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CALCULATION AND VERIFICATION OF THE NEW NEUTRON ABSORBERS IN A WELL-DEFINED CORE IN LR-0 REACTOR

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ABSTRACT

The research is focused on special neutron absorbers designed to improve the optimization of medium-term storage and final storage of spent nuclear fuel. The solution aims to improve nuclear safety, and it is also reasonable from an economic perspective so that the final product can be transferred into practice. The case's merit is based on fixed neutron absorbers effectively placed within the nuclear fuel assembly. The first theoretical part of the research is devoted to optimizing a suitable material from a neutronic and economic point of view. It is about determining the ratio between the appropriate neutronic properties and the cost of the material and form. The second practical part of the research focuses on the prototype's production and verification in the research reactor LR-0.

KEYWORDS: neutron absorber, LR-0, spent fuel, cask, Sm_2O_3

1 INTRODUCTION

This research follows previous studies [1], [2], [3], [4] dealing with the concept of special fixed neutron absorbers, which increased nuclear safety and improved economics. With the presented absorber solution, it is possible to reduce the boron content in the cask basket, decrease the fuel assembly pitch and minimize the neutron dose in the vicinity of the cask. The efficiency of this concept was demonstrated in the criticality safety analysis of the GBC-32 spent fuel cask [2] or casks for VVER fuel type [1].

The principle consists of placing the absorber material directly within the fuel assembly. A neutron absorber is permanently connected in specially designed tubes. It decreases system reactivity more efficiently than absorber sheets between the assemblies. The solution is more efficient than absorber tubes, even with a neutron flux trap.

This paper is mainly dedicated to the first experimental validation of this concept. For our verification, we used a well-known VVER-1000 fuel assembly within the LR-0 zero-power reactor in the Czech Republic. The main goal is to determine the critical state parameters for fuel without absorbers and for fuel with absorbers, compare them with the calculation and determine absorption weight. The position of absorbers in the guide tube has been defined by earlier studies [1]. The Sm_2O_3 in powder was chosen as the absorber material based on the neutronic study in [4] and also from the economic point of view. For neutronic comparison with the other basic elements, see Figure 1. It has been calculated all available elements with natural abundance in the periodical table in the position of guide tubes for model GBC-32 with fresh fuel (0 MWd/MTU).

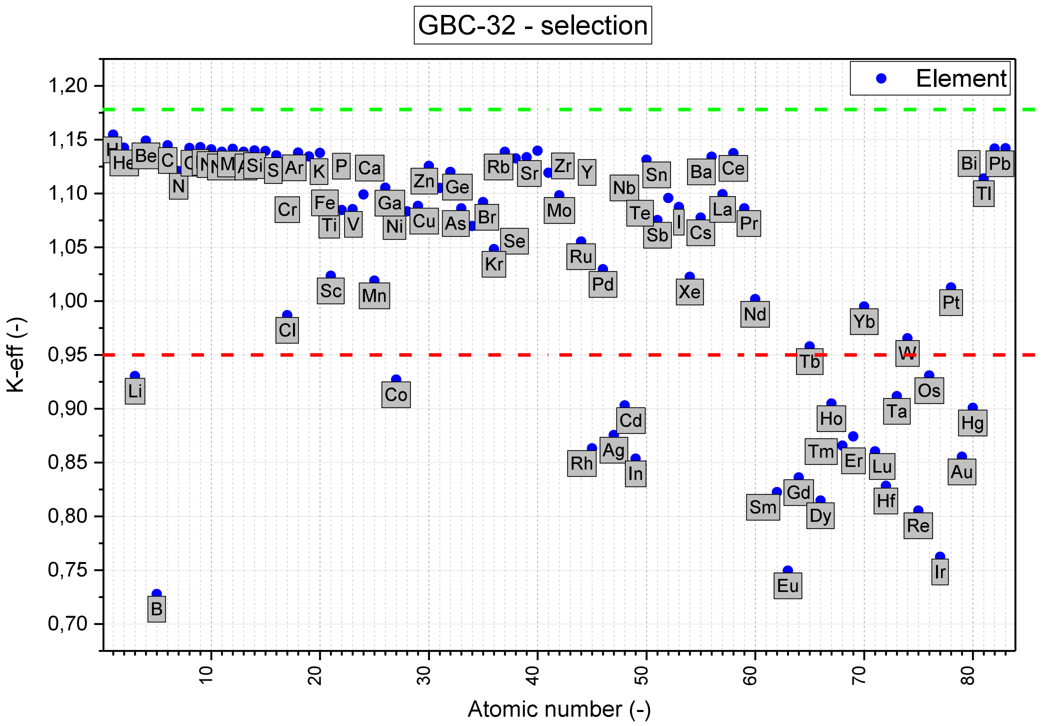

Figure 1: Spent fuel cask GBC -32 results for different absorber materials.

