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TRANSLATION OF REPORTS FROM THE FIRST INTERNATIONAL CONFERENCE ON NEUTRON PHYSICS, KIEV, USSR, 14-18 SEPTEMBER 1987

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Contents

NEUTRON LEAKAGES FROM Pb AND Be SPHERICAL SHELLS WITH A CENTRAL 14-MeV NEUTRON SOURCE

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This paper describes the results of measuring neutron leakages from spherical shells of different thicknesses of Pb and Be materials, which are promising materials for nuclear fusion neutron breeders [1]. The experimental results are compared with calculations using the BLANK [2], ANISN [3], and MORSE [4] programs. Calculations with the ANISN and MORSE programs were carried out using data from the ENDF/B-IV, ENDL-II and JENDL-2 data files. The SUPERTOG-LTT [5, 6] program was used to prepare 54-group constants for calculations in the P5-approximation in the 0.1-15 MeV range for Pb and Be, and 25-group constants for calculations in the P3-approximation in the 4.14×10^{-7} to 15 MeV range for Be. In addition, 100-group neutron constants from the EURLIB [7] and DLC37F [8] libraries, based on the ENDF/B-IV file, were used in the calculation. For the calculation using the BLANK program, 65-group constants were used in the 0.1-15 MeV energy range and 21 group constants for calculations in the P1-approximation below 0.1 MeV, based on the ENDL and UKNDL files.

The isotropic point source of neutrons was defined by an energy distribution in the 54-group approximation (in the first six groups). In the 26- and 100-group approximations, the source was monolinear in the first energy group with a width of 12.2-14.9 MeV and 13.5-14.9 MeV, respectively.

The neutron leakages were measured by the total absorption method [8]. The spherical shells were placed in the centre of a large spherical layer filled with an aqueous solution of boric acid. The dimensions of the layer were D_{ext} = 132 cm, D_{int} = 40 cm. A 14-MeV

Table 1.

Experimental and calculated neutron leakages for the Pb-assembly, nuclear density 0.0335 $(\text{cm}\cdot\text{barn})^{-1}$

Thickness of the assembly, cm	Experiment		BLANK (INDL)			ANISN			MORSE			Group constants
	M	N_{sec}	M	T	N_{sec}	M	T	N_{sec}	M	T	N_{sec}	
ΔR = 3 r = 9 R = 12	1,26±0,03	0,51±0,04	1,19	0,75	0,44	1,182	0,757	0,424				INDL,54 gr (15-0,1) MeV
						1,196	0,76	0,436				INDF,54 gr (15-0,1) MeV
						1,205	0,749	0,456	1,183±0,2% 1,195±0,2%	0,756 0,763	0,425 0,442	INDF,26 gr (15-0,1) MeV
						1,191	0,749	0,442	1,168±0,2%* 1,183±0,2%	0,758 0,763	0,410 0,420	INDF,26 gr (15-0,1) MeV
						1,195	0,748	0,448				DLC37F,100 gr (15-0,1) MeV
ΔR = 9 r = 3 R = 12	1,53±0,05	1,05±0,05	1,45	0,45	1,00	1,429	0,433	0,996				INDL,54 gr (15-0,1) MeV
						1,461	0,438	1,026	1,415±0,6%	0,479	0,940	INDF,54 gr (15-0,1) MeV
						1,426	0,423	1,003	1,400±0,9%	0,478	0,951	INDF,26 gr (15-0,1) MeV
						1,470	0,423	1,046	1,429±0,9%	0,478	0,951	(15-0) MeV
									1,415±0,7%	0,459	0,958	EURLIB,100 gr (15-0,1) MeV
									1,452±0,7%	0,459	1,00	(15-0) MeV
						1,458	0,420	1,036				DLC37F,100 gr (15-0,1) MeV
						1,494	0,420	1,074				(15-0) MeV

* Calculation without taking the channel into account.

Table 2.

Experimental and calculated neutron leakages for the Be-assemblies, nuclear density 0.124 $(\text{cm}\cdot\text{barn})^{-1}$

Thickness of the assembly, cm			BLANK (JENDL)			ANISN			MORSE			Group constants
	M	N_{sec}	M	T	N_{sec}	M	T	N_{sec}	M	T	N_{sec}	
ΔR = 5 r = 6 R = 11	1,36±0,04	0,76±0,04	1,36	0,60	0,76	1,281	0,58	0,701	1,252±0,5%	0,602	0,650	JENDL-2;54 gr (15-0,1) MeV
									1,283±0,5%	0,604	0,679	
						1,193	0,547	0,646				DLC37F;100 gr (15-0,1) MeV
						1,350	0,547	0,834				(15-0) MeV
ΔR = 8 r = 3 R = 11	1,53±0,05	1,07±0,5	1,52	0,46	1,06	1,326	0,487	0,839	1,312±0,9%	0,445	0,687	JENDL-2;54 gr (15-0,1) MeV
									1,356±0,6%*	0,442	0,913	
						1,199	0,381	0,815				DLC37F;100 gr (15-0,1) MeV
						1,581	0,381	1,200				(15-0) MeV
									1,129±0,4%	0,426	0,701	JENDL-2,99 gr (15-0,1) MeV
									1,463±0,5%	0,428	1,055	15 – 0,414 MeV

* Calculation without taking the channel into account.

neutron source - the Ti-T target of an NG-150 m neutron generator - was placed in the centre of the assemblies to be studied, and the rate of absorption of delayed neutrons by boron-10 was measured.

