**Detailed Reflector and Drum Modeling of the SNAP8 Criticality Configuration Experiments using Serpent with**

**ENDF/B-VII.1 and ENDF/B-VIII.0 Libraries**

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INTRODUCTION

The Systems for Nuclear Auxiliary Power (SNAP) program was developed to explore novel microreactor technology for space applications. While the designs varied, the theme and core principle of their designs were light, mobile, highly enriched cores with reflecting materials at the periphery of self-moderated fuel [1]. There is an abundance of work—thoroughly demonstrating design principles, criticality experiments, manufacturing principles, etc.— that lend themselves well to validation and benchmarking.

Previous work looked to capitalize on this by examining the SNAP8 Experimental Reactor (S8ER) core design and a certain subsection of the dry critical experiments [2]. Specifically, the work detailed initial efforts in developing a Serpent [3] model validating the critical configuration experiments at dry, cold start conditions [4]. This work looks to continue and extend these efforts by remedying insufficiencies in 1) mirroring experimental conditions 2) component geometry and 3) cross-section data and thermal scattering inclusion.

These efforts are part of an ongoing collaboration between Georgia Tech, University of Wisconsin-Madison, BWX Technologies, and Idaho National Laboratory. The end-objective is to use the S8ER experiments for benchmarking specific NEAMS tools and capture unique phenomena in a novel microreactor environment [5]. Additionally, this will culminate in the complete modeling and validation of all dry and wet critical experiments documented for the SNAP8 system.

Methodology

In the S8ER the primary means of reactor control is by manipulating leakage via Beryllium reflector element insertion, removal, or rotation. Therefore, modelling insufficiencies will stem from reflecting components and their portrayal in simulation.

**Task 1: Reflector Shim Remodeling**

The reflector shims are slabs of Beryllium metal that are inserted or removed within each of the reflecting drums. The A shim geometry are rectangular prisms of known width, height and depth resulting in simple implementation. The exact B shim geometry is not clear with dimensioning that is ambiguous and inconsistent among different experiments [1].

At times it is also unclear whether the drum or shims are being shown. As a result, two images were used to guide the remodeling of the B shims the first of which is shown below in Fig. 1 [4].

Diagram

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Fig 1. S8ER cutaway view highlighting several components.

In Fig. 1 above, the image clearly presents the B shims as having angled cuts at their edges. However, it is still unclear if the core tie rods run directly in the center of the shims. This distinction is made clearer in Fig. 2 below, which depicts the core tie rod running right at the edge of the drum.

Diagram

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Fig. 2 S8ER core assembly view [4].

Thus, the B shims are modelled to be composed of two portions that are installed surrounding the core tie rod, with angled cuts at their edges. This results in Fig. 3 shown below with dimensioning in cm.

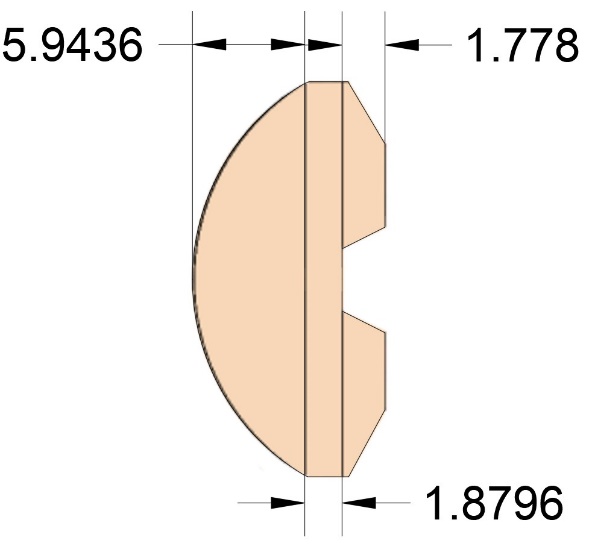


Fig 3. Drum, A, and B shim dimensioning and geometry.

It is important to note that the thickness of the B shim are described in effective and actual measurements [4]. The former was utilized for this work.

**Task 2: Reflector Drum Reconfiguration**

In the critical configuration experiments, reactivity was examined with fuel assembly and reflecting element manipulation. Uniquely, the C-4 configuration was coupled with control drum No. 6 being in the ‘OUT’ position, rotated 105° counterclockwise. This position is illustrated for clarity in Fig. 4 below [4].

Diagram

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Fig 4. S8ER core depicting ‘OUT’ position for drum No. 5.

Early attempts opted to completely remove the drum as a first approximation for drum rotation. Results suggested there was an overestimation of leakage in the core due to this modelling choice which would not correctly depict operating conditions [2]. All drum and shim definitions were remade to accommodate for uniform rotation in any configuration that were to be used in later dry and wet critical experiments. This is illustrated in Fig. 5 below, with the C-4 configuration being recreated.

