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Proof of concept neutronics calculations for the Bunker Feed Throughs

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1. SCOPE

This report describes the studies performed to establish the amount of the radiation escaping the utilities-feed-throughs located in the bunker roof. The goal of these calculations is to establish, if the proposed design for the bunker feed throughs, is mature enough for CDR.

2. CONTRIBUTORS

The calculation were carried out by Valentina Santoro.

3. ISSUING ORGANISATION

European Spallation Source ERIC.

4. METHODOLOGY

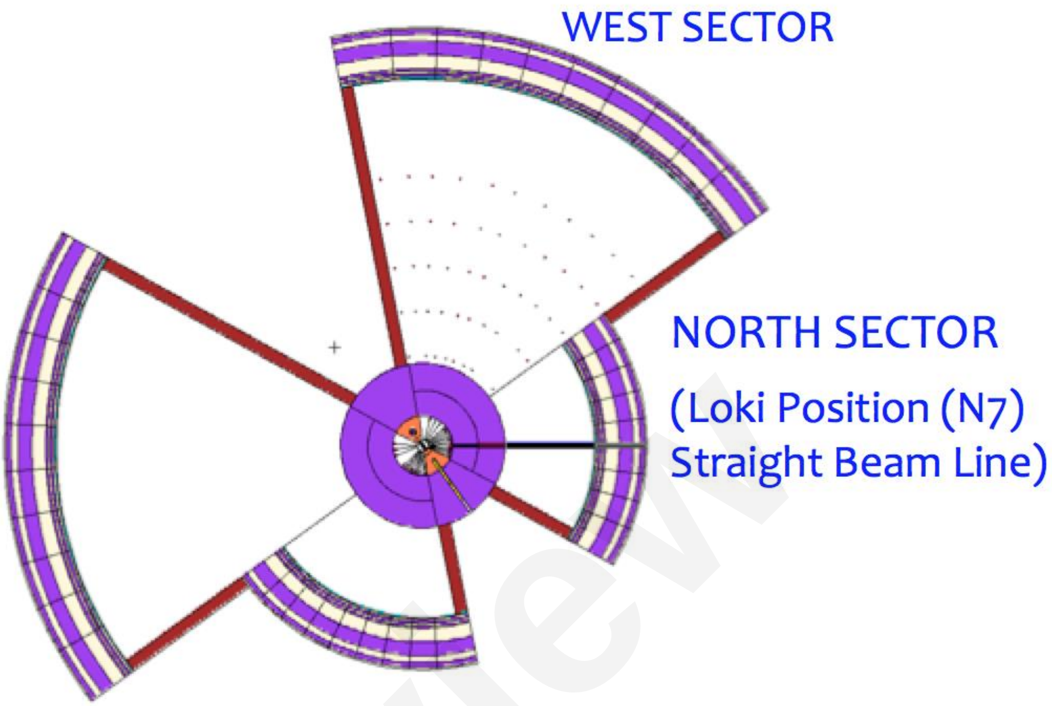
The Radiation transport calculations were performed using the MCNP6 [1] code. The MCNP6 model has been built using Comblayer. Comblayer [2] is a C++ package that can write MCNP input files with a detailed geometrical description of the ESS model. A snapshot of the ESS-Comblayer model is shown in Figure 1. (a).

The source term, for all the studies shown in this report, was a neutron spectrum at 2m with angular information. This spectrum has been generated at the beam port entrance of the NMX beam line that is located in the west sector on the beam port W1.