Analysis of the calculated leakage spectra showed that they could be described by the superposition of a 14-MeV neutron source and a spectrum of inelastically scattered secondary neutrons. Thus the total leakage of the assembly being studied can be written as:

$M = T + N_{sec}$,

where T is the transmission of 14-MeV neutrons through the assembly; and

N_{sec} is the number of secondary neutrons which escape from the assembly.

The values of M and N_{sec} were found by integration of the experimental distributions of the KNT-10 boron chamber counting rate over the volume of the "boron tank" at various angles to the direction of the deuteron beam. The results were normalized to a single 14-MeV neutron from the source.

Calculation of leakages by means of the three-dimensional MORSE program "without the source channel" and "with the channel" showed that the presence of the experimental channel in the assemblies did not have any significant effect on the total leakage.

Comparison of the experimental results with calculated data showed that all calculations underestimate the leakage of neutrons from the Pb assembly. The results based on data from the ENDL library are lower than those based on ENDF/B-IV data. This difference may be attributed to the cross-sections which figure most prominently in these calculations (in barns); for ENDF/B-IV: $\sigma_t = 5.3$, $\sigma_{in} = 3.36$; for ENDL-II: $\sigma_t = 5.35$, $\sigma_{in} = 3.04$.

The total fluxes, and also the neutron fluxes in the 0.1-15 MeV range in the 26-group approximation, are lower than the results obtained in the 54- and 100-group approximations. This appears to be due to the averaging spectrum, which has a significant effect when the groups are insufficiently narrow.

The calculation for the beryllium assembly using ENDF/B-IV (DLC37F) data and the ANISN program overestimates the total neutron flux by 3%. Of special note is the underestimated transmission value T and the corresponding overestimate of the number of secondary neutrons by comparison with the experimental data and with calculations using the BLANK program with URNDL constants and the MORSE program with JENDL-2 constants. Since the main quantities, such as σ_t and $\sigma_{n,2n}$, are identical in the ENDF/B-IV and JENDL libraries, the difference in the results must be due to differences in the inter-group matrices.

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INTEGRAL EXPERIMENT ON TRANSMISSION OF 14-MeV NEUTRONS IN A FLiBe-ASSEMBLY

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Fluorine-lithium-beryllium assemblies are being considered as possible blanket materials for fusion reactors. The ^{9}Be and ^{7}Li nuclei in them service neutron breeders by way of the (n,2n) reaction with primary 14-MeV neutrons, while the ^{6}Li isotope produces tritium through the reaction ^{6}Li(n,T), ^{4}He + 4.8 MeV.

In order to study the breeding properties of lithium and beryllium, the spectral indices for neutron leakages from a spherical assembly were measured and compared with model calculations. The assembly contained molten LiF and BeF_2 salts in equal molar units.

The FLiBe-assembly consisted of a sphere with an external diameter of 41.6 cm and an internal diameter of 12 cm. The ion guide of the SAMES 150D neutron generator of the Nuclear Research and Power Institute in Sofia is constructed so that a tritium target with a working spot diameter of 34 mm can be placed in the geometrical centre of the sphere. The whole surface of the target spot can be studied by means of an Si-Au surface-barrier detector shielded from scattered deuterons by an aluminium foil 1.3 mg/cm^{-2} thick. The spectrum of pulses from the alpha particles accompanying the 14-MeV neutrons was measured by a multichannel analyser. This made it possible to calibrate the absolute neutron flux with respect to the background base of the alpha spectrum. Then the pulses from the detector were discriminated by a single-channel analyser whose resolving limits included the alpha peak. The signals from this discriminator were passed to a multiscanning electronics unit, which finally gave information about changes in the neutron flux over time.

