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# Transient Analysis for the SPERT III E-Core Benchmark with STREAM/RAST-K Code System

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## 1. Introduction

The Special Power Excursion Reactor Test (SPERT) III E-Core is a research reactor that has key features of conventional light water reactors (LWRs), except for its small size. It is designed to conduct a series of reactivity-initiated experiments to study the kinetic behavior and safety of the reactor under various initial core conditions [1]. The experimental data obtained from the SPERT III E-Core program is extensive and well-documented on both steady-state and transient core conditions. It provides a unique opportunity to validate reactor kinetic models and methods of reactor analysis codes, especially for reactivity-initiated accidents (RIAs) with the Doppler effect [2, 3].

STREAM/RAST-K, which was developed by a computational reactor physics and experiment (CORE) laboratory at Ulsan National Institute of Science and Technology (UNIST), is the combination of a lattice physics code STREAM [4] and a novel nodal diffusion coed RAST-K [5]. It is an advanced two-step code system for the reactor cored design and analysis under steady and transient conditions both. The code system has been verified and validated sufficiently for the steady-state core against various benchmark problems. Validation of transient conditions was also conducted in the previous work [6], but it has not been thoroughly validated due to the lack of international benchmarks for LWR cores.

In this paper, the preliminary transient analysis of the SPERT III E-Core experiment using STREAM/RAST-K is presented. STREAM was used to generate 2-group cross-section data. The selected case of the SPERT III program, such as Test 83, was performed using RAST-K. The results obtained by STREAM/RAST-K were compared with the experimental data to validate the capability and accuracy of the code system for transient calculation.

## 2. Modeling of SPERT III E-Core with STREAM

The SPERT III E-Core is a small pressurized-water reactor without any soluble boron. The core consists of 60 fuel assemblies, each surrounded by a stainless steel can with a 7.62 cm square. Of the 60 assemblies, 48 contain 25 fuel rods each (25FA). Four assemblies contain 16 fuel rods each with a cruciform-shaped transient rod (16FA), and the remaining eight assemblies are control rod assemblies (CRA). Figure 1 is illustrated radial configuration of the core.

All assemblies in the E-Core use the same fuel; it is 4.8 wt. %-enriched $UO_2$ rods with 10.5 g/cm$^3$ mass density and surrounded by stainless steel cladding. The fuel rods are arranged into a square lattice array and contained in stainless steel fuel cans. Detailed design data of the fuel is represented in Table 1.

Spatial homogenization, which requires various assumptions, has been often used in the two-step code system to handle the complex and highly heterogeneous geometry of the SPERT III E-Core [2, 3]. To verify the 2-dimensional lattice model in STREAM, its solutions were compared to solutions of the explicit model obtained by Monte Carlo code MCS. However, this paper does not provide reference solutions of MCS.

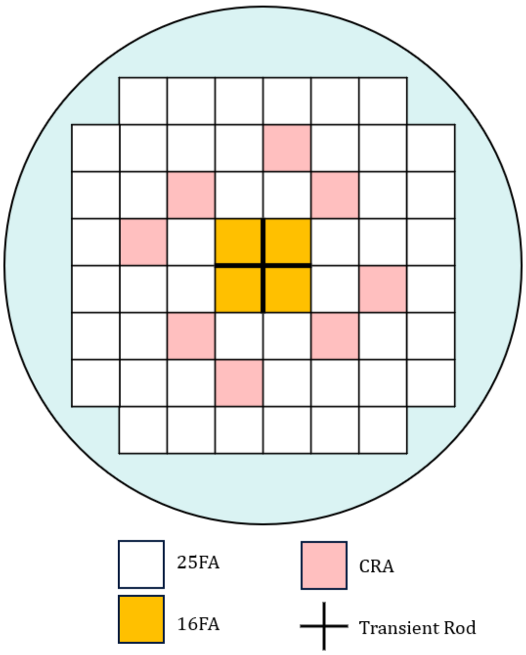



Figure 1. Radial configuration of the E-Core

Table. 2. Fuel design data of the E-Core

| Parameter | Value |
|---|---|
| Fuel | 4.8 wt% $UO_2$ pellet |
| Fuel density | 10.5 g/cm$^3$ |
| Fuel outer radius | 0.53340 cm |
| Clad inner radius | 0.54102 cm |
| Clad outer radius | 0.59182 cm |
| Fuel rod pitch | 1.4859 cm |
| FA pitch | 7.62 cm |
| Fuel active height | 97.282 cm |

