Evaluation of Radiation Shielding Properties for Innovative Concrete With Oil Shale and Basalt-Boron Fiber Additives

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Abstract:
Cement-based concretes are commonly used for managing radioactive waste due to their low cost and acceptable radiation shielding properties. However, the potential of using oil shale ash as an admixture in concrete for the radioactive waste packaging has been overlooked. Estonia generated millions of tons of ashes collected at landfills by burning oil shale for energy production.

In 2021, four research institutes in Latvia, Lithuania, Estonia and Norway started a cooperation project – Innovation in CONcrete DEsign for hazardous waste management applications (ICONDE) – with the aim to develop innovative concrete mixtures for the safe disposal of hazardous waste, including radioactive waste. The project promotes a circular economy by using oil shale ash, an industrial waste product created in energy production in Estonia, as a supplementary cementitious material in concrete production.

The mechanical properties of concrete will be improved by the addition of dispersed fibers. Furthermore, the use of basalt fibers infused with boron oxide will increase the material's ability to shield neutrons. These properties make the concrete mixtures suitable for radioactive waste management. A possible application for innovative concrete mixtures is the waste created during the decommissioning of nuclear power plants and other types of radioactive/hazardous waste from industry or medicine.

The waste containers used in Ignalina Nuclear Power Plant for the short-lived, low and intermediate level liquid waste were chosen for analysis in this study. Cementation is chosen for the solidification of radioactive liquid waste at the Ignalina nuclear power plant. The liquid waste is cemented and solidified into 200 l drums. Drums are stored in a concrete container with a storage capacity of 8 drums. The drums within the container will be immobilized with cemented grout before the final disposal. In this study, the cemented grout within the container is changed with the concrete with oil shale and basalt-boron fiber additives to evaluate the radiation shielding properties of innovative concrete.

This study investigates the radiation shielding properties of oil shale ash as an additive in concrete for waste packaging. Both Monaco and MAVRIC modules within SCALE 6.2.4 for radiation transport simulations were used to conduct two independent evaluations. The Monaco module is a Monte Carlo transport code for shielding applications with direct particle transport simulations. The MAVRIC module is designed for deep penetration problems as one analyzed and is based on the same Monaco module using an automated variance reduction method.

The MAVRIC module performs a radiation shielding analysis in two steps including the calculation of adjoint flux as a function of position and energy using the Denovo module (3D Cartesian geometry discrete ordinates transport code) and particle transport calculations. An importance map generated by the Denovo module is applied for biasing during Monte Carlo particle transport to accelerate Monte Carlo simulations. It enables to obtain good statistics (i.e., low relative uncertainty) in the regions of interest without sacrificing computation time.

The estimated photon flux and the relative computation efficiency were compared between Monaco and MAVRIC modules in addition to the demonstration of radiation shielding properties for concrete with oil shale and basalt-boron fiber additives in comparison with the cemented grout.

Keywords: radioactive waste, concrete, oil shale ash, basalt boron, radiation shielding modeling, Monate Carlo method, variance reduction method.