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The Assessment of Dose Rates during MPC Loading and Drying in frame of the Nuclear Power Plant Krško First SFDS Loading Campaign

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ABSTRACT

In this paper, dose rates around HI-TRAC cask are assessed at specific locations in Fuel Handling Building (FHB) where plant personnel are expected to spend some time during activities related to Multi Purpose Container (MPC) loading and drying as a part of the first Nuclear Power Plant Krško (NEK) Spent Fuel Dry Storage (SFDS) loading campaign. Considered FHB location is Decontamination Area (DA). Other potentially interesting locations might be Cask loading area (CLA) and characteristic locations on the path between CLA and DA. In DA both wet and dry (helium in MPC) configurations of the cask are expected. The actual neutron and gamma sources for real casks are used in hybrid shielding MCNP6/ADVANTG calculation. The main intention of this work is to make the obtained results available for estimation of typical doses to be acquired by plant personnel during the most demanding spent fuel transfer activities in NEK before the start of the loading campaign and to compare them later to available measurements.

1 INTRODUCTION

The first loading campaign of the Spent Fuel Dry Storage (SFDS) project in Nuclear Power Plant Krško (NEK) started in March and ended in August 2023. In total 16 HI-STORM FW overpacks were filled and placed in the Dry Storage Building (DSB). Spent Fuel Assemblies (SFAs) were transferred from the Spent Fuel Pool (SFP) into the DSB using HI-TRAC VW transfer cask. The SFAs are confined in the interchangeable Multi-Purpose Container (MPC) which can fit both HI-STORM FW overpack and HI-TRAC VW transfer cask. Depending on the stage of the transfer process, the MPC can be in a wet or dry configuration. In a wet configuration, the annulus (a gap between MPC and HI-TRAC body) and MPC contain water and in a dry configuration, the MPC is dried out, closed, decontaminated, and filled with helium, and the annuls is empty [1].

All activities related to transfer preparations are conducted in the Fuel Handling Building (FHB). Transfer preparations include MPC loading, drying, closing, decontamination and filling with helium. Locations in the FHB of interest are Cask Loading Area (CLA), Decontamination Area (DA), and characteristic locations on a transfer path between them.

In our earlier work we had modelled a standalone HI-TRAC transfer cask [2] as well as a standalone HI-STORM storage cask [3] using MCNP6 code. The calculations had been performed in a hybrid shielding fashion using MCNP6 and ADVANTG. The same calculation approach was applied in this work.

In this paper, dose rates around HI-TRAC cask were assessed at specific locations in the FHB where plant personnel are expected to spend some time during activities related to welding and drying as a part of the first NEK SFDS loading campaign. Considered are both wet and dry configurations of the cask placed in DA. The actual neutron and gamma sources for real Cask 1 are used in hybrid shielding MCNP6 [4] and ADVANTG [5] calculation. Initially the calculations were used to estimate typical doses to be acquired by plant personnel during the most demanding spent fuel transfer activities in NEK and to plan radiation protection. Later, the results were compared to available measurements.

2 MCNP6 MODEL

2.1 Geometry and materials

The FHB is a three-floor reinforced concrete structure which houses spent fuel pool. The lowest floor is at the elevation 100.3 m, middle floor is at the elevation 107.62 m and the last floor is at 115.55 m. Except from the spent fuel pool, the FHB consists of cask loading area, decontamination area, new fuel storage area, truck bay area and cask unloading area. All activities related to MPC loading take place in the cask loading area and welding and drying take place in the FHB decontamination area. In this work only parts of interest of the FHB were modelled in such a fashion that wall structures were taken into account without any mobile shielding and equipment (platform, FHD skid, external chiller, removable shielding). The model of the MPC contained within the HI-TRAC transfer cask was taken from our earlier work [2] and adjusted to be included in the FHB model. The HI-TRAC model is shown in Figure 1. It consists of a fully loaded MPC, HI-TRAC VW body, bottom lid, and top ring. MPC is an enclosed steel vessel and can contain up to maximum 37 SFAs within a Metamic basket supported with aluminum shims. The remaining space in the MPC is filled either with water from the SFP or helium, depending on the stage of the fuel loading. The SFA is divided into eight nonequidistant axial layers, which are radially homogenized in order to simplify the calculations. These are bottom nozzle, space, active fuel, plenum spring, space, top nozzle, and fuel spacer at the top and assembly gap. The active fuel part is conservatively material-wise homogenized for fresh fuel. The body of the cask is in a multilayer form consisting of a carbon steel inner and outer shell and a layer of lead in between, followed by a water jacket and water jacket shell. The bottom lid is a plate made of carbon steel and upper lid is a carbon steel ring. 3D MCNP model of a cask placed in the decontamination area (elevation 107.62 cm) is shown in Figure 2. This is a reference position of the cask.

