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# NEUTRON ABSORBER CONCEPT IN SPENT FUEL CASKS AIMING AT IMPROVED NUCLEAR SAFETY AND BETTER ECONOMICS

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## ABSTRACT

The recent increasing demand for better nuclear fuel utilization requires higher enriched uranium fuels which is a challenge for spent fuel handling facilities in all countries with nuclear power plants. The operation with higher enriched fuels leads to reduced reserves to legislative and safety limits of spent fuel transport and storage facilities.

This study addresses the spent fuel solution with significantly increased nuclear safety and improved economics where a new concept of inseparable neutron absorber is introduced to achieve spent fuel reactivity decrease. Same or better criticality safety is achieved with significantly lower boron content in the cask basket. Alternatively, it is possible to reduce fuel assembly pitch with the same boron amount and subsequently decrease overall cask dimensions and its cost. Moreover, it is also feasible to reduce the subcritical multiplication of the neutron source, thus reducing the neutron dose in the vicinity of the cask. The efficiency of the new concept is demonstrated on criticality safety analysis of the GBC-32 spent fuel cask.

## INTRODUCTION

Criticality safety in spent fuel cask systems is commonly achieved by placing neutron absorbers in the cask basket design. Aluminum or stainless steel tubes spatially separate fuel assemblies in the cask basket. Currently, boron is exclusively used as the absorber material. The reason is the chemical and mechanical properties of light boron nuclei that can be added directly to basket tubes material, or placed in extra sheets between the tubes. However, with increasing fuel enrichment and limit on boron content as the additive material [1], criticality safety criteria for various transport and storage systems are hard to met. The most common solution is the introduction of burnup credit methodology. Another proposed solution is the neutron absorber concept that is based on placing neutron absorbers directly into the fuel assembly where the absorber efficiency is much higher. In order to be accepted by a regulatory body, the absorber will be inseparably fixed to the fuel assembly guide tubes. Moreover, materials other than boron can be introduced due to higher absorber efficiency [2].

Neutron absorber concept significantly decreases reactivity that can be used in cask optimization in various ways. For example, boron content in the absorber tubes can be lowered, or fuel assembly pitch can be decreased. The efficiency of the neutron absorber concept is illustrated in GBC-32 benchmark analysis of PWR spent fuel cask [3]. The neutron absorber concept has been studied recently [4], [5].

## CALCULATION MODEL

GBC-32 benchmark cask is described in [3]. It is a simplified cask for burnup credit benchmark purposes. For neutron absorber concept feasibility, a 2-D model of the cask was analyzed. Fuel was assumed uniform in all fuel rods as one material. Uncertainties were not taken into account.

Fuel composition was calculated with TRITON code sequence from SCALE-6.2.3 code package [6]. Fuel assembly depletion model is depicted in Figure 1, uniform material was assumed since other parameters (fuel enrichment, fuel burnup, cooling time) have a significantly larger effect on the reactivity, especially for feasibility study. Actinide and fission product burnup credit level with NRC approved set of 28 nuclides [7] was used. Nuclide set is very similar to French selection of 27 nuclides [8], Eu-151 fission product makes the only difference. Isotopic correction factors were not applied since the absorber reactivity worth is around 10 times larger.

