VERIFICATION OF EVALUATED NEUTRON DATA FOR LEAD ON THE LEAKAGE NEUTRON SPECTRUM FROM SPHERE WITH CENTRAL ^{252}Cf SOURCE

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Abstract

The leakage neutron spectrum from sphere of lead with wall thickness of 227 mm with ^{252}Cf neutron source at its center has been measured by the time-of-flight method from 200 keV up to 10 MeV. The measurements was performed with use of a specially designed fast ionization chamber, supplied the stop pulses for the time-of-flight technique as well as total number of disintegrations during the experiment. The neutrons leaking from the outer surface of a sphere were detected with a scintillation counter composed of a paraterphenyl crystal of 5 cm in diameter and 5 cm long and FEU-143 photomultiplier tube. The measured data were compared with the MCNP-4 code calculations with nuclear data libraries processed from ENDF/B-6.3, BROND-2m and FENDL-2. The results of comparison by the spectrum shape and the calculation/experiment values in energy groups qualitativly confirm the discrepancies found out by us earlier with 14 MeV neutron source.

Introduction

Lead is planned to use as a coolant in the new designs of fast neutron fission reactor for realization of natural safety and as a neutron multiplier in an important class of fusion reactor blanket designs. That is why the requirements to the existing files of evaluated nuclear data for lead raise is actively studied. The evaluated data files have to be verficated through benchmark experiments. Among various kinds of benchmark experiments the measurement of leakage neutron spectra from homogeneous spherical shells with neutron source at their center by time-of-flight method is one of the best experiments. Compared with other geometrics the spherical symmetry greatly facilitates the measurements, since measurements at only one space point outside the sphere suffice for determination of the neutron leakage from sphere completely

The purpose of the present study is to verify evaluated neutron data for lead on the measurement of leakage neutron spectrum from spherical shell of lead with wall thickness of 227 mm with ^{252}Cf neutron source at its center. The measurements with a such large thickness of spherical shell is the most informative one for verification at lower neutron energies because of multiple collisions, that is very important for fission reactor designs.

Experiment

The measurements of leakage neutron spectrum with ^{252}Cf neutron source have been performed by time-of-flight technique. The experimental setup is shown in fig.1. The ^{252}Cf chamber was a cylinder of 35 mm diameter, 0.35 mm wall thickness and 120 mm length, filled with 90% Ar+10%CO_2 gas. Inside this tube there were two disc electrodes of 20 mm diameter by 0.2 mm thicknees, spaced 2 mm apart. The ^{252}Cf layer was deposited on one electrode and covered by a thin gold film. The active spot of 10 mm diameter emitted about

10^6 neutrons per second. The drawing of the ^{252}Cf fission chamber is shown in fig.2. The output of the chamber with discrimination against low amplitude pulses originating from α-particles supplied the stop pulses for the time-of-flight measurements as well as the total number of fission fragments for monitoring during the experiment. The chamber was placed in the spherical lead shell so that the center of the ^{252}Cf layer coincided with the geometric center of the sphere.

The sphere had outer and inner diameters of 500 mm and 46 mm respectively. The sphere had also a radial hole of 46 mm diameter for instalation of ^{252}Cf ionization chamber.

The neutron leakage from outer surface of a spherical shell were detected with a scintilation counter composed of a paraterphenyl crystal of 5 cm in diameter and 5 cm long and FEU-143 photomultiplier tube. The detector was located at 6.52 m flight path from center of the sphere and was installed in a lead house behind a 1 m thick concrete wall. The detector efficiency was determined by measuring of the ^{252}Cf prompt fission neutron spectrum by time-of-flight method in the same geometry of the experiment.

The electronic circuits of the spectrometer are separate units integrated in several data lines controlled by the computer. The details of the electronic circuits diagram are presented in the work [1]. The parameters of the electronic units were adjusted so as to obtain the best time resolution, low neutron threshold and sufficient γ-ray suppresion. Time resolution of the spectrometer was ~3 ns, neutron threshold ~70 keV and γ-ray suppressing factor ~10. For the control of the spectrometer stability was used time-of-flight monitor with scintillation detector composed of a fast plastic scintillator (d=2 cm, h=2 cm) and photomultiplier tube FEU-87.

