International Atomic Energy Agency

INDC(CCP)-392
Distr. L

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

COMPILATION OF LEAKAGE NEUTRON SPECTRUM MEASUREMENTS FOR SPHERICAL ASSEMBLIES WITH T(d,n) AND ^{252}Cf NEUTRON SOURCES

S.P. Simakov

Institute of Physics and Power Engineering
Obninsk, Kaluga Region, Russia

Translated from Jadernye Konstanty 1993/1 p. 43-51

December 1994

IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA

Printed by the IAEA in Austria
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94-11796 (23)
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UDC 539.125.5

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ABSTRACT

The present work reviews spherical benchmark experiments. An attempt has been made to compile numerical data on experimental specifications and leakage neutron spectra. The data were obtained either from the literature or private communication with authors. Tables of the main experimental parameters for measurements performed in the USA, Japan and Europe are presented. These data can be used for intercomparison of experimental data measured in different laboratories and for testing evaluated data libraries.

Integral experiments which model parts of nuclear facilities can be used to verify calculation methods and test evaluated nuclear data files under simpler conditions. Among the wide variety of integral experiments, we can distinguish the class of experiments which have the simplest geometry, where the materials under study are in the form of spheres and have point sources in the centre - "benchmark" experiments. Because of their spherical symmetry (in other words, one-dimensional geometry) these experiments are used mainly for verifying and correcting evaluated data files.

Two types of sources are considered in this paper: the spontaneously fissioning isotope ^{252}Cf with a continuous spectrum of prompt fission neutrons and the reaction T(d,n), which gives neutrons with an energy of 14 MeV. Studies with these sources are important because they model the spectrum of facilities using the energy of fission of heavy nuclei or of the T-D fusion [1, 2]. The paper presents the results of compiling experimental data on leakage neutron spectra measured at a sufficiently large distance form the surface and corresponding to a neutron flux normalized to one source neutron.

A review of such studies up to 1982 can be found in Ref. [2]. However, new studies have appeared since then, and as far as we know no attempt has been made to date to collect the original numerical data (i.e. to generate a bank of experimental data), which could be used for testing contemporary evaluated nuclear data libraries, and also for detecting systematic uncertainties in experiments by means of comparative analysis.

For this purpose, it is necessary to obtain numerical values which characterize the neutron source, the dimensions and composition of the spherical samples, the leakage neutron spectra themselves together with uncertainties, and also to know measurement conditions which influence the comparison of calculation and experimental results.

SUMMARY OF EXPERIMENTS

Studies on leakage neutron spectra have been carried out in various laboratories in the USA, Japan and Europe under national or international programmes. In order to give a general idea of the volume of available data, Table 1 lists the scientific centres (their names abbreviated in accordance with IAEA recommendations) which carried out the respective studies using different sources, and also gives the approximate number of spheres studied. It is clear that there exists a large amount of experimental data which are of interest for testing calculation methods and evaluated data files.

More detailed information on these experiments is presented in Tables 2-4 (measurements with a T(d,n) source) and Table 5 (^{252}Cf), and is also discussed in the following sections.

NEUTRON SOURCES

T(d,n). Neutrons from this reaction are obtained in electrostatic accelerators (neutron generators), generally by bombarding solid tritium targets with 200-400 keV deuterons. The neutron energy and yield are functions of the emission angle with respect to the incident deuteron beam, the deuteron energy, the number of tritium atoms absorbed in the target material and a number of other factors. In order to give a quantitative evaluation of the anisotropy of this type of source, we give the dependence of energy E and relative neutron yield Y on emission angle θ for a thick TiT target and a deuteron energy of 250 keV [29]:

$$E(\theta) = 14.1 + 0.77\cos(\theta) + 0.022\cos^2(\theta)$$

$$Y(\theta) = 1 + 0.054\cos(\theta) + 0.0011\cos^2(\theta) \qquad (1)$$

It will be seen that the anisotropy of the source is $Y(0°)/Y(150°) = 11\%$, and the change in energy is $E(0°) - E(150°) = 1.5$ MeV. However, in addition to the factors associated with the reaction cross-section, the angle-energy distribution of neutrons is influenced both by the design of the target assembly - the interaction of 14 MeV neutrons with the target materials may introduce distortions in the angular dependence of the yield - and by the source neutron spectrum. It is therefore essential to know the source neutron spectrum in order to make an appropriate comparison with the transport calculations. In many cases the neutron angle-energy distribution was investigated in the experiments, and in others an expression of the type (1) is a more accurate approximation in the absence of other information.