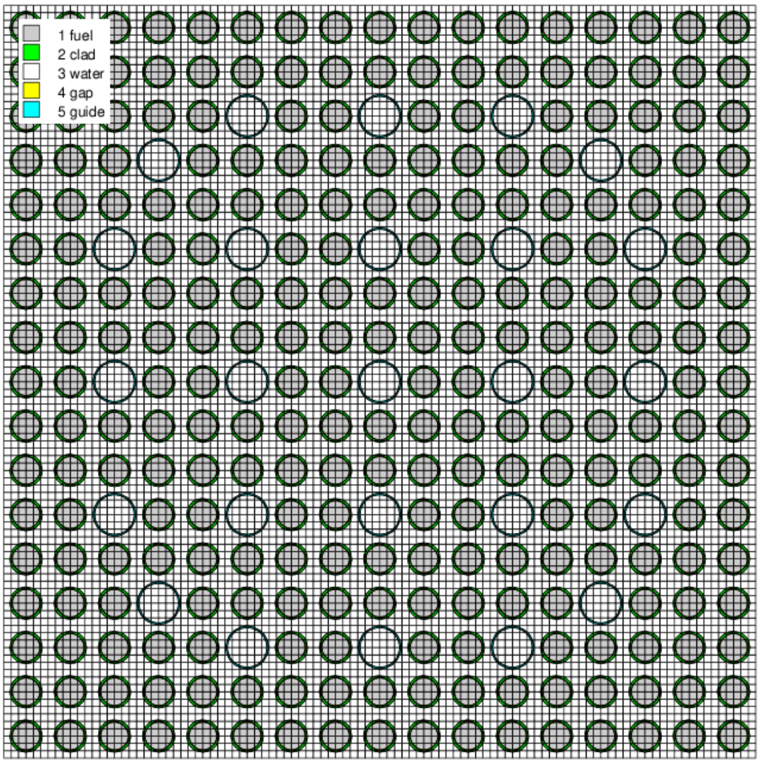

**Figure 1. Fuel assembly depletion model in SCALE/TRITON.**

Criticality calculations were performed with Serpent (version 2.1.30) transport code [9] and ENDF/B-VIII.0 continuous energy nuclear data library [10]. Geometry model of the whole cask, regular cell of the basket and detail of the absorber sheet with a boral panel is depicted in Figure 2.The boral panel is 0.2057 cm thick with boron density of 0.0225 g B-10/cm$^2$. The cask is flooded with unborated water.

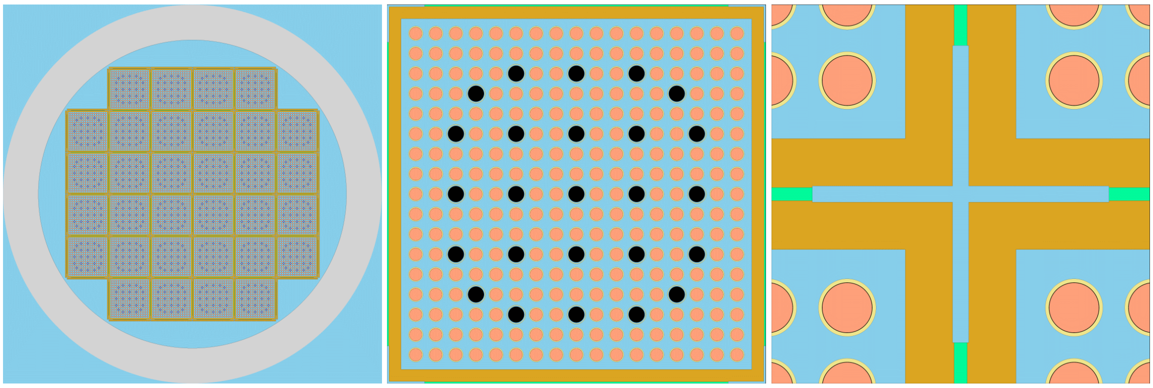

**Figure 2. Spent fuel cask criticality model in Serpent 2.**

## CALCULATION RESULTS

GBC-32 cask criticality for benchmark specifications (Figure 3) is achieved with borated sheets placed between basket tubes. Cask criticality with novel neutron absorber concept for a traditional absorber (boron) and an alternative absorber (gadolinium) for the same fuel composition is compared in Figures 4 and 5. Fuel enrichment and burnup influence reactivity distinctly, on the other hand, cooling time plays a minor role. Therefore, a final comparison of current solution with newly proposed neutron absorber concept in Figure 6 is displayed only for zero cooling time.

