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Dose Rate Assessment Around The PCFV Release Line During Severe Accident Conditions In Nuclear Power Plant Krsko

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ABSTRACT

Passive Containment Filtered Vent (PCFV) was installed in Nuclear Power Plant (NPP) Krško in 2013 as a part of safety upgrade program. It is intended for severe accident consequences prevention and mitigation by ensuring the containment integrity. When the pressure in the containment reaches limiting value, the containment atmosphere is released in the environment through the PCFV system exhaust line. But, before release in the environment, the containment atmosphere passes through five aerosol filters in containment and an iodine filter in the auxiliary building to reduce isotopic activity. In this paper, dose rates around the exhaust line of the PCFV system resulting from radioactivity release in case of a severe accident are determined. The assumed severe accident scenario is a beyond design basis station blackout (SBO) in NPP Krško, which is simulated by using the MELCOR code. Its results are input for the radiological calculations to obtain the activities released in the containment. The obtained activities are then transformed into the gamma source intensity and spectrum using the ORIGEN-S libraries. This form of the source term is required for the Monte Carlo calculations. The source is present in the containment and in the PCFV duct. The dose rates around the duct are calculated using MCNP6.2 code.

1 INTRODUCTION

Passive Containment Filtered Vent (PCFV) was installed in Nuclear Power Plant (NPP) Krško in 2013 as a part of safety upgrade program. The PCFV system has a purpose to prevent and mitigate severe accident consequences. The containment integrity is preserved in a way that when the pressure in the containment reaches limiting value, the containment atmosphere is released in the environment through the PCFV system exhaust line. But, before release in the environment, the containment atmosphere passes through five aerosol filters in the containment and an iodine filter in the Auxiliary Building (AB) to reduce isotopic activity. It is important to know the dose rate around the PCFV vent line if the access to the exhaust radiation monitor is needed.

In this paper, dose rates around the exhaust line of the PCFV system resulting from radioactivity release in case of a severe accident are determined. The assumed severe accident scenario is NPP Krško beyond design basis station blackout, which is simulated by using the MELCOR code [1]. Its results are input for the radiological calculations to obtain the activities released in the containment. The obtained activities are then transformed into the gamma source intensity and spectrum using the ORIGEN-S libraries [2]. This form of the source term is required for the Monte Carlo calculations. The radiation source is present in the containment and in the PCFV duct (and to the smaller extent in an iodine filter at AB elevation 115.55). The dose rates around the duct are calculated using MCNP6.2 code [3].

2 MELCOR CALCULATIONS

To obtain the radioactive materials content present in the containment and in the duct, an SBO sequence with PCFV actuation has been modeled in the severe accident code MELCOR assuming no action taken by the operators in the first 24 hours. After that, mitigation actions using Design Extension Conditions (DEC) equipment and containment spray are assumed.

The NPP Krško model with explicit PCFV system is shown in Figure 1.

