Available online at www.sciencedirect.com

ScienceDirect

Nuclear Energy and Technology 2 (2016) 97–101

www.elsevier.com/locate/nucet

Examination of Silicon-28 and Uranium-235 resonance parameters based on integral and differential experiments

O.N. Andrianova*, G.B. Lomakov, G.N. Manturov

JSC «SSC RF-IPPE», 1 Bondarenko sq., Obninsk, Kaluga reg. 249033, Russia

Available online 24 May 2016

Abstract

The article presents the results of a calculation-to-experiment (C/E) discrepancy analysis for a new evaluation of differential (measuring neutron transmission) and integral experiments from the International Handbook of Evaluated Criticality Benchmark Safety Experiments. The experiments were carried out to examine the properties of fuel and structural materials. Based on these experiments, proposals were made for silicon-28 and uranium-235 resonance parameters corrections. This series of studies is considered as a sample joint analysis framework for differential and integral experiments required to correct nuclear data files of the ROSFOND evaluated neutron data library. The authors investigate the possible sources of the C/E discrepancies in their relation to uncertainties in the neutron cross-section resonance structure as well as resonance effects influencing the measured characteristics.

Keywords: Resonance parameters; Neutron data; The ROSFOND library; Critical experiments; BFS critical assembly; Neutron transmission function measurements.

Introduction

Over the last few decades, data on BFS reactor physics experiments carried out at the SSC RF-IPPE have been widely used for correcting both nuclear data systems and software tools [1] to be applied in calculation support for power and research reactors [2]. Neutron cross-section data were obtained from the experiments carried out at different times with different BFS core configurations and compositions to examine the properties of fuel and structural materials [3–5]. These data were used for corrections of the ABBN group constant system [6] and the ROSFOND evaluated nuclear data library [7].

The article presents the results of a C/E discrepancy analysis of differential (measuring neutron transmission functions) and integral experiments (on the BFS critical assemblies) carried out to examine the properties of fuel and structural materials. Based on these results, proposals were made for correcting neutron data files of the ROSFOND library. The calculations were made using the MCNP-5 transport code [8] in point-wise neutron cross-section representation. As applied to calculations of nuclear reactor neutronics, the quality of calculations carried out using precision codes is determined by the reliability of neutron data files, because their application makes it possible to minimize the model uncertainty.

Description of experimental programs

Integral experiments on the BFS critical assemblies: In cooperation with Idaho National Laboratory (INL, USA) a program of critical experiments was executed on the BFS-1 facility at the SSC RF-IPPE. The program consisted of two series [9]. The calculation models are described in the International Handbook of Evaluated Criticality Benchmark Safety Experiments—ICSBEP (HEU-MET-MIXED-005 and PU-MET-MIXED-001) [10].

In the first series of experiments (BFS-79), the core was composed of aluminum pipes filled with metal uranium pellets

* Corresponding author.

E-mail addresses: oandrianova@ippe.ru (O.N. Andrianova), glomakov@ippe.ru (G.B. Lomakov), mant@ippe.ru (G.N. Manturov).

Peer-review under responsibility of National Research Nuclear University MEPhI (Moscow Engineering Physics Institute).

Russian text published: Izvestia Visshikh Uchebnikh Zavedeniy. Yadernaya Energetika (ISSN 0204-3327), 2016, n.1, pp. 61-69.

http://dx.doi.org/10.1016/j.nucet.2016.05.005

(^{235}U enrichment ≈ 90%) and silicon dioxide. In the second series (BFS-81), instead of uranium, the core was filled with plutonium pellets (^{239}Pu enrichment ≈ 95%). An analysis of a series of experiments on criticality perturbation measurements by introducing highly enriched ^{235}U samples of different sizes into the center of these assemblies showed that the results were significantly different from those obtained by means of precision calculated codes which use point-wise neutron cross sections.

The measurements in the BFS-79 and BFS-81 critical assembles discovered that the reactivity introduced by ^{235}U (90%) pellets becomes negative. This effect was thoroughly examined [11]. It is obvious that this reactivity behavior may be due to the effect of ^{235}U resonance self-shielding within the intermediate neutron spectrum. First of all, the negative reactivity effect is caused by the core composition and configuration.

