Neutron Cross Sections

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Donald J. Hughes and John A. Harvey

July 1, 1955

BROOKHAVEN NATIONAL LABORATORY · UPTON · NEW YORK

Associated Universities Inc. under contract with the United States Atomic Energy Commission

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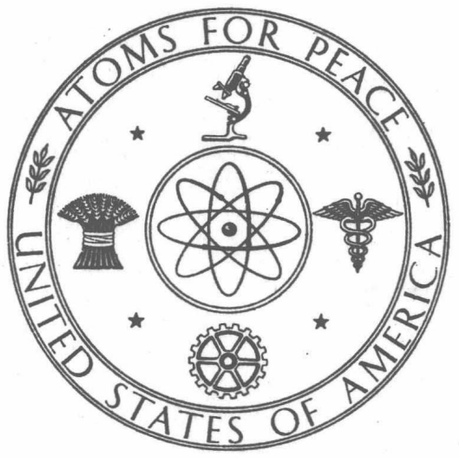
UNITED STATES ATOMIC ENERGY PROGRAM

Neutron Cross Sections



UNITED STATES OF AMERICA

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VOLUME THREE Reactor Handbook: Engineering
VOLUME FOUR Reactor Handbook: Materials
VOLUME FIVE Neutron Cross Sections
VOLUME SIX Chemical Processing and Equipment
VOLUME SEVEN Eight-year Isotope Summary
VOLUME EIGHT Information Scurces

VOLUME FIVE

Neutron Cross Sections

UNITED STATES OF AMERICA

GENEVA: AUGUST 1955

Foreword

Interchange of scientific and technical knowledge will greatly facilitate the work of the scientists and engineers whose skills will be devoted to the future development of the peaceful uses of atomic energy.

The United States has made available to the world's scientific community a large body of such data. In honor of this historic Conference and to stimulate further exploration and development of the beneficial applications of nuclear energy, the United States Atomic Energy Commission has prepared this special collection of technical data for the use of the delegates and the nations represented.

The purpose of this collection is to provide information concerning the ways that we have found in which fissionable materials can be put to work in nuclear reactors for research purposes and for the production of power and radioisotopes.

It is our sincere hope that this material will be of practical value to the men and women of science and engineering in whose hands the great power of the atom is becoming a benign force for world peace.

Lewis L. Strauss

Chairman, U.S. Atomic Energy Commission

Acknowledgment

This series of volumes was sponsored by the United States Atomic Energy Commission for presentation by the United States of America to the countries represented at the International Conference on Peaceful Uses of Atomic Energy.

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PREFACE

The present compilation actually constitutes the second edition of AECU-2040, which was published in May 1952 and followed by three supplements. All of these publications have been prepared at Brookhaven National Laboratory, under the auspices of the Atomic Energy Commission's Neutron Cross Section Advisory Group. The motivation of AECU-2040 was primarily a result of the needs of reactor physicists, and, while it has turned out to be of important use to physicists in general, its organization is still a result of the reactor needs. Thus the energy range extends over that appropriate for pile neutrons and the cross sections at thermal energy occupy a prominent place because of their importance to reactors. Material that appeared in the classified compilation BNL-250 is now to be found in the present volume as a result of its recent declassification.

In the present compilation it has been attempted to present the experimental data in a form most useful to physicists in general as well as reactor specialists. Where possible "best values" for the cross sections are given, together with estimated errors, rather than a complete list of all measured values. The cross sections listed are based on all published values as well as those unpublished ones available to the authors. References only to those experimental values actually used are listed, a compromise that it is hoped will satisfy those desiring the source of the pertinent information, without making the data too cumbersome for those desiring only the carefully evaluated best values.

The specific treatment of data and references is described in the introductory text at the beginning of each data section. As can be seen by comparing the Table of Contents with AECU-2040, several types of data appear here that were not compiled in the earlier edition, primarily resonance parameters, but also angular distributions and inelastic scattering data.

