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Evaluation of dose rate variation during very long term storage of RBMK-1500 reactor used fuel

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ABSTRACT

The duration of dry storage of RBMK-1500 used fuel in casks is foreseen to be 50 years. It is expected that a deep geological repository will be implemented in Lithuania after this storage period. Research activities on used nuclear fuel disposal in a deep geological repository have lasted for several decades and are still ongoing in different countries. However, until now there is no such repository in operation worldwide. Therefore, there is a possibility that due to the various reasons the deep geological repository cannot be constructed in the planned time. In such a case, an option of used fuel storage beyond 50 years needs to be considered. Various nuclear research centres in different countries are already performing investigations on subjects related to extension of the used fuel storage period. This paper presents modelling results of the total dose rates for CASTOR®RBMK-1500 and CONSTOR®RBMK-1500 casks during long-term storage (up to 300 years). Also, contributions of neutron and gamma doses to the total dose rate, variations of the neutron and gamma doses and influence of different gamma and neutron energy groups on dose rates during long-term storage are analysed.

1. Introduction

Currently different decommissioning activities are under implementation at the Ignalina NPP. One such activity is removal of remaining used RBMK-1500 fuel from the storage pools and its transfer to the newly built interim dry storage facility. Part of the used fuel has been already transferred into an existing dry storage facility that has been in operation since 1999 and contains 20 pcs CASTOR® RBMK-1500 and 98 pcs CONSTOR® RBMK-1500 casks. According to the "Development Programme for Radioactive Waste Management in Lithuania" that was approved by the authorities in 2015, the duration of dry storage of RBMK-1500 used fuel in the casks is foreseen to be 50 years. Afterwards, implementation of a deep geological repository for used fuel and long-lived radioactive waste in Lithuania is planned. Until now there has been no deep geological repository for used fuel in operation worldwide, despite the fact that R&D activities in this field have been ongoing for several decades. Therefore, there is a possibility that the deep geological repository, for various reasons, cannot be constructed in the planned time. In such a situation, an option of used fuel storage prolongation over 50 years needs to be considered. It must be ensured that safety objectives such as criticality and radiation safety, decay heat removal, and containment, are also fulfilled during the prolonged storage period. Consequently, this makes research necessary on long-term effects in fuel rods, storage cask components, and structures of the storage facility; material ageing issues must be considered as well. Various nuclear research centres in different countries are already performing investigations on these subjects. The International Atomic Energy Agency (IAEA) has initiated a few coordinated research projects (CRP) where experts from different countries can share their knowledge and identify the specific research objectives. One of the CRPs was focused on research into the behaviour of used fuel and storage materials during a prolonged storage period (International Atomic Energy Agency, 2003, 2012a, 2015), another concentrated on peculiarities of the storage of the fuel used in light water reactors (International Atomic Energy Agency, 2012–2016). This paper presents an analysis performed in the framework of the IAEA CRP (International Atomic Energy Agency, 2012–2016) on a safety related subject: evaluation of dose rate variations on the surface of RBMK-1500 used fuel dry storage casks for long-term periods. CASTOR® type storage casks are widely used in different countries for used fuel storage from PWR, BWR, VVER, RBMK, MTR, and THTR reactors. More than 1000 CASTOR® casks are loaded and stored in facilities worldwide (Wimmer et al., 2015). Currently, only VVER (in Bulgaria) and RBMK (in Lithuania) used fuel is stored in CONSTOR® type casks. Published papers mostly focus on the comparison

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of measured and modelled gamma and neutron fluxes, and dose rates for CASTOR® and CONSTOR® type casks (Ringleb et al., 2005; Thiele and Börst, 2009; Kralik et al., 2002; Poškas et al., 2006; Plukis et al., 2006). In the previous dose rate modelling for CASTOR® RBMK-1500 and CONSTOR® RBMK-1500 casks (Šmaižys and Poškas, 2001; Poškas et al., 2003) that was performed in 2001–2003, radiation characteristics of these casks were estimated for storage periods of up to 50 years, and numerical modelling including estimation of the fuel inventory was done with the SCALE 4.3 (Scale, 1997) computer code system. Since then the developer (Oak Ridge National laboratory, USA) of the SCALE code system has introduced a lot of improvements and changes in the system. This paper presents dose rate modelling results for CASTOR® RBMK-1500 and CONSTOR® RBMK-1500 dry storage casks during very long-term storage obtained using the SCALE 6.1 (Scale, 2011) system.