### *2.1. 25-rod fuel assembly (25FA)*

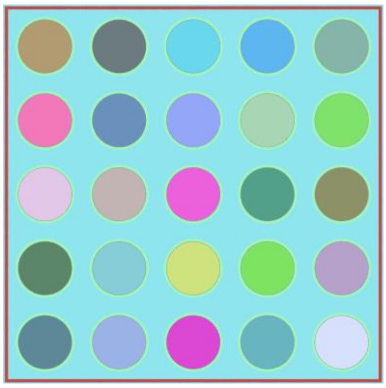


Figure 2. STREAM 25FA lattice model

The 25FA contains 25 fuel rods arranged in a 5×5 rectangular array with a pitch of 7.5565 cm. It is surrounded by a fuel can and bypass water that flows outside of the fuel can. The fuel can has some slots with a total area of 774 cm$^2$ to allow cross-flow of the coolant. These slots were considered a homogenized mixture of stainless steel and water in the lattice model due to their geometrical complexity. The fuel can and bypass water were modeled explicitly as shown in Figure 2.

Each fuel assembly has two intermediate grids within the active fuel region; however, its detailed geometry and weight are not given in the documentation [1]. The grids were estimated to be 50 g of mass each and considered to smear in the coolant material.

### *2.2. 16-rod fuel assembly with a transient rod (16FA)*

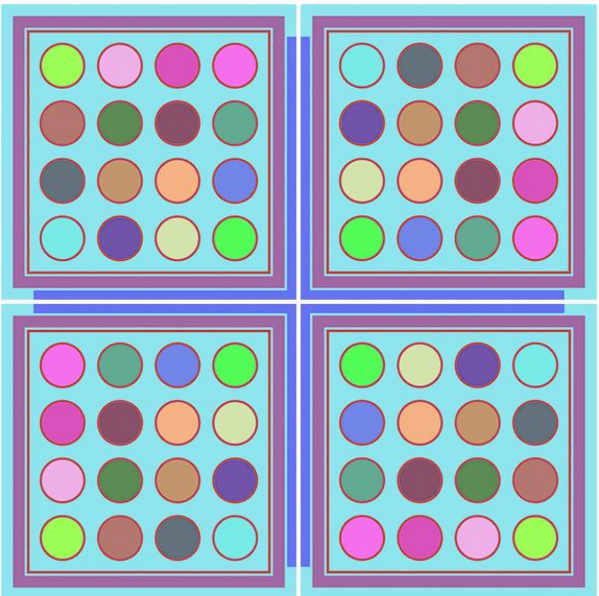


Figure 3. STREAM 16FA with a transient rod lattice model

The 16FA is similarly constructed to the 25FA except for a 4×4 fuel rod arrangement with a square pitch of 6.2890 cm. The fuel can and bypass water were also modeled explicitly.

One of the characteristics of the E-Core is a cruciform-shaped transient rod at the center of the core. Each 16FA lattice includes half of the transient rod blade at the corner as shown in Figure 3. The transient rod is surrounded by a Zircaloy-2 guide tube to prevent damage to adjacent fuel assemblies [1]. The thickness of the guide tube is unknown. It was estimated to be 3mm in the lattice of STREAM. The transient rod is axially divided into two sections, which are made of stainless steel in the upper and 1.35 wt.%-borated steel in the lower. Two sections of the transient rod were modeled each as a movable control rod in STREAM.

### *2.3. Control rod assembly (CRA)*

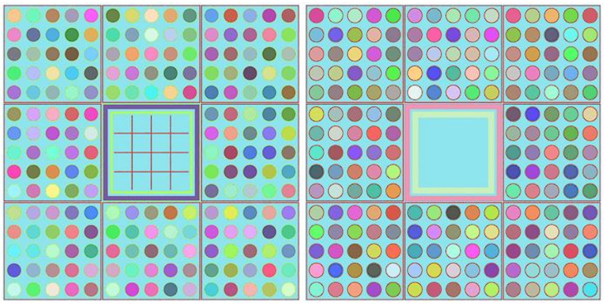


Figure 4. STREAM CRA lattice model
: The flux suppressors (left) and the neutron absorber (right)

The control rod assemblies are divided into three sections along the z-axis including the lower 4×4 fuel follower, the middle flux suppressors, and the upper neutron absorber.

The fuel follower section consists of 16 fuel rods arranged in the fuel can. It is similar to the 16FA except for its overall dimension (6.33984 cm thick). The flux suppressors are used to prevent sharp discontinuities in the neutron flux and are placed at the region between the bottom of the absorber and the top of the fuel rods. The suppressors are axially divided into two sections. The upper and lower sections consist of 6 small plates made of 1.35 wt.%-borated steel each. The part of the lower section is overlapped to the top of the fuel; however, it is not considered in this work. The neutron absorber is a hollow square box composed of the same material as the flux suppressor. The overall dimension is 6.33984 cm square, and the thickness is 0.47244 cm. The CRA is also guided in the Zircaloy-2 tube with 4 mm of estimated thickness.