The presence of much recent data is possible because of the excellent cooperation of experimenters in making their data available to the authors; its rapid production as a compilation is largely a result of the effective work at Brookhaven of H. Strasser and E. Becker in handling the data, of G. Cox in the preparation of curves and cover, and of R. Brown in preparing the texts and tables. The work of the compilation group at Brookhaven will be assisted greatly if workers in the field continue to be as generous as they have with their contributions and comments.

CONTENTS

THERMAL CROSS SECTIONS

INTRODUCTION

The tables of Thermal Cross Sections are divided for convenience into two parts: Z < 84 and Z > 83, the latter containing the fissionable isotopes. They contain the "best values" of several types of slow neutron cross sections, based on a careful consideration of all available data. Most of the cross sections have been measured several times, sometimes by different methods, and the error quoted in the table (standard error) is estimated from the consistency of the results as well as from the errors quoted for the individual measurements. References are given to the results actually used in the evaluation only; earlier work is usually described in the quoted references. The references shown for individual elements and isotopes are grouped according to laboratories and chronologically under each laboratory.

The types of cross sections in the table correspond closely to methods of measurements and the cross sections themselves are the actual measured, rather than derived quantities, as far as possible. All values given for an element refer to the natural mixtures of isotopes, that is, they are atomic cross sections, while those given for specific isotopes are isotopic cross sections. All cross sections, unless marked "mb" (millibarns) or "μb" (microbarns), are in barns.

The "reaction cross sections" refer to all cases in which the neutron is not re-emitted, that is, to (n,γ), (n,p), (n,α), and (n,F) reactions. Practically all the reaction cross sections for $Z < 84$ are for (n,γ)'s, and the few that are not are marked. The absorption cross sections, σ_{abs}, are those particular reaction cross sections that are measured by observing the reaction itself in which the neutron is absorbed. The principal method used is the pile oscillator, which measures the effect on the reactivity of a pile caused by the absorption of the neutron. Pile oscillator results mainly from Argonne, Oak Ridge, and Harwell are represented in the table. In some cases (n,p) and (n,α) reactions have been measured in cloud chambers and counters, while other absorption cross sections have been estimated from the changes in isotopic abundances after long pile irradiations. In several instances, examples being boron, gold, and the uranium isotopes, the absorption cross section has been obtained from the total cross section by subtraction of scattering, or by extrapolation from subthermal energies, where scattering is negligible.

The activation cross sections, σ_{act}, are those determined from the radioactivity of the product nucleus, usually the result of an (n,γ) reaction, and in a few cases, which are specially marked, by (n,p) or (n,α) reactions. The activation cross sections always refer to particular isotopes, and hence are isotopic cross sections; for monoisotopic elements they are atomic cross sections as well. The absorption cross section, if measured for a single isotope or monoisotopic element, should agree with the activation cross section if the latter includes all activities produced. The activation cross sections for isomeric states are sometimes difficult to measure, as well as to understand in tables. In this table the upper (metastable) state is listed above the ground state (where the order is known) and the cross sections refer to the direct formation of each state. In those cases for which the amount of an isomeric activity would be increased indirectly by decay of another (shorter-lived) state, the percentage of the parent state that augments the activity is given. An example is cobalt for which there is a 20 b cross section for direct formation of the 5.28 y activity, and a 16 b cross section for the 10.4 m activity, practically all of which decays into its 5.28 y daughter.

The quantity α, the ratio of the capture to the fission cross section, is measured directly from mass spectrographic analysis of highly irradiated fissionable materials to determine the amount of the isotope produced by capture and the amount of the fissionable isotope destroyed. It can also be calculated from the total and fission cross sections if one corrects for the scattering cross section. The number of fission neutrons produced per thermal neutron absorbed, η, is usually measured by the pile oscillator method. The number of neutrons emitted per fission, ν, can be measured relative to a

standard source but is most accurately calculated from ν and α by the equation $\nu = \eta(1 + \alpha)$.

