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**Monte Carlo modeling and variance
reduction technique applications for heavily
shielded geometries in the decommissioning
of nuclear power plants**

By

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Monte Carlo modeling and variance reduction technique applications for heavily shielded geometries in the decommissioning of nuclear power plants

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An in-depth study is presented addressing the challenges associated with the residual activation in nuclear power plants, specifically focusing on their decommissioning processes in scenarios characterized by heavily shielded geometries, exemplified by the reactor pressure vessel of a pressurized water reactor.

More in detail, the main topic is the development of a 3D calculation scheme for the evaluation of the residual activation generated by neutron interactions within the structural material of the vessel and internal components of a pressurized water reactor. The focus of the scheme is primarily the analysis of the Enrico Fermi nuclear power plant in Trino, Italy, which is currently undergoing decommissioning.

The scheme is initially developed to analyze the thermal shield of the reactor, and benefits from measurement campaigns conducted in 1969 and 1992: these campaigns provide crucial data for scheme validation, enabling testing across the shield and for various isotopes, with a focus on key isotopes such as ^{60}Co , ^{59}Ni , and ^{63}Ni , significant in waste classification and as powerful gamma emitters. The scheme exhibits robust performance, offering accurate estimates of the residual activation of the thermal shield.

The scheme is later expanded to analyse the vessel's internal liner, considering that the vessel itself is usually the largest and most complex component to dismantle and the internal stainless steel liner is quite prone to activation. In order to do so, a few modifications are introduced and the scheme is applied a second time to perform a detailed analysis of the irradiation history of several points at different heights and angular coordinates along the entire life of the reactor. It became clear after a few preliminary calculations that most of the vessel exhibits a uniform angular distribution of the neutron flux, therefore many regions can be treated as uniformly irradiated. The scheme envisions the analysis of four different core configurations representing the entire operating life of the reactor and the modifications introduced

both in terms of geometry and in terms of power produced. Two separate sets of measurements are used to validate the scheme results, the first one coming from the analysis of a liner sample and the second coming from a set of dosimeters used in the framework of the vessel surveillance program. The scheme performs well, and is able to correctly assess the residual activation in many different points along the vessel liner and in agreement with the measurements. It also proves flexible enough to consider different combinations of materials, irradiation history, spectra and geometric position.

The scheme undergoes then a final modification to test the Representative Operating Cycle (ROC) hypothesis. This hypothesis, suggested for the analysis of nuclear reactors with relatively constant operation and geometry, is assessed for its applicability to the Trino reactor. The ROC approach shows promising results, yielding a slightly conservative estimate of residual activations and contact dose rates compared to the hybrid model, validating its suitability for a reactor characterised by a rather complex history. This approach is particularly convenient in decommissioning studies, considering its simplified implementation and reduced computational cost.

Considering that activation calculations are just the initial step of the complex process required for a successful decommissioning project, with the actual dismantling coming afterwards, an additional contribution to the engineering studies is carried out in collaboration with the Department of Mechanical and Aerospace Engineering (DIMEAS). The aim of this contribution is to provide a more complete overview of the issue of nuclear decommissioning and offer insights on the multidisciplinary nature of the process. The topic addressed is the development of a methodology designed for selecting the optimal cutting technique for the decommissioning of a nuclear power plant, as this is one of the most difficult choices the stakeholders involved in the process have to make. Tailored to align with site-specific requirements inherent in diverse decommissioning projects, this methodology addresses challenges associated with dismantling such complex facilities.