For measuring of the background neutron spectra iron shadow bar (1 m long) with an additional borated polyethylene cylinder (30 cm long) was placed between sphere and detector.

Data processing

The leakage neutron spectrum measurement procedure had been consisted in measuring many times with and without shadow bar to average over possible fluctuations of the spectrometer. The final time-of-flight distribution of the leakage neutrons were obtained after careful selection of measured spectra and normalization to the same of fission fragments counts. Then time-of-flight distribution was converted to energy spectrum and was integrated over 4π sr. The normalization to one neutron of source was obtained from fission fragments count for ^{252}Cf neutron source. The measured leakage neutron spectrum were corrected for the distortions connected with scattering of neutrons on the ^{252}Cf chamber materials and with the conversion of time-of-flight spectrum to energy spectrum [2]. Corrections for these effects were obtained by simulating the experiment in Monte-Carlo calculations with the MCNP-4 code [3].

The uncertainties in measured leakage neutron spectrum were evaluated with taking into account of next component:

1. Counting statistics - (2- 20) % in the neutron energy range of (0.2-10) MeV.
2. Stability of the neutron spectrometer ~ 3 %.
3. Uncertainty of the neutron detector efficiency determination ~ 3 %.
4. Uncertainty of the neutron flux determination ~ 2%.
5. Uncertainty of calculations of the correction, connected with scattering of neutrons on the ^{252}Cf chamber materials (~1 %) and with time delay of neutrons in the spherical shell (~2%).

The total uncertainty of the measured spectrum varied from 5 % to 20 % in the neutron energy range of (0.2 - 10) MeV.

Experimental result and comparison with calculations.

The leakage neutron spectrum measured from lead sphere with ^{252}Cf neutron source is shown in fig. 3. The measured neutron leakage fluences for energy groups are presented in table.

Table. Measured neutron leakage fluences and calculations/experiment (C/E) for lead sphere.

Energy Range (MeV)	Experiment	C/E ENDF/B-6.3	C/E BROND-2m	C/E FENDL-2
0.2-04	(1.32±0.08)E-01	1.12	1.19	1.19
0.4-0.8	(2.46±0.16)E-01	1.15	1.11	1.22
0.8-1.4	(2.20±0.16)E-01	1.10	0.87	1.17
1.4-2.5	(1.56±0.11)E-01	1.18	1.21	1.08
2.5-4.0	(7.48±0.41)E-02	1.03	1.58	0.66
4.0-6.5	(1.82±0.12)E-02	0.82	1.19	0.34
6.5-10.5	(2.31±0.23)E-03	0.99	1.55	0.53

The calculations of the leakage neutron spectra were performed using a three-dimensional Monte-Carlo transport code MCNP-4 [3] with ENDF/B-6.3, BROND-2m and FENDL-2 evaluated data files. The details of ^{252}Cf ionization chamber and configuration of the sphere assembly have been taken into account. The transport constants for the calculations were made with using Nuclear Data Processing System NJOY [4].

The comparison of the measured and calculated results with ^{252}Cf neutron source shows that the calculation with the ENDF/B-6.3 evaluated data file is in a satisfactory agreement with the experimental result in the all neutron energy range. The calculations with BROND-2m data file overestimates and with FENDL-2 underestimates in average on ~40% the experimental result in the neutron energy range of (2.5-10.5) MeV. The comparison of the measured and calculated leakage neutron spectra for the same sphere with 14 MeV neutron source, performed by us earlier [5], shows analogous results (fig.4).

Conclusion

The leakage neutron spectrum from a thick sphere of lead with ^{252}Cf neutron source have been measured by time-of-flight method. The measured data have been compared with MCNP-4 code calculations with neutron data processed from ENDF/B-6.3, BROND-2m and FENDL-2 libraries. Analysis of the present benchmark experiment has shown that is observed a satisfactory agreement of measured leakage neutron spectrum and calculated one with ENDF/B-6.3 data file, BROND-2m data file essentially overestimates and FENDL-2 underestimates neutron leakage in the neutron energy range of (2.5-10.5) MeV in average on ~40%. The obtained results confirm the discrepancies found out for the same sphere with 14 MeV neutron source.