The reaction cross sections listed are those for a neutron velocity of 2200 m/s even though the actual measurements were usually made with neutrons of wide energy spread. It should be remembered that thermal flux values (nv) are always stated for a velocity of 2200 m/s (even though the neutrons may be above room temperature), hence the cross section at this velocity must be used in calculations of reaction rate. In some cases, such as irradiation with well thermalized neutrons, it is quite simple to obtain the 2200 m/s value from experimental results. In other cases, such as activation cross sections for pile neutrons, it is difficult, and for still others, such as isotopic cross sections measured by the mass spectrometer, it is almost impossible. Each reaction cross section, unless marked "not 1/v," will have the same reaction rate in a Maxwell distribution as a 1/v absorber with the same 2200 m/s cross section. In other words, the unmarked cross sections are either strictly 1/v in the thermal region or indistinguishable from 1/v within the accuracy quoted. The few marked "not 1/v" will have an effective 2200 m/s cross section in a Maxwell distribution (at, or within about 100°C of, room temperature) obtained by multiplication of the 2200 m/s value by the factor shown. This effective cross section, when used with a thermal flux stated for 2200 m/s, will give the correct reaction rate in a Maxwell distribution. For a few cases in which the 2200 m/s value could not be determined, the cross sections are still included but are marked "pile neutrons" by means of an asterisk.

The scattering cross sections are usually constant with energy in the thermal region, except for crystal effects, and are hence not quoted for 2200 m/s. The coherent cross section, σ_{coh}, is listed with the sign of the amplitude, where the positive sign corresponds to hard sphere scattering. The coherent scattering is that part of the total "bound atom cross section" which contributes to such interference effects as Bragg scattering and mirror reflection. The "bound atom cross section" is the cross section that would be observed if the atoms were completely bound (hence no thermal diffuse scattering) and yet scattered completely independently. Such a cross section, of course, is not observable experimentally but is calculated by applying the reduced mass correction, $(A+1)^2/A^2$, to the free atom cross section, σ_{fa}, which is the scattering cross section measured in the energy region (usually 10 - 20 ev) where the atom can be considered as a "free atom." No free atom values are listed when the presence of resonances near thermal prevents the calculation of the bound atom cross section. If there are no sources of incoherent scattering, such as spin dependent, isotopic, or inelastic incoherent scattering, then the measured value of σ_{coh} should be equal to $\sigma_{fa}\,(A+1)^2/A^2$, as it is for Be as an example, compared to H in which σ_{coh} is much less than the bound atom cross section. Sometimes the only scattering cross section that has been measured for a particular element is that averaged over the Maxwell distribution. This average scattering cross section, $\bar{\sigma}_s$, will depend on the crystalline form of the sample and even upon the size of the crystal grains, but it is listed because of utility in certain practical applications.

It is the purpose of the compilation to list only the actual directly measured quantities, even though it is possible in some cases to infer certain cross sections from other measurements. For instance, the calculated bound atom cross section, which is sometimes known quite accurately, could be listed as the coherent cross section if it is assumed that there are no sources of incoherent scattering. However, only the measured value of the coherent scattering (a measurement of σ_{coh} itself, or both σ_{fa} and the incoherent cross section) is given in the column for σ_{coh} even though in some cases the value inferred from the bound atom cross section has smaller error. An example is fluorine, where the bound atom value is more accurate than σ_{coh} and an assumption of negligible incoherent scattering would seem justified. Nevertheless, only the measured coherent cross section is listed in the σ_{coh} column.

