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ABSTRACT

The given work concludes the series of total neutron leakage multiplication experiments performed in the RRC "Kurchatov Institute" with the perspective neutron multiplying materials, such as U, Th, Bi, Pb and Be. It is devoted to the measurements and calculations for seven beryllium spheres combined from the spherical shells belonging to the USA, PRC and RF.

The total leakage multiplication measurements were done by the TAD (Total Absorption Detector) method with the use of boron tank. The calculations were carried out by MCNP/4A transport code with FENDL-1 data.

A comparison of experimental and calculational results has shown excellent agreement (within the experimental errors ~ 3-4 %) of the leakage multiplication values for all the spheres covering the range of beryllium layer thickness from 3 cm to 20 cm.

Introduction

The problem of perfection and testing the neutron data of beryllium, as one of the effective neutron multiplying materials for perspective fusion reactors, is still valid. From practical point of view the important characteristic of multiplying material is a dependence on the material layers thickness of its total multiplication - the total number of neutrons generated under 14 MeV neutrons. The most accurate method of experimental testing of this characteristic is a method of total absorption detector (TAD), enabling to measure the total neutron leakage from the samples with the accuracy up to 3-4 % [1,2]. It has caused the application of this method in various its modifications to testing of beryllium data in different countries [1-5]. The experiments with leakage spectrum measurements [6] are also involved in testing of beryllium neutron multiplication.

The idea of carrying out the series of experiments on beryllium spherical layers with the thickness ranging from 3 to 20 cm using the combination of the existing compatible spherical shells, belonging to the USA and PRC, with additional outer spherical shell proposed to be manufactured in Russia, has arisen during the IAEA AGM held at November 19-21, 1990 in Chengdu, China. As a result of a discussion under chairmanship of Dr. E.T.Cheng the recommendations were done for mutual exchange by spheres with the purpose of executions of neutron leakage experiments in Russia and PRC. The realization of this arrangement in granting of spherical beryllium shells from USA and PRC, on the one hand, and manufacturing in Russia of additional outer shell, on the other hand, has allowed to carry out in the RRC KI the series of experiments considered below. Unfortunately, on independent from the authors of this work reasons, the Russian shell still was not presented for the similar experiments in China.

Under the IAEA RC the experimental measurements with the combined beryllium spheres done in 1994-95 were processed and compared with the calculations.

Experiment

The neutron leakage from beryllium spheres was measured by the TAD (total absorption detector) method in a "boron tank" [1]. The studied spherical assemblies were placed in the center of the large tank in shape of a spherical layer filled with a solution of boric acid in water.

The dimensions of the tank were: D_{outer} = 1320 mm, d_{intern} = 600 mm. The thickness of the tank walls made of stainless steel was 2 mm. The nuclear density of ^{10}B in water made $7{,}95 \cdot 10^{19}$ cm^{-3}. The boron in boron acid was enriched to 88.6% by the isotope ^{10}B.

The characteristics of the studied beryllium assemblies are given in Table 1.

Table 1. The characteristics of beryllium shells and assemblies

№	R_{intern}, cm	R_{outer}, cm	Layer thickness, cm	Layer mass, kg	Total thickness, cm	Country
1	2.5	5.7	3.2	1.31	3.2	USA
2	5.7	6.9	1.2	1.11	4.4	PRC
3	6.9	9.7	2.8	4.53	7.2	PRC
4	9.7	12.8	3.1	9.18	10.3	PRC
5	12.8	15.25	2.45	10.96	12.75	USA
6	15.25	17.35	2.1	13.25	14.85	USA
7	17.35	22.3	4.95	47.79	19.8	RF

Table 2. Nuclear contents of beryllium shells

№	Country	R_{inner}, cm	R_{outer}, cm	Thickness, cm	Density, g/cm^3	Contents, wt %
1 5 6	USA	2.5 12.8 15.25	5.7 15.25 17.35	3.2 2.45 2.1	1.84	Be-98.82, O-0.72, Fe-0.13, C-0.11, Al, Si, Mg, Ni
2 3 4	PRC	5.7 6.9 9.7	6.9 9.7 12.8	1.2 2.8 3.1	1.82	Be-98,9, O-0.5, Fe-o.6
7	RF	17.35	22.3	4.95	1.76	Be-99.6, C-0.1, O-0.1, Fe-0.09, Al-0.03, Mg-0.017, Ni, Si, Cu

The neutron generator NG-150M with the modernized ion beam tube was used as a neutron source. A TiT-target 20 mm in diameter (manufactured from the standard target 28.5 mm in diameter) was placed in the assemblies center. The normalization of the measurement results to one source neutron was done by the associated α-particle method with the help of a silicon surface-barrier counter DKPs-25.

