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Numerical Visualization of Gamma Radiation Distribution in Nuclear Decommissioning Processes

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KATEDRA ENERGETYKI JĄDROWEJ I RADIOCHEMII

Introduction:

The radiological characterization of nuclear power plant components in the decommissioning process is crucial for planning dismantling operations and ensuring radiation safety. One of the most significant challenges in nuclear decommissioning is the accurate assessment of residual radiation levels, particularly in the vicinity of large, highly activated components such as the Reactor Pressure Vessel (RPV).

Description of the research problem:

This study presents a numerical approach to visualize the gamma radiation distribution from the RPV of the Italian Trino Vercellese Nuclear Power Plant (NPP). The Trino NPP with a 280 MWe Pressurized Water Reactor (PWR) was operational from 1965 to 1987 [1]. Over three decades after shutdown, its structural components, particularly the RPV, remain radioactive due to neutron activation and surface contamination. The analysis focuses on the spatial distribution of ambient dose equivalent (H*(10)) in both horizontal and vertical cross-sections of the RPV, considering Ni-63, Co-60, Ni-59, and Fe-55 isotopes as primary radiation sources.

Methodology:

The calculations were performed using the Monte Carlo-based RayXpert software [2]. The geometry and material composition of the RPV were numerically implemented using available engineering data [1,3]. Figure 1 shows the developed numerical model with division into the main structural sections. Table 1 presents the material composition and levels of specific radioactivity used for simulations. The model contains ten radiation sources, which correspond to the structural sections of the RPV. The highest activity was reported in the mid RPV internal cladding, close to the core region.

Table 1 Materials and levels of specific radioactivity of RPV components.

Component	Material	Radioactivity [Bq/g]
RPV		
Flange	ASME SA336	2.08E-01
Top RPV wall	ASME SA302 GR B	1.35E+01
Mid RPV wall	ASME SA302 GR B	2.86E+04
Bottom RPV wall	ASME SA302 GR B	2.73E-01
Nozzels	ASME SA336	1.35E+01
Inner Cladding		
Flange	AISI-304	5.62E+00
Top RPV wall	AISI-304	3.01E+03
Mid RPV wall	AISI-304	8.69E+06
Bottom RPV wall	AISI-304	3.22E+01
Shell bottom	AISI-304	1.23E-01

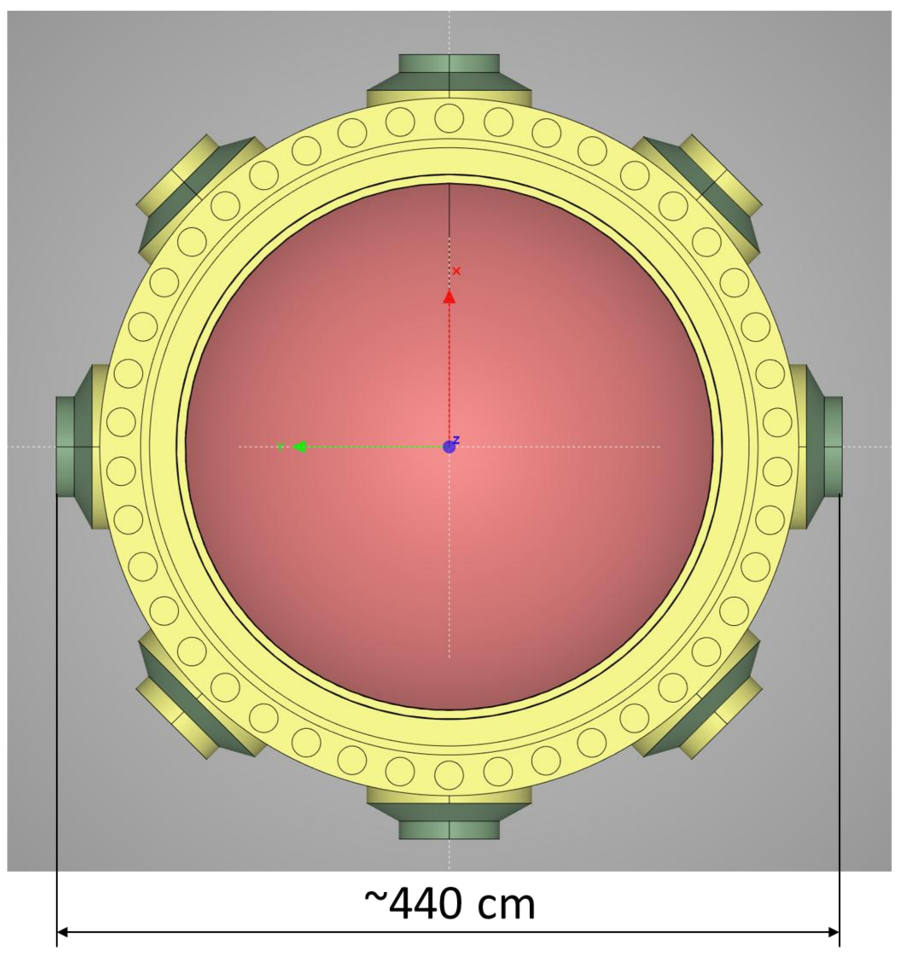

Fig. 1 Top view of the numerical model.

