# STEK Experiment – Opportunity for Validation of Fission Products Nuclear Data

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## INTRODUCTION

Until the beginning of the 1970's the STEK (Fast Thermal Experiment in KRITO) facility was operational at ECN (Energy Centrum of the Netherlands), Petten. In this experiment, measurements of the reactivity worth for the most important fission products in fast neutron spectra were performed. The main goal was to validate nuclear data evaluations. These fission products are of great importance in fast reactor development and constitute one of the sources of uncertainties in the prediction of their behavior. These integral data provide an important platform for the study of the influence of the inaccuracy of cross sections of fission products on fast reactor parameters. STEK is also a unique facility to benchmark existing nuclear data evaluations for fission products playing a key role on the neutronic behavior of thermal reactors.

Five different cores at the STEK facility were built with different spectrum hardness: STEK-4000, -3000, -2000, -1000 and -500, in increasing order of spectral hardness. In this way information could be obtained regarding the energy-dependence of the cross sections to be measured. This paper reports on the multi-year studies ongoing at NRG, which concerns the modeling of the STEK facility and the simulation of the measured fission product samples. For testing these models the reactivity worth of three samples (C, In, and Eu) was simulated using different nuclear data evaluation files: ENDF/B-VII.0 [1], TENDL-2011 [2] and JEFF3.1 [3]. The results could be compared with the experimental results of STEK-4000, where we noticed that some evaluated libraries perform better than others. This illustrated the potential of the STEK experiment for testing nuclear data evaluations for different fission products.

## STEK FACILITY

The STEK experiment was constructed at ECN at the end of the 60's in the framework of the co-operation between the former German Federal Republic, Belgium and the Netherlands on research for fast breeder reactor development. The main goal of the experiment was to measure integral cross sections of fission products. This was a rather unique experiment by the comprehensive list of fission products (and other materials) measured, and the diversity of core configurations. It is also considered worldwide as an important source of validation data.

STEK was a fast-thermal coupled reactor facility. The central fast zone was built of fuel elements placed in a rectangular grid and surrounded by rows of lead and graphite assemblies, working as reflector and buffer zones. The fast fuel assemblies are constituted of a pile-up of graphite (C) and enriched Uranium (U), surrounded by an Aluminum case. By varying the number of fast fuel assemblies and the ratio C/U (carbon to uranium ratio) five different cores with different spectra were created. Table I shows the $C/^{235}U$ ratio for the different core configurations, and other parameters. The fast core was surrounded by a thermal zone, which worked as driver zone for the fast core. The thermal zone consisted of MTR (Material Test Reactor) fuel elements submerged in water. These fuel elements consist of boxes filled with a variable number of highly enriched U-Al alloy plates (about 90% $^{235}U$ enrichment) and with Aluminum cladding. Figure 1 gives an impression of the facility.

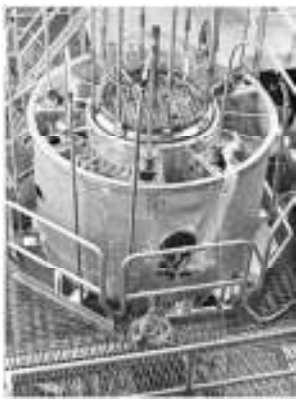

Fig. 1. STEK facility - Top View

At the very center of the fast core a normal fuel element was replaced by a special oscillator element, containing the sample holder with the sample to be measured. Details on the facility and the reactivity worth measurements are described in detail elsewhere [4,5].

TABLE I. STEK core configurations. The quoted $^{235}U$ mass is the mass within the fast zone exclusively.

| *Configuration* | *$C/^{235}U$ atomic ratio* | *$^{235}U$ mass [kg]* |
|---|---|---|
| STEK-4000 | 72 | 89.693 |
| STEK-3000 | 48 | 95.044 |
| STEK-2000 | 35 | 92.164 |
| STEK-1000 | 23 | 88.038 |
| STEK-500 | 11 | 77.063 |

## CALCULATION TOOLS AND MODELLING

The modeling of the facility was performed in the transport code MCNPX, version 2.7 [6]. The modeling is set-up in a modular form, and parts of the model that were expected to change from configuration to configuration were programmed such that the model could be automatically generated using scripting language and by changing only some key parameters. The model is also such that the new fission product samples (and sample capsules) could be easily introduced in the model, and does not require major changes to the rest of the model. Fig. 2 shows a cross section of the MCNPX model for the STEK-4000 core configuration.

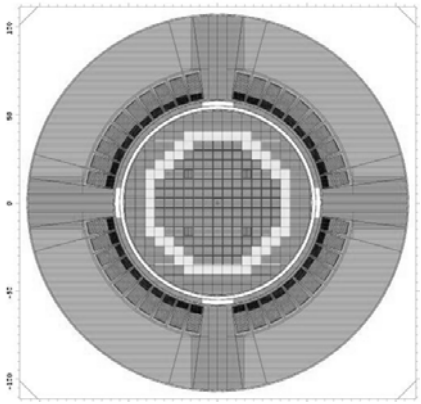

Fig. 2. MCNPX model of STEK-4000 core

All calculations were performed using nuclear data taken from JEFF3.1 evaluation library for all materials. The exception is the nuclear data used for the measured samples, as the source of them was varied (either from TENDL-2011, ENDF/B-VII.0, or JEFF3.1 libraries).

The reactivity effect of most of the measured fission products samples is very small and amounts to a few pcm ($10^{-5}$ $\Delta\rho/\rho$). In order to simulate these reactivity changes using the differential method with a Monte-Carlo code required the simulation of billions of particles in order to keep the statistical uncertainty at values below the expected differences in reactivity. The application of parallel computing (using MPI protocol) was required to reduce the runtime of the simulations.