Table 1

Reaction	Total number of nuclei x 10^{21}	$E_{threshold}$, MeV	$T_{1/2}$	E_γ, keV	Quantum yield %	Activity x 10^{-30}
$^{103}Rh(n,n')^{103m}Rh$	1.38	0,05	56,1 min.	20	7	(390 ± 40)
$^{115}In(n,n')^{115m}In$	5,18	0,50	4,5 hours	336	46	(19,3 ± 1,5)
$^{204}Pb(n,n')^{204m}Pb$	1,22	3,00 ?	66,9 min.	375	93	(24 ± 3)
$^{64}Zn(n,p)^{64}Cu$	5,40	1,5	12,71 hours	511	38	(71 ± 1,2)
$^{65}Cu(n,2n)^{64}Cu$	2,62	10,5	12,71 hours	511	38	(184 ± 50)
$^{19}F(n,2n)^{18}F$	9,47	11	109,8 min.	511	194	(5,3 ± 0,6)

Table 2

Distance from surface, cm	$^{115}In(n,\gamma)^{116}In$	$^{115}In(n,n')^{115m}In$		$^{19}F(n,2n)^{18}F$	
	Experiment	Experiment	Calculation	Experiment	Calculation
0	1	1	1	1	1
50	0,80 ± 0,05	0,08 ± 0,005	0,065 ± 0,001	0,097 ± 0,005	0,085 ± 0,001
100	0,78 ± 0,02	0,03 ± 0,002	0,022 ± 0,0003	0,031 ± 0,002	0,029 ± 0,0004

Table 3

Program	Data	Φ*	I*	Activity x 10^{-30*}		
				$^{65}Cu(n,2n)^{64}Cu$	$^{115}In(n,n')^{115m}In$	$^{19}F(n,2n)^{18}F$
ANISN	54 gr. ENDF, JENDL	1,059	0,771	51,8	25,1	2,31
ANISN	ENDF, DLC37F	1,048	0,772	54,1	26,5	2,72
MORSE For total leakage	54 gr. ENDF, JENDL	1,053 ±0,9%	0,776 ±0,6%	(52,7 ±1,3%)	(25,8 ±1,2%)	(2,41 ±1,4%)
MORSE, For evaluation at the detector point	54 gr. ENDF, JENDL	0,843 ±9,0%	—	(50,3 ±8,0%)	(21,5 ±16,0%)	(2,44 ±10,0%)

[*] F and J - Total flux and fluence across the whole surface of the sphere.

In the experiment, the tubes with water for cooling the target were withdrawn coaxially with the deuteron beam in a forward direction. The measurements were made at a point on the surface of the sphere 150° from the beam using a set of threshold activation detectors (Table 1). The foil was irradiated at the same time. Samples of F, Rh and Pb were irradiated for four hours, samples of Cu, Zn, In and F for seven and a half. The induced gamma activity was measured using 100 x 100 mm NaI(Tl) scintillation detectors, a Ge(Li) semiconductor detector with a volume of 70 cm^3, and a hyperpure germanium detector (20 cm^3) with a beryllium window.

The following measurement factors were taken into account in calculating the induced activities: the efficiency of the detector system; the dependence of the absolute neutron flux on time; the quantum yield of the gamma activity to be measured; reduction of the activities to saturated activities; self-absorption in the thickness of the samples; and time corrections for irradiation, cooling and measurement.

The data obtained on the activities for one nucleus by one neutron from the target are shown in the last column in Table 1.

The geometrical conditions of the experiment are such that the effect of the walls of the measuring chamber has to be taken into account. For this purpose, a measurement was made in which one pair of F and In activation detectors was placed on the surface of the sphere and a second and third pair at distances of 50 and 100 cm from the surface, respectively. Data on the activities measured relative to the activity on the surface are shown in Table 2. As can be seen from the results obtained and from the numerical calculations using the MORSE program, the effect of the experimental geometry is small.

The neutron transport was calculated using the one-dimensional program ANISN [1] and the three-dimensional Monte Carlo MORSE program [2]. The data on interactions between the neutrons and the material were taken from the evaluated data library ENDF/B-IV for ^{6}Li, ^{7}Li and ^{19}F and from JENDL-2 for ^{9}Be. Constants in a 54-group approximation and in the P5-approximation in the 15-0.1 MeV energy range were obtained using the SUPERTOG program [3]. Calculations were also made with data from the DLC37F library [4] in the 15-0.1 MeV range.

The source was assumed to be an isotropic point source with a linear distribution for the neutron energies in the first six groups. In order to calculate the functionals corresponding to the induced activities of the threshold detectors, data from the ENDF/B-IV library were used.

The evaluations of the integral flux F, the fluence I and the activities A produced by the neutron leakage, which were made using the MORSE program and which are given in Table 3, correspond to the results obtained for the actual geometry of the experiment (taking into account the experimental channels). Comparison of the results using the ANISN and MORSE programs shows that taking into account the inhomogeneity of the sphere has scarcely any effect on the evaluation of the total leakage. The slight overestimation of the activities obtained using the MORSE program correctly reflects the harder spectrum due to leakage in the channels.

The difference in the results using the ANISN program obviously arises from the difference in the initial data on neutron interactions with beryllium.

The discrepancy between the experimental data and the calculation results shows that it is necessary to continue work to refine neutron data, to improve the reliability of the methods and to expand the range of threshold detectors studied.

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