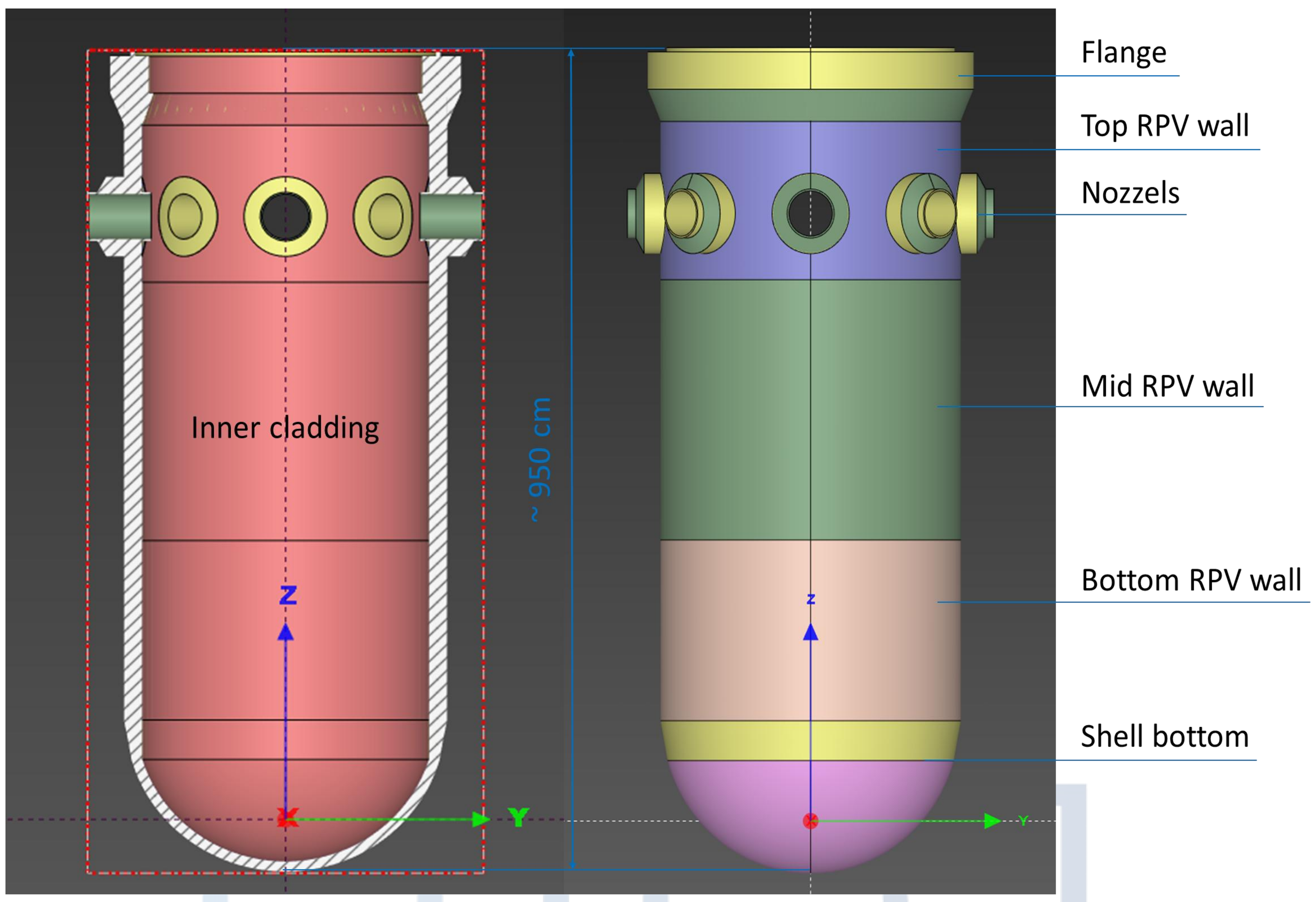

Fig. 2 Side view of the numerical model.