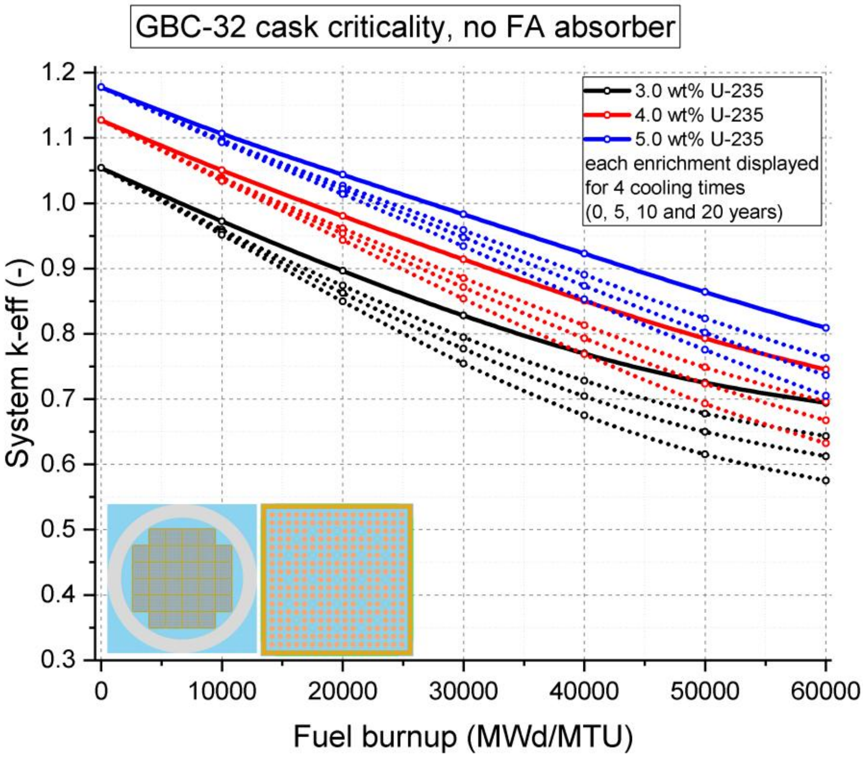

**Figure 3. Spent fuel cask criticality without neutron absorber concept.**

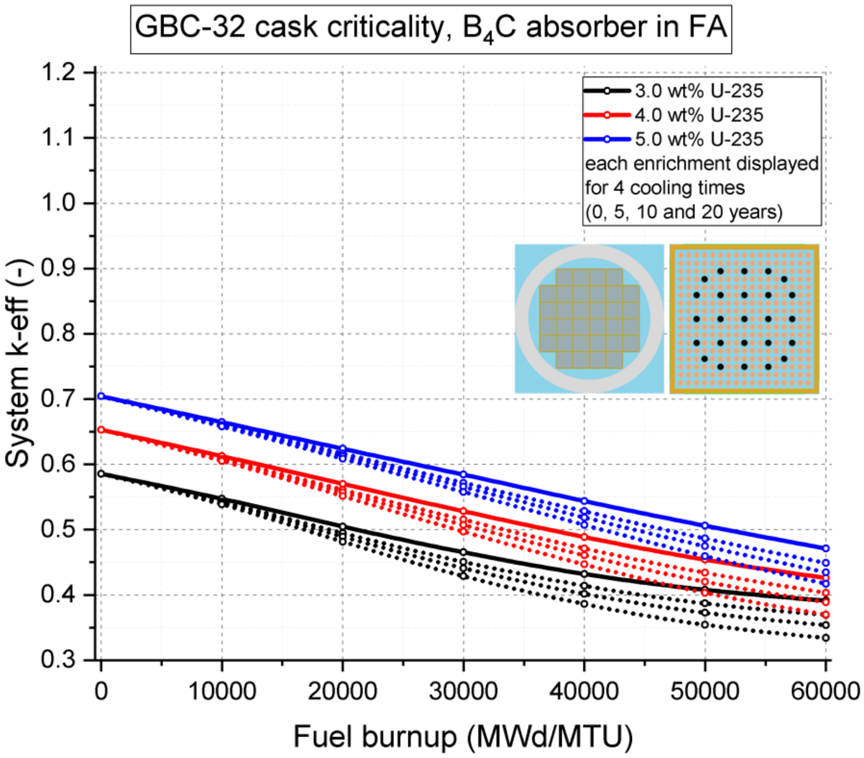