Again, for the activation cross sections, it could be inferred that the more accurate absorption value, measured with the pile oscillator, is correct to list for activation as well, if it is certain that only one activity is produced. Here an example is Al^{27} where the activation agrees with the absorption but is not as accurate. The principle of listing only the directly measured quantities in the appropriate columns is again followed in this case. Some judgment is thus necessary in using the table, especially in those cases where values of different types of cross sections, which presumably should agree, do not. For instance, it would be safe to use the more accurate absorption value, 0.19 ± 0.03 b, for the production of 14.3 day P^{32}, even though the directly measured activation cross section is 0.23 ± 0.05 b. On the other hand, the cross section for production of 87 day S^{35} by the $Cl^{35}(n,p)$ reaction has been measured as 0.30 ± 0.10 b by direct observation of the reaction (in a cloud chamber) and as 0.17 ± 0.04 b by activation. In this case it is certainly not clear that one value is right and the other wrong, hence a weighted average probably should be used. The present status of thermal cross sections is sufficiently good that very few examples of such discrepancies still remain.

This introduction to the listed thermal cross sections is not intended to be a complete discussion of the experimental techniques of cross section measurements or interpretations. Further details may be found in the section on The Neutron by B.T. Feld in Experimental Nuclear Physics Vol II (Wiley, 1953), and Pile Neutron Research by D.J. Hughes (Addison-Wesley, 1953).

THERMAL CROSS SECTIONS, Z < 84

Element	Isotope (%, $T_{1/2}$)	Reaction Cross Sections (2200 m/s) σ_{abs}		σ_{act}	Scattering Cross Sections σ_{coh} (sign)	$\sigma_{fa}\left(\frac{A+1}{A}\right)^2$	$\bar{\sigma}_s$	References
$_1$H		330 ± 3 mb			1.79 ± 0.02 (-)	81.5 ± 0.4	38 ± 4 (gas)	ANL 30,34,35; Cav 3; CR 4; Col 1; LA 5
	H^1(~100)							
	H^2(0.015)	0.46 ± 0.10 mb	12.4y	0.57 ± 0.01 mb	5.4 ± 0.3 (+)	7.6 ± 0.1	7 ± 1	ANL 23,31; Cav 1; CR 3,16; ORNL 4
$_2$He					1.1 ± 0.2 (+)	1.3 ± 0.2	0.8 ± 0.2	ANL 41; BNL 4
	He^3(0.00013)	np 5400 ± 300					1.0 ± 0.7	LA 2,3
	He^4(~100)	0		0				
$_3$Li		71.0 ± 1.0			0.40 ± 0.03 (-)	1.2 ± 0.3	1.4 ± 0.3	ANL 31,41; CR 1; Fr 7; Har 2; ORNL 4,6
	Li^6(7.52)	(nα 945)		<0.1	6 ± 3 (+)			ANL 41; Comp 1; ORNL 4
	Li^7(92.48)		0.85s	33 ± 5 mb	0.80 ± 0.05 (-)	1.4 ± 0.2		ANL 5; ORNL 4
$_4$Be	Be^7(54d)	np 51,000 ± 6000 nα <1						Har 10
	Be^9(100)	10 ± 1 mb	2.7×10^6y	9 ± 3 mb	7.53 ± 0.07 (+)	7.54 ± 0.07	7 ± 1	ANL 2,41; BNL 5,6; Cav 1
$_5$B		755 ± 4				4.4 ± 0.2	4 ± 1	ANL 34,41; BNL 12; Col 2; Har 9,10; LA 5; ORNL 2,15; Swed 5
	B^{10}(18.8)	(nα 4010) np <0.2				4.0 ± 0.5		ANL 41; Comp 1; ORNL 2
	B^{11}(81.2)		0.03s	<50 mb		4.4 ± 0.3		ANL 41; ORNL 2
$_6$C		3.2 ± 0.2 mb			5.50 ± 0.04	5.51 ± 0.03	4.8 ± 0.2	ANL 41; Han 1; ORNL 2,8
	C^{12}(98.89)			3.3 ± 0.2 mb				ANL 41
	C^{13}(1.11)	0.5 ± 0.2 mb	5570y	0.9 ± 0.3 mb	4.5 ± 0.6 (+)	5.5 ± 1.0		ANL 39,41; ORNL 8
	C^{14}(5570y)	<200	2.4s	<1 μb				CR 9; ORNL 2