^{252}Cf. The advantage of using this source is that the fission neutron spectrum for californium is sufficiently well studied and has been accepted as a standard [30]. The uncertainty of the data for the standard spectrum is 1.2-10% in the 0.01-20 MeV energy range. In integral experiments, a source based on ^{252}Cf is usually a metal ampoule with a radioactive isotope or, as suggested for such investigations in Ref. [33], a fast ionization chamber with a source installed at one of the electrodes. These structural elements may of course also influence the source neutron spectrum. The relevant original studies show that such distortions are generally small compared to the accuracy of measurements of the leakage neutron spectra themselves.

SPHERICAL ASSEMBLIES

The measurements were made with a great variety of materials which are listed in Tables 2-5 in the order of increasing mass number. The tables give the external (R) and internal (r) radii, and wall thickness of the sphere (R-r), expressed in centimetres and in the number of mean free paths (mfp) in a given medium for neutrons with energies of 14 MeV or 2.13 MeV respectively (the mean energy of neutrons from spontaneous fission of ^{252}Cf). The last value characterizes the average number of collisions experienced by the neutron. The spheres generally have an opening through which the source can be inserted, and its radius is indicated in the fifth column. In experiments conducted at the Livermore Laboratory, the internal cavity had the shape of a truncated cone (the angle between the generatrices is 8°); therefore, the radii of the sphere (inner) and the source-insertion opening can only be given approximately.

The chemical composition of the material in the spheres and the concentrations of the main nuclei are given on the basis of data taken from original studies or, in cases where they were not indicated, from the handbook [31] and are marked with an asterisk. Some materials are packaged in a spherical shell (container), in which case the material from which they are made, and its thickness, are indicated. For example, SS-0.47 Cu-0.2 means that the sphere was lined on the outside with 0.47 cm of stainless steel and on the inside with 0.2 cm of copper.

It is clear from the tables that some important parameters are not given for a number of experiments. This means that these parameters are not contained in the publications currently available to the present author.

MEASUREMENT METHODS AND LEAKAGE NEUTRON SPECTRA

The majority of leakage neutron spectrum measurements were made by the time-of-flight method (TOF), and the rest by the proton recoil method (PRS). It is generally recognized that time-of-flight spectrometry is comparatively more accurate since the response function of this type of spectrometer is close to a Gaussian distribution. In the proton recoil method it is further necessary to unfold the neutron spectrum from the instrument spectrum of recoil protons, and this introduces an additional error of 10-15%.

Scintillation detectors based on hydrogen-containing scintillators (NE-213 or stilbene) or lithium-containing glass and proportional counters were used for the measurements. This combination of detectors makes it possible to cover a range of neutron energies from 10 keV to 15 MeV. The energy region of the measured data for each experiment is indicated in the tables.

The magnitude of the distance (L) between the source and the detector is of some importance for comparison with the calculations. For L ≥ 3R the sphere may be considered to be a point source, the neutron velocity vectors to be parallel to the detector axis and the measured spectral characteristic to correspond to the neutron current at the point of location of the detector. For measurements with a T(d,n) source, the angle of the detector's position with respect to the deuteron beam axis is also important, since the neutron energy and yield for this source are functions of the angle (1).

The present author obtained the numerical data on the leakage neutron energy spectra from publications or by direct communication with the authors of the original papers. The data currently available are indicated by a plus sign in the final column of Tables 2-5. The data from Ref. [32] are not included in the tables, since they are presented in the form of instrument time distributions and their analysis would require transport codes to calculate the time distribution of the leakage neutrons, as well as additional initial data - detector efficiency, channel width and other parameters.

CONCLUSION

An attempt has been made to compile numerical data on the leakage neutron spectra for spherical assemblies with T(d,n) and ^{252}Cf sources in the centre. It should be noted that the material published in articles, reports and other sources rarely contain exhaustive numerical data on the experiments carried out, and it was therefore necessary to approach directly the authors of the original papers. As a result, by the beginning of 1993 numerical data on leakage neutron spectra were available for approximately 50% of all known measurements. In this connection, I would like to thank the authors who made their experimental data available. I would hope that the present compilation will contribute to a wider intercomparison of experimental data and also their comparison with transport calculations in order to verify the calculation methods and the accuracy of the evaluated nuclear data.

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Table 1.