Figure 4. Spent fuel cask criticality with neutron absorber concept based on boron.

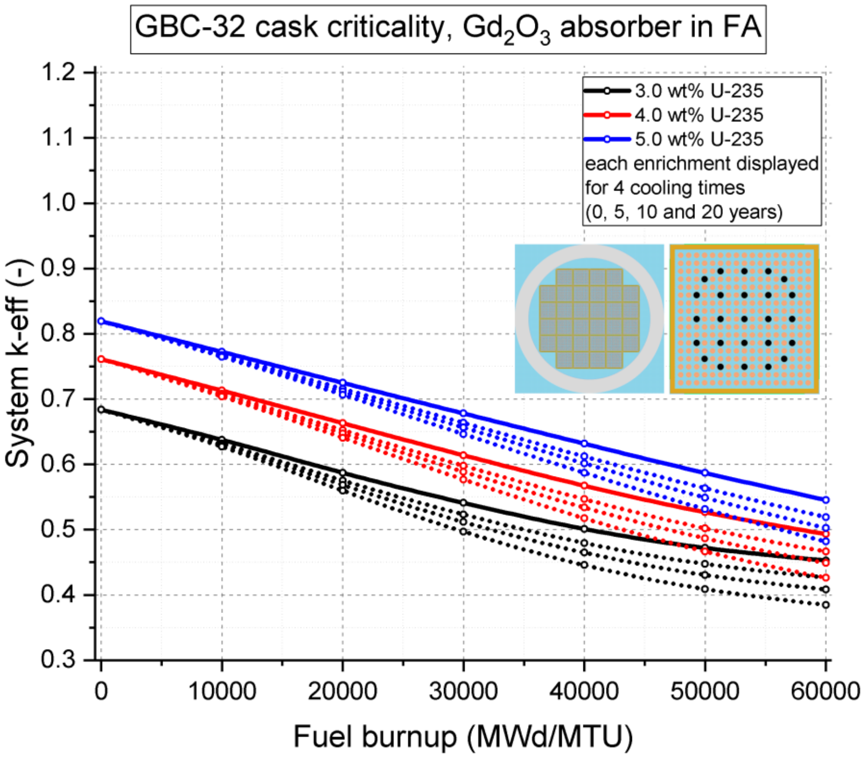

Figure 5. Spent fuel cask criticality with neutron absorber concept based on gadolinium.