References:

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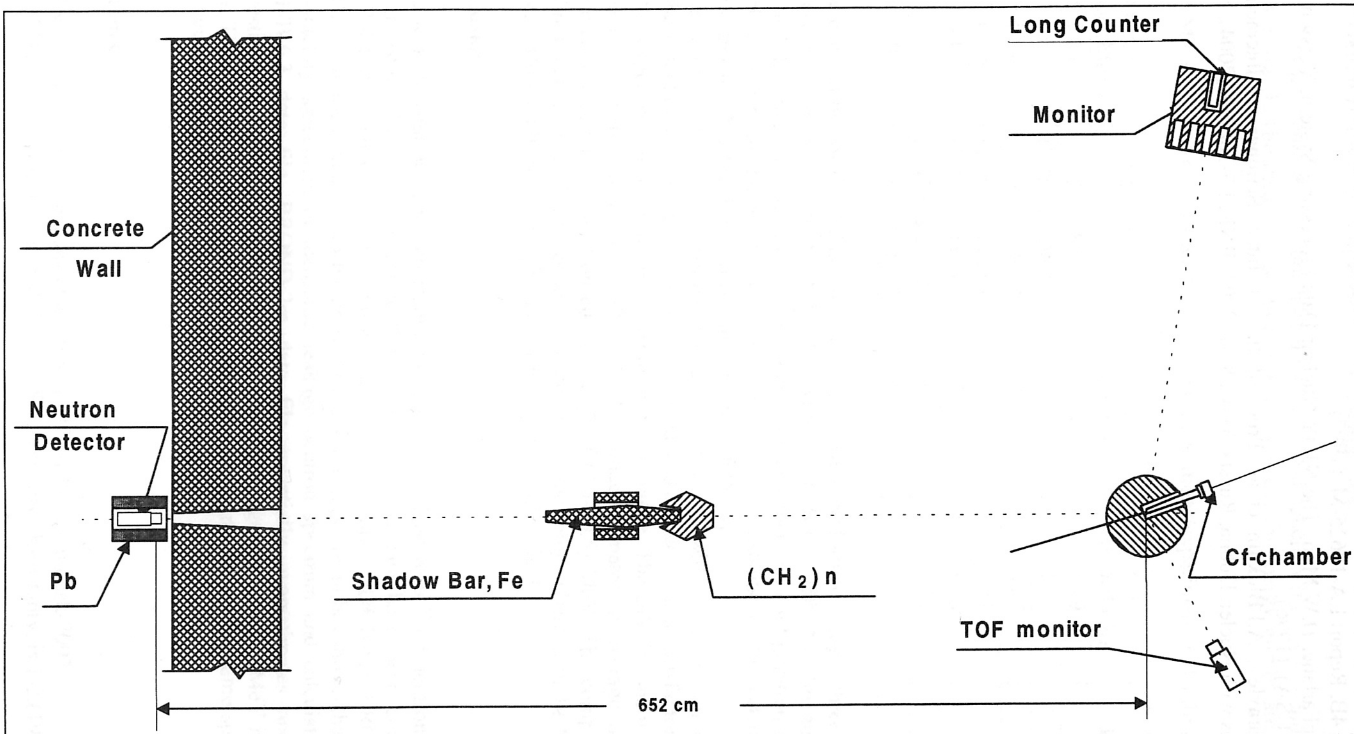

Fig.1 Lay-out of experiment for measuring the neutron leakage spectra from thick spheres