THERMAL CROSS SECTIONS, Z < 84

Element	Isotope (%, $T_{1/2}$)	Reaction Cross Sections (2200 m/s) σ_{abs}		σ_{act}	Scattering Cross Sections σ_{coh} (sign)	$\sigma_{fa}\left(\frac{A+1}{A}\right)^2$	$\bar{\sigma}_s$	References
$_7$N		1.88 ± 0.05			11.0 ± 0.5 (+)	11.4 ± 0.5	10 ± 1	BNL 4; Har 2; ORNL 2,6,9
	N^{14}(99.63)	np 1.75 ± 0.05 $n\gamma$ 0.10 ± 0.05						CR 7; Har 10; LA 2
	N^{15}(0.37)		7.4s	24 ± 8 μb				ANL 41; CR 18
$_8$O		<0.2 mb			4.2 ± 0.3 (+)	4.24 ± 0.02	4.2 ± 0.3	BNL 8; Cav 1; CR 3; ORNL 4
	O^{16}(99.59)							
	O^{17}(0.037)		5570y	C^{14} 0.5 ± 0.1				CR 2
	O^{18}(0.204)		29s	0.21 ± 0.04 mb				ANL 6
$_9$F	F^{19}(100)	<10 mb	11s	9 ± 2 mb	3.8 ± 0.3 (+)	4.0 ± 0.1	3.9 ± 0.2	ANL 1,6,16,41; Cav 1; ORNL 4
$_{10}$Ne		<2.8				2.9 ± 0.2	2.4 ± 0.3	ANL 25,41; ORNL 2
	Ne^{20}(90.92)							
	Ne^{21}(0.26)							
	Ne^{22}(8.82)		40s	36 ± 15 mb				CR 18
$_{11}$Na	Na^{23}(100)	505 ± 10 mb	15.0h	0.56 ± 0.03	1.55 ± 0.05 (+)	3.4 ± 0.2	4.0 ± 0.5	ANL 6,26,41; CR 15,23; Har 2; ORNL 2,4,6
$_{12}$Mg		63 ± 4 mb			3.60 ± 0.10 (+)	3.70 ± 0.10	3.6 ± 0.4	ANL 26; Cav 1,2; Har 2,6; NYU 1; ORNL 6
	Mg^{24}(78.60)	33 ± 10 mb						ORNL 10
	Mg^{25}(10.11)	270 ± 90 mb						ORNL 10
	Mg^{26}(11.29)	60 ± 60 mb	9.5m	50 ± 10 mb				ANL 6; ORNL 10
$_{13}$Al	Al^{27}(100)	230 ± 5 mb	2.27m	0.21 ± 0.04	1.5 ± 0.1 (+)	1.51 ± 0.03	1.4 ± 0.1	ANL 6,26; Fr 3; Har 2; ORNL 2,4,6

