Studies supporting the derivation of the radioactive waste for European Spallation Source target station

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Introduction

European Spallation Source (ESS) is a next generation neutron facility for scientific and applied purposes. It is a common European project taking place in Lund, Sweden. There are 22 neutron research instruments planned for application in different fields of research. Up to 10 times higher neutron intensity will be one of the main ESS advantages over current spallation sources. Spallation induced high energy neutron flux will cause radiation safety problems. For safe operation and decommissioning of the facility radiological evaluation is mandatory. This study focused on shielding and activation estimation for ESS target station monolith.

Calculation Model

Calculations were performed using Monte Carlo programs MCNPX2.6.0[1] and FLUKA[2] for validation. MCNPX was coupled with CINDER'90[3] to evaluate activation of the materials. MCNPX used CEM03 model for nuclear cascade and evaporation treatment. To simplify calculation it was split into three parts: lateral to, above and below target. Biasing techniques were applied for each case. Model included helium cooled tungsten target, moderators, beryllium and stainless steel reflectors, composite steel/ concrete shielding (see Fig. 1 and 2). Target design was taken from TDR [4] . Soil was included to calculate source term for environmental impact analysis. Two different shielding scenarios below the target were considered: 3 meters steel and 2 meters of concrete or 4 meters of steel and 2 meters of concrete.

Neutron and photon dose rate coefficients were taken from [5]. Considered average proton beam power is 5 MW. Maximum proton beam energy 2 GeV. Irradiation time for target was 5 years and 40 years for shielding. Expected facility operation is 5000 hours per year.

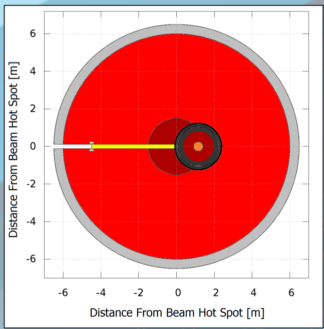

Fig 1. Target station geometry model cut at target level. Center is at beam hot spot.

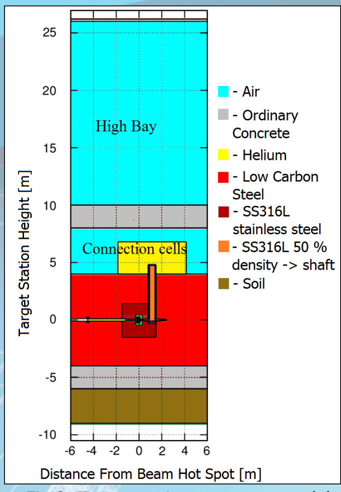

Fig 2. Target station geometry model cut.

Results

Lateral dose rate distribution comparison between FLUKA and MCNPX is presented in Fig. 3. MCNPX estimates higher dose rate than FLUKA. Also MCNPX yields 79 neutron per proton while FLUKA only 56. This lead to assumption that MCNPX should be used for conservative approach. Dose rate maximum after the shielding at the target level is 6 μSv hr^{-1} with 25 % error (MCNPX results). Calculated neutron dose rate attenuation length in steel in forward direction (Angle 0°) is 225±5 g cm^{-2} and lateral to (Angle 90°) 218±3 g cm^{-2}.

Neutron ambient dose equivalent rate for two shielding options below the target are presented in Fig. 4. Calculated attenuation length in iron is 221±1 g cm^{-2}. Attenuation in concrete was estimated by double exponential λ_1=19.6±0.1 g cm^{-2}; λ_2=142±48 g cm^{-2}. Thicker shielding option was selected as optimal to avoid activation of soil.

Most of the produced radioactive waste will be in steel shielding (see Fig. 5, 6). After the final shutdown concrete shielding below the target station have activity values less than 300 Bq g^{-1}, however activity will be dominated by short lived radionuclides (see Fig. 5). Activity values in concrete above the target and soil will be below the exempt limit. Activity in iron shielding is dominated by short lived isotopes and it drops one order of magnitude in first 10 years. Activity below the target station follows the same trend as above.

Calculated target activity and decay heat after the irradiation. FLUKA gives a specific activity of 59 GBq g^{-1} and decay heat of 140 kW m^{-3} after the irradiation, however after 1 year of decay it drops to 1.9 kW m^{-3}.

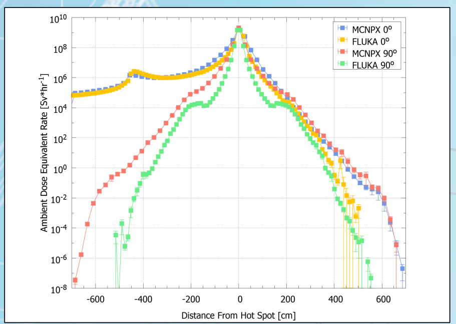

Fig 3. Neutron ambient dose equivalent distribution at the target level 0° and 90° to beam direction.

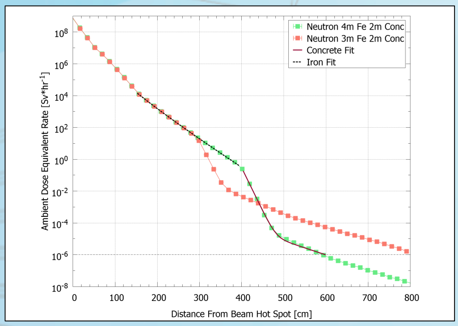

Fig 4. Neutron ambient Dose equivalent rate profile below the beam hot spot for different shielding set-up.

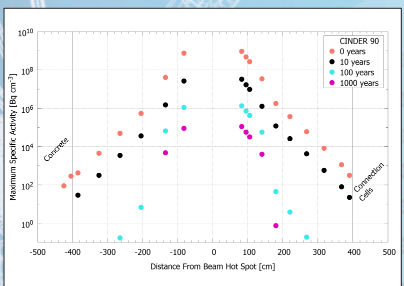

Fig 5. Specific activity profile above and below the hot spot at different times after the final shutdown.

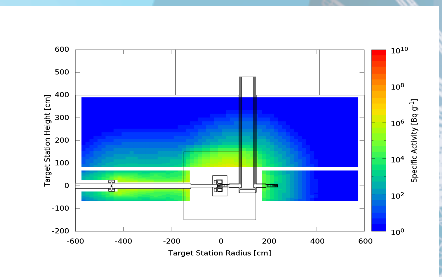

Fig 6. Specific activity distribution in target station shielding after 50 years from the final shutdown.

Conclusions

1. MCNPX estimates higher neutron yield and dose rate than FLUKA and should be used for conservative approach.
2. Neutron Streaming through beam opening will cause radiation safety issues and should be investigate more in future works.
3. Due to high decay heat, after shutdown the tungsten target will stay inside the monolith for cooling until reaching handling temperature (~100°C).
4. Soil activity will be below the exempt limit and no ground water contamination with H^3 is expected.

References

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