## RESULTS

Three samples were chosen for the initial testing of the STEK models. Table II includes the samples considered in our study, together with some of their specifications. These three samples were selected because they gave rise to a relatively large reactivity effect, and therefore only a relatively short runtime was required for the simulations. In [7] a list of all the samples measured in STEK was discussed in detail, together with a description of the measurement technique and the experiment equipment.

TABLE II. Samples considered in this study. All elements have natural composition

| *Main isotope* | *Chemical compound* | *Weight mass[g]* |
|---|---|---|
| C | C | 92.4 |
| In | In | 39.8 |
| Eu | $Eu_2O_3$ | 3.0 |

The reactivity effects of all samples were calculated using the differential method which entails performing two calculations with and without sample, and by calculating the difference in reactivity between the two runs. When removing the sample from the model the sample capsule was kept in place.

### Results for Different Evaluations

Table III below includes the experimental values of reactivity worth together with the simulation results for three different evaluations: TENDL-2011, JEFF3.1 and ENDF/B-VII.0. Calculations were performed only for the STEK-4000 configuration.

From these results it is apparent that for the Eu sample nuclear data from TENDL-2011 and ENDF/B-VII.0 give better agreement with the experimental values, whereas for the In sample JEFF3.1 data seems to perform better. For the C sample no data file is available in TENDL-2011, and clearly the data from ENDF/B-VII.0 give results that are in better agreement with the experimental value than JEFF3.1 data.

### Results for Different Core Configurations

The Eu sample was selected to test the different configurations. The results are shown in Table IV for four configurations. Nuclear data taken from JEFF3.1 evaluation library was used.

The trend of decreasing reactivity worth with the hardness of the spectrum is apparent from the simulations. However, not a good agreement was found between the simulations and the experimental values (except for the value for STEK-3000), with *C/E* values varying between 0.6 and 1.5. These results can give important information to the nuclear data evaluators for the re-evaluation of capture cross sections of Eu. Following the *C/E* values obtained for different configurations, the slope of the capture cross section of a given sample can be adjusted: (1) each configuration gives an indication of the quality of the capture cross section in a specific energy range, where often no differential data exist and evaluations rely on theoretical calculations; (2) by applying the method described in Refs.[8,9], random nuclear data files for the given isotope can be checked, and the one providing the best *C/E* can then be selected as the final evaluation. This will be subject of a follow-up study.

TABLE III. Reactivity worths ($\Delta\rho$) for each of the samples simulated for the STEK-4000 configuration using nuclear data originated from different evaluations. Results are also shown for the experimental values (uncertainties inside parentheses). *C/E* - ratio calculated over measured values.

| | *Europium* | | | *Indium* | | | *Carbon* | | |
|---|---|---|---|---|---|---|---|---|---|
| | TENDL | ENDF | JEFF | TENDL | ENDF | JEFF | TENDL | ENDF | JEFF |
| $\Delta\rho$-cal [pcm] | -14 ± 3 | -14 ± 3 | -20 ± 3 | -28 ± 3 | -29 ± 3 | -21 ± 3 | ---- | +13 ± 3 | +8 ± 3 |
| $\Delta\rho$-exp [pcm] | -13.2 (0.1%) | | | -23.8 (0.1%) | | | +13.09 (0.6%) | | |
| *C/E* | 1.1 ± 0.2 | 1.1 ± 0.2 | 1.5 ± 0.2 | 1.2 ± 0.1 | 1.2 ± 0.1 | 0.9 ± 0.2 | ----- | 1.0 ± 0.2 | 0.6 ± 0.2 |

TABLE IV. Reactivity worths for the Eu sample, as calculated and measured within four different core configurations. *C/E* - ratio calculated over measured values.

| | *STEK-4000* | *STEK-3000* | *STEK-2000* | *STEK-1000* |
|---|---|---|---|---|
| $\Delta\rho$-cal [pcm] | -20 ± 3 | -11 ± 1 | -5 ± 1 | -4 ±1 |
| $\Delta\rho$-exp [pcm] | -13.2 (0.1%) | -10.0 (0.22%) | -8.2 (0.26%) | -5.9 (0.28%) |
| C/E | 1.5 ± 0.2 | 1.1 ± 0.1 | 0.6 ± 0.2 | 0.7 ± 0.2 |

## CONCLUSIONS

The STEK experiment offers a unique opportunity for validation and improvement of nuclear data evaluation for fission products. In a multi-year project the vast number of measurements of reactivity worth of the main fission products is going to be compared with simulations.

This document reported on the modeling of the five core configurations using MCNPX as the main tool. MCNPX could be run under MPI, which reduced substantially the runtime for the simulations. First calculations of the reactivity worth caused by Carbon, Indium and Europium samples were performed, using nuclear data from three different evaluations: TENDL-2011, ENDF/B.VII, and JEFF3.1. A difference in results is observed and showed that for C and Eu the best agreement with the experimental values is obtained using either ENDF (C and Eu) or TENDL (Eu) evaluations. Regarding the In sample the simulations with JEFF3.1 data give the best agreement with the experiment value.

The Eu sample was also simulated in four of the five core configurations, using the JEFF3.1 evaluation library. *C/E* values vary between 0.6 and 1.5, and the best agreement with experiment is found for the STEK-3000 configuration. These results could give important information to the evaluators to try to improve the nuclear data for this element.

In the follow-up of this study a larger number of fission products will be simulated for the different configurations and results compared with the STEK measurements. This will provide valuable information for the re-evaluation of nuclear data of the important fission products and hence improve the quality of the nuclear data in the future version of the TENDL library, and other evaluated libraries.

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