Summary of leakage neutron spectrum measurements

Country	Institution	Sources	Number of spheres
Germany	Technical University of Dresden (TUD)	T(d,n)	2
	Central Institute of Nuclear Research (ROS)	Cf	2
	Nuclear Research Centre, Karlsruhe (KFK)	Cf, T(d,n)	3
USSR	Institute of Physics and Power Engineering, Obninsk (FEI)	T(d,n)	28
	Institute of Technical Physics, Chelyabinsk (ITF)	T(d,n)	16
	Kiev State University (KGU)	T(d,n)	4
USA	Livermore National Laboratory (LRL)	T(d,n)	33
	Illinois State University (UI)	Cf, T(d,n)	4
	Los Alamos National Laboratory (LAS)	T(d,n)	1
Czechoslovakia	Institute of Radiation Technology, Prague (IRT)	T(d,n)	4
Japan	Osaka City University (OSA)	T(d,n)	22
	Tokyo University (TOH)	T(d,n)	1
	TOTAL		120

Table 2.

Leakage neutron spectrum measurements with a T(d,n) source (USA)

Material	Radius		Wall	Opening	Chemical composition	Concentration	Container		Detector		E_1 - E_2 MeV	Method	Laboratory	Reference	Numerical data
	R, cm	r, cm	cm(mfp)	r,cm		10^{23} cm^{-3}	outer	inner	Beta°	L, m					
H_2O	10.48	≈0.8	≈9.7(1.0)	≈1.8	H	0.669*	SS-0.05	SS-0.05	27	7.5		TOF	LRL	[3]	
	19.05	≈0.8	≈18.3(1.8)	≈2.4	O	0.334*	SS-0.20	SS-0.20							
N	10.5	≈0.8	≈9.7(0.6)	≈1.8	N		SS-0.03	SS-0.03	27	7.6	10^{-4}-15	TOF	LRL	[4]	
	55.9	≈0.8	≈55.1(3.0)	≈5.0			SS-0.25	SS-0.25							
	183.95	129.8	34.12(1.8)				SS-0.47	Cu-0.53	26, 125	9.8		TOF	LRL	[5]	
C	4.19	≈0.8	≈3.4(0.5)	≈1.3	C	0.939			30, 120	7-10	2-15	TOF	LRL	[6, 7]	
	10.16	≈0.8	≈9.4(1.3)	≈1.4		0.892									
	20.96	≈0.8	≈20.2(2.9)	≈1.8		0.926									
O	10.5	≈0.8	≈9.7(0.7)	≈1.8	O				30, 120	7-10	2-15	TOF	LRL	[4, 6]	
Al	8.94	≈0.8	≈8.1(0.9)	≈1.4	Al	0.603*			30, 120	7-10	2-15	TOF	LRL	[6, 8]	
			(1.6)	≈											
			(2.8)	≈											
Si	10.16	≈0.8	≈9.3(0.9)	≈1.4	Si	0.519*			30, 120	7-10	2-15	TOF	LRL	[8]	
Ti		≈0.8	(1.2)	≈	Ti	0.566*			30, 120	7-10	2-15	TOF	LRL	[8]	
			(2.2)	≈											
			(3.5)	≈											
Fe	4.46	≈0.8	≈3.7(0.9)	≈1.3	Fe(98.5%)	0.834*			30, 120	7-10	.01-15	TOF	LRL	[9, 6]	
	13.41	≈0.8	≈12.6(2.9)	≈1.6	Mn(0.5%)	0.004*									
	22.30	≈0.8	≈21.5(4.8)	≈1.9											
Fe	36.0	7.5	28.5(6.4)	4.25	Fe	0.847*			90	2	1-15	PRS	IU	[10]	
Cu	4.0	≈0.8	≈3.9(1.0)	≈1.3	Cu	0.842*			30, 120	7-10		TOF	LRL	[8]	
Ho	4.60	≈0.8	≈3.8(0.8)	≈1.3	Ho	0.320*			26	10	1-15	TOF	LRL	[11]	
Ta	3.40	≈0.8	≈2.6(1.0)	≈1.2	Ta	0.553*			26	10	1-15	TOF	LRL	[11]	
	10.20	≈0.8	≈9.4(3.0)	≈1.4											
W	10.36	≈0.8	≈9.6(2.2)	≈1.4	W	0.632*			30, 120	7-10	1-15	TOF	LRL	[8]	
Au	6.21	≈0.8	≈5.4(1.9)	≈1.3	Au	0.589*			26	10	1-15	TOF	LRL	[11]	
Pb	5.60	≈0.8	≈4.8(1.0)	≈1.3	Pb	0.330*			20	10	1-15	TOF	LRL	[11]	
Th	5.76	≈0.8	≈5.0(1.0)	≈1.3	Th(100%)	0.298*			30, 120	7-10		TOF	LRL	[12]	
^{5}U	3.145	≈0.8	≈2.3(0.7)	≈1.2	^{5}U(93.2%)	0.432			26, 120	10	1-15	TOF	LRL	[12]	
	5.925	≈0.8	5.1(1.5)		^{8}U(6.8%)	0.030									
^{5}U	7.996	2.233	5.773(1.5)		^{5}U(93.5%)	0.432	Cd(0.076)		0	39	0.2-15	TOF	LAS	[13]	
					^{8}U(6.5%)	0.030									
^{8}U	3.64	≈0.8	≈2.8(0.8)	≈1.2	^{8}U(99.0%) C(1%)	0.470			30, 120	7-10	1-15	TOF	LRL	[12]	
^{9}Pu	3.50	≈0.8	≈2.7(0.7)	≈1.2	^{39}Pu(93.7%)				20, 120	7-10	1-15	TOF	LRL	[12]	
	6.30	≈0.8	≈4.6(1.3)	≈1.3	^{40}Pu(5.90%)										
					^{41}Pu(0.41)										