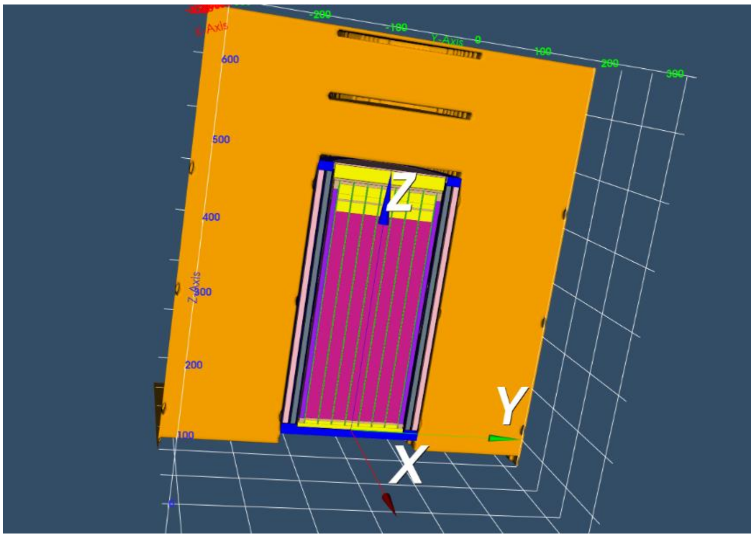

Figure 1: Standalone HI-TRAC model XZ view

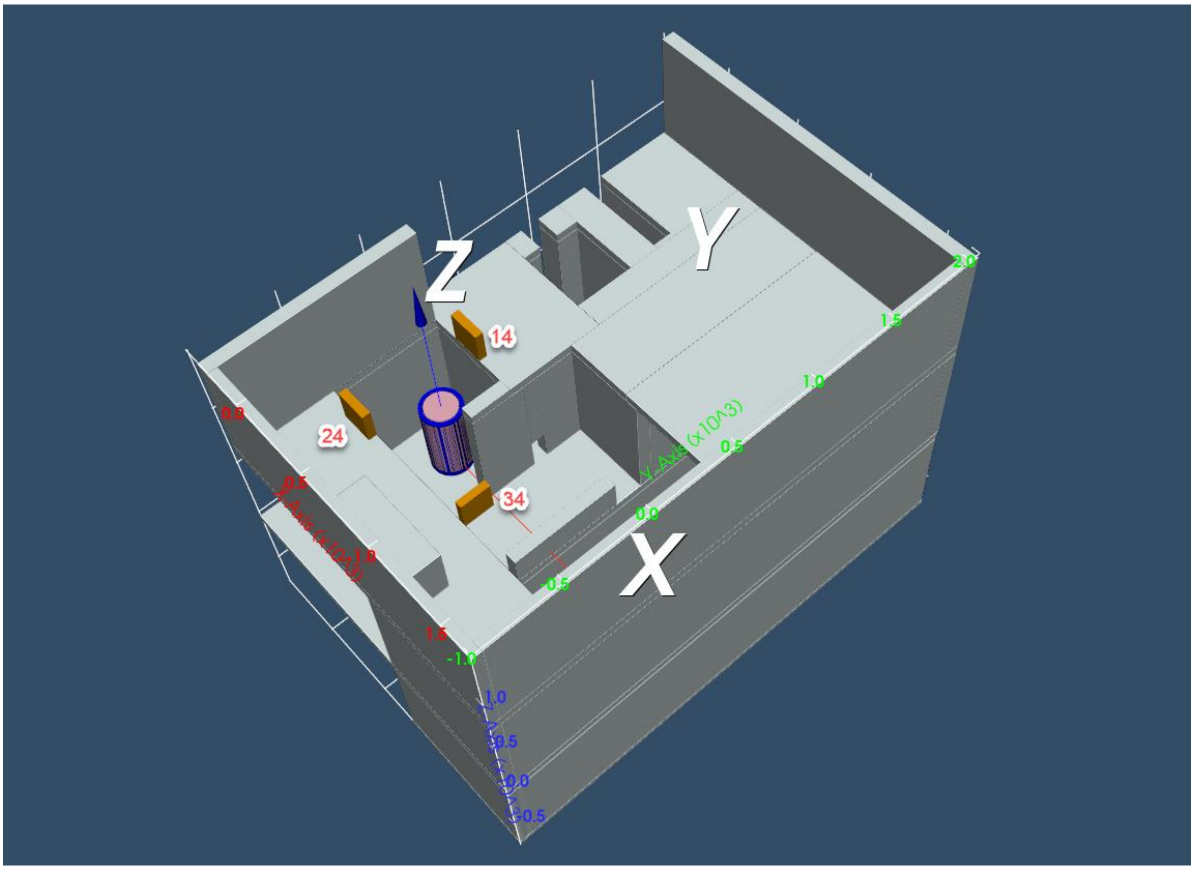

Figure 2: HI-TRAC in decontamination area in FHB and used tally locations

Other expected positions in DA include HI-TRAC placed 150 cm above the elevation 115.55 m, the position just before lowering to seismic platform (30 cm above it), and HI-TRAC placed in CLA and above CLA. Those results are out of scope of this paper.

2.2 Source

MCNP input requires a source in terms of intensity and spectra. In this work, neutron and gamma source is calculated using ORIGEN-S from SCALE6.2.4 [6] for Cask 1 SFAs based on their real operating history (burnup, enrichment, and cooling time of each SFA). The source was modelled on an assembly-by-assembly basis. The source intensity of each SFA in the MPC was taken into account by introducing the corresponding relative weights which were calculated as the ratio of the specific SFA intensity and the total intensity of all SFAs. The sampling in x and y directions for each SFA was defined uniformly and to account axial variation of particles source, we used burnup dependent weighting function. We used generic neutron and gamma source burnup dependence [1] and the sampling was proportional to the burnup distribution for gammas, whereas for neutrons, it was proportional to the burnup raised to the power of 4.2 [7]. More details on the source modelling approach can be found in our earlier work [2].

2.3 Tallies and conversion factors

Tally locations are shown in Figure 2. Three wall tallies (marked 14, 24 and 34) were modelled at specific locations where NEK personnel are expected to spend most of the time there during welding and drying activities.