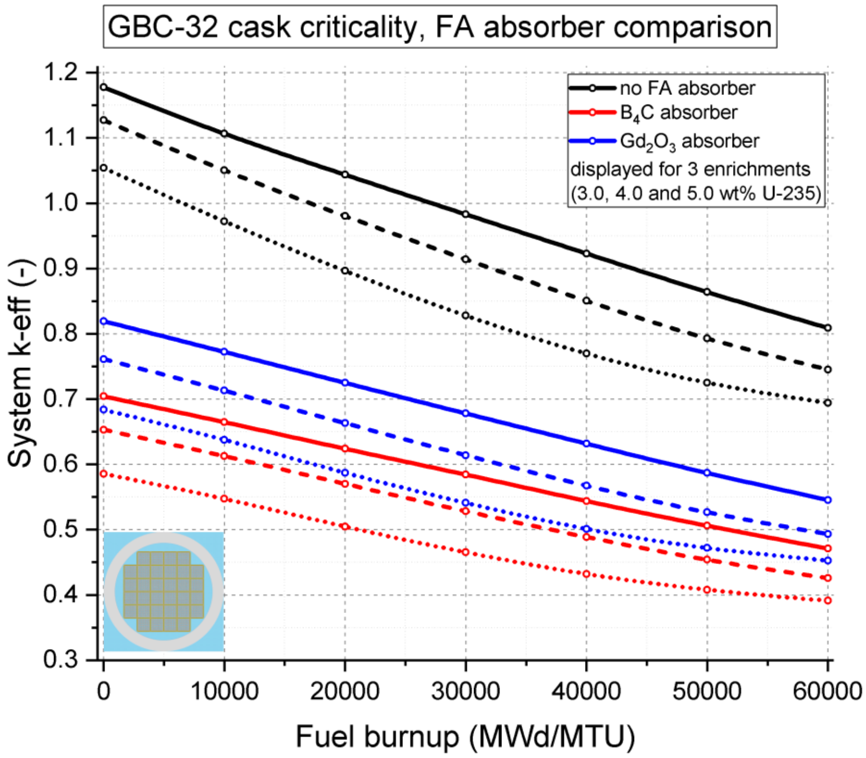

**Figure 6|. Neutron absorber concept summary comparison.**

The most important results from Figure 6 are the absorber worth in the cask. For the comparison, cask neutron multiplication factors for all 3 models (i.e., no FA absorber, $B_4C$ FA absorber, $Gd_2O_3$ FA absorber) with the highest enrichment and zero cooling times were compared in Table 1. Boron-based absorber decrease k-eff by 0.47 for fresh fuel, while gadolinium-based absorber is slightly less effective with k-eff difference of 0.36. However, both absorbers are strong enough that burnup credit is not required and even the boral panel can me redesigned in a less expensive way.

The neutron absorber concept has proven to be very effective. Calculated fresh fuel k-eff decrease (0.47 for boron, 0.36 for gadolinium) can be seen as a maximum absorber reactivity worth. Further study of absorber optimization can decrease the number of absorber positions (placed in every guide tube and in central tube in this study) and the absorber volume (1.0 cm diameter rods without cladding assumed for GBC-32).

**Table 1. Spent fuel cask criticality for 5.0 wt% U-235 nuclear fuel.**

| Burnup (MWd/MTU) | no FA absorber | $B_4C$absorber | $Gd_2O_3$absorber |
|---|---|---|---|
| 0 | 1.177 | 0.704 | 0.819 |
| 10000 | 1.106 | 0.665 | 0.772 |
| 20000 | 1.044 | 0.624 | 0.725 |
| 30000 | 0.983 | 0.584 | 0.678 |
| 40000 | 0.923 | 0.544 | 0.632 |
| 50000 | 0.864 | 0.506 | 0.587 |
| 60000 | 0.809 | 0.471 | 0.545 |

## CONCLUSIONS

A novel concept of neutron absorber with significantly increased nuclear safety and improved economics is introduced. The absorber placed directly within fuel assembly guide tubes significantly decrease cask reactivity. For boron-based absorber, k-eff decrease of 0.47 was concluded for GBC-32 reference cask. Gadolinium-based absorber was also successfully analyzed with k-eff decrease up to 0.36. Both absorbers are strong enough that burnup credit is not required and even the boral panel can be redesigned with a less expensive options. Mechanical absorber inseparability as the regulatory requirement is the subject of further research in the following years.

Same or better criticality safety is achieved with significantly lower boron content in the cask basket. Alternatively, it is possible to reduce fuel assembly pitch with the same boron amount and subsequently decrease overall cask dimensions and cost. Moreover, it is also feasible to reduce the subcritical multiplication of the neutron source, thus reducing the neutron dose in the vicinity of the cask.

## ACKNOWLEDGMENTS

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