Table 3.

Leakage neutron spectrum measurements with a T(d,n) source (Japan)

Material	Radius		Wall	Opening	Chemical composition	Concentration	Container		Detector		E_1 - E_2 MeV	Method	Labo-ratory	Refer-ence	Numer-ical data
	R, cm	r, cm	cm(mfp)	r,cm		10^{23} cm^{-3}	outer	inner	Beta°	L, m					
Li	60.0	10.0	50.0(3.1)	≈2.5	Li	0.463*	SS-0.5	SS-0.2		9.5		TOF	OSA	[14]	-
Li	19.75	10.2	9.55(0.6)	5.75	Li	0.463*	SS-0.2	SS-0.2	55	11	0.1-15	TOF	OSA	[15,16]	+
LiF	30.0	2.5	27.50(3.5)	2.8	Li(98.1%)	04075	SS-0.5	SS-0.3	55	11	0.1-15	TOF	OSA	[15]	+
					F(98.1%)	0.4178									
CF_2	19.75	10.2	9.55(07)	5.75	C(99.9%)	0.1564	SS-0.2	SS-0.2	55	11	0.1-15				
					F(99.9%)	0.3128									
					Cl(0.09%)	0.0019									
Al	19.75	10.2	9.55(05)	5.75	Al(99.7%)	0.2715	SS-0.2	SS-0.2	55	11	0.1-15	TOF	OSA	[15]	+
					Si(0.15%)	0.0039									
					Fe(0.20%)	0.0026									
Si	30.00	10.5	19.50(1.1)	5.75	Si(99.9%)	0.2764	SS-0.5	SS-0.2	55	11	0.1-15	TOF	OSA	[15]	+
Ti	19.75	10.2	9.55(0.5)	5.75	Ti(99.4%)	0.1925	SS-0.2	SS-0.2	55	11	0.1-15	TOF	OSA	[15]	+
					O(0.06%)	0.0035									
					Cl(0.08%)	0.0022									
					Fe(0.08%)	0.0014									
					Mg(0.03%)	0.0011									
Cr	19.75	10.2	9.55(0.7)	5.75	Cr(99.8%)	0.4301	SS-0.2	SS-0.2	55	11	0.1-15	TOF	OSA	[15]	+
					Fe(0.16%)	0.0064									
					C(0.02%)	0.0039									
Mn	30.00	2.5	27.50(3.4)	2.80	Mn(99.95%)	0.4788	SS-0.5	SS-0.3	55	11	0.1-15	TOF	OSA	[15]	+
Co	19.75	10.2	9.55(0.5)	5.75	Co(99.5%)	0.5439	SS-0.2	SS-0.2	55	11	0.1-15	TOF	OSA	[15]	+
					Ni(0.15%)	0.0003									
					Fe(0.12%)	0.0007									
Ni	16.00	≈2.5	≈14.50(3.3)	≈2.5	Ni(99.6%)	0.9046			0	9.5	0.04-15	TOF	OSA	[17]	+
					Si(0.16%)	0.0304									
					Mn(0.15%)	0.0146									
Cu	30.00	2.5	27.50(4.7)	2.80	Cu(99.99%)	0.1628	SS-0.5	SS-0.3	55	11	0.1-15	TOF	OSA	[15]	+
As	19.75	10.2	9.55(0.8)	5.75	As(99.99%)	0.2484	SS-0.2	SS-0.2	55	11	0.1-15	TOF	OSA	[15]	+
Se	19.75	10.2	9.55(0.6)	5.75	Se(99.9%)	0.1747	SS-0.2	SS-0.2	55	11	0.1-15	TOF	OSA	[15]	+
Zr	30.00	2.5	27.50(2.0)	2.80	Zr(99.9%)	0.1875	SS-0.5	SS-0.3	55	11	0.1-15	TOF	OSA	[15]	+
Nb	14.00	2.95	11.05(1.1)	2.45	Nb(99.8%)	0.2640	SS-0.3	SS-0.3	55	11	0.1-15	TOF	OSA	[15]	+
					Ta(0.10%)	0.0001									
Mo	30.00	2.5	27.50(1.5)	2.80	Mo(99.9%)	0.1350	SS-0.5	SS-0.3	55	11	0.1-15	TOF	OSA	[15]	+
W	19.75	10.2	9.55(0.8)	5.75	W(99.98%)	0.2765	SS-0.2	SS-0.2	55						
					O(0.023%)	0.0038									
Pb	8.0	5.0	3.0(0.7)	4.5	Pb	0.33*			0, 50	6-9	0.02-15	TOF	OSA	[14]	
	11.0	5.0	6.0(1.4)	4.5											
	14.0	5.0	9.0(2.0)	4.5											
	17.0	5.0	12.0(2.7)	4.5							0.2-15	TOF	TOH	[18]	
Pb	8.0	3.0	5.0(1.1)	2.25	Pb	0.33*									