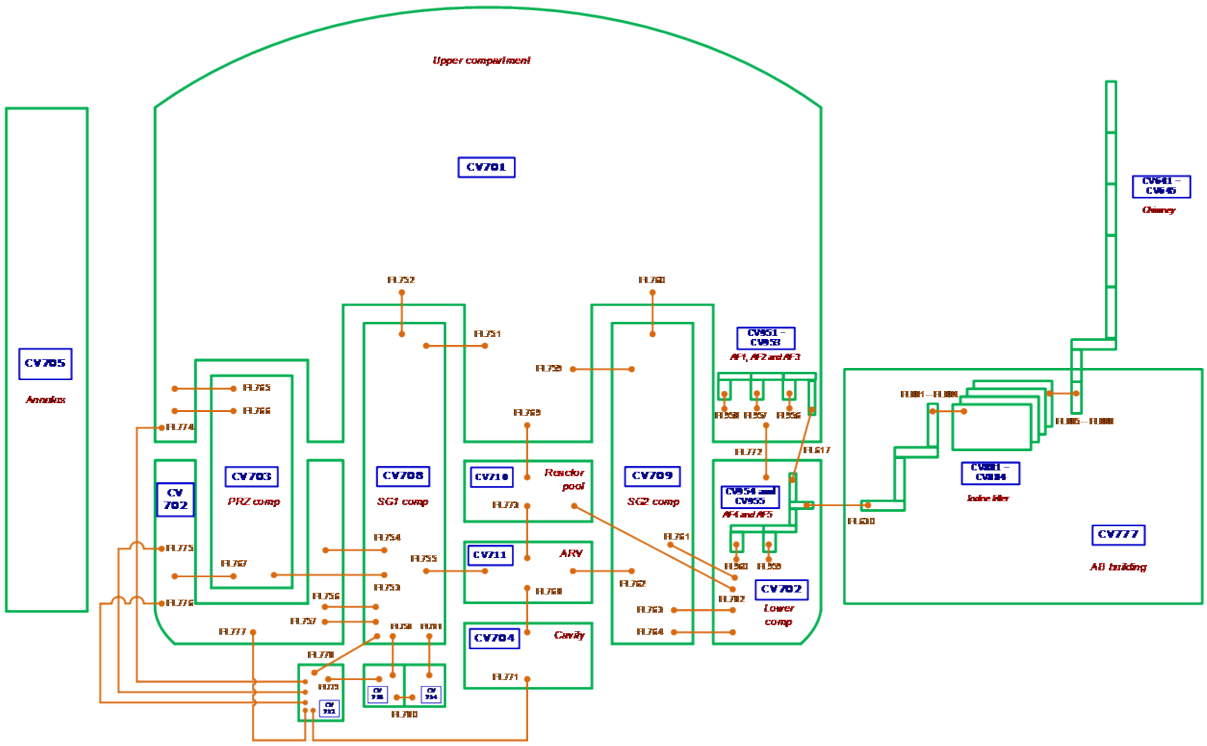


Figure 1: MELCOR NPP Krško model with explicit PCFV system

The sequence assumes initial leakages in reactor coolant pump seals and in letdown line isolation valve. The only available water source are passive accumulators and as a consequence of that complete core melt is assumed and corium is relocated to the containment cavity. Figure 2 shows the containment, annulus and environment pressures during analysed sequence. After reaching pressure of 6 bars, at about 19.3 hours after accident initiation, the PCFV system is actuated in a passive mode. The pressure is decreased to the closing pressure of PCFV valves after about 3 hours. The next cycle of pressure increase is terminated by mitigation actions (containment spray using alternative Residual Heat Removal - RHR pump) initiated at 24 hours. Containment volumetric discharge flow through the PCFV system during single cycle of opening is shown in Figure 3. Isotopic concentrations in containment and PCFV duct, time and duration of opening and densities of containment atmosphere and in relevant segments of PCFV duct were used as inputs for gamma radiation shine calculations. The radioactive effluents released due to containment leakage and due to material released during PCFV actuation (responsible for immersion dose in the environment) are not subject of this analysis.

