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Neutron dose rate contribution from the bunker roof to the instrument hall

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1. SCOPE

This report describes simulations carried out to assess the impact of the bunker [1] roof design on the neutron dose rate in the instrument hall. These calculations are based on a more updated detailed design than those presented in [2], which includes additional engineering details.

2. CONTRIBUTORS

The calculations were carried out by Stuart Ansell and the document was written together with Douglas Di Julio.

3. ISSUING ORGANISATION

European Spallation Source ERIC

4. METHODOLOGY

The radiation transport calculations were performed using MCNP6.1 driven with an input file created by CombLayer [3]. The model includes the target, moderator, reflector, monolith, bunker, and a number of instruments, described below. This model consists of semi-realistic engineering approximations, typically resulting in model sizes of 20,000-50,000 components.

Specifically, the roof components within the model (Table 1) include the multi-layered structure, engineering details such as 20 mm clearance gaps between blocks and a 135 mm dilation joint filled with 95 mm of zinc bromide solution in a can. The height of the bunker roof is 1.7 m from Target Coordinate System (TCS) [4] with roof beams that are at a height of 1.5 m. The roof beams include a 300 mm 50 % filled polyethylene section sitting under a 100 mm steel plate[1]. The roof pillars are placed on the R6-R24 radii every three meters and interconnected with the roof beams in the radial and outward directions with the exception that roof beams across the dilation joint have been removed. The model also includes the high-bay over the D01 floor which connects to the monolith curtain. The high-bay roof was modelled as 2 m thick regular concrete, located at 7 m above the TCS. The multi-layered 3.5 m bunker wall was modelled, however the outer layer was set to importance zero prohibiting neutrons escaping the wall.

The high-bay is only over the D01 floor which extends to the boundary of the short sector, and therefore this work was carried out for an instrument in the short sector of the bunker. As the neutron instruments are still undergoing detailed design, a model loosely based on the LoKI [5] instrument was chosen for the calculations. This model includes instrument components such as collimator blocks, neutron guides, a bender,

[1] The engineering model currently has a 200 mm 50% filled polyethylene box under a 100 mm steel plate.

choppers and housing, and vacuum pipes and windows. This selection was made because the bender produces a significant radiation load on the roof and the model is fairly advanced so it is a good representation of a realistic instrument. A general description of the instrument is given in Table 2. Fig. 1 also shows the bunker geometry used in the calculations and Fig. 2 is a horizontal cut through the roof indicating the pillar positioning.

Table 1: Description of the roof geometry. Starting from the bottom of the roof.

Layer	Material	Thickness (cm)
1	Borated Polyethylene[2]	10
2	Steel	5
3	Polyethylene	20
4	Steel	45
5	Polyethylene	40
6	Steel	25
7	Borated Polyethylene	10

Table 2: Description of the main components in the instrument model.

Component	Description
Guide aperture	2.5 cm x 2.5 cm in the monolith
Guide aperture	3 cm x 3 cm in the bunker
Guide	9 km radius bender from 2 m to 7 m and then straight and slopping down
Guide substrates	0.5 cm thick Al substrates
Vacuum housing	Vacuum pipe has radius of 8 cm Six 0.5 mm thick Al windows along the guide
Chopper	Double disc chopper, 2 mm thick B4C blades, separated by 1 mm and with 3 mm thick Al windows on the chopper housing
Collimator blocks	Two 5 cm thick tungsten collimator blocks filling the vacuum pipe at positions of 5.95 m and 7.6 m.

[2] Polyethylene was modelled at 0.97 g/cc and with a boron content of 0.5% atomic fraction.