2 CALCULATION METHOD

The criticality calculations were done by Serpent transport code in version 2.1.32 [6] with the ENDF/B-VIII.0 continuous energy nuclear data library [7]. The core configuration in the LR-0 reactor chosen for the experiment is a modified IRPhEP (International Handbook of Evaluated Reactor Physics Benchmark Experiments) benchmark core [9], with low-enriched FA at the central position with average enrichment of 2.014 wt% U-235. The other six fuel assemblies have an enrichment seen in Figure 2. A low-enriched FA was placed in the central position to increase the reactivity worth of the measured absorbers.

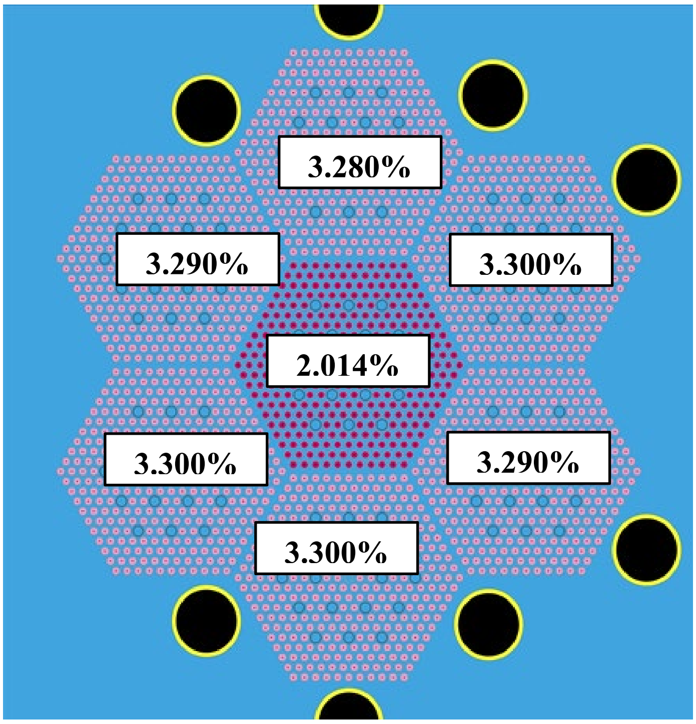

Figure 2: LR-0 core configuration GK-07 (avg. enrichment of U-235).

3 EXPERIMENTAL ARRANGEMENT AND VERIFICATION

The reactor's criticality in LR-0 is reached by adjusting the moderator level to the critical level H_{cr} [5]. The critical level of the moderator is defined by the core loading and specially prepared neutron absorbers inserted in the central fuel assembly. Using this method, the reactivity of the absorbers can be determined. The experiment was designed for two cases. The first case was without absorber (reference). And the second case was with Sm_2O_3 absorbers. Both cases are described below.

3.1 Absorber preparation

The neutron absorber is based on an oxide powder form placed inside a steel tube (pin). The inner diameter of the steel tube is 9 mm, the outer diameter of the steel tube is 10 mm, and the height is 140 cm. The absorber steel tube is inserted into guide tubes with an inner diameter of 11 mm.

Contrary to the assumptions, it was impossible to fill the pin with the powder with the expected 85 % volume fraction. The actual volume fraction used in the experiment was about half of the expected value due to a very fine powder structure of the two oxides. Based on the weights and volumes, we were able to determine the amount of absorber used as input to calculations. The preparation of experimental absorbers in seen in Figure 3.

Figure 3: The Sm_2O_3 absorber in steel tube.

3.2 Experimental verification

As was mentioned, the objective of the experimental verification of the neutron absorber for the VVER-1000 fuel in the LR-0 is to determine the critical water level for two different absorber distribution states:

- **Case 1 (reference):** core configuration with seven fuel assemblies according to Figure 2, low enriched fuel in the central position is ready for absorbers insertion in the steel tubes.
- **Case 2 (Sm_2O_3)**: six pieces samarium absorbers are inserted into the inner row of guide tubes of the central fuel assembly.

Inserting six samarium absorbers in the core (Case 1) was designed to determine of samarium absorber reactivity worth.

The insertion of the absorbers into the guide tubes was carried out manually; see Figure 4.