In this paper, the experiments on the BFS-79 and BFS-81 assembles, mainly composed of uranium, plutonium, and silicon, are used for correcting and verifying neutron data on uranium and silicon neutron cross-sections within the resonance region.

Neutron transmission function measurements: As part of the work, a large cycle of studies was considered in order to make a calculational description of experiments on the IBR-2 fast pulsed reactor (Dubna, Russia) on measurements of neutron beam transmission through ^{235}U sample filters with the impurity content up to 10% (^{238}U—8.8%, ^{234}U—1.2%). The results of these studies [12] were entered into the fundamental experiment database EXFOR (No.40082.2005) [13] and ICSBEP (FUND-JINR-1/E-MULT-TRANS-001). The experiments were focused on the resonance self-shielding effects of ^{235}U sample filters during a neutron beam transmission; the energy range for total transmission measurements was within 0.1–200 keV.

An analysis of the experimental data and values $\alpha = \sigma_\gamma / \sigma_f$ necessitated ^{235}U neutron capture cross-section increasing within the resonance energy region. The analysis results of a set of benchmark experiments in the uranium critical systems with fast and intermediate neutron spectra from the ICSBEP gave cause for revision of the existing evaluation of ^{235}U resonance parameters within the energy region of 500–2500 eV.

A number of studies were analyzed on measurements of neutron transmission through natural Si sample filters within the energy region of 0.3–3 MeV. The results of the experiments carried out on the FP-1 and FP-2 Van de Graaff accelerator facilities at the SSC RF-IPPE during the 1960s [13] are available in the EXFOR database (No. 40,082.005).

The neutron transmission function measurements are very important because they are the main source of information about neutron cross section self-shielding. Based on the results of these measurements, average resonance parameters for nuclear data files are estimated within the energy regions where there is no direct information about the neutron cross section resonance structure.

An analysis of C/E dependencies of neutron beam transmissions through U and Si samples of different thicknesses showed that, in the case of silicon, one can observe significant discrepancies between C/E dependencies in total transmission functions. These discrepancies are indicative of uncertainties in the descriptions of the silicon resonance region in the existing nuclear data libraries within the energy region of 0.3–0.8 MeV. These experimental data made it possible to analyze the Si resonance parameters.

Methods and software tools for nuclear data correction

Joint analysis of differential and integral experiments for neutron data correction: One of the current trends in reactor physics is improving the accuracy of predicted reactor performance by reducing the nuclear data uncertainty in the calculation error. Since new experiments require considerable time and resources, the most realistic way to reduce the nuclear data uncertainty in reactor characteristics would be to use evaluated neutron data obtained with due account for the total experimental information (including data previously unaccounted for). It should be noted that this cycle of studies represents a suggested approach to neutron data corrections by sharing data of differential and integral experiments, and includes the following stages.

1. Sets of neutron data are formed based on the combinations of different evaluated data file sections, theoretical and statistical approaches; for further consideration only those sets are retained which have no significant disagreements with differential experiments.
2. Reactor characteristics and errors measured during the integral experiments on the critical systems are calculated using neutron transport codes according to the evaluated set of neutron data chosen with account of errors in the differential experiments.
3. The most appropriate (compromise) option of neutron data is chosen based on a complex comparison of C/E discrepancies for the selected set of differential and integral experiments provided that it does not conflict with the proposed evaluation of neutron data.

*Calculation models***:** The calculation analysis was carried out using the MCNP-5 transport code and the most up-to-date versions of nuclear data libraries (ROSFOND-2010, ENDF/B-VII.1, JEFF-3.2, and JENDL-4.0). For the experiments on measurements of neutron transmission through Si samples, precision calculation models were made similar to the benchmark models for the experiments on neutron transmission through U samples in the ICSBEP. The models for the BFS-79 and BFS-81 assemblies from the ICSBEP were complemented with the calculations of reaction rates and central reactivity coefficients.

Results

Uranium-235 resonance parameters correction: Based on the methods of stochastic optimization and resonance statistics (Porter–Thomas and Wigner distributions), the ^{235}U resonance region (Leal et al., 2002 [14]) was reevaluated within