2. Methodology of dose rate numerical evaluation

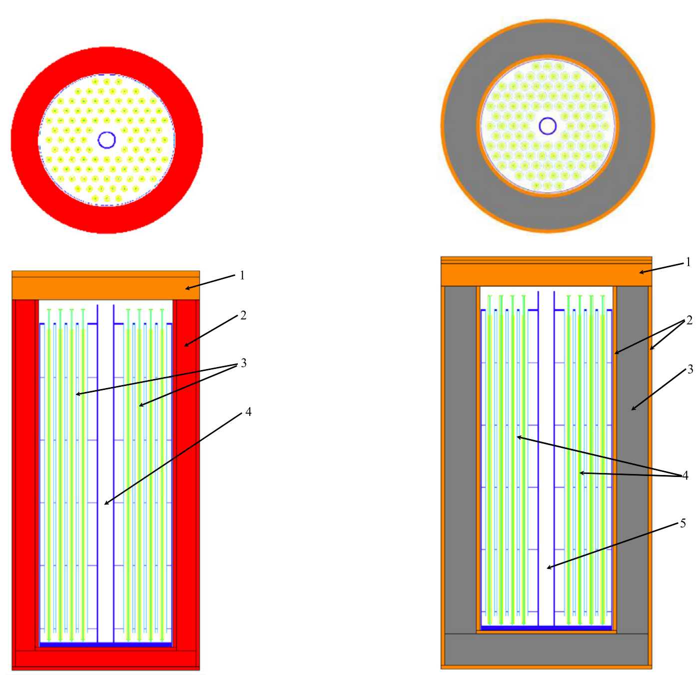
CASTOR®RBMK-1500 and CONSTOR®RBMK-1500 dry storage casks are designed to store 102 used RBMK-1500 fuel half-assemblies positioned in a 32 M basket inside the cask. Nuclear fuel with different U-235 enrichments was used during Ignalina NPP operation. These casks are licensed to store used fuel only with 2.0% initial enrichment. Remaining used fuel, including fuel with other enrichments (2.4%, 2.6%, and 2.8%, all containing burnable erbium absorber), will be stored in the new increased capacity CONSTOR®RBMK-1500/M2 storage cask, which is not considered in this paper.

CASTOR®RBMK-1500 and CONSTOR®RBMK-1500 casks have a cylindrical shape; the outer diameter is more than 2 m, height is more than 4 m. The main differences between the casks are in materials and dimensions of the side walls and bottoms. The side wall and the bottom of CASTOR®RBMK-1500 (see Fig. 1, a) are made from ductile cast iron, whereas these parts of CONSTOR®RBMK-1500 (see Fig. 1, b) are made from two carbon steel liners filled with heavy concrete. The lids (the primary and secondary lids of both casks and the additional seal plate for the CONSTOR®RBMK-1500 cask) are manufactured from carbon steel. Internal cavities (geometrical shapes, dimensions, material compositions, baskets) are identical for both casks.

Dose rate numerical evaluation consists of two steps. First of all, the nuclide inventory and the characteristics of the fuel assembly during irradiation in the reactor core and afterwards during long-term storage periods have to be obtained. The evaluation method and results of this step are described in Šmaižys et al. (2014). Secondly, when the characteristics of the used fuel are available, dose rate calculations for the casks can be performed. The MAVRIC control module from the SCALE 6.1.2 code system was used for dose rate evaluation. This control module performs 3-D radiation transport modelling, calculates gamma and neutron fluxes and dose rates exterior to a cask using the Monte Carlo method. The following main assumptions were accepted for the modelling:

- The neutron and gamma source in the MAVRIC input file was described as a homogenous cylinder that contains 102 used fuel half-assemblies and the 32 M basket structures.
- Point detectors are located on the outer cask surface (0 m) and at a two-meter distance exterior to the cask at the centres of the lid and the bottom and at mid height of the side wall.
- The modelling was performed for a storage period of 5–300 years. It should be mentioned that used fuel unloaded from the reactor core must be cooled down for at least 5 years in pools before loading it into a dry storage cask. Therefore, the storage period of 5 years means that the used fuel has just been loaded into a cask.

(a) CASTOR®RBMK-1500 **(b) CONSTOR®RBMK-1500**



(a) 1 – lid system; 2 – cask body (ductile cast iron); 3 – 32M basket with fuel half-assemblies; 4 – cavity filled with He

(b) 1 – lid system; 2 – carbon steel liners; 3 – heavy concrete; 4 – 32M basket with fuel half-assemblies; 5 – cavity filled with He

Fig. 1. Cross-sections of the casks.