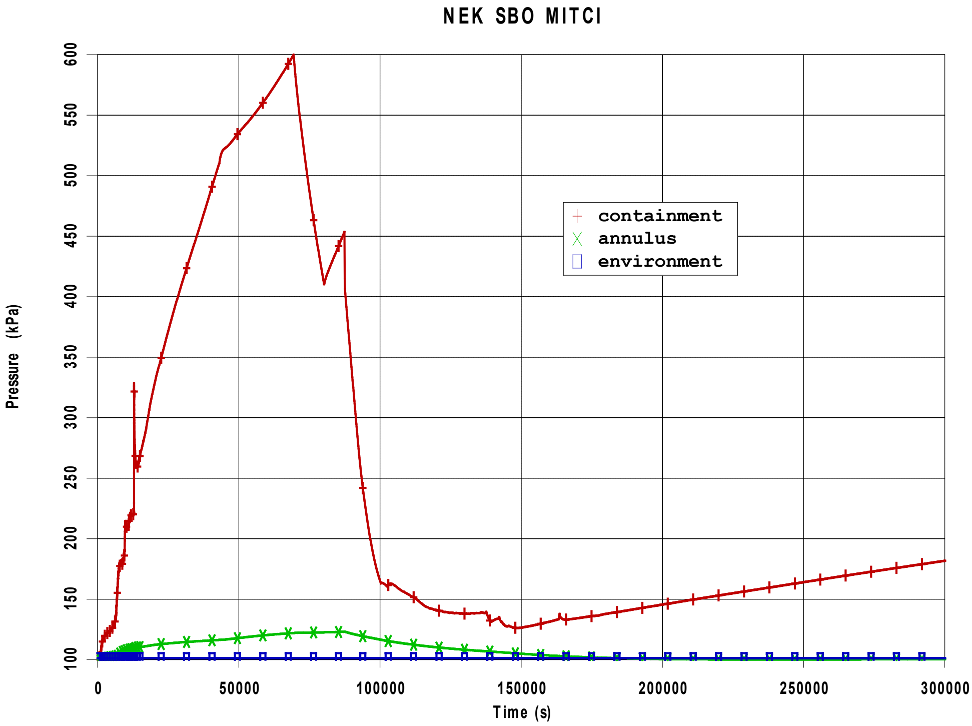


Figure 2: Containment pressure

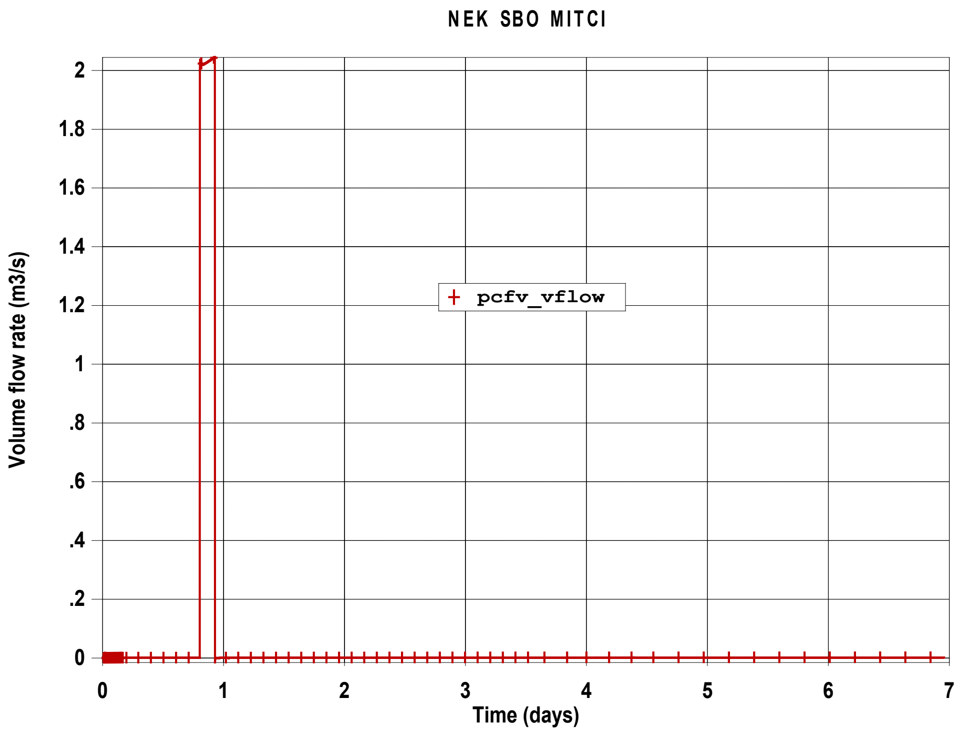


Figure 3: Containment volumetric flow discharge through PCFV system

3 RADIOLOGICAL CALCULATIONS

Radiological calculations have been conducted using the RADTRAD 3.03 code [4]. In these calculations, plant specific fuel source term was used (ORIGEN-S calculation on assembly by assembly basis with real plant operation history). Release fractions to the containment and other assumptions were set according to Accident Source Term (AST) requirements [5] and the PCFV actuation is based on the MELCOR calculations. The RADTRAD nodalization of the NPP Krško with PCFV is shown in Figure 4. The containment was modeled as sprayed and unsprayed volume with communication by natural convection. There is no spray actuation in first 24 hours and only natural settlement processes was responsible for removing radioactive material from containment atmosphere. Flow paths were provided to release material as a consequence of leakage to the annulus (2, 5) and directly to the environment (3, 6). The flow path 12 is used to model PCFV release based on MELCOR data. The single filter is used to reproduce removal of radioactive isotopes in aerosol and iodine filters. The model is originally used to estimate environmental consequences of radioactive release, but in this analysis it is providing information on isotopic activities needed to determine gamma source for shielding calculation.

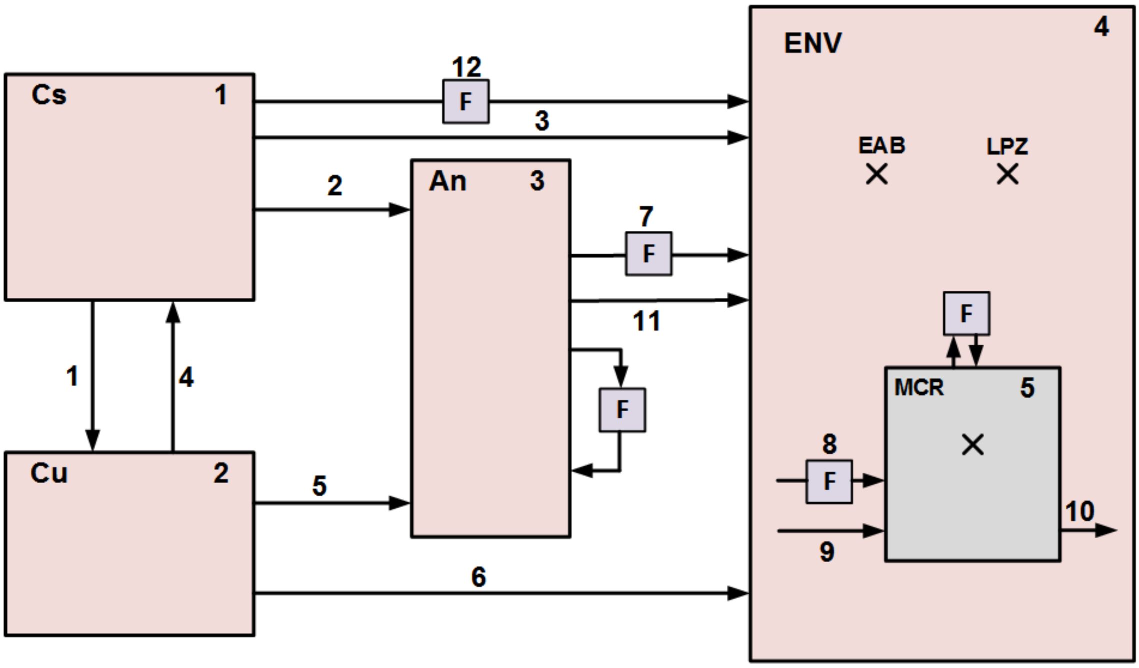


Figure 4: RADTRAD nodalization for the NPP Krško SBO PCFV

For the MCNP calculations, we need a radiation source present in the containment during SBO sequence, and in the duct during PCFV release. For the containment gamma source, the specific activities of the 60 isotopes were calculated just before the PCFV actuation using the RADTRAD code. For example, time dependent Iodine isotopes concentrations in containment are shown in Figure 5. Most of the Iodine and Caesium isotopes will be kept in filters during PCFV release. In Figure 6, activity of released Krypton isotopes is shown. Krypton and Xenon, being noble gases, cannot be filtered and are responsible for most of the radiological consequences in the environment. Label sbo_01 is used for integral released activity and label sbo_02 is used for activity of the isotope present in the environment. The second value takes into account the radioactive decay after release and first value is without the decay after release.

For the PCFV duct gamma source, the activities are calculated from sbo_01 values, release interval and the MELCOR volumetric flow rate (specific isotopic activity).