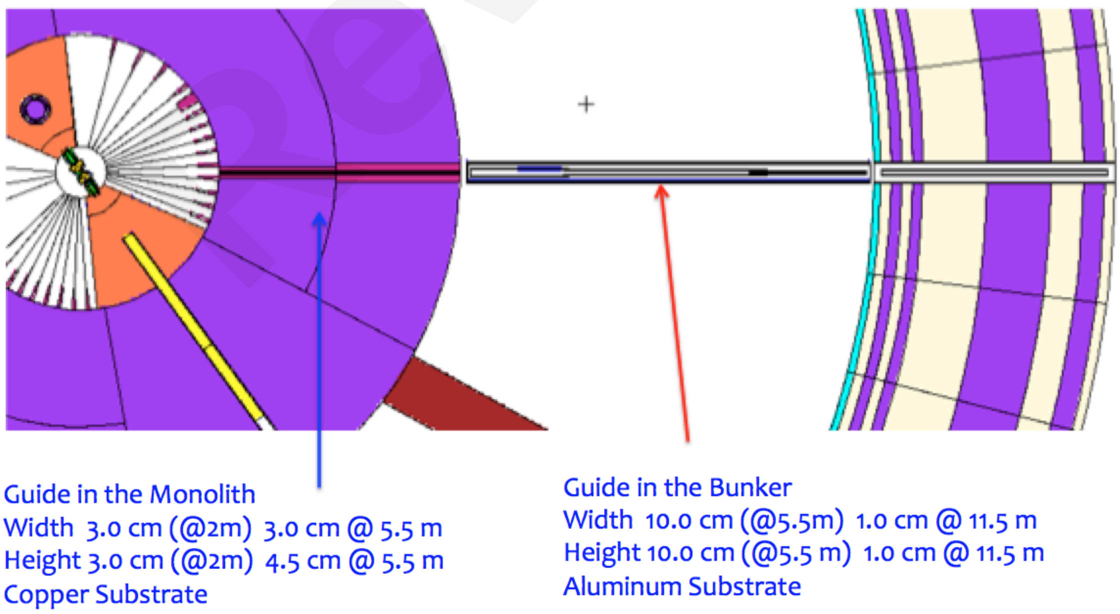
The studies performed in this report have used a straight beam line located in the short sector of the bunker. The beam line has been placed at the location of the Loki beam line (N7) in the north sector (see Fig1. (b))

The beam line has been simulated with a straight neutron guide with a copper substrate in the monolith and aluminium substrate in the bunker. The neutron guide has a section of 10x10 cm^2 at the exit of the monolith and a 1x1 cm^2 at the entrance of the bunker wall. This beamline configuration it is assumed to be a worst-case-scenario for spreading radiation to the bunker roof [3]. While preliminary calculations for other beam line configurations, in particular adding a chopper seems to support this theory, this needs to be verified before the CDR of the bunker project.

In the simulation, different variance reduction techniques have been used. A basic cell energy based weight window was used throughout all the model, forced collisions have been applied in the guide to increase the number of scattering events, and dxtran spheres and f5 tallies have been used for estimating the radiation at the beginning of the bunker roof and inside the bunker feed-through.



(a)



(b)

Fig.1 (a) CombLayer ESS model: the model includes the proton beam, moderator, monolith and all sector of the bunker. (b) Zoom of the short sector at the Loki beam line position N7. A straight tapered metallic guide has been simulated.