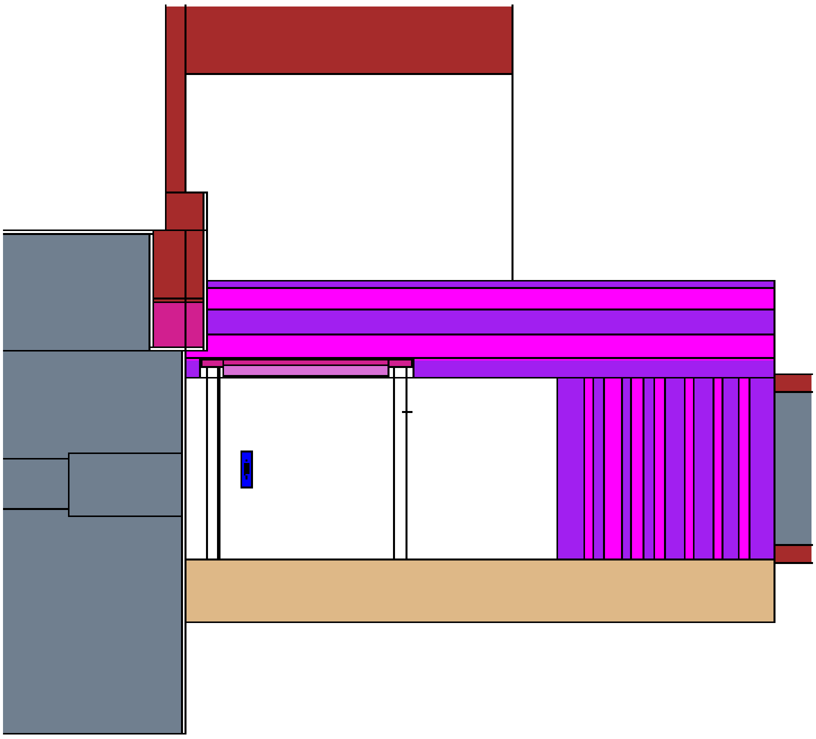

Fig. 1: Vertical cut showing the geometry of the bunker and high-bay used in the calculations. The vertical cut is off-plane of the beam axis and the geometry of the instrument is not seen. The grey area on the left is the monolith, the purple and pink layers are the alternating layers of polyethylene and steel in the bunker wall and roof, the blue object is the chopper, and the tan and red indicate different types of concrete.

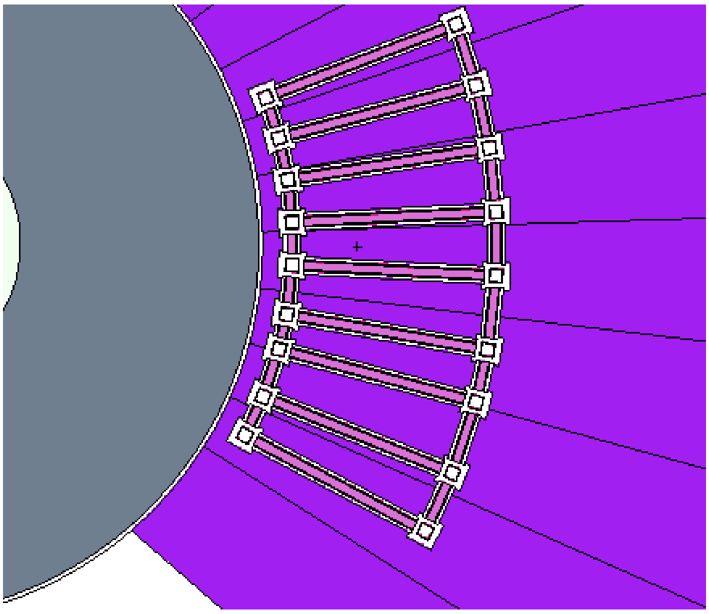

Fig.2: Horizontal cut through the roof indicating the pillar structure and roof beams.

The model was run assuming that the facility operates at 5 MW power and at a proton energy of 2 GeV. The calculations were carried out in a two-step procedure. First, a source term at 2 meters from the moderator position was used and the neutrons which leaked from the bunker roof were tallied at 30 cm from the top of the roof. This was carried out using an SSW surface. Second, a new source term was created using the information collected by the SSW surface and by assuming 6 identical copies of the instrument in the short sector, with 11.7 degrees and 12.3 degrees separation and skipping every other beamport. Variance reduction techniques were used to bias the sampling of neutrons in the upward direction and also to more heavily sample the neutrons of higher energy (lethargy biasing).

Additionally, MCNP6.1 has been modified to allow both cell and mesh-based weight window variance reduction with preference to mesh weight windows when both are available

5. ACCEPTANCE CRITERIA

[6] shows that the instrument halls are supervised zones. [7] sets the dose limit for a supervised area at 3 μSv/h. In accordance with [8] the acceptance criteria therefore is 1.5 μSv/h.

6. OPEN ITEMS

This report only addresses the radiation dose due to neutrons and does not include the contribution from photons.

The calculations do not include an instrument penetration in the bunker wall and are only for the short sector of the bunker.

The calculations focus on the impact of the bunker roof design on the neutron dose rate leakage into the instrument hall and not a complete dose rate map above the entire bunker roof.

7. ASSUMPTIONS

In addition to assumptions already described in the methodology section, a number of other assumptions were made. The simulations started from the 2 m source SSW card which had been biased to remove all neutrons in the backward direction and all other particles except photons. In the forward direction, weight-biased selection was carried out on a cosine angle distribution over the port size +/- 2 cm. Therefore, neutrons on the outer angular selection will enter the monolith shielding but still have a probability to either penetrate through the shielding or scatter back into the monolith void.

8. LIMITATIONS

Limitations are related to the above open items, assumptions and statistical sampling and biasing of the SSW card. The instrument description in section 4 is a representative case of a realistic neutron instrument and may not be a worst case scenario.