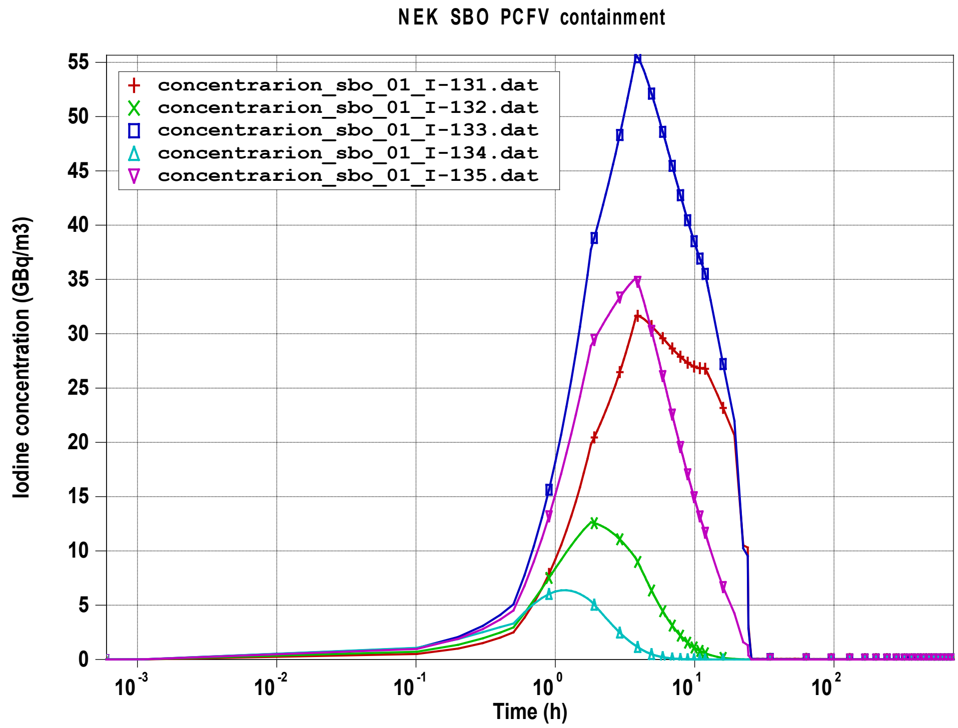


Figure 5: Iodine specific activity in containment during SBO PCFV

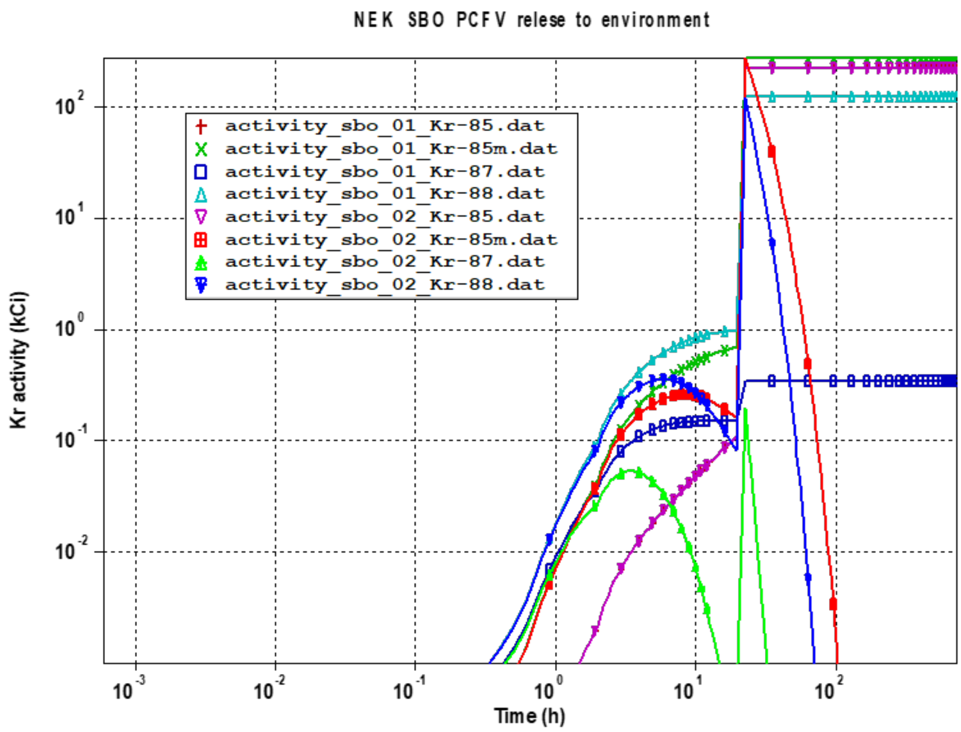


Figure 6: Krypton activity released to the environment and present in the environment, log

Finally, to obtain the source in the form required by the MCNP code, the calculated activities are converted to gamma source and spectra using methodology similar to the one present in the ORIGEN-S and corresponding gamma libraries, as seen on Figure 7. The difference in spectra is due to missing isotopes (decreased activity) in effluent release stream.