ANSI/ANS-6.1.1-1977 Neutron and gamma flux-to-dose rate conversion factors [8] were used to convert tally results to dose rate in rem/h. All output and mesh tally results are postprocessed by multiplication with corresponding source intensity and with 10^4 factor to obtain dose rates expressed in μSv/h.

3 RESULTS

In this section, neutron and gamma dose rates resulting from Cask 1 SFAs are presented for a dry and wet configuration. Recall, a dry configuration means that the annulus between the MPC and cask body is empty of water and MPC is dried out, sealed, and filled with helium. A wet configuration assumes water in the annulus and MPC.

Neutron dose rates XZ distribution in the cask midplane is shown in Figure 3 for a dry and in Figure 4 for a wet cask configuration. The drying equipment is located on the right of the concrete wall shown in the center of the figures. The access platform is in the decontamination area, attached to the HI-TRAC. The top of the platform is slightly below the top of the cask to provide access to MPC top lid during welding. Expectedly, neutrons dose rates are lower in a wet configuration since water, i.e. hydrogen in water thermalizes and attenuates neutrons efficiently. Neutrons might lose on the average one half of their kinetic energy per collision with hydrogen. The resulting moderated neutrons can be absorbed in materials with high neutron absorption cross sections at the energies near or above 0.025 eV. The maximum neutron dose rates are on the side of the cask at mid height and just above MPC top lid.

The neutron dose rate axial distribution at the cask centreline is shown in Figure 5 for a wet and dry configuration. As can be seen, neutron dose rates are increasing for more than one order of magnitude above HI-TRAC after drying.

To quantify the difference between the two configurations, neutrons dose rates are given in Table 1 at tally locations described above. The difference is quite high in all cases (more than order of magnitude higher dose rates for upper locations (tallies 14 and 24) and about 6 times for lateral location (tally 34), after drying). The importance of radiation protection and role of mobile neutron shielding are stressed for dry configuration and for drying and welding activities lasting for more than one day. The tally volumes for location 14, 24 and 34 are shown for dry configuration.

To get a better qualitative insight into the dose rate distribution in DA and surroundings, 3D neutron dose rate distributions, limited to the range 0.1-1000 μSv/h, are presented in Figure 6 for wet and dry configurations. The neutron contact dose rates as well as dose rates in the surrounding area were significantly increased after removal of water from MPC. The visual representation of the results was prepared from mesh tally file using Gxsview [9]. The mesh tallies are calculated for the cube with x-extents -4 to 9 m, y-extents -6 to 7 m, and z-extents -0.5 to 14.5 m. The voxel side size is slightly above 10 cm.

Table 1: Neutron dose rates (μSv/h) at selected tally locations, wet and dry configurations

Tally	Neutron dose rate (μSv/h)	
	Wet	Dry
14	2.9659E-01 (2.65%)	8.3692E+00 (0.07%)
24	3.4938E-01 (1.46%)	5.8127E+00 (0.09%)
34	3.1117E+00 (0.60%)	1.8416E+01 (0.07%)

