

THESIS BOOK

**COMPLEX RADIOLOGICAL EVALUATION
OF SHIELDING CONCRETES**

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Introduction

The thesis explores the changes occurring in concrete structures playing a role in radiation protection, particularly due to ionizing radiation (primarily neutron radiation), and their effects. Significant neutron radiation occurs in nuclear power plants and various experimental facilities. Since continuous renewal of available infrastructure is essential to ensure the sustainability of research and guarantee energy security, there is a need for the construction of new facilities, maintenance of existing ones, extension of operational lifetimes, and the safe decommissioning of these facilities after their lifespan has expired.

The main material in the previously mentioned processes is concrete since this highly popular building material is fundamental and extensively used in facilities generating neutron radiation. Concrete used in nuclear facilities must meet numerous radiation protection requirements, and the purely experimental examination of these requirements is often quite costly and sometimes unfeasible. Therefore, simulation codes are increasingly employed nowadays to investigate material-radiation interactions. The thesis focuses on these interactions, along with their effects on material composition and structure, and it illustrates the possibilities inherent in exploiting the synergies between measurements and simulations through specific examples.

Goals

There are two main negative consequences of the activation of concrete due to neutron radiation: firstly, the resulting radioisotopes expose personnel working in the facility to radioactive radiation during operation, and secondly, during decommissioning, it may require the placement of the radioactive waste into a waste storage facility. One goal was, therefore, to develop procedures for the most accurate and efficient estimation of concrete activation. To ensure the credibility of these procedures, I considered the joint use of measurements and simulations important, because in this way, measurements can serve as input and validation data for simulations, which are less resource-intensive and intended for long-term use.

In addition to research related to activation, I also studied the degradation and aging of concrete due to neutron radiation in this thesis. In this less-explored area, one major problem is the scarcity and inaccuracy of available measurement results. Therefore, I set the goal of examining the suitability of the Budapest Research Reactor for executing experiments on concrete aging and determining the main parameters necessary for these experiments.

New scientific findings

The new scientific findings of the dissertation can be summarized in the following key points:

1. Activation studies were conducted on three concrete samples intended for use at the Budapest Research Reactor (BKR) and the European Spallation Source (ESS): on the Reference concrete, Skanska concrete, and PE-B4C concrete. The aim of the experiments was to better estimate the exposure of maintenance personnel of ESS. In the thesis, I demonstrated that the dose contribution of beta-emitting radioisotopes, like ^{31}Si and ^{32}P is negligible compared to the dose contribution of gamma emitting radioisotopes. Based on measurements I identified the key gamma emitting isotopes. Comprehensive elemental analysis was conducted on the concrete samples using NAA, PGAA, and XRF techniques. Inhomogeneity of the concretes have been revealed based on the measurements, which was important in the further evaluations. [P1] [P2] [P3] [P4]
2. Taking into account the isotopes crucial for neutron activation I compiled material compositions for all three concrete samples. These compositions can be used as input parameters for simulations, allowing for the consideration of not only the shielding capabilities of the concrete but also radiation protection aspects related to activation (decay gamma radiation, radioactive waste management) during modelling. I created an MCNP model for the detailed geometry used in irradiations of the Thermal and Fast channels of the Budapest Research Reactor (BKR). Using this model, I replicated the irradiation experiments described in the first key point on concrete samples, employing the material cards prepared as described. The deviation between measurements and simulations remained below the uncertainties, proving the proper compilation of the material cards. The compiled material can be used not in ESS, but in other neutron producing facilities as well. [P2] [P3] [P4]
3. For the Reference concrete, I examined the impact of the material card that I created, as detailed in the second key point, on radiation protection models. To do this, I modelled a maintenance scenario: I simulated the dose field around one of the concrete walls of the ESS Bunker (a building part serving as radiation shielding around neutron outlets)

after 3 days of cooling following irradiation during operation. I used MCNPX and Cinder1.05 codes for the simulation. Applying the material card I compiled resulted in a dose rate 30-70% higher in the vicinity of the irradiated wall compared to simulations performed with the nominal composition. The precise determination of components prone to activation (e.g., Na, Fe) and trace contaminants (e.g., W, Co, Eu) in the material composition allows for accurate calculation not only of personal dose estimates but also of the radioactive waste index beyond what is presented here. [P3]

4. Since very little scientific data is available regarding the activation of radiation protection concrete around nuclear reactors, including neutron fluence data necessary for calculating the deep activation of concrete, I created a simulation model using MCNPX and Cinder1.05 simulation codes to establish a simple method for deep penetration problems. I examined the activity concentrations of 7 activation products (^{152}Eu , ^{154}Eu , ^{60}Co , ^{65}Zn , ^{54}Mn , ^{134}Cs és ^{133}Ba) in the concrete depth range of 5-60 cm for a total of 8 different models and compared the results with data obtained from measurements. The research quantified the impact of the investigated models on deep concrete activation for various isotopes. While the creation of most isotopes was significantly enhanced by placing a neutron scattering volume and/or reflector surface around the modelled volume, these changes had a negligible effect on the activity of ^{54}Mn due to the fast neutron reactions leading to its formation. [P6]
5. Utilizing the results of the concrete activation simulations described in the 5th key point, I created a model in which the ratio of measured to simulated activities remained stable throughout the entire investigated depth of the concrete for all isotopes except ^{54}Mn . For the four isotopes that behaved quite similarly during simulations (^{154}Eu , ^{60}Co , ^{65}Zn , és ^{133}Ba), the measured-to-simulated ratio was approximately between 2-5, similar to simulation results found in the related literature. The examination of the 7 investigated radioisotopes, with different neutron capture cross-sections and numerous modeled arrangements also highlighted that the cause of the discrepancy between measurement and simulation results was a systematic error introduced into the system by the initial neutron spectrum. [P6]

Publications

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Conferences

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