The distribution of neutron absorption in a boron tank was measured by the boron counter KNT-10 along a radius and a polar angle to the deuteron beam. The measurements were done under the angles of 0^0, 40^0, 80^0, 120^0 and 140^0 to the deuteron beam. Inside the channels the measurements were carried out in 15 radial positions. The radial step of measurements followed to the gradient of the neutron flux: the step was 1 cm close to the inner wall of the tank, and raised along the radius up to 5 cm close to the outer wall of the tank.

Measurement method

The method of the measurement was in details presented in [1,2]. The total neutron leakage was considered as a sum of two components: a group of the source neutrons T (including elastically scattered neutrons) and the secondary neutrons from inelastic collisions N_{sec}:

$$M = T + N_{sec}.$$

The response function of the TAD (boron tank) to M was determined as

$$\langle M \rangle = \langle T \rangle + \langle \varepsilon \rangle \cdot N_{sec},$$

where

$\langle T \rangle$ - the leakage of the source neutrons and elastically scattered neutrons, determined as $\int_{\Delta E} \phi(E) \cdot \varepsilon(E) dE$,

$\varepsilon(E)$ - the registration effectiveness of neutrons with the energy E in the boron tank,

$\phi(E)$ - the flux density of neutrons with the energy E in the leakage spectrum,

$\langle \varepsilon \rangle$ - the registration effectiveness for secondary neutrons.

In difference from previous experiments with multiplying assemblies [1,2] where the value $\langle T \rangle$ was measured by activation detectors, in the given work the leakage of the source neutrons was determined basing on the results of the leakage spectra measurements on the same spheres carried out in IPPE (Obninsk) with the TOF spectrometer having a base of 7 m. The energy range for integration of the source neutrons and elastically scattered neutrons was chosen ΔE = 10.5 - 16 MeV. The registration effectiveness for secondary neutrons $\langle \varepsilon \rangle$ was measured with the use of ^{252}Cf source. Basing on values of $\langle M \rangle$, $\langle T \rangle$ and $\langle \varepsilon \rangle$ the value of N_{sec} was determined and , after that, the value of M.

Calculations

The calculations were done with the transport code MCNP/4A using FENDL-1 data. The calculational model was prepared in 3-D geometry, including the channel in the spherical shells for ion beam tube. In 1-D calculations the channel was filled with beryllium. The neutron source was considered as a pointwise and isotropic one having the energy linearly distributed from 14.7 to 15.3 MeV. The ratio of boundary probability densities of the energy distribution due to the kinematics was taken 0.9. All the calculations were done with about 10^6 histories which ensured the total neutron leakage statistical error less than 0.1%.

Comparison of the results

The preliminary results of the total neutron leakage from beryllium assemblies in comparison with calculations are shown in Table 3 and Fig.1.

From the comparison it follows that for all the measured spheres both 1-D and 3-D calculations in a whole perfectly (within experimental errors ~3-4%) agree with the experiments. On Fig.1 one may notice a little smaller slope of experimental curve comparing to calculated ones. The difference between 1-D and 3-D calculations is small and practically does not depend on the sphere thickness.

Table 3. Total neutron leakage from beryllium assemblies.

№	Experiment		3-D calculation		1-D calculation	
	<T>	M_{exp}	M_{calc}	C/E	M_{calc}	C/E
1	0.808±0.023	1.226±0.038	1.186	0.967	1.198	0.977
2	0.734±0.022	1.305±0.041	1.261	0.966	1.274	0.976
3	0.627±0.018	1.450±0.044	1.435	0.989	1.447	0.998
4	0.515±0.015	1.615±0.045	1.613	0.999	1.626	1.007
5	0.424±0.013	1.715±0.043	1.740	1.014	1.752	1.021
6	0.347±0.010	1.827±0.057	1.833	1.003	1.844	1.009
7	0.245±0.007	1.940±0.062	1.986	1.024	1.993	1.027

Conclusions

As a result of the carried out experiments with a combined beryllium sphere, consisting from the shells belonging to the USA, PRC and RF, a set of total neutron leakage multiplication benchmark-experiments was created covering the range of beryllium thickness from 3 to 20 cm.