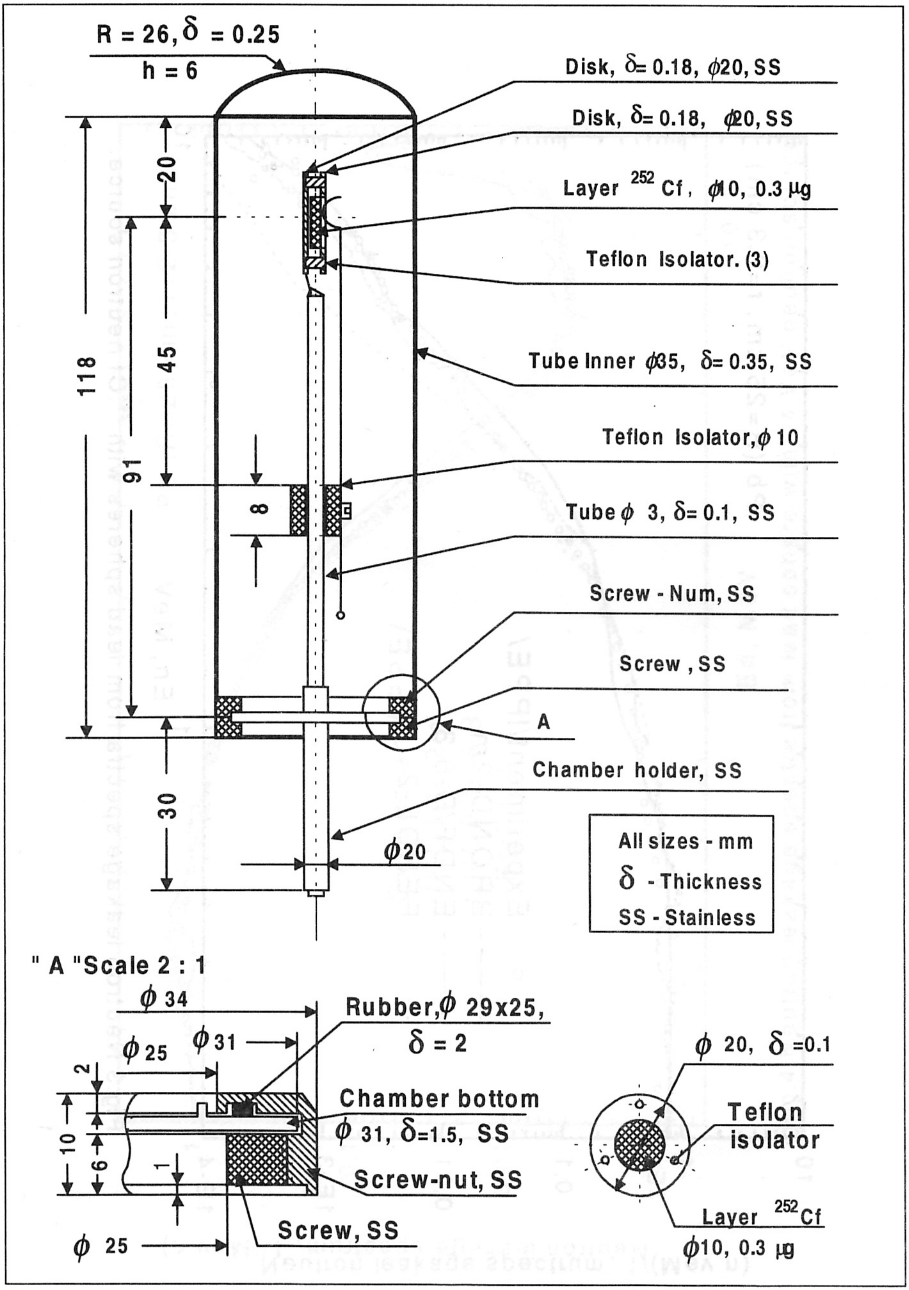

Fig.2 Cf-chamber

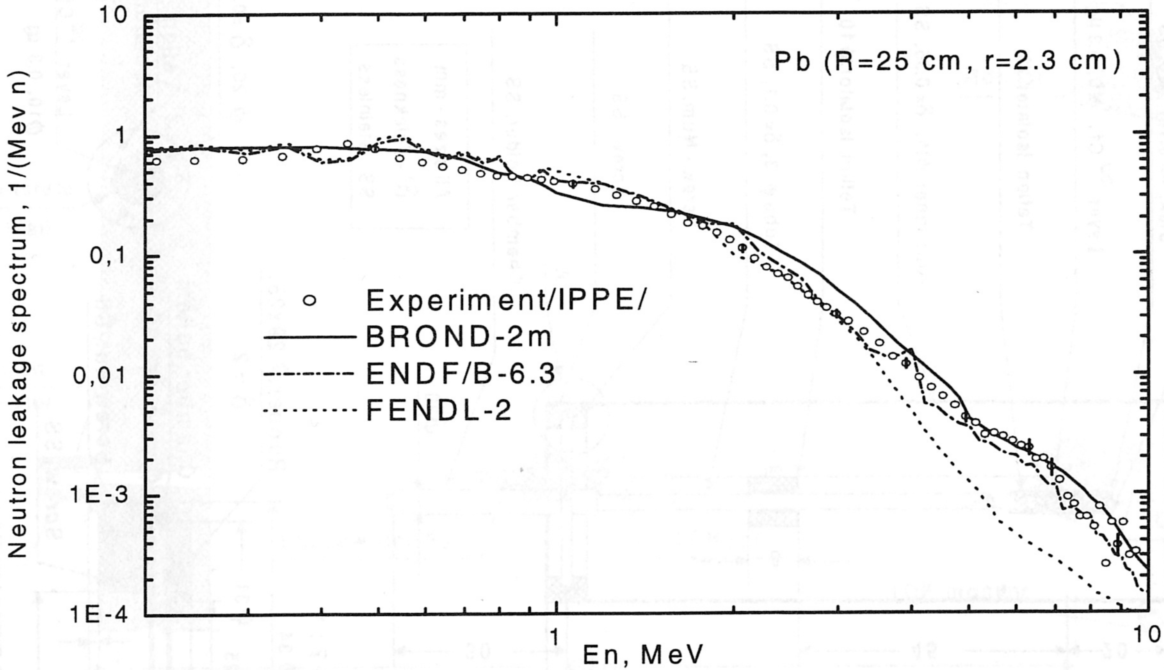

Fig.3 Neutron leakage spectra from lead spheres