THERMAL CROSS SECTIONS, Z < 84

Element	Isotope (%, $T_{1/2}$)	Reaction Cross Sections (2200 m/s) σ_{abs}		σ_{act}	Scattering Cross Sections σ_{coh} (sign)	$\sigma_{fa}\left(\frac{A+1}{A}\right)^2$	$\bar{\sigma}_s$	References
$_{14}Si$		0.13 ± 0.03			2.0 ± 0.2 (+)	2.4 ± 0.2	1.7 ± 0.3	ANL 26; BNL 3; Cav 1; Har 2; ORNL 6
	Si^{28}(92.27)	80 ± 30 mb						ORNL 10
	Si^{29}(4.68)	0.27 ± 0.09						ORNL 10
	Si^{30}(3.05)	0.4 ± 0.4	2.62h	110 ± 10 mb				ANL 6; ORNL 10,14
$_{15}P$	P^{31}(100)	0.19 ± 0.03	14.3d	0.23 ± 0.05	3.1 ± 0.16 (+)	3.6 ± 0.3	5 ± 1	ANL 6,41; Har 2; ORNL 6,15
$_{16}S$		0.49 ± 0.02			1.20 ± 0.08 (+)	1.2 ± 0.2	1.1 ± 0.2	ANL 26; Cav 1; Har 2; ORNL 4,6
	S^{32}(95.018)							
	S^{33}(0.750)		25.1d P^{33}	2.3 ± 1.0 mb				Swed 4
	S^{34}(4.215)		87d	0.26 ± 0.05				ANL 6
	S^{36}(0.017)		5.0m	0.14 ± 0.04				ORNL 2
$_{17}Cl$		31.6 ± 1.0			12.1 ± 0.8 (+)		16 ± 3	ANL 26; Cav 1; CR 15; Fr 2; Har 2; ORNL 4,6
	Cl^{35}(75.4)	np 0.30 ± 0.10	3.08 x 10^5y 87d S^{35}	30 ± 20 0.17 ± 0.04				ANL 6; Ger 2; ORNL 2; Switz 2
	Cl^{36}(3.08 x 10^5y)			90 ± 30				CR 27
	Cl^{37}(24.6)		37.5m	0.56 ± 0.12				ANL 6
$_{18}A$		0.62 ± 0.04			0.5 ± 0.1 (+)	0.9 ± 0.2	1.5 ± 0.5	ANL 25; BNL 4; Har 2; ORNL 2
	A^{36}(0.37)		35d	6 ± 2				CR 8
	A^{38}(0.063)		265y	0.8 ± 0.2				BNL 7
	A^{40}(99.600)		109m	0.53 ± 0.02				BNL 7
	A^{41}(109m)		>3.5y	>60 mb				BNL 7

Element	Isotope (%, $T_{1/2}$)	Reaction Cross Sections (2200 m/s) σ_{abs}	σ_{act}	Scattering Cross Sections σ_{coh} (sign)	$\sigma_{fa}\left(\frac{A+1}{A}\right)^2$	$\bar{\sigma}_s$	References
$_{19}$K		1.97 ± 0.06		1.5 ± 0.1 (+)	2.2 ± 0.1	1.5 ± 0.3	ANL 23,26; Cav 1; Har 2; ORNL 4,6
	K^{39}(93.08)	1.87 ± 0.15	1.3 x 10^9y 3 ± 2*				ORNL 10; Wis 1
	K^{40}(0.012)	70 ± 20 np <1					ORNL 2,10
	K^{41}(6.91)	1.19 ± 0.10	12.4h 1.0 ± 0.2				ANL 6; ORNL 10
$_{20}$Ca		0.43 ± 0.02		3.0 ± 0.1 (+)	3.2 ± 0.3		ANL 26; Har 2; ORNL 4,6
	Ca^{40}(96.97)	0.22 ± 0.04		3.0 ± 0.1 (+)	3.1 ± 0.3		ORNL 4,10
	Ca^{42}(0.64)	40 ± 3					ORNL 10
	Ca^{43}(0.145)						
	Ca^{44}(2.06)		152d 0.63 ± 0.12	0.40 ± 0.03 (+)			ANL 6; ORNL 4
	Ca^{46}(0.0033)		4.8d 0.25 ± 0.10				CR 22
	Ca^{48}(0.185)		8.5m 1.1 ± 0.1				BNL 10
$_{21}$Sc	Sc^{45}(100)	24.0 ± 1.0	20s 10 ± 4 85d 12 ± 6 20s+85d 22 ± 2 (20s → 85d)	17.5 ± 1.5 (+)		24 ± 2	ANL 6,11; Har 5; ORNL 11,13,15
$_{22}$Ti		5.6 ± 0.4		1.4 ± 0.3 (−)	4.4 ± 0.2	4 ± 1	ANL 26,41; BNL 3; Har 2; ORNL 4,6
	Ti^{46}(7.95)	0.6 ± 0.2			3.3 ± 1.0	2 ± 2	ANL 41; ORNL 10
	Ti^{47}(7.75)	1.6 ± 0.3			5.2 ± 1.0	4 ± 1	ANL 41; ORNL 10
	Ti^{48}(73.45)	8.0 ± 0.6			9 ± 4	4 ± 2	ANL 41; ORNL 10
	Ti^{49}(5.51)	1.8 ± 0.5			2.8 ± 1.0	1 ± 1	ANL 41; ORNL 10
	Ti^{50}(5.34)	<0.2	5.8m 0.14 ± 0.03		3.3 ± 1.0	3 ± 1	ANL 6,41; ORNL 10