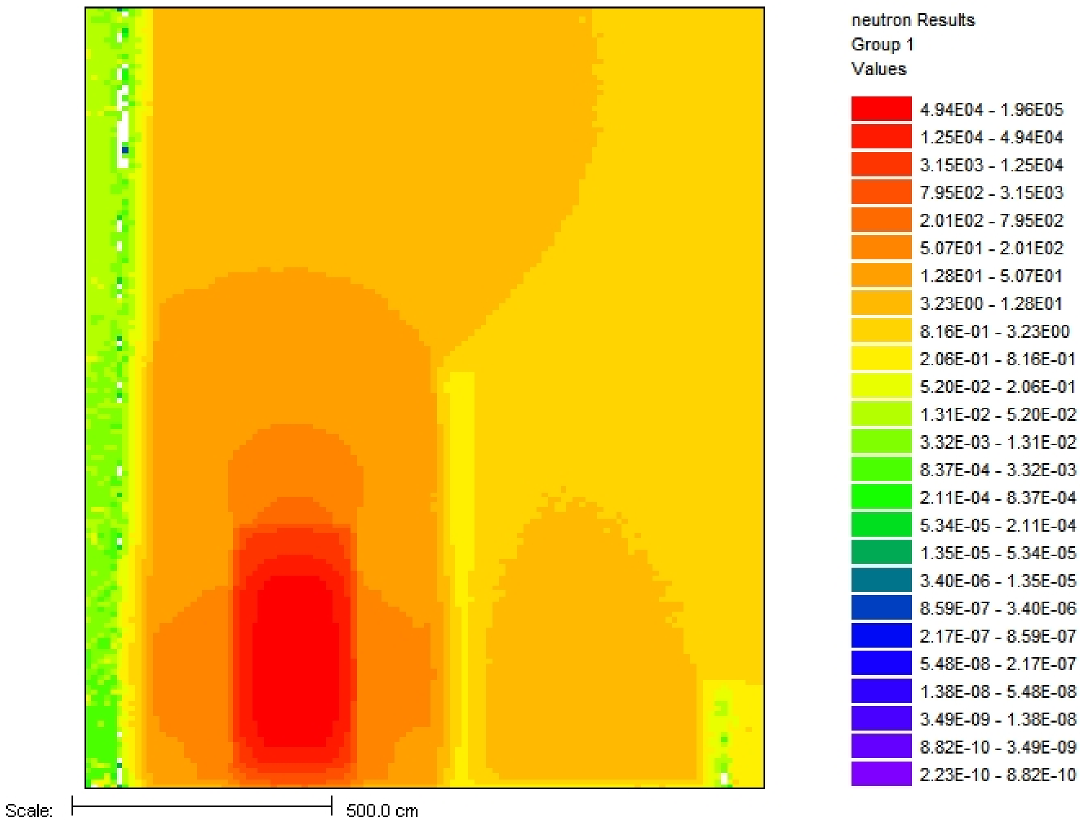

Figure 3: Dry configuration, neutron dose rate XZ distribution (μSv/h), Y=0

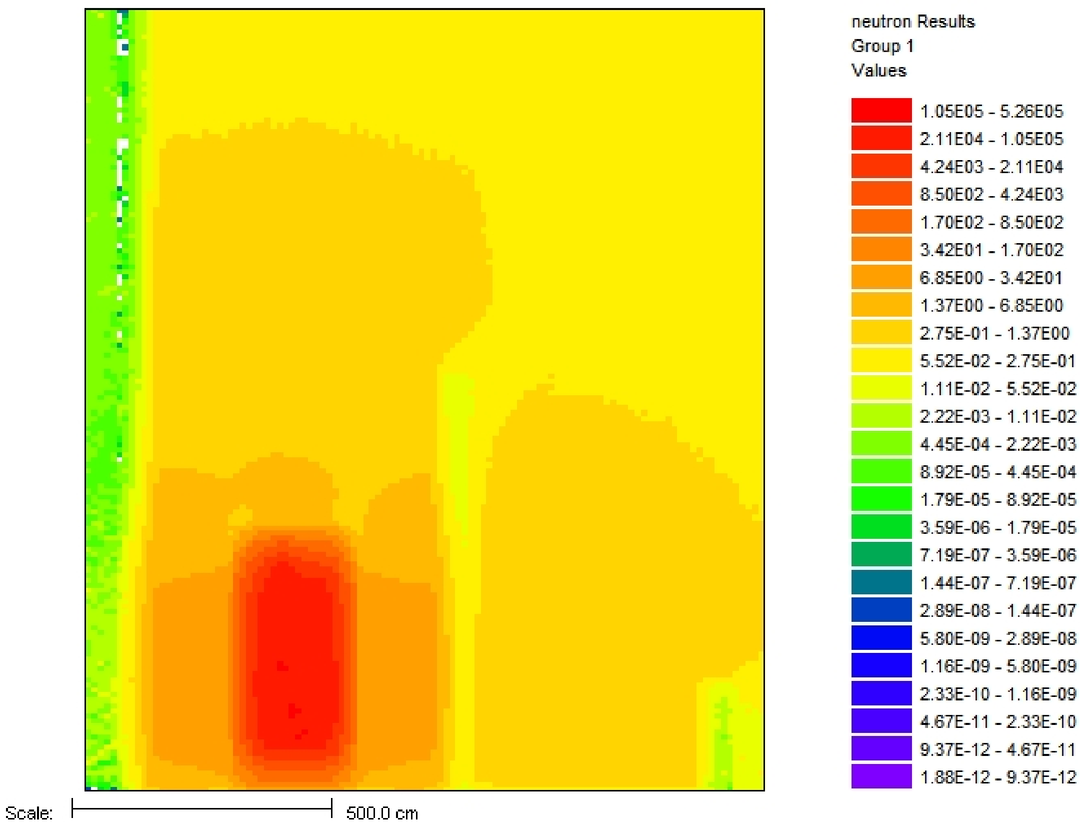

Figure 4: Wet configuration, neutron dose rate XZ distribution (μSv/h), Y=0

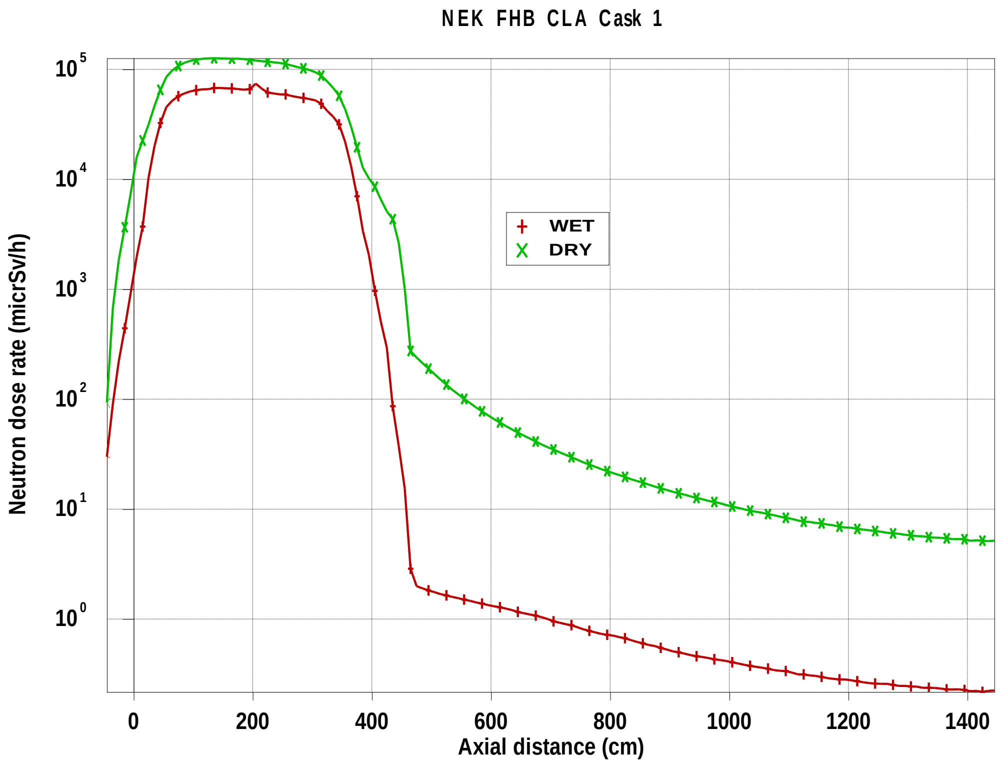

Figure 5: Wet/dry configuration, neutron dose rate Z distribution (μSv/h), cask centreline