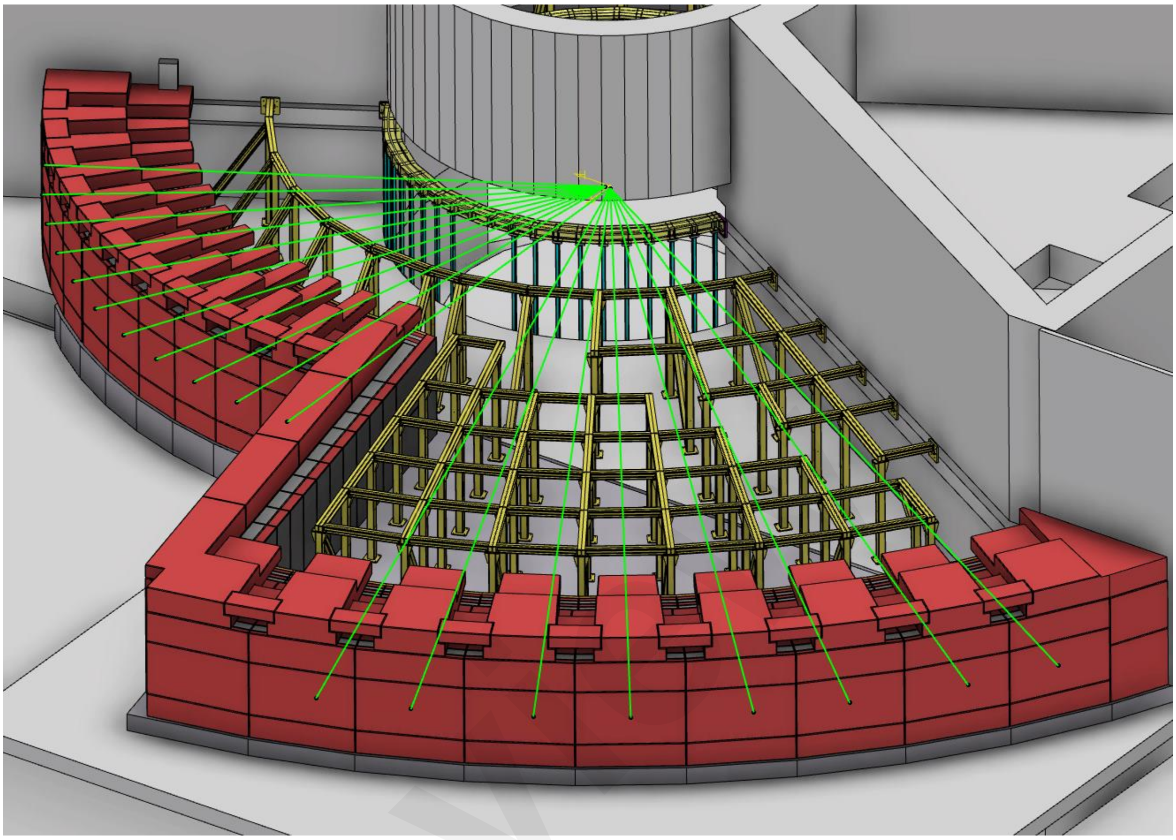


Fig. 2 The Bunker wall with all the utilities feed-throughs. The green lines represent where the beam line should be located.

5. ACCEPTANCE CRITERIA

[ESS-0057090] shows that the instrument halls are supervised zone. [ESS-0001786] sets the dose limit, for a supervised area is 3 μSv/h. In accordance with [ESS-0019931] the acceptance criteria therefore is 1.5 μSv/h.

6. OPEN ITEMS

For the calculations shown in this report the bunker wall and the bunker roof design is the one described and presented during the PDR review. These calculations must be redone when the final design of the bunker will be decided.

In addition to that a higher statistic source term is now available but it has not been used for calculations performed after the PDR to be consistent with previous calculations.

7. ASSUMPTIONS

The service feed throughs can be seen from the 3-D CAD drawing shown in Fig.2 and Fig.3. They are located horizontally above the beam lines. Vertically the utilities opening inside the bunker are situated at 1.7 m above TCS [3]. The beam line position is represented by the green line (the green line represents the beam line in the case it has a straight neutron guide. For curved neutron guides the beam line will go through the bunker wall at a slightly different point).

In the following calculation, to estimate the worst case scenario for the radiation travelling inside the feed through, we have assumed that the feed through is located just above the beam line (see Figure 4.) .

In addition to that we have assumed that the radiation coming from the albedo scattering in the metallic substrates of the guide is the worst possible source of radiation for the feed through. The feed through contamination as been computed only for the short sector since it is assumed to have higher radiation compared to the long sector.

