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Modelling of RBMK-1500 SNF storage casks activation during very long term storage

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HIGHLIGHTS

- Neutron activation modelling of RBMK-1500 SNF storage casks components during 300 years interim storage period is presented.
- Induced activity in every component of CASTOR®RBMK-1500 cask is higher compared to the same component of CONSTOR®RBMK-1500.
- Main nuclides in the metal parts of both casks are: short-lived Fe-55, Co-60 Mn-54 and long-lived Ni-59, 63, Mo-93 and Nb-94.
- For the concrete components of CONSTOR®RBMK-1500 cask, long-lived Ca-41, Ba-133 and C-14 also appear.

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ABSTRACT

Existing interim spent nuclear fuel storage facility (SNFSF) at Ignalina nuclear power plant in Lithuania is fully loaded with CASTOR®RBMK-1500 and CONSTOR®RBMK-1500 storage casks. The planned lifetime of these casks is 50 years and the first loaded cask was moved to the SNFSF in 1999. The start of operation of disposal facility in Lithuania is foreseen later than the planned interim storage ends. So, the possibilities to extend the storage period over 50 years should be considered. Therefore, the casks decommissioning issues should be taken into account, as due to prolonged neutron irradiation casks materials could became activated.

This paper presents modelling results of storage casks neutron activation during 300 year storage period. Modelling results show, that after 50 years of storage, side-wall and bottom of CASTOR®RBMK-1500 cask are activated above clearance criteria. However, for 100–300 year storage period all of the casks components could be free released.

1. Introduction

The current spent nuclear fuel (SNF) management concept in Lithuania foresees interim dry storage of SNF from Ignalina nuclear power plant (NPP) (Ragaisis et al., 2014). Existing SNF storage facility (SNFSF) is fully loaded with 20 CASTOR®RBMK-1500 and 98 CONSTOR®RBMK-1500 storage casks, see Fig. 1 (Ignalina Nuclear Power Plant, 2016). CASTOR®RBMK-1500 is metallic while CONSTOR®RBMK-1500 is reinforced concrete storage cask, each weighting (empty) respectively ~60 and ~70 t, designed by German company GNB. These casks are so called "dual purpose casks", i.e. they are licenced for transport and interim storage of SNF.

There is a new SNFSF under construction now, which is designed to store the remaining SNF from the reactor units in a new CONSTOR®RBMK-1500/M2 dry storage casks. The planned lifetime of CASTOR®RBMK-1500 and CONSTOR®RBMK-1500 casks is 50 years and the first cask (loaded with SNF) was moved to the existing SNFSF in 1999. Therefore, in ~2050 the interim storage period ends.

At present, deep geological disposal is considered as final management option for SNF in Lithuania, and start of operation of such disposal facility is foreseen in 2066 (Lithuanian Development Programme for Radioactive Waste Management, 2015). So it is clear, that at least 15 years gap exists between planned termination of interim storage and disposal, and SNF storage beyond of 50 years period should be considered. However due to possible uncertainties in the future, it could be expected that deep geological disposal facility will not be commissioned in due time and interim storage of SNF in the cask for much longer period than the initially foreseen should be analysed.

This problem is specific not only to Lithuania, but also for many other countries and as there is no operating deep geological

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Fig. 1. CASTOR®RBMK-1500 (on the left) and CONSTOR®RBMK-1500 (on the right) storage casks in existing SNFSF at Ignalina NPP (Ignalina Nuclear Power Plant, 2016).

disposal facility in the world yet, and many uncertainties and difficulties associated with it exist. As a proof of this, the IAEA coordinated research project (CRP) "Demonstrating Performance of Spent Fuel and Related Storage System Components during Very Long Term Storage" could be referenced, where more than 10 countries participate dealing with necessity to prolong light water reactor spent fuel management licences as dry storage durations extend, e.g. exceeding 100 years (International Atomic Energy Agency, 2016).

Storage period prolongation is possible, however, for a very long term storage it is necessary to understand and evaluate long term effects on SNF assemblies and cask components. The performance of SNF assemblies and storage cask components is of most importance during very long term period. Besides, cask decommissioning issues after very long term storage should be taken into account, as due to the prolonged neutron interaction with the cask's materials, these could became activated (International Atomic Energy Agency, 1999). For example, if all CASTOR®RBMK-1500 and CONSTOR®RBMK-1500 casks in existing SNFSF of Ignalina NPP could became activated above clearance level during very long term storage, this would produce a huge amount (~8000 t) of radioactive waste.