A comparison of experimental results with calculations by MCNP/4A code with FENDL-1 data has shown good agreement, practically within the limits of experimental error ~3-4%, both for 3-D and 1-D calculations.

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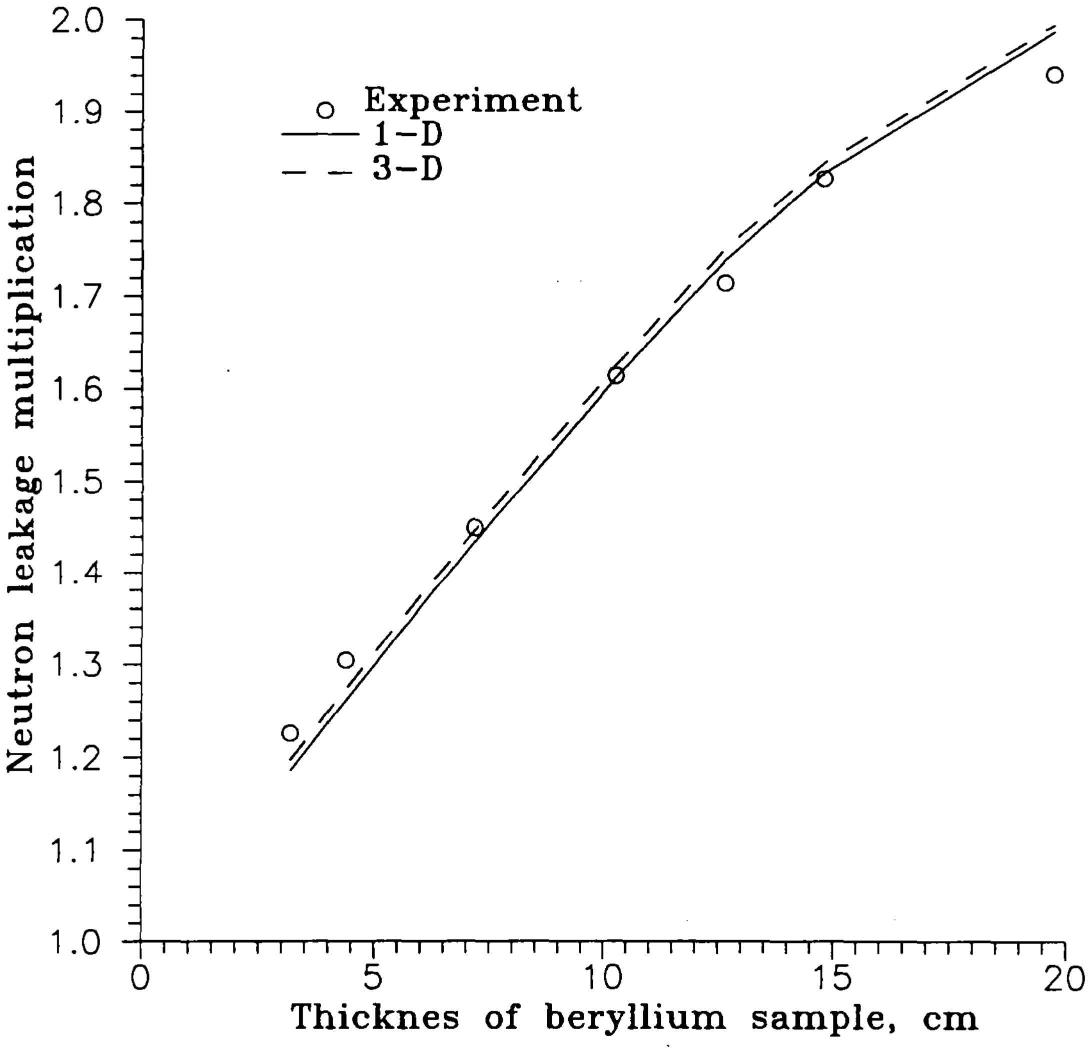

Fig.1. Total neutron leakage multiplication as a function of beryllium sample thickness.

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