Table 4.

Leakage neutron spectrum measurements with a T(d,n) source (Europe)

Material	Radius R, cm	Radius r, cm	Wall cm(mfp)	Opening r,cm	Chemical composition	Concentration 10^{23} cm^{-3}	Container outer	Container inner	Detector Beta°	Detector L, m	E_1 - E_2 MeV	Method	Laboratory	Reference	Numerical data
Be			5.0(0.9) 10.0(1.8) 17.0(3.1)		Be	1.229*					10^{-8}-15	TOF	KFK	[19]	
Be	11.0	6.0	5.0(0.9)	2.5	Be	1.236			0, 30, 60	3.8	0.4-15	TOF	FEI	[20]	+
Be	11.0	6.0	5.0(0.9)	2.5	Be	1.236			0	10	6-15	TOF	KGU	[21]	
Al	12.0	4.5	7.5(0.6)	3.1	Al(99%) Si(0.3%) Fe(0.3%) Ti(0.3%)	0.5966			0, 40, 75,	3.8	0.2-15	TOF	FEI	[20]	+
Al	12.0	4.5	7.5(0.6)	3.1	Al(99%)	0.5966			0	10	6-15	TOF	KGU	[21]	+
Al	20.0	10.0	10.0(0.8)	~1.5	Al	0.603			0, 90	0.6	3-15	PRS	KGU	[21]	+
Al	12.0	4.5	7.5(0.6)	3.1	Al	0.5966				3.0	1-15	PRS	IRD	[22]	+
Fe	12.0	4.5	7.5(1.7)	3.1	Fe	0.8374				3.0	1-15	PRS	IRD	[22]	+
Fe	12.0	4.5	7.5(1.7)	3.1	Fe(99%) Mn(0.45%) Cr(0.3%) C(0.15%)	0.8374			0, 40, 75	3.8	0.2-15	TOF	FEI	[20]	+
Ni	12.0	4.5	7.5(1.7)	3.1	Ni	0.9016			0, 40, 75	3.8	0.2-15	TOF	FEI	[20]	+
Ni	12.0	4.5	7.5(1.7)	3.1	Ni	0.9016				3.0	1-15	PRS	IRD	[22]	+
PbLi	20.0	6.0	14.0(2.2)	2.5	Pb(83%) Li(17%)	0.276 0.0565	SS-0.1		40	3.8	0.2-15	TOF	FEI	[20]	+
Pb	12.0	4.5	7.5(1.7)	2.5	Pb	0.330			0, 30, 60	3.8	0.2-15	TOF	FEI	[20]	+
Pb	12.0	4.5	7.5(1.7)	2.5	Pb	0.330				3.0	1-15	PRS	IRD	[22]	+
Pb	25.0	2.5	22.5(4.1)		Pb	0.330*			90	4.3	0.1-15	TOF PRS	TUD	[23]	
Bi	12.0	3.0	9.0(1.4).	2.5	Bi	0.282			0, 60, 95	3.8	0.4-15	TOF	FEI	[20]	+
U	16.0	10.0	6.0(1.7)		^{8}U(99.6%) ^{5}U(0.4%)	0.471* 0.002*			90	4.5	0.1-15	TOF PRS	TUD	[24]	
U	12.0	4.0	8.0(2.2)	2.5	^{8}U(99.6%) ^{5}U(0.4%)	0.4760 0.0019			0, 60, 95	3.8	0.4-15	TOF	FEI	[20]	+
U	14.0	5.0	9.0(2.5)	~1.5	^{8}U(99.6%) ^{5}U(0.4%)	0.471 0.0019			0, 90	1.0	0.6-15	PRS	KGU	[21]	+
Th	13.0	3.0	10.0(1.7)	2.5	Th	0.293	Al-0.15		0, 60, 95	3.8	0.4-15	TOF	FEI	[20]	+