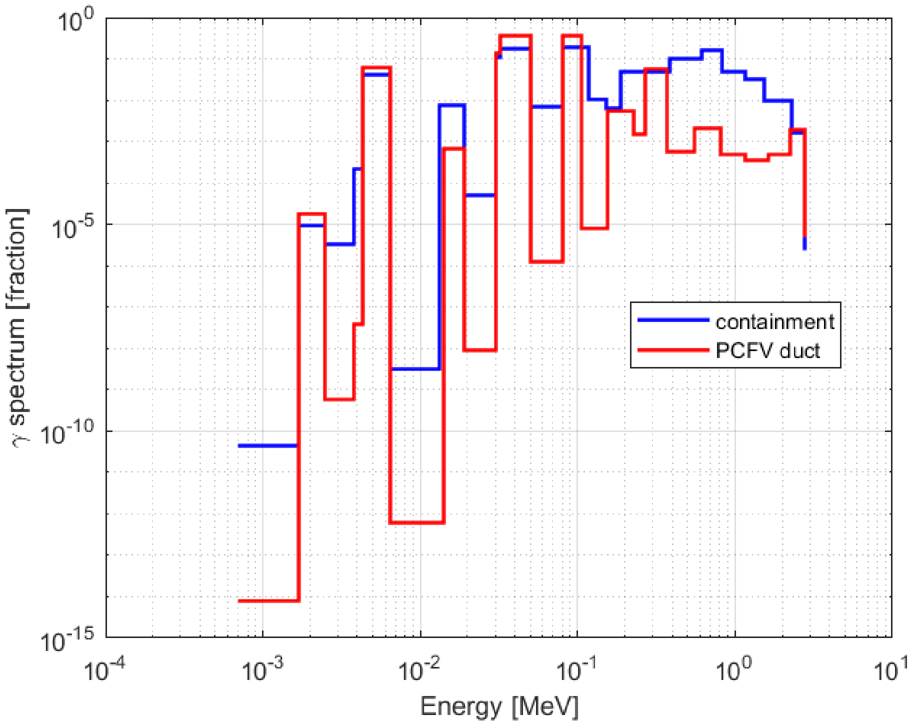


Figure 7: Gamma spectrum for the source in the containment and in the PCFV duct

4 MCNP6.2 CALCULATIONS

The 3D plant model with the PCFV system duct is shown in Figure 8. The PCFV system consists of aerosol filters in the containment, an iodine filter in the AB and release line. In this work, the containment, part of AB, iodine filter in the AB and the PCFV exhaust line with mounted detector are modelled in MCNP6.2 code. The dose rates are calculated only for the source in the containment and in the part of the duct line above AB roof.

The PCFV release line is modelled as a stainless steel pipe of 0.55 cm thickness. It extends from the iodine filter in the AB to the containment top. Radiation monitoring system was required to be able to determine amount of released activity as an input for off-site emergency planning measures. Therefore, the detector was mounted on the duct and it is shielded to measure only the dose resulting from the source in the duct. The containment is an air filled space surrounded by the 3.8 cm carbon steel. It is contained within the reactor shield building made of concrete. All internal concrete structures are conservatively neglected. The AB is modelled (only concrete walls) just next to the reactor building. It is a three floor building made of concrete and on the last floor (el. 115.55) there is an iodine filter which is part of the PCFV system. The filter is modelled as a box with the 0.4 cm thick sides made of steel.

The total gamma source intensity in the containment is 2.13E+19 gamma/s and in the part of duct 2.65E+14 gamma/s. The corresponding energy spectra are shown in Figure 7.