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Results:

Figure 3A shows the visualization of the particle trajectories in the numerical model. The green trajectories show primary photons, yellow ones secondary photons, and red ones primary electrons. The trajectories are visible in the sphere with a radius of 10 meters around RPV. The visualisation of trajectories estimates areas with potentially the highest radiation intensity. The highest intensity is visible in the top part of the vessel. Next, the 3D Cartesian map with 1000 voxels was introduced for detailed radiation dose calculations. Fig.2 shows the 3D heat map of H*(10) in the developed geometry. The relative error for each voxel is below 5%. The analysis shows that the highest values of H*(10) occur inside RPV, close to the core region, where radioactivity of the structural elements is the highest. The highest values of H*(10) outside RPV occur above the flange and around RPV walls at the core mid-plane, which is presented in Figures 3B and 4. It is worth noting that H*(10) distribution forms a conical stack above the flange.

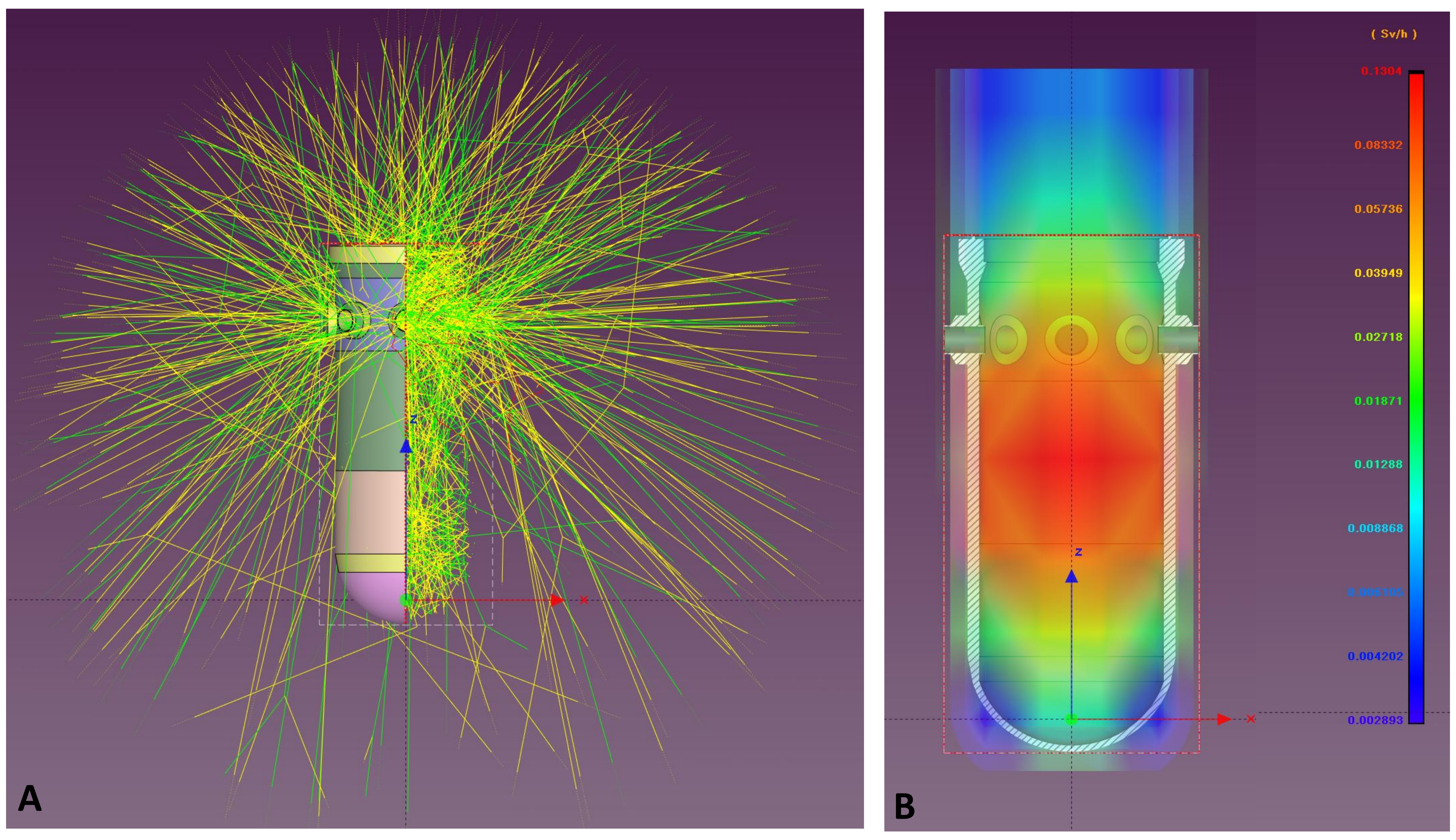

Fig. 3 Distribution of particle trajectories around RPV (A) and rescaled H*(10) distribution inside RPV (B).