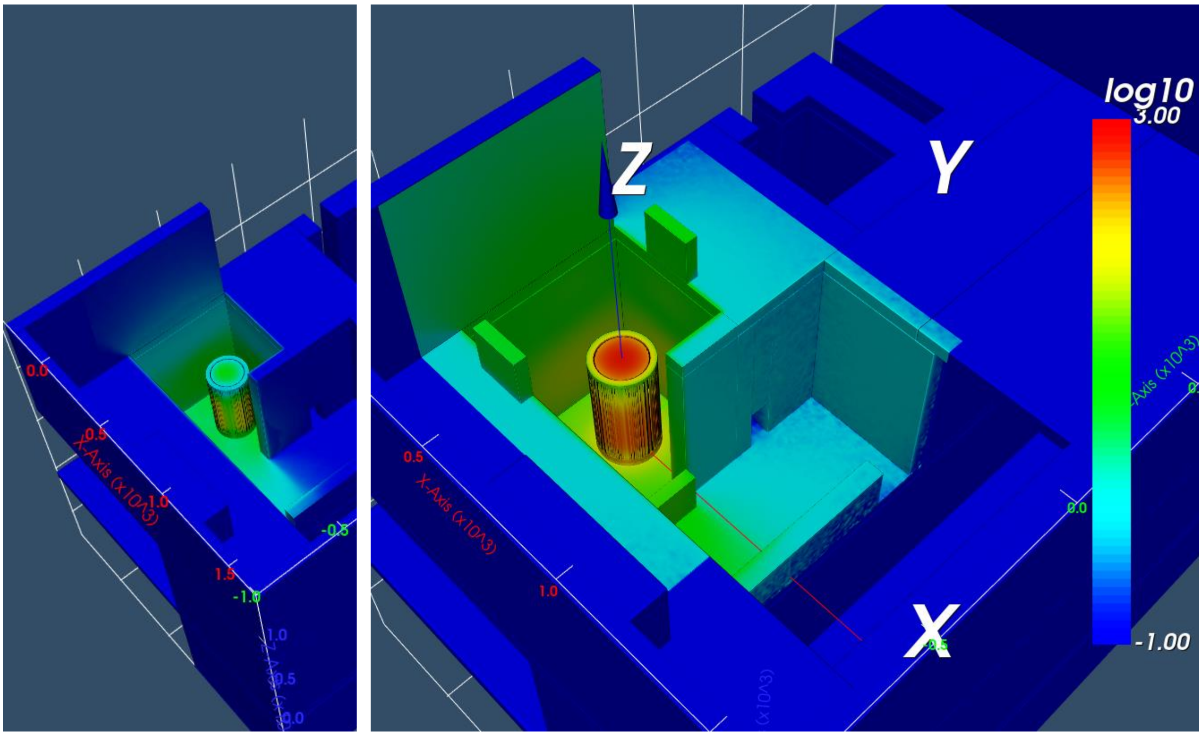

Figure 6: Wet/Dry configuration, 3D neutron dose rate distribution, range (0.1-1000) μSv/h

Gamma dose rates XZ distribution in cask mid plane is shown in Figure 7 for a dry and in Figure 8 for a wet cask configuration. The characteristic gamma rays streaming dose rates above the annulus (gap between MPC and HI-TRAC shell) can be observed in case when the annulus is empty of water.

To quantify the effect of a transition to dry configuration, Table 2 gives gamma dose rates for tallies 14, 24, and 34. The dose rates without water are increased 5 do 9 times for upper tally locations due to streaming and around 2 times for lower side locations. As expected, the increase is not as high as for neutrons. This is because gamma rays are already efficiently attenuated in materials consisting of heavy elements such as iron or lead. Most of the increase is related to scattering in the gap between MPC and HI-TRAC body.

Gamma dose rate YZ distribution (dry cask) and XZ distribution (wet cask) in cask mid plane in air are presented in Figure 9 and Figure 10, respectively. The characteristic gamma rays streaming is present for dry configuration and special ‘snake’ removable shield was used as a protection during welding.

Again, to get a better insight into the dose rate distribution in DA and surroundings, 3D gamma dose rate distributions limited to the range 0.1-1000 μSv/h are presented in Figure 11 for wet and dry configurations. The tally mesh is the same as in the case of neutron transport calculation.

Table 2: Gamma dose rates (μSv/h) at selected tally locations, wet and dry configurations

Tally	**Gamma dose rate (μSv/h)**	
	Wet	**Dry**
14	3.0518E-01 (0.84%)	2.7424E+00 (4.81%)
24	1.6547E-01 (0.82%)	8.2390E-01 (1.27%)
34	2.3266E+00 (0.29%)	4.3502E+00 (0.27%)

During the first fuel loading campaign, the field measurements were performed at multiple locations around the HI-TRAC (side, top side, top center, and top gap) to measure contact doses for different MPCs. The results of measurements for MPC16, having the largest source, are summarized in Table 3. Neutron dose rates in a dry configuration are generally about one to two orders of magnitude higher than in a wet configuration, whereas gamma dose rates are two to six times higher in a dry configuration, depending on the position. The most critical positions are gap, cask side mid height, and the center of top lid for gammas, while side mid height, gap and top lid center are the most critical for neutrons. Provided measured dose rates are representative for cask having around 30% higher neutron and gamma source intensities than the cask MPC01 for which the calculation was performed. Calculated gamma doses are just due to fuel gamma source and the gammas due to activation are typically important for doses at MPC top locations, but still measured and calculated dose rates are similar with the same trends due to change from wet to dry MPC content.