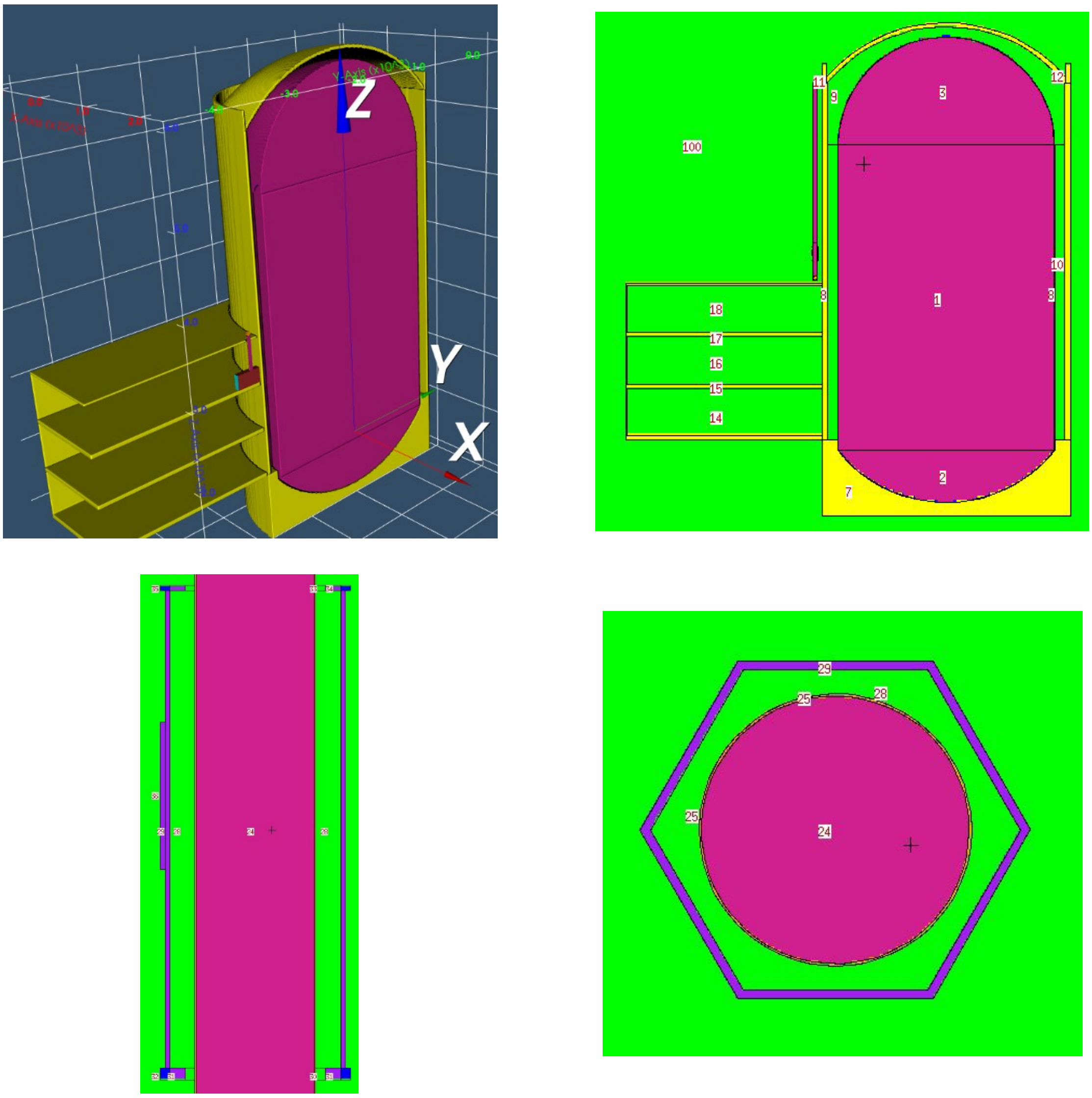


Figure 8: MCNP model of the containment, AB, and the PCFV exhaust pipe

Two point detector tallies and one mesh tally have been used in the calculations to obtain the dose rates. One point detector tally is located 1 m above the AB roof close to the PCFV duct, and the other is placed above the radiation monitoring platform. These are the location where personnel can be found during maintenance works. The mesh tally covers the entire AB building and extends from its roof up to the containment top.

The response in terms of dose rates is obtained using the ANI/ANS-6.1.1, 1977 gamma ray flux to dose rate conversion factors [6] and ENDF/B-7.1 cross section libraries are used in the calculations [7].

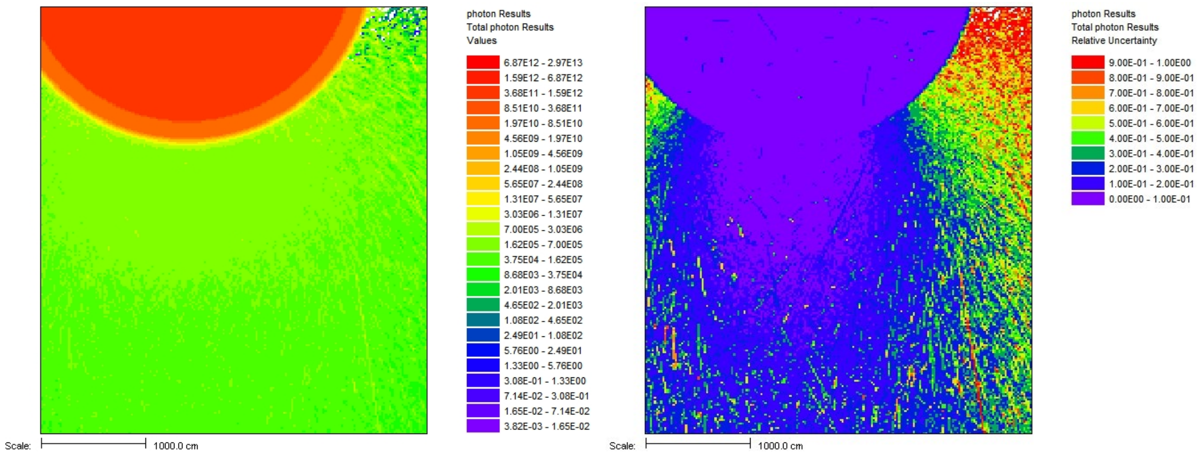
Two separate calculations have been performed, one for the source present in the containment and the other for the source in the PCFV duct. In both cases homogenous source is assumed.

5 RESULTS

5.1 Source present in the containment

The dose rate XY distribution around the PCFV duct resulting from the source in the containment, at the time of PCFV actuation, and associated relative uncertainties are shown in Figure 9 for Z=2300 cm (one meter above AB roof). Figure 10 shows dose rate distribution along y axis at Z=2300 cm. and Figure 11 shows YZ distribution at X=0 plane. The attenuation due to containment liner and shield building can be clearly seen.

At a point detector tally location 1 m above AB roof, the calculated dose rate is 8.06E+5 μSv/h (0.11% relative uncertainty). The results for the other point detector tally located above the radiation monitoring platform are 1.37E+6 μSv/h (0.60% relative uncertainty). Both dose rates are the highest expected at that locations, due to conservative assumptions in source calculation and simplifications in the MCNP model.



a) b)

Figure 9: Dose rate (μSv/h) XY distribution at Z=2300 cm a) and associated relative uncertainties b), from the source in the containment