The flux suppressors and neutron absorber lattice do not contain the fuel. Thus, homogenized cross-section data were generated in the same way as the reflector lattice. They were modeled by a 3×3 array in STREAM to consider the effect of adjacent fuel assemblies. The lattice models of the flux suppressor and absorber are represented in Figure 4.

## 3. Results

STREAM uses the 72-group cross section library generated from ENDF/B-VII.1 for the neutron transport calculation. All assemblies use the same MOC ray condition, which is a ray spacing of 0.05 cm, 48 azimuthal and 3 polar angles. The pointwise energy slowing-down method (PSM) is employed for resonance treatment [4].

### *3.1. Transient rod worth measurements*

The transient rod reactivity worth calculation in the RAST-K was performed by inserting the transient rod while the reactor core was near critical state. The worth is compared with the measured experimental data [4] as shown in Fig. 7. It can be seen a good agreement is observed for both CZP (294 K) and HZP (533 K) conditions.

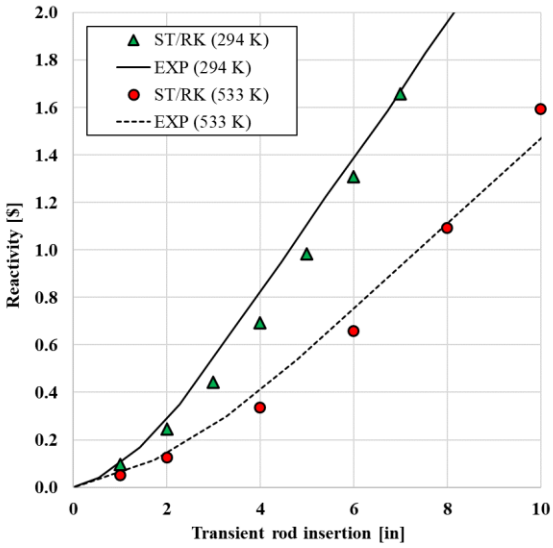



Fig. 7. Measured and calculated transient rod reactivity worth for CZP (294 K) and HZP (533 K).

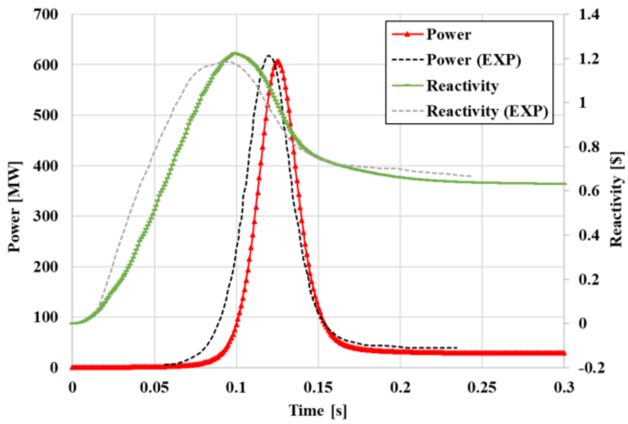
### *3.2. Preliminary transient calculation*

The SPERT III E-Core Transient experiments were performed for various initial conditions. In this paper, the study was focused on Test 83. It conducted at hot-standby conditions with a super prompt critical initial reactivity insertion of 1.25 ± 0.04 $, initial coolant inlet temperature and reactor power is 535 ± 2 K and 11 ± 1 MW, respectively [1].

The transient is initiated by ejecting the transient rod with the acceleration as 50.8 m/s$^2$ from its initial steady state insertion position to the bottom of the core. The time step size using the transient calculation is 1 ms.

The calculated max. reactor power is 607.25 MW at 0.125 s and experimental max. reactor power is 620 ± MW at 0.117 ± 0.002 s. The calculated time to peak power is slightly late. Power and reactivity excursion curve is shown as Fig. 8.

Fig. 8. Test 83 power excursion curve




## 4. Conclusion

The goal of this work to validate neutronic models and core kinetic calculation methods of the STREAM/RAST-K code system by solving the SPERT III E-Core benchmark problem. The SPERT III E-Core cannot be explicitly modeled by the STREAM/RAST-K due to its complicated geometry. Some assumptions and homogenized materials are used to model the E-Core with STREAM. Even considering them, the STREAM/RAST-K results showed sufficient agreement with the experiment data.

The future work is to perform transient analysis of the SPERT III E-Core with the STREAM/RAST-K for the other initial conditions. The generated model will be used to the base for the future work.

## ACKNOWLEDGEMENT

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