Table 3: Neutron and gamma dose rate measured during transfer activities

Location	**Neutron dose rate (μSv/h)**		**Gamma dose rate (μSv/h)**	
	Wet	**Dry**	**Wet**	**Dry**
Side	22	225	80	380
Top side	0.5	35	3	18
Top center	0.5	90	80	140
Top gap	1	130	1700	10000

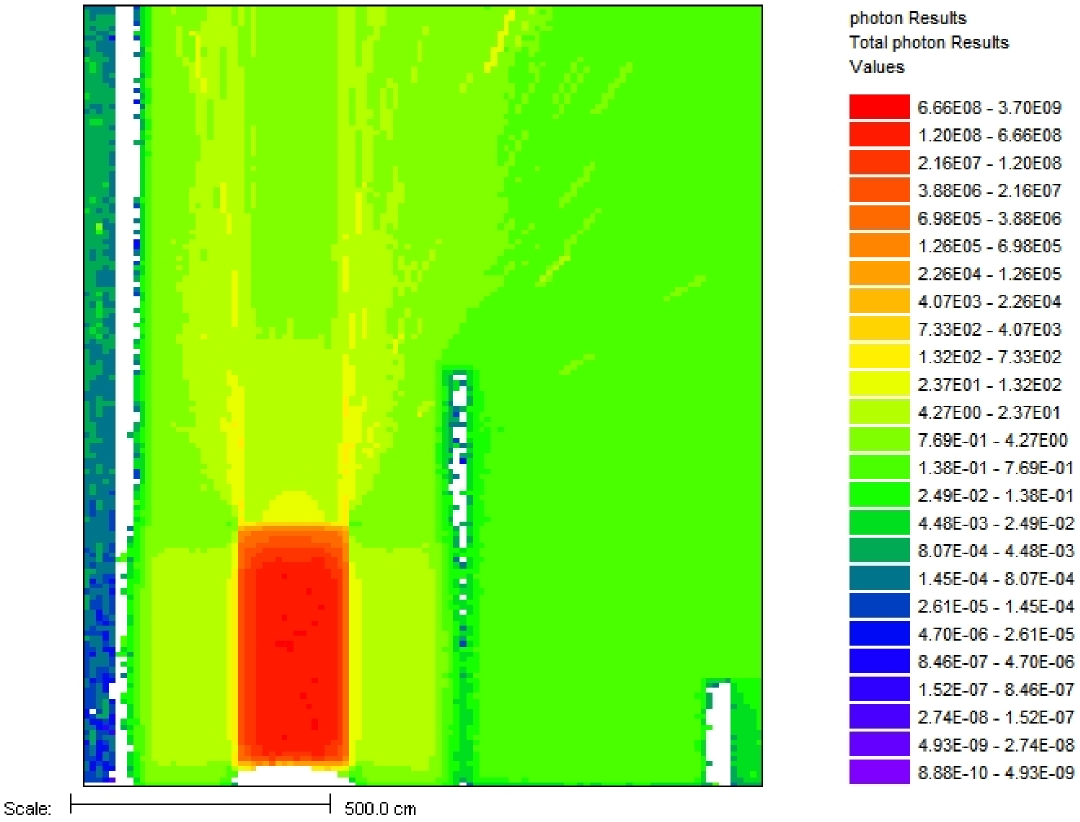