*Pile neutrons

THERMAL CROSS SECTIONS, Z < 84

Element	Isotope (%, $T_{1/2}$)	Reaction Cross Sections (2200 m/s) σ_{abs}		σ_{act}	Scattering Cross Sections σ_{coh} (sign)	$\sigma_{fa}\left(\frac{A+1}{A}\right)^2$	$\bar{\sigma}_s$	References
$_{23}V$		5.1 ± 0.2			0.032 ± 0.008 (−)	5.1 ± 0.1	5 ± 1	ANL 26; Fr 2; Har 2; ORNL 6,9,15
	V^{50}(0.24)	250 ± 200						CR 19
	V^{51}(99.76)		3.76m	4.5 ± 0.9				ANL 6
$_{24}Cr$		2.9 ± 0.2			1.56 ± 0.03 (+)	4.1 ± 0.3	3.0 ± 0.5	ANL 26; Cav 1; Fr 2; Har 2; NYU 1; ORNL 4,6
	Cr^{50}(4.31)	16.3 ± 1.3	27.8d	11 ± 5				ANL 6; ORNL 10
	Cr^{52}(83.76)	0.73 ± 0.06						ORNL 10
	Cr^{53}(9.55)	17.5 ± 1.4						ORNL 10
	Cr^{54}(2.38)	<0.3	3.6m	0.37 ± 0.04				MIT 1; ORNL 10
$_{25}Mn$	Mn^{55}(100)	13.2 ± 0.4	2.58h	13.4 ± 0.3	1.7 ± 0.1 (−)	2.0 ± 0.1	2.3 ± 0.3	ANL 26,27; CR 23; Fr 2; Har 2; ORNL 2,4,6
$_{26}Fe$		2.53 ± 0.06 $n\alpha$ <5 mb			11.37 ± 0.05 (+)	11.80 ± 0.04	11 ± 1	ANL 26; BNL 9; Fr 1,2,8; Har 2; ORNL 2,6; Switz 1
	Fe^{54}(5.84)	2.2 ± 0.2	2.96y	2.2 ± 0.5	2.20 ± 0.13 (+)	2.5 ± 0.3		ORNL 4,10,15
	Fe^{56}(91.68)	2.6 ± 0.2			12.8 ± 0.2 (+)	12.8 ± 0.2		ORNL 4,10,15
	Fe^{57}(2.17)	2.4 ± 0.2			0.64 ± 0.04 (+)	2.0 ± 0.5		ORNL 4,10
	Fe^{58}(0.31)	2.5 ± 2.0 $n\alpha$ <1.5 mb	46d	0.9 ± 0.2				ORNL 2,15
$_{27}Co$	Co^{59}(100)	37.0 ± 1.5	10.4m 5.28y 10.4m+5.28y (99.7% of 10.4m⟶5.28y)	16 ± 3 20 ± 3 36.0 ± 1.5	1.00 ± 0.06 (+)	6 ± 1	7 ± 1	ANL 6,26,41; BNL 2; Cav 1; CR 14,24; Fr 2,7; Har 2; ORNL 4,6
	Co^{60m}(10.4m)		1.75h	100 ± 50				CR 26
	Co^{60}(5.28y)		1.75h	6 ± 2				CR 26