The aim of this paper is to model CASTOR®RBMK-1500 and CONSTOR®RBMK-1500 storage casks neutron activation during very long term storage and to check if this results in the activity levels of casks components above the clearance criteria.

2. Modelling

CONSTOR®RBMK-1500 cask (Fig. 2(a)) has cylindrical shape with diameter of more than 2 m, height more than 4 m, total thickness of the side-wall 0.43 m. The side-wall of the cask consists of two carbon steel TStE 355 liners (4 cm thick each) and heavy concrete layer between them. The bottom consists of the same materials and arrangement as the side-wall. The lids system of the cask consists of primary (25 cm thick) and secondary (4 cm thick) lids and seal plate (4 cm thick) between them made from carbon steel TStE 355.

CASTOR®RBMK-1500 cask (Fig. 2(b)) is made of ductile cast iron GGG-40 (29.4 cm thick side-wall and 25.5 cm thick bottom). Lids system is similar to CONSTOR®RBMK-1500 cask, however, the lids of CASTOR®RBMK-1500 are made from carbon steel TStE 500, secondary lid is 7 cm thick and lids system has no seal plate.

Both casks are designed to accommodate 32 M basket loaded with 102 SNF half-assemblies. The geometrical shape and dimensions of the internal cask cavity, the geometrical parameters of the 32 M basket (including SNF) and design materials are the same for both casks types. The main differences of dimensions and materials are in the side-walls and bottoms of the casks.

Numerical modelling of the neutron activation of the casks components deals with three problems. Firstly, the characteristics (concentrations of nuclides and/or neutron sources) of irradiated fuel (SNF) needs to be modelled. Secondly, when properties of SNF are modelled, neutron flux modelling in the casks components has to be performed using obtained SNF data. Then, using modelled neutron flux, neutron activation modelling of the casks components could be performed. As the first two steps of the modelling are a kind of intermediate steps in order to evaluate neutron activation of the casks components, thus, the modelling procedure and results of these two steps are not discussed in detail here – main focus is on the final step, i.e. neutron activation.

Computer code TRITON from SCALE 6.1 computer codes system (SCALE ORNL/TM-2005/39, 2011), MCNP 5 computer code (X-5 MONTE CARLO TEAM, 2003) and ORIGEN-S computer code from SCALE 5 codes system (SCALE ORNL/TM-2005/39, 2005) were used for solution of these problems.

2.1. SNF neutron source

RBMK-1500 SNF characteristics were modelled using computer code TRITON from SCALE 6.1 computer codes system (SCALE ORNL/TM-2005/39, 2011). This code could be used for transport, depletion, sensitivity and uncertainty analysis for 1D, 2D, and 3D configurations of complex fuel assemblies or other nuclear systems.

Detailed description of RBMK-1500 SNF characteristics modelling and results could be found in (Smaizys et al., 2014). Keeping in mind the fact, that only SNF of 2.0% initial enrichment is stored in CONSTOR®RBMK-1500 and CASTOR®RBMK-1500 casks, only results of this type SNF (2.0% initial enrichment, 22 MWd/kgU burnup (conservative)) characteristics variation over a 5–300 year cooling period are relevant for the subsequent modelling of neutron transport in the storage casks components. The time period of 0–5 years is not relevant here, because RBMK-1500 SNF could be placed in the storage casks only after (at least) 5 cooling years.

TRITON modelling results, showing neutron source strength variation of 2.0% initial enrichment and 22 MWd/kgU burnup RBMK-1500 SNF over 5–300 years cooling period, are presented in Fig. 3.

Total neutron source strength at the time just after removal from the reactor is the highest (reaches more than 2×10^8 n/s for 1 tHM of analysed RBMK-1500 SNF) and decreases more than 2.5 times during 5 cooling years, i.e. until the earliest possible loading time to the storage casks. Total neutron source of SNF consists of neutrons coming from the alpha-n reactions and from the spontaneous fission, however neutrons from the alpha-n reactions comprises less than 1% of total source during the analysed 5–300 years time period, see Fig. 3. During this time period, the total neutron flux further decreases nearly 30 times, where the the main radionuclides emitting neutrons (spontaneous fission) are Cm-244 and Pu-240.

2.2. Neutron transport

Modelling of neutron flux in components of CASTOR®RBMK-1500 and CONSTOR®RBMK-1500 storage casks was performed using MCNP 5 computer code (X-5 MONTE CARLO TEAM, 2003) with ENDF/B-VII nuclear data library. This code is a