Figure 7: Dry configuration, gamma dose rate XZ distribution (μSv/h), Y=0

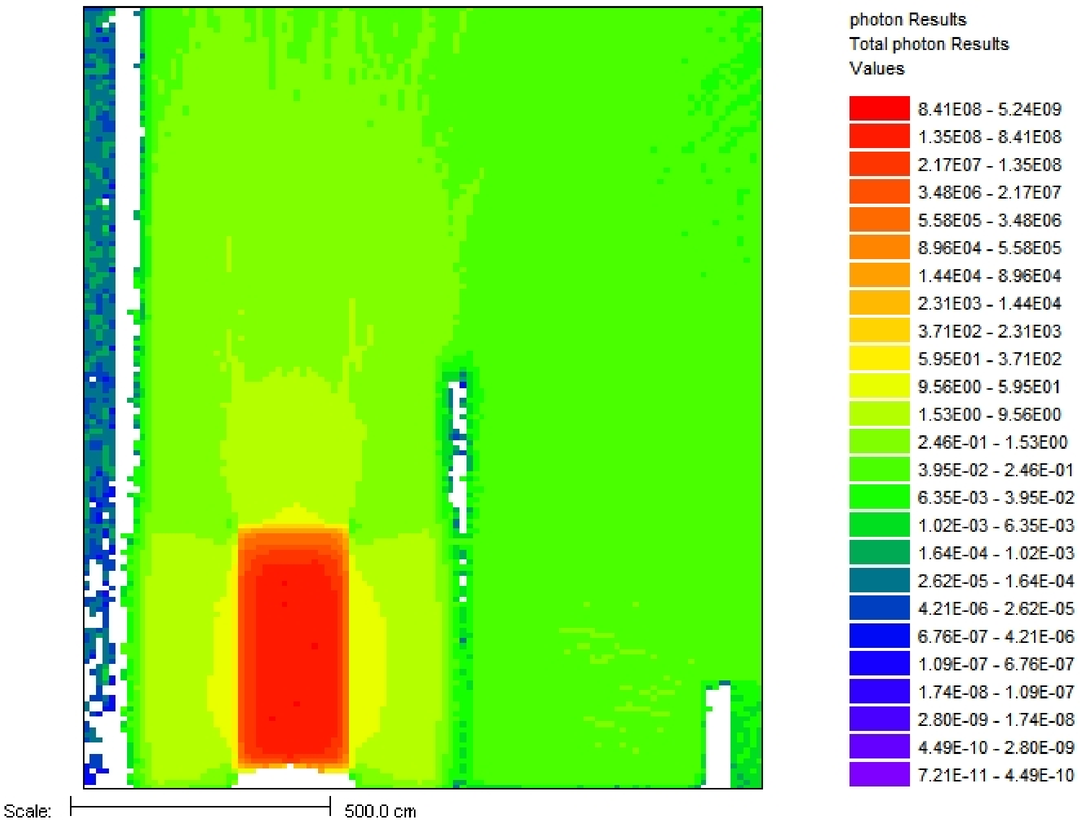

Figure 8: Wet configuration, gamma dose rate XZ distribution (μSv/h), Y=0

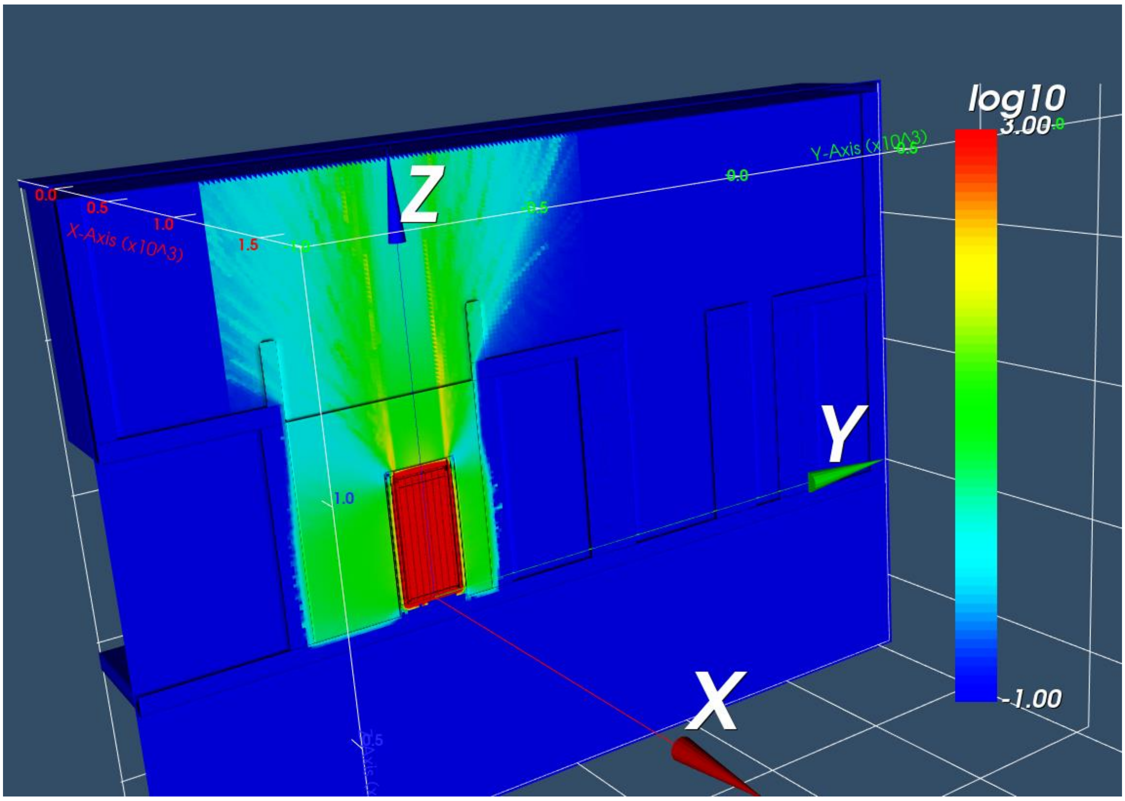

Figure 9: Dry configuration, gamma dose rates in air, YZ distribution (μSv/h)