Table 5.

Leakage neutron spectrum measurements for spherical assemblies with a ^{252}Cf source

Material	Radius	Wall		Opening	Chemical composition	Concentration	Container		Detector	E_1 - E_2 MeV	Method	Laboratory	Reference	Numerical data
	R, cm	r, cm	cm(mfp)	r,cm		10^{23} cm^{-3}	outer	inner	L, m					
H_2O	25.0				H	0.660*			0.8	0.6-15	PRS	FEI	[26]	+
	35.0				O	0.334*								
Be	11.0				Be	1.229*			2.0	1-14	PRS	UI	[10]	
CH_2	23.0				H				2.0	1-14	PRS	UI	[10]	
					C									
CH_2	30.0				H				1.5	0.01-14	PRS	FEI	[2,24]	+
					C									
Na	26.0				Na	0.254*	Al-0.4		1.5	0.01-14	PRS	FEI	[2,25]	+
	50.0													
Cr	35.0				Cr	0.801*				0.01-14	PRS	FEI	[26]	+
Cr	7.89	1.6	6.29(1.5)		Cr(99.8%)	0.5119	Cu-0.11	Cu-0.15	0.23	0.04-10	PRS	UJF	[27]	
Fe	10.0	1.0	9.0(2.6)		Fe		Fe		0.6-1.0	0.01-14	PRS	FEI	[2,20]	+
	15.0	1.0	14.0(4.0)											
	25.0	1.0	24.0(6.9)											
	20.0	1.0	19.0(5.5)											
	30.0	1.0	29.0(8.4)											
	35.0	1.0	34.0(9.8)											
Fe	12.0	4.5	7.5(1.7)	3.1	Fe	0.8374			3.8	0.2-14	TOF	FEI	[20]	
Ni	8.5	1.5	7.0(2.2)		Ni(99.5%)				0.23	0.04-10	PRS	ROS	[27]	
Nb	12.7	3.09	9.61(2.5)		Nb(99.05%)				2.0	1-14	PRS	UI	[10]	
					Zr(0.95%)									
PbLi	20.0	6.0	14.0(2.2)	2.5	Pb	0.276	SS-		3.8	0.2-14	TOF	FEI	[20]	+
					Li	0.0565								
Pb	20.0	1.0	19.0(3.0)		Pb		SS-0.15		0.9	0.02-14	PRS	FEI	[2]	+
	30.0	1.1	28.9(4.5)											
Bi	12.0	3.0	9.0(1.4)	2.5	Bi	0.282			3.8	0.4-14	TOF	FEI	[20]	+
U	12.0	4.0	8.0(2.8)	2.5	^{8}U(99.6%)	0.4760			3.8	0.4-14	TOF	FEI	[20]	+
					^{5}U(0.4%)	0.0019								
U	11.0	1.0	10.0(3.5)		^{8}U(99.6%)	0.4760				0.01-14	PRS	FEI	[26]	+
Th	13.0	3.0	10.0(2.1)	2.5	Th	0.293	Al-0.15		3.8	0.4-14	TOF	FEI	[20]	+

Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna
Austria

e-mail, INTERNET: SERVICES@IAEAND.IAEA.OR.AT
e-mail, BITNET: RNDS@IAEA1
fax: (43-1) 20607
cable: INATOM VIENNA
telex: 1-12645 atom a
telephone: (43-1) 2060-21710

online: TELNET or FTP: IAEAND.IAEA.OR.AT
username: IAEANDS for interactive Nuclear Data Information System
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