with ^{252}Cf neutron source.

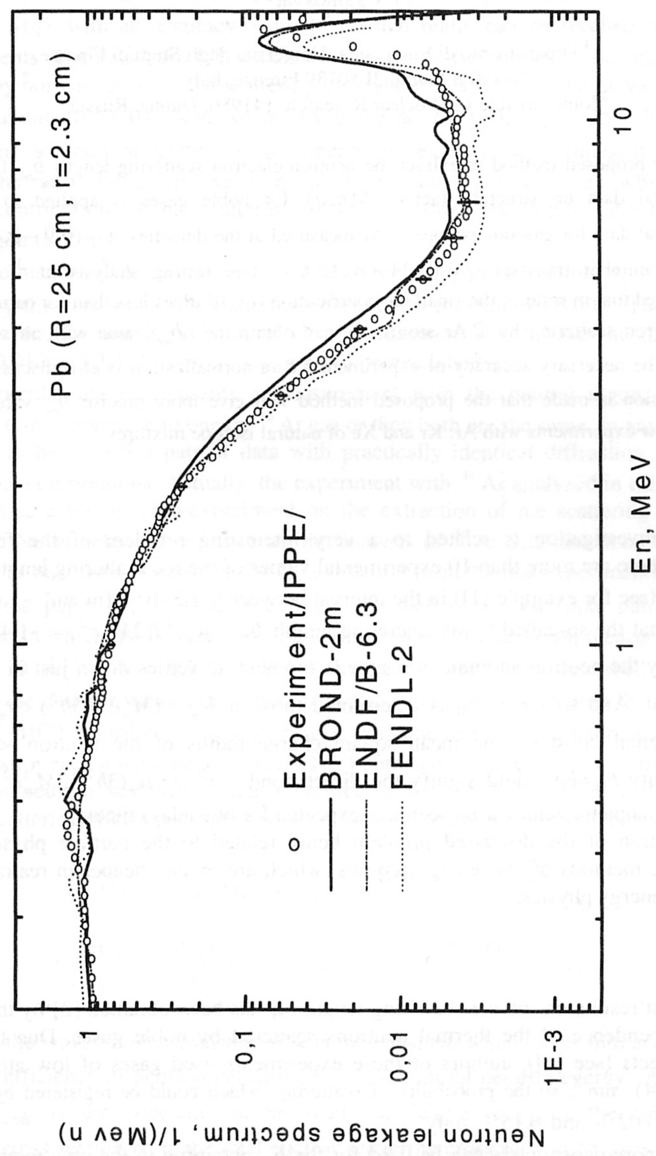

Fig.4 Neutron leakage spectra from lead sphere with 14 VeV neutron source.