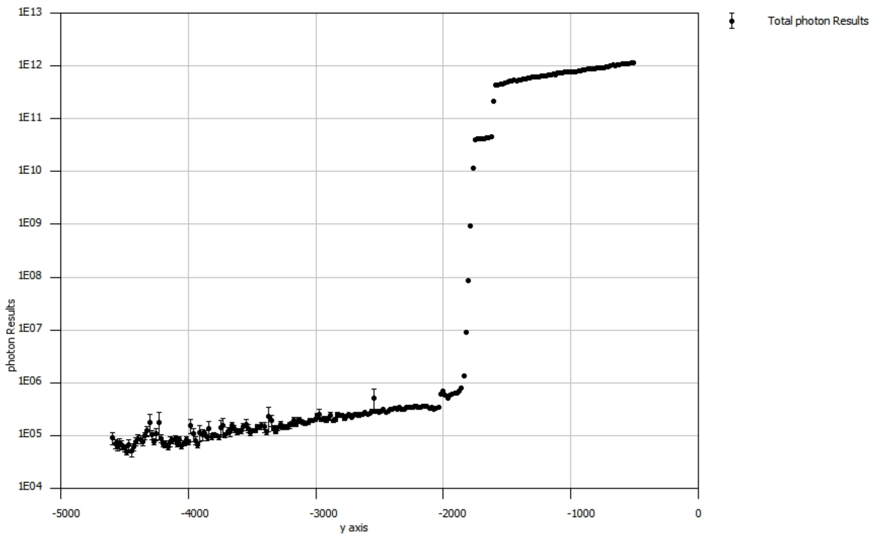


Figure 10: Dose rate (μSv/h) distribution along Y axis at Z=2300 cm

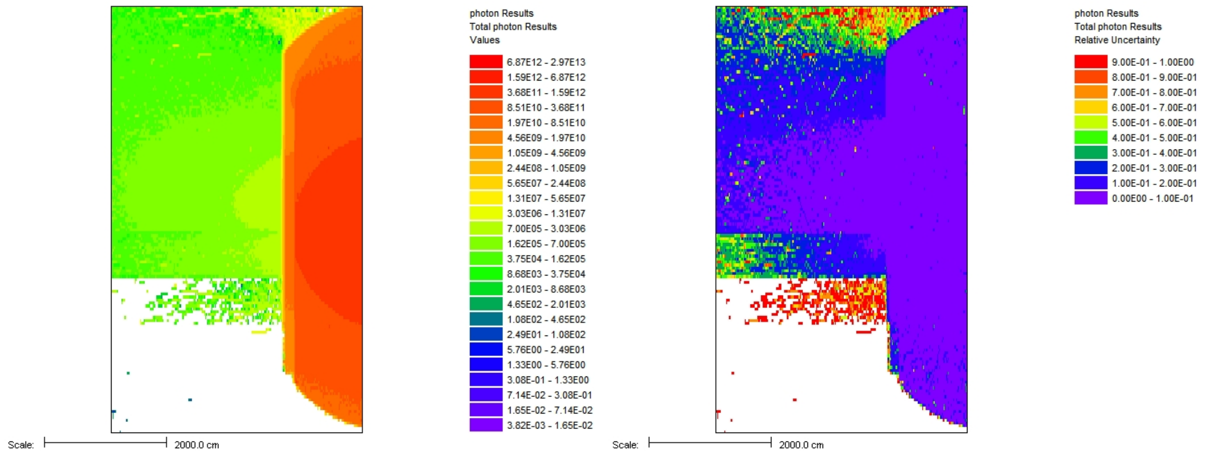
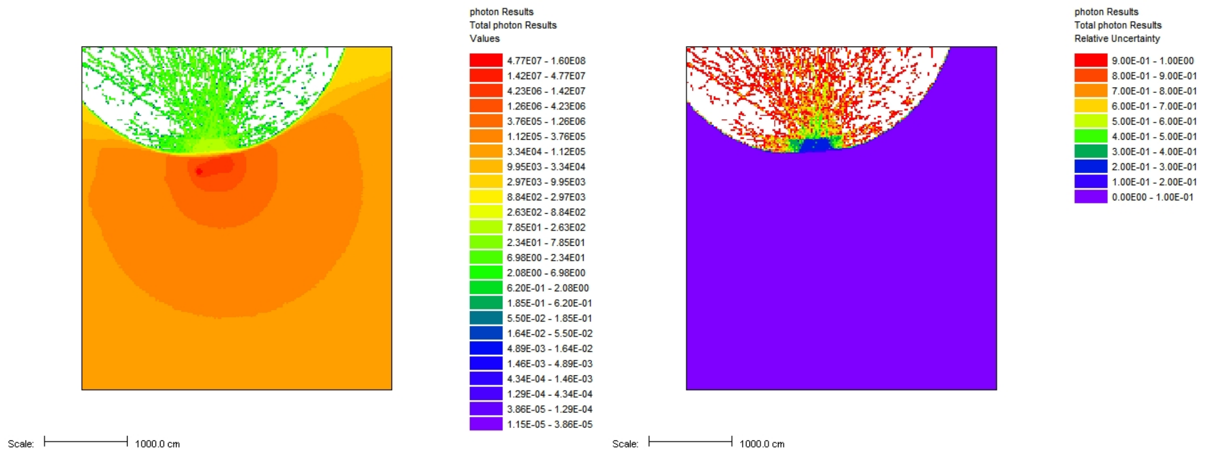


Figure 11: Dose rate (µSv/h) YZ distribution at X=0 cm a), and associated relative uncertainties b), from the source in the containment

