	7631.2	26.9	24.	28.51	"
^{59}Co	229.7	15.2	--	25.95	84Ko29
^{58}Ni	8998.4	35.8	37.	37.74	93Ha05 (*1.01)
^{63}Cu	7916.3	27.2	--	30.82	83De28
^{67}Zn	1077.4	19.3	--	18.93	71Ot01 (*0.75)

For most isotopes and elements, there now exist gamma-ray energies and yields measured using high-quality gamma-ray spectrometers. When available, we have adopted the energies and gamma-ray yields from papers reporting gamma-ray measurements made at the Los Alamos Omega West Reactor before it shut down several years ago. The Los Alamos and Oak Ridge team that performed this work have tried to include as many gamma rays as possible into a decay scheme for levels in the nucleus of interest (e.g., 6), thus showing that the gamma rays are from the isotope of interest.

One uncertainty in the elemental gamma-ray yields is the fraction of thermal neutrons captured by each isotope. Gamma rays measured from natural samples can be used to better determine the fractions of thermal neutrons captured by various isotopes (e.g., 6).

The adopted gamma-ray energies are often better than previously published in various compilations. Some energies in the older compilations are more than a keV different than the presently-accepted energies. Often, especially with older measurements, we have adopted gamma-ray energies determined by using recent evaluations for the nuclear levels involved (plus a correction for recoil). Our yields usually are within a few percent of previous compilations. Some yields in the often-used compilation by Lone et al. (4) are poor, e.g., for F, Cl, K, Sc, Ti, and Co.

There are a few elements that require better measurements, such as Mn, Co, Zn, Ge, and W. Measurements for these elements often do not cover the entire energy range, or the quality of data at the lowest gamma-ray energies are poor. There have been many elements that were measured at the Los Alamos Omega West Reactor, but the results have not been published. Among the elements with such unpublished measurements are Na, P, Cl, Ca, Mn, Fe, Ni, Ge, Zr, Cd, Sm, and Gd (E. Jurney and J. W. Starner, priv. comm., 1992). It would be very good if these gamma-ray measurements were quickly published, especially for elements with poor quality data, e.g., Mn and Ge.

CONCLUSIONS

Our compilation of evaluated gamma-ray yields for thermal-neutron-capture reactions is often an improvement over previous compilations, especially for $A \leq 44$ ($Z \leq 20$). However, better measurements of capture gamma rays are needed for some elements. Our compilation will be incorporated into new Evaluated Nuclear Data Files (ENDF) for use with transport codes such as the Monte Carlo N-Particle (MCNP) code.

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