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Spectra of leakage neutrons from a Pb–Li spherical shell with central ^{252}Cf and 14 MeV neutron sources and verification of evaluated neutron data

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Abstract

The spectra of leakage neutrons from a $Pb_{83}Li_{17}$ spherical shell with a ^{252}Cf neutron source at its center have been measured by the time-of-flight method in a neutron energy range of 200 keV to 10 MeV. The outer radius of the spherical shell was 200 mm, and the inner radius was 60 mm. Measurements were performed with the use of a dedicated fast ionization chamber which simultaneously supplied stop pulses for the time-of-flight technique and recorded the total number of ^{252}Cf decays for the experiment time. From the outer surface of the shell, the leakage neutrons were detected by a scintillation counter based on a paraterphenyl crystal with a diameter of 5 cm and a height of 5 cm and a FEU-143 photomultiplier tube. Earlier, spectra of leakage neutrons from the same spherical shell were measured with a 14 MeV neutron source using the same time-of-flight technique [1]. The results of the both measurements have been compared with the MCNP-4 Monte-Carlo code calculations with the ENDF/B-VII.1 and BROND-3 neutron data libraries.

Keywords: Neutron spectrum; Time-of-flight method; Ionization chamber with a ^{252}Cf neutron source; Scintillation neutron counter; Verification of evaluated neutron data.

Introduction

In an important class of fusion reactor designs, it is planned to use lithium for tritium breeding and to use lead for neutron multiplication. Besides, it is suggested that lead should be used as the coolant in new fast-neutron natural-safety fission-type nuclear reactor designs. This dictates the need for increased requirements to the existing files of evaluated neutron data for lithium and lead. Evaluated data files shall be checked in integral neutron transport experiments. One of the best experiments in the number of those for nuclear data verification is based on the measurement of the leakage neutron spectrum from a homogeneous spherical specimen with a neutron source at its center by the flight-of-time method. As compared to other geometries, spherical symmetry provides for a much greater accuracy of measurements since measurements only in a single detector position, relative to the shell's outer surface, are sufficient for measuring the neutron leakage from the whole of the shell.

The purpose of the study is to measure the spectrum of leakage neutrons from a 14 cm thick $Li_{17}Pb_{83}$ spherical assembly with a ^{252}Cf neutron source at its center and to verify the evaluated neutron data based on these measurements and earlier measurements with a 14 MeV source of neutrons [1].

Experiment

The flight-of-time method was used to measure the leakage neutron spectrum with a ^{252}Cf neutron source. The experiment setup is shown in Fig. 1. The californium fission chamber is a cylinder with a diameter of 35 mm, a length of 120 mm and a wall thickness of 0.35 mm filled with a gas mixture of 90%Ar + 10%CO_2. There are two disk electrodes with a diameter of 20 mm and a thickness of 0.2 mm mounted inside the cylinder at a distance of 2 mm between them. A californium layer was applied to one of the electrodes and covered with a thin gold film. The active spot with a diameter of 10 mm emitted about 10^6 neutrons per second. The pulses from the chamber

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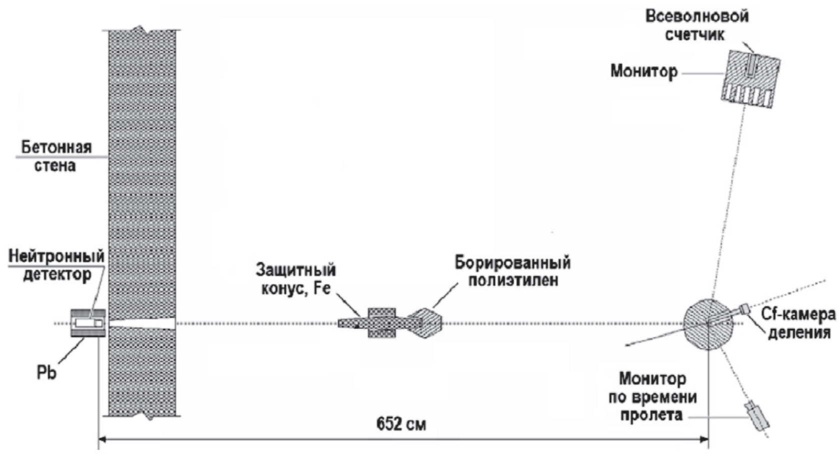

Всеволновой счетчик = Long counter
Монитор = Monitor
Бетонная стена = Concrete wall
Нейтронный детектор = Neutron detector
Защитный конус = Shadow bar (Fe)
Борированный полиэтилен = Borated polyethylene
Cf-камера деления = Cf fission chamber
Монитор по времени пролета – Time-of-flight monitor
652 см = 652 cm

Fig. 1. Geometry of the experimental facility for measuring the spectrum of leakage neutrons from thick sphere.

with discrimination of low-amplitude pulses from α-particles supplied stop signals for the time-of-flight measurements and enabled the counting of fission fragments for monitoring during the experiment. The chamber was positioned inside the spherical shell such that the center of the ^{252}Cf layer coincided with the geometric center of the shell.

The spherical shell is made from a lead–lithium alloy (the atomic ratio of Pb/Li is 83/17), and has the outer and inner diameters of 400 and 120 mm, respectively. It also has a cylindrical hole with a diameter of 50 mm for the installation of the ^{252}Cf ionization chamber.

Leakage neutrons were detected from the spherical specimen's outer surface by a scintillation counter based on a paraterphenyl crystal (with a diameter of 5 cm and a height of 5 cm) and a FEU-143 photomultiplier tube. The counter was installed in a lead castle behind a 1 m thick concrete wall on a 6.5 m path length from the shell's center. The efficiency of the counter was determined by measuring the ^{252}Cf fission neutron spectrum by the flight-of-time method in the same geometry of the experiment.

The spectrometer's electronic equipment had a highway-module arrangement and, structurally, was a computer-aided data measuring system. The electronic system parts are described in [2]. The parameters of electronic units were selected such that to have the best time resolution, a low neutron threshold and the sufficient γ-quanta background suppression. The spectrometer's time resolution was ~3 ns, the neutron threshold was ~70 keV and the γ-quanta suppression factor was ~10. The spectrometer stability was monitored using a time-of-flight monitor with a detector based on a fast plastic scintillator (a cylinder with a diameter of 2 cm and a length of 2 cm) and a FEU-87 photomultiplier tube.

To measure the background neutron spectrum, a 1 m long iron cone with an additional 30 cm long borated-polyethylene cylinder was installed between the spherical shell and the detector.

Processing of measurement results

The procedure for measuring of the leakage neutron spectrum consisted in repeated measurements with and without a shadow cone for averaging the potential spectrometer fluctuations. The final time-of-flight distribution of leakage neutrons was obtained after the spectra measured were carefully selected and normalized for the equal number of fissions. The time-of-flight spectrum was then converted to an energy spectrum and integrated in 4π steradian. The normalization per one source neutron was determined from the count of fission fragments in the ^{252}Cf ionization chamber. The measured leakage neutron spectra were corrected to allow for the distortions caused by the neutron scatter on the structural materials of the ^{252}Cf chamber and by the conversion of the time-of-flight spectrum to an energy spectrum [3]. The corrections for these effects were calculated using the MCNP-4B code [4].

The total error of the measured leakage neutron spectra was estimated with the following components taken into account:

- the statistical error was from 2 to 15% in the neutron energy range of 0.2 to 10 MeV;