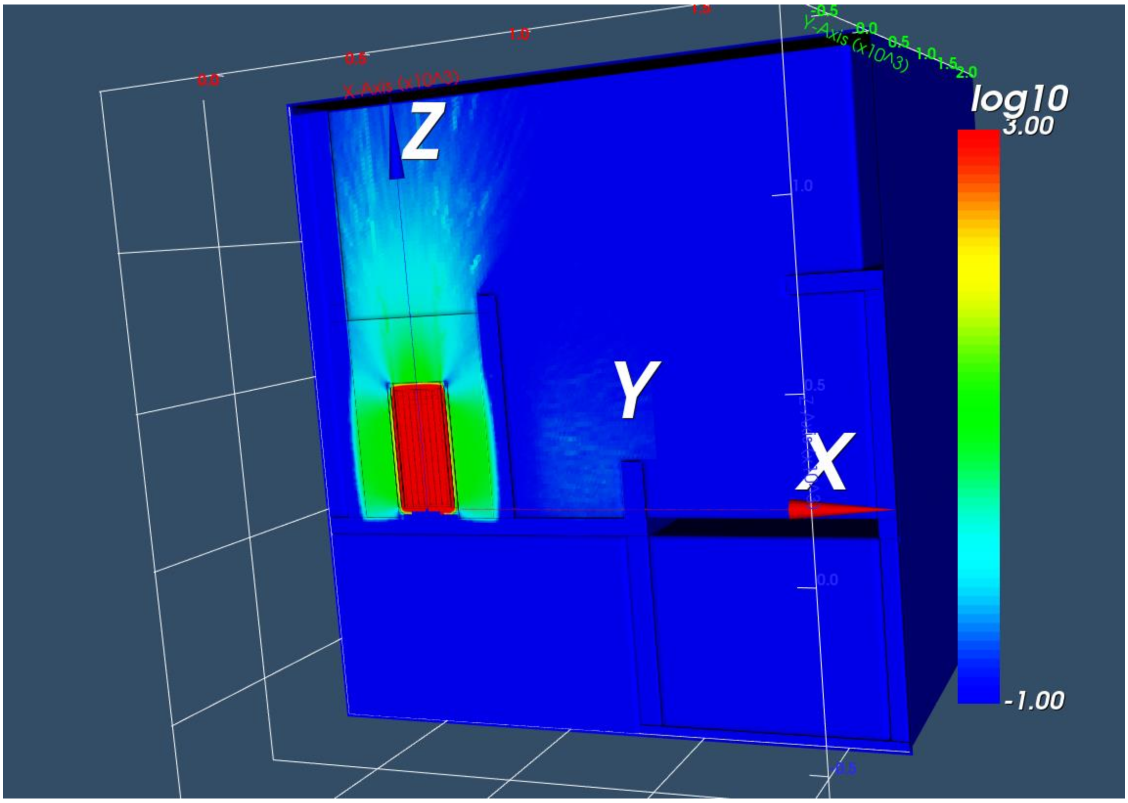

Figure 10: Wet configuration, gamma dose rates in air, XZ distribution (μSv/h)

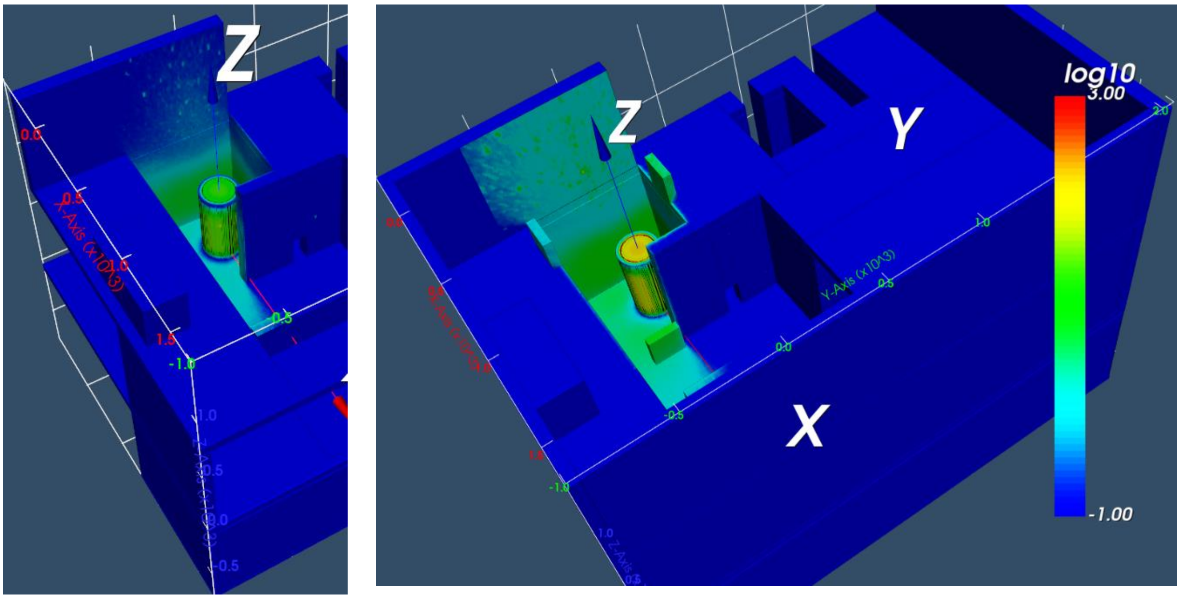

Figure 11: Wet/dry configuration, 3D gamma dose rate distribution, range (0.1-1000) μSv/h

The calculated neutron and gamma dose rates in the surrounding after blowdown at the most populated shielded positions (behind the wall) were around 2 microSv/h (typically neutrons were higher than gammas). In positions with unobstructed view of the cask, at the same distance, the dose rates were typically 10 times higher (again more neutrons than gammas).

4 CONCLUSIONS

The calculation was used to estimate the expected dose rates in the initial phase of the loading campaign. The calculation was focused on the decontamination area where personnel spend most of the time during welding and drying. Only HI-TRAC and wall structures were taken into account without any mobile shielding and equipment (platform, FHD skid, external chiller). The influence of water within MPC (before blowdown) on external dose rate is, as expected, very important. The gamma dose rate increases in dry conditions 2 to 4 times depending on position (almost order of magnitude in the gap area). In the case of neutrons, that is typically order or magnitude higher or even more (again depending on the position). The most critical positions are mid height at the cask side and a gap between the MPC and HI-TRAC (especially for gammas). The dose rates in the surrounding after blowdown at the most populated shielded positions (behind the wall) were around 2 microSv/h (typically neutrons were higher than gammas). In positions with unobstructed view of the cask, at the same distance, the dose rates were typically 10 times higher (again more neutrons than gammas). The measured doses were similar to calculated ones with the same trends when changing MPC configuration from wet to dry.

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