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Fig 5. S8ER core in C-4 configuration, shims A&B shown.

This is an important adjustment to make considering future critical experiments use the C-4 configuration as the reference model.

**Task 3: Cross-Section Library Comparison**

Previous work did not utilize thermal scattering data libraries for moderating materials. Consequently, scattering effects were not well captured. For instance, although some positive reactivity is inserted via swapping fuel pins for lucite pins due to hydrogen moderation, the magnitude of that insertion may be over-estimated and could inaccurately offset the negative reactivity seen from removing a fuel source. Table I below lists all materials for which thermal scattering data was included in this work.

TABLE I. Thermal Scattering Material Data

|  |  |  |
| --- | --- | --- |
| Material | Isotopes in ENDF/B-VIII.0 | Isotopes in ENDF/B-VII.1 |
| Uranium Zirconium-Hydride | H-1  Zr-90 | H-1  Zr-90 |
| Lucite | H-1 | N/A |
| Beryllium Metal | Be-9 | Be-9 |
| Beryllium Oxide | Be-9  O-16 | Be-9 |

Previous work utilized the ENDF/B-VII.1 libraries, but there were significant changes made for four of the six materials listed above for the release of ENDF/B-VIII.0 [6]. Additionally, ENDF/B-VIII.0 released with thermal scattering data for Oxygen in BeO and Hydrogen in Lucite; ideally ENDF/B-VIII.0 data should better reflect experimental conditions. This work will re-evaluate the criticality configuration experiment using both libraries with and without thermal scattering effects to properly examine their discrepancies.

RESULTS

The critical loading schemes were run in Serpent for loading designations C-1 to C-4. Table II provides a summary of each configuration’s conditions.

TABLE II. S8ER Critical Loading.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Loading Designation | | | |
|  | C-1 | C-2 | C-3 | C-4 |
| Shims installed | A & B | A | None | A & B |
| Drums locked out | None | None | None | No. 6 |
| Number lucite rods | 38 | 25 | 0 | 20 |

Previous work included the C-5 configuration but has been omitted here as it was estimated but not measured in experiment [2] [4]. Fig. 6 and 7 compare each library against itself with and without thermal scattering data.

Fig. 6 ENDF/B-VII.1 data with and without S(α,β) data.

Fig. 7 ENDF/B-VIII.0 data with and without S(α,β) data.

Subsequently, Fig. 8 and 9 compare both libraries with and without thermal scattering data.

Fig. 8 Inter-library comparison without S(α,β) data

Fig. 9 Inter-library comparison with S(α,β) data

It should be noted that experimental data has a reported reactivity uncertainty of “less than 1%” [4]. Furthermore, all uncertainties in the modelled cases are less than or equal to 11 pcm.

Discussion

Results indicate marked improvements in modelling with thermal scattering inclusions for both sets of data. As seen in Fig. 6 and 7 the inclusion of thermal scattering leads to results within 900 pcm of experimental results, indicating improvements with respect to initial efforts [2]. From Fig. 8 it is apparent that ENDF/B-VIII.0 shows improved agreement across all cases. However, Fig. 9 suggests that with the inclusion of S(α,β) data this is not always true, particularly for cases C-1 and C-3. It is important to note however that the ENDF/B-VII.1 libraries did not include thermal scattering data for H-1 in lucite nor O-16 in BeO. The absence of thermal scattering data for lucite especially would explain the deficit seen in Fig. 9 for the C-1 case, as it's moderating capabilities are likely being overestimated using ENDF/B-VII.1.

In Fig. 9 cases C-1 and C-4 are the configurations with worst agreement. As both cases contain the B shim reflecting element, this is likely the culprit for the discrepancy in modelling vs experimental results. The B shims are a source of uncertainty due to vagueness with respect to the thickness of the reflecting element. In this work, the ‘effective’ thickness was used although the term is not specifically defined in Ref. [4]. A possible solution may come in the form of how this thickness was used in other SNAP references, where it was defined to be the thickness of a simplified reactor model composed of concentric material layers [1]. If so, this would mean that current modelling efforts are under-sizing the B shims, which is what is implied in Fig. 9. Future work will also conduct sensitivity studies where the central void of the B shim is replaced with reflecting material to determine if agreement improves and quantify modelling uncertainty.

The C-3 configuration is the second closest to experimental results, although there is still some discrepancy. Given that C-3 does not contain any shims installed, this is likely due to modelling error with the internal reflectors or drums. Initial calculations suggest that current drum model sizing is slightly larger than what documentation would suggest.

The C-2 configuration is the closest to measured results compared to its counterparts. The discrepancy, although small, may lie in the sizing of the stationary reflectors which are nested between the drums and core. There are no dimensions provided for this specific component and illustrations do not clearly depict the clearance needed to physically insert the component. As a result, the stationary reflectors could be oversized.

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