9. COMPUTER HARDWARE AND SOFTWARE

MCNP6.1 and CombLayer. The CombLayer Git version number is
b2074d5f65521daf826ecc37ae944fe3c32c77b3

10. CALCULATION INPUTS

As described in section 4.

11. CALCULATIONS

The results of the calculations are given in Fig. 3, which shows the neutron dose rate above the bunker, starting at the 10 m position, and extending out to around 25 m. It can be seen that the dose rate rises above 3 μSv/h above the bunker roof. The leakage into the instrument hall is less than 1 μSv/h after about 17.5 m, however the dose rate above 1 μSv/h is confined to the area above the bunker roof, as indicated in the figure. Roughly 10% of the neutron dose rate at the 10-15 m position above the roof leaks down into the instrument hall out to about 25 m.

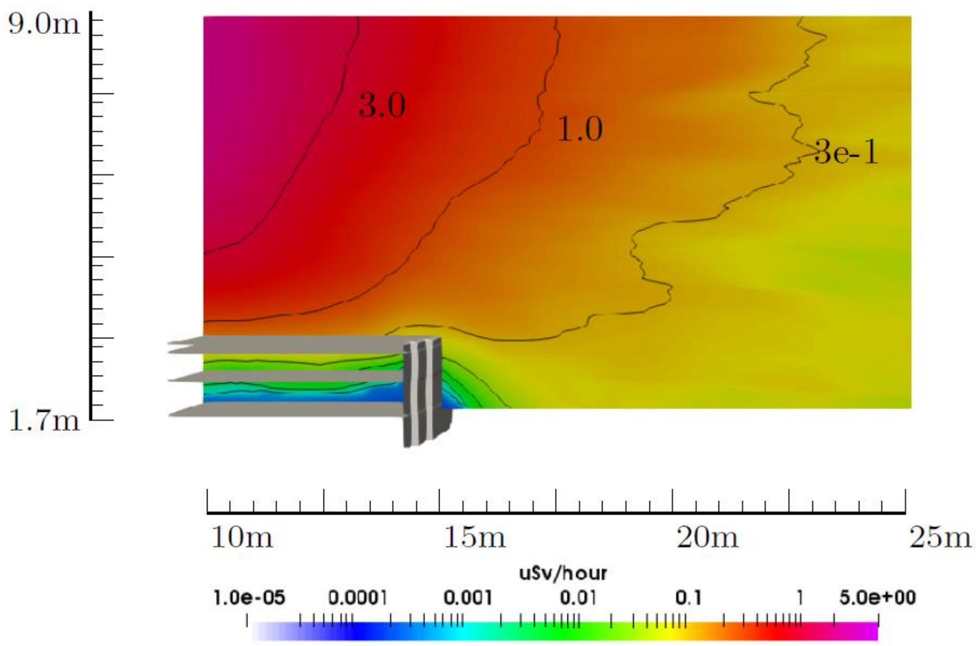

Fig. 3: The neutron dose rate above the bunker along the plane central to the instrument with each pixel representing the average dose rate within the local 1 m^3 volume.

12. CONCLUSIONS AND RECOMMENDATIONS

If re-zoning of the area above the bunker roof is permitted, then the calculations with the current baseline design (and representative instrument) show that roughly 10% of the neutron dose rate above the bunker roof at 10-15 m leaks down into the instrument hall out to around 25 m. The results indicate however that the current baseline design does not meet the requirements for a supervised zone directly above the roof.

In the case that the roof shielding or local instrument shielding within the bunker is increased to make the roof a supervised zone, we expect that the leakage fraction between the roof area and instrument hall will remain constant because the spectrum on the roof is lethargy dominated.

13. GLOSSARY

Term	Definition

14. REFERENCES

[1] ESS-0052629, Neutronic Design of the Bunker

[2] ESS-0087853, Neutronics of the Bunker Wall and Roof

[3] S. Ansell, "CombLayer: A fast parametric MCNP(X) model constructor", Proceedings of the 21st Meeting of the International Collaboration on Advanced Neutron Sources, Mito, Japan, Feb. 2016

[4] ESS-0035090, MAIN COORDINATE SYSTEMS AT THE ESS

[5] Andrew Jackson and Kalliopi Kanaki, ESS Construction Proposal: LoKI – A broad-band SANS instrument

[6] ESS-0051603, NSS zoning document – part I (safety)

[7] ESS-0001786, Definition of Supervised and Controlled Radiation Areas

[8] ESS-0019931, ESS Procedure for designing shielding for safety

DOCUMENT REVISION HISTORY

Revision	Reason for and description of change	Author	Date
1	First issue	Stuart Ansell Douglas Di Julio	2017-09-25