5.2 Source present in the PCFV duct

The dose rate XY distribution around the PCFV duct resulting from the source in the duct and associated relative uncertainties are shown in Figure 12 for elevation Z=2300 cm (one meter above AB roof). Figure 13 shows dose rate distribution along y axis at Z=2300 cm, and Figure 14 shows YZ distribution at X=0. The dose rates within containment are not of interest and are associated with large uncertainties. The dose rates at point detector tallies are 1.21E+6 µSv/h (0.02% relative uncertainty) at 1 m above the AB roof, and 6.27E+5 µSv/h (0.11% relative uncertainty) above the radiation monitoring platform. The gamma source intensity in the containment is about 5 orders of magnitude higher than in the duct, but attenuation of the thin duct wall is much lower than the attenuation due to containment liner and shield building wall. As a consequence, dose rates predicted close to the duct, 1 m above AB roof are similar. Dose rates due to containment source at the same location but at different heights are increasing due to exposure to the volumetric containment source without shielding by AB roof. The dose rates due to duct source are decreasing with height due to increased distance from duct elbow.



a) b)

Figure 12: Dose rate (µSv/h) XY distribution from the source in the duct a) and associated relative uncertainties b)

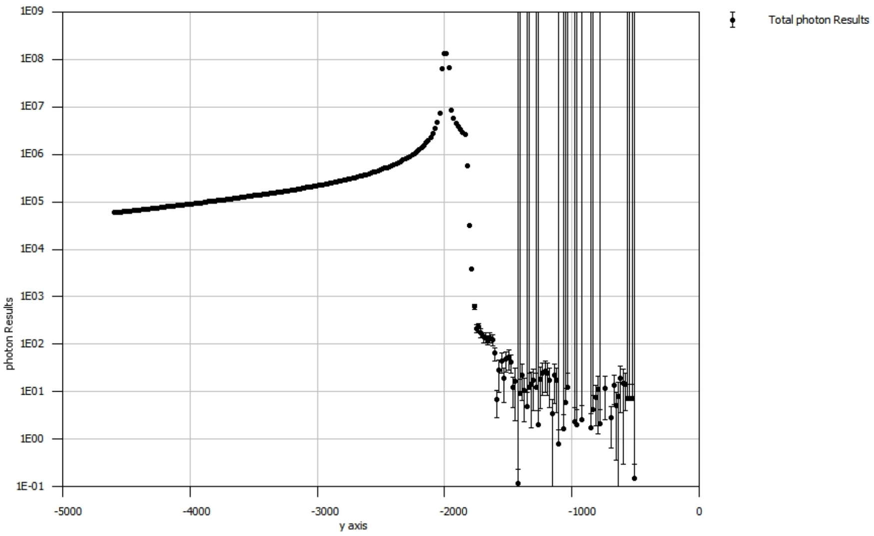
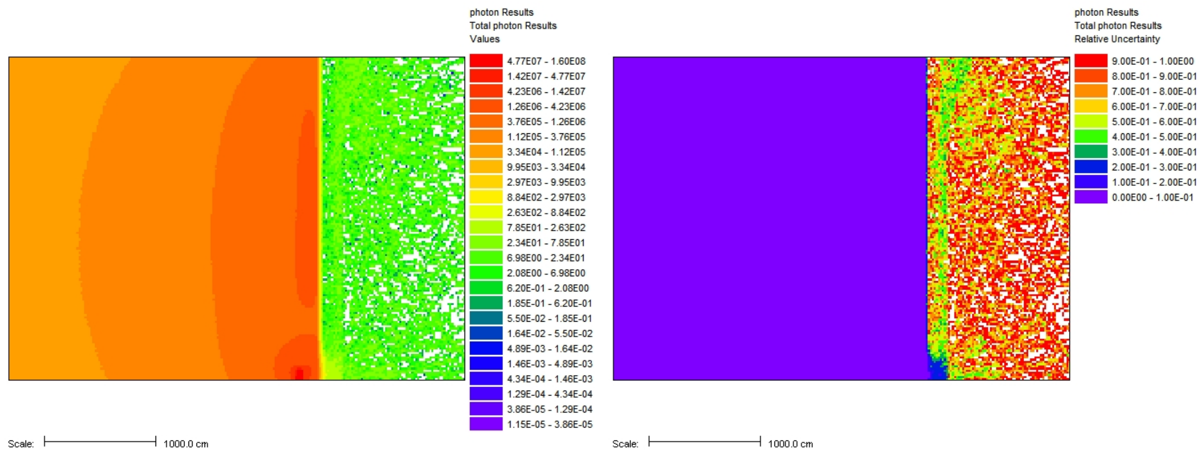


Figure 13: Dose rate (µSv/h) along Y axis at Z=2300 cm



a) b)

Figure 14: Dose rate (µSv/h) and associated relative uncertainties YZ distributions, for the source in the duct

6 CONCLUSIONS

Calculations using MELCOR code (accident scenario), RADTRAD3.03 code (radiological conditions) and MCNP6.2 code (shielding calculation) were performed to obtain gamma dose rate near containment surface at the location of PCFV radiation monitor, mounted on exhaust duct, during bounding NPP Krško SBO sequence (nothing works). Specific isotopic activities were obtained in the first part of the calculation using conservative assumptions. They were converted to gamma source intensity and spectra required for the MCNP6 calculation using the methodology similar to one present in ORIGEN-S. Peak gamma dose rates were predicted, as expected, during PCFV actuation. The dose rates below detector position are mainly determined by the source present in the PCFV duct. Above the detector platform the influence of the containment source is increasing, especially for positions at higher distances from the duct. In any case the peak dose rates are prohibitive for any plant personal presence.

Due to conservative assumptions predicted dose rates are the highest expected at that location for any severe accident scenario.

ACKNOWLEDGMENTS

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