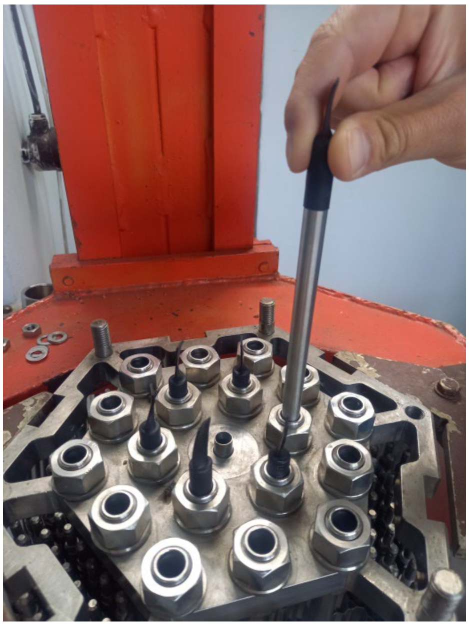

Figure 4: Insertion of absorber tubes into the inner row of the fuel assembly.

3.3 Calculation verification

The same H_{cr} as in the experimental configuration is chosen in the calculation to evaluate the reactivity difference (k-eff) in pcm.

This result is compared with the experimental $H_{cr.}$ Uncertainty based on the nuclear data library was not included. The simulations were performed with 100 000 neutrons per generation, 2 600 active cycles and 100 non-active cycles with statistical uncertainty up to 6 pcm.

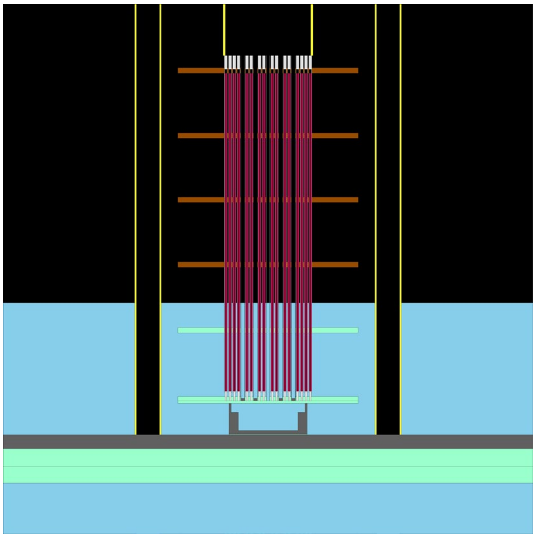

Figure 5: Axial cut of the Serpent core model for Case 1 (H_{cr} = 34.63 cm).

4 RESULTS

A summary of experimental data is given in the Table 1 below.

Table 1: Data for experimentally determined critical state set by moderator level.

Case [-]	1 (reference)	2 (Sm_2O_3)
Number of Sm_2O_3 absorbers [-]	0	6
Moderator critical level – H_{cr} [cm]	34.63	37.39
Absorber weight [pcm]	**0**	**1 481**

The critical parameter, multiplication factor (k-eff) with measured H_{cr} was determined for both studied cases by neutronic simulation. Comparisons between simulation and experimental data are in Table 2. The difference between the experiment and calculation is determined by Δ k-eff ($k\text{-}eff_{reference}$ - $k\text{-}eff_{calculation}$) [pcm].

Table 2: Evaluation of the calculation with measured moderator critical level.

Case [-]	1 (reference)	2 (Sm_2O_3)
Serpent k-eff	0.99978	0.99994
Δ k-eff [pcm]	**22**	**6**

5 CONCLUSION

The experimental verification presented in this paper describes the newly designed neutron absorber Sm_2O_3 in powder form in special steel tubes. The experiment was performed in the well-known reference neutron field in reactor LR-0 operated by the Research Center Řež in the Czech Republic.

The experiment considered a reference state (Case 1) without neutron absorbers with H_{cr} = 34.63 cm and a experiment with samarium absorbers inserted in the central fuel assembly for Case 2. The final critical moderator level was H_{cr} = 37.39 cm, and absorber weight was 1 481 pcm. The results show good neutron absorption properties for the newly designed absorber with samarium compared to used standard absorbers in LR-0 (1 014 pcm [8]).

The reference model was also verified. The difference between the Serpent model (based on the IRPhEP benchmark) and the measurement was only 22 pcm.

In conclusion, the neutronic properties of the newly proposed concept of fixed neutron absorbers have been successfully demonstrated. At the same time, it is a reasonable solution from an economic point of view with interesting potential at the back-end of the fuel cycle.

ACKNOWLEDGMENTS

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