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Sensitivity analysis for a 14 MeV neutron benchmark using Monte Carlo and deterministic computational methods

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Abstract

A sensitivity analysis has been performed for a 14 MeV neutron benchmark on an iron assembly, typical for a fusion neutronic integral experiment. Probabilistic and deterministic computational methods have been used in the sensitivity calculations with the main objective to check and validate the novel Monte Carlo technique for calculating point detector sensitivities. Good agreement has been achieved between the Monte Carlo and the deterministic approaches for the individual calculated sensitivity profiles, the uncertainties and the neutron flux spectra. It is thus concluded that the Monte Carlo technique for calculating point detector sensitivities and related uncertainties as being implemented in MCSEN, a local version of the MCNP4A code with the capability to calculate point detector sensitivities, is well qualified for sensitivity and uncertainty analyses of integral experiments.

Keywords: 14 MeV neutron benchmark; Monte Carlo technique; Computational methods

1. Introduction

Sensitivity and uncertainty analysis is a powerful means to assess uncertainties of nuclear responses in neutron transport calculations and track down these uncertainties to specific nuclides, reaction cross-sections and energy ranges. When applied to the analysis of integral experiments, it enables the assessment of the calculational accuracy and provides information for improving the cross-section data evaluations.

The differential operator method developed originally by Hall [1] is a suitable method to calculate sensitivities with the Monte Carlo technique. Based on this method, an algorithm has been developed at the Hebrew University of Jerusalem [2] for calculating point detector sensitivities which has been implemented into a local update to the Los Alamos Monte Carlo code MCNP4A [3]. The point detector method is best suited for analysing integral benchmark experiments when leakage spectra are measured by detectors that are located far from the irradiated material assembly. Experiments of this kind are in frequent use for testing and validating fusion nuclear data evaluations, as well as for assessing their uncertainty margins. In

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these experiments, material assemblies are irradiated with 14 MeV (d, t) neutrons and the neutron leakage flux spectrum is measured by means of experimental techniques such as the time-of-flight (TOF) method.

This work is devoted to the sensitivity analysis of a 14 MeV neutron benchmark on an iron assembly typical for a fusion neutronic integral experiment. Probabilistic and deterministic computational methods have been used in the sensitivity calculations with the main objective to check and validate the novel Monte Carlo technique for calculating point detector sensitivities. There follows a short description of the benchmark problem, the computational procedures for both the deterministic and the Monte Carlo calculation of point detector sensitivities as well as a detailed presentation and discussion of the sensitivity results obtained in this analysis.

2. Benchmark problem

A simple benchmark, typical for fusion neutronic integral experiments, has been defined for the sensitivity analysis. It consists of a spherical iron shell assembly with a 14 MeV neutron point source in the centre. The source is assumed to be isotropic, with a flat energy distribution between 13.84 and 14.19 MeV. The benchmark task is to calculate first the neutron flux spectra at a detector location of 6.8 m, second the sensitivity profiles for neutron flux integrals with energy boundaries 0.09804, 1.003, 4.966, 7.408, 10.0, 13.84, 14.19 MeV and, on this basis, the related uncertainties due to the uncertainties of the underlying cross-section data. Two different iron assembly configurations are considered, one with a wall thickness of 7.5 cm (4.5 cm inner and 12 cm outer radius) where single or few neutron collisions take place only, and one with a wall thickness of 28 cm (2 cm inner and 30 cm outer radius) to take into account transport phenomena involving multiple neutron collisions. The benchmark problem has been adapted from an integral 14 MeV neutron transmission experiment on spherical iron shell assemblies with measurement of the neutron leakage flux spectrum by the TOF method [4]. This enables the comparison, in an additional step, of the calculated neutron spectra with the measured ones. Nuclear data are taken from the European fusion file EFF-3.1 for ^{56}Fe [5] and FENDL-1 [6] for the other iron isotopes. The data were processed with the NJOY code [7] in pointwise energy representation for use with MCNP-calculations and in the 175 VITAMIN-J group structure for use with the discrete ordinates (S_N) calculations.

3. Methodological approach

The methodological approach is as follows. In the first step, neutron flux spectra are calculated and compared at the location of the detector. In the Monte Carlo calculation, the point detector estimator (MCNP tally 5) is used. In the S_N-transport calculations using spherical geometry, the neutron flux spectra are calculated at the spatial mesh of the detector location. Two different discrete ordinates codes for one-dimensional geometry, ANISN [8] and ONEDANT [9], are used in these calculations.

The second step is devoted to the calculation of the sensitivities of the specified neutron flux integrals. In the Monte Carlo approach, this requires one calculational run including the related point detector sensitivity estimator in the proper energy bin segmentation. With the deterministic approach, this step requires a direct and several adjoint ANISN or ONEDANT calculations followed by SUSD [10] calculations to provide the sensitivity profiles. Two different versions of the SUSD code are employed: SUSD-fusion neutron source (FNS) developed by Kosako et al. [11] at JAERI, and SUSD3D developed by Kodeli [12]. Another approach used in addition in this work to calculate sensitivities is based on the direct calculation of the neutron flux integrals with cross-sections modified for specific reactions and energy ranges.

The next step consists of calculating the uncertainties, using the calculated sensitivity profiles and the covariance matrices processed again with the NJOY code. The final step is devoted to a detailed comparison of the sensitivity profiles, the integrated sensitivities and uncertainties for all considered reactions.

4. Computational techniques

4.1. Monte Carlo point detector sensitivities

At the Hebrew University of Jerusalem, an algorithm has been developed for calculating point