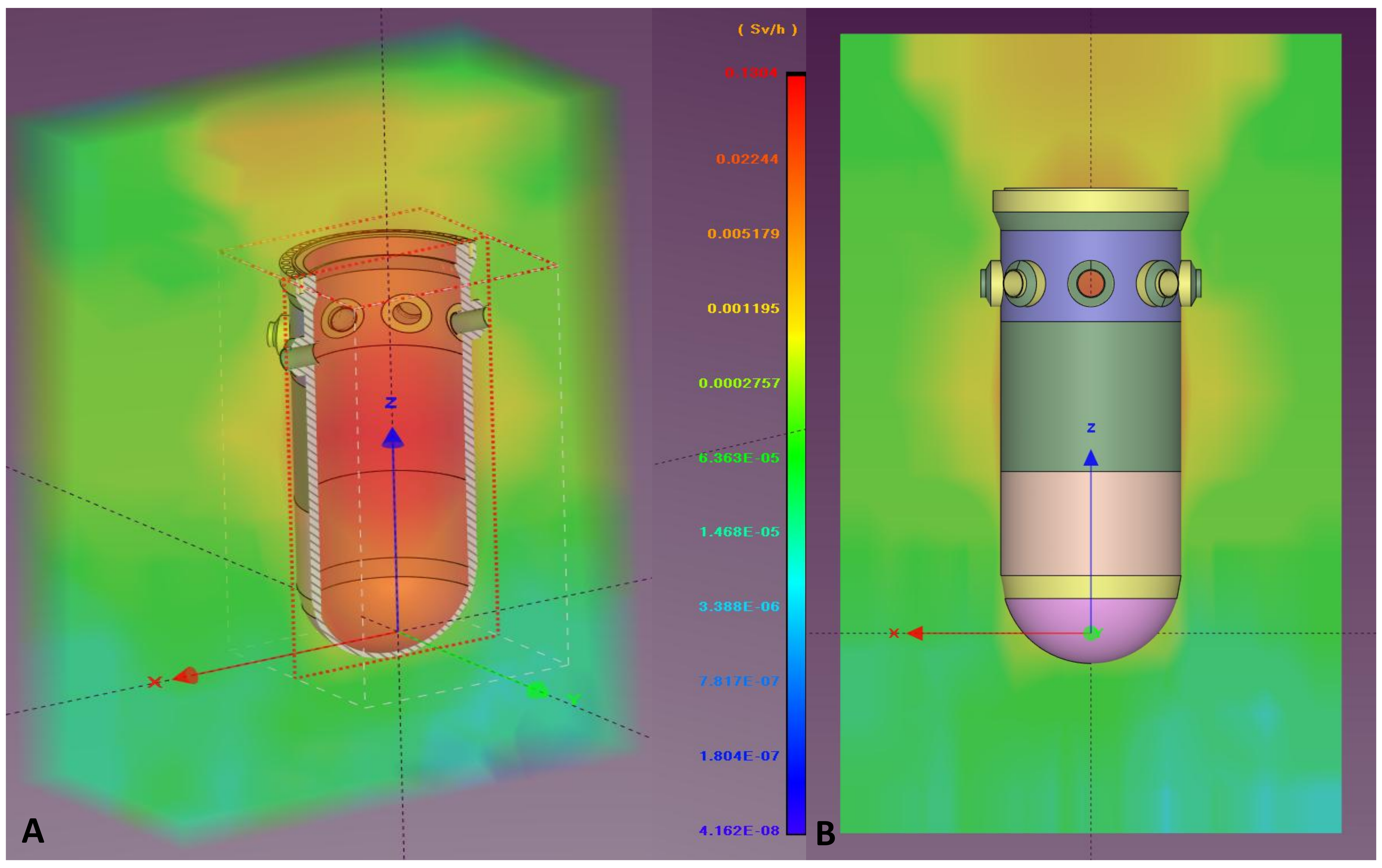

Fig. 4 H*(10) distribution inside RPV (A) and side view of H*(10) distribution (B).

Conclusions:

- Advanced numerical modelling enables reliable estimation of radiation doses during technological processes related to the dismantling of nuclear facilities.
- Software functionalities with three-dimensional representation of geometric and material environment significantly facilitate the reliable estimation of the spatial radiation dose distribution.
- Built-in visualization tools for the formation of three-dimensional maps of the radiation dose distribution help to plan all necessary operations related to the decommissioning of nuclear facilities.
- The future research will focus on the development of detailed models of other highly activated reactor elements and dose estimation using functionalities of numerical detectors for increasing Monte Carlo precision.

References:

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