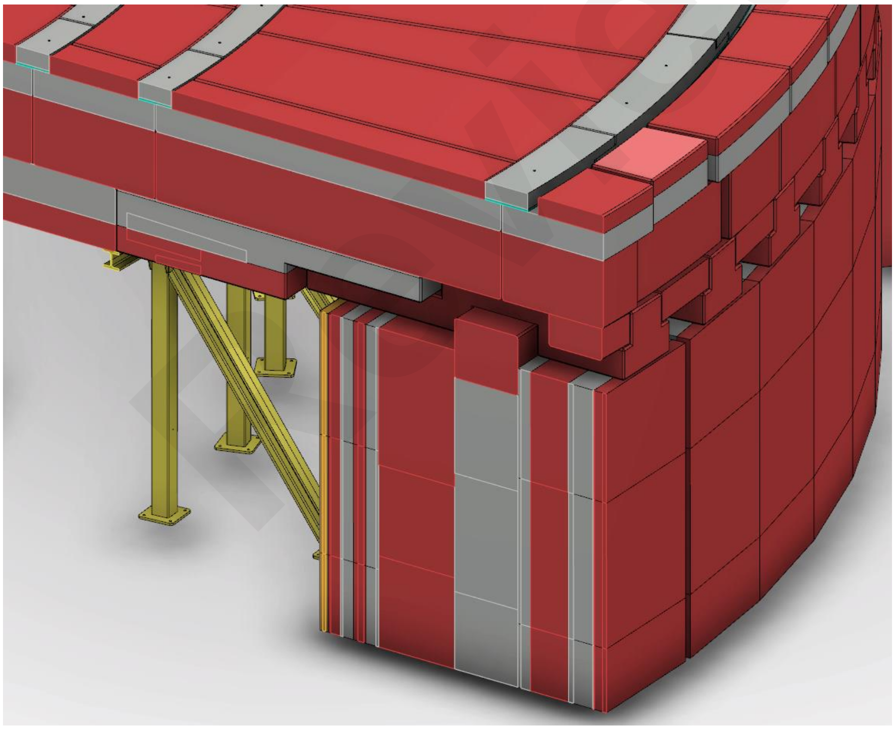


Fig.3 3-D CAD Model of the feed through in the bunker wall.

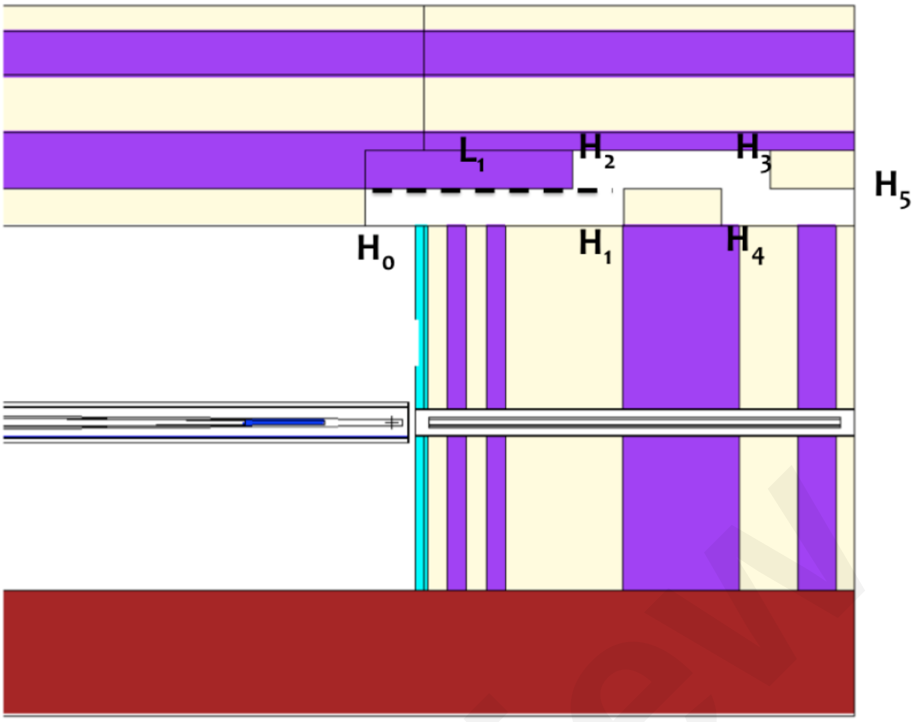


Fig.4. MCNP6 model of the feed through in the bunker wall. H_0 is the location of the initial source for the analytical calculation; H_5 represents the radiation at the exit of the feed through.

8. LIMITATIONS

None.

9. COMPUTER HARDWARE AND SOFTWARE

- MCNP6 [1].

10. CALCULATION INPUTS

The source term used in all these calculations has been generated at the beam port entrance of the NMX beam line. This source term is preliminary but it has been bench marked with simulations starting from protons as it can be seen from Fig. [5]. A higher statistics source term is now available (see Sec. 6) but it has not be used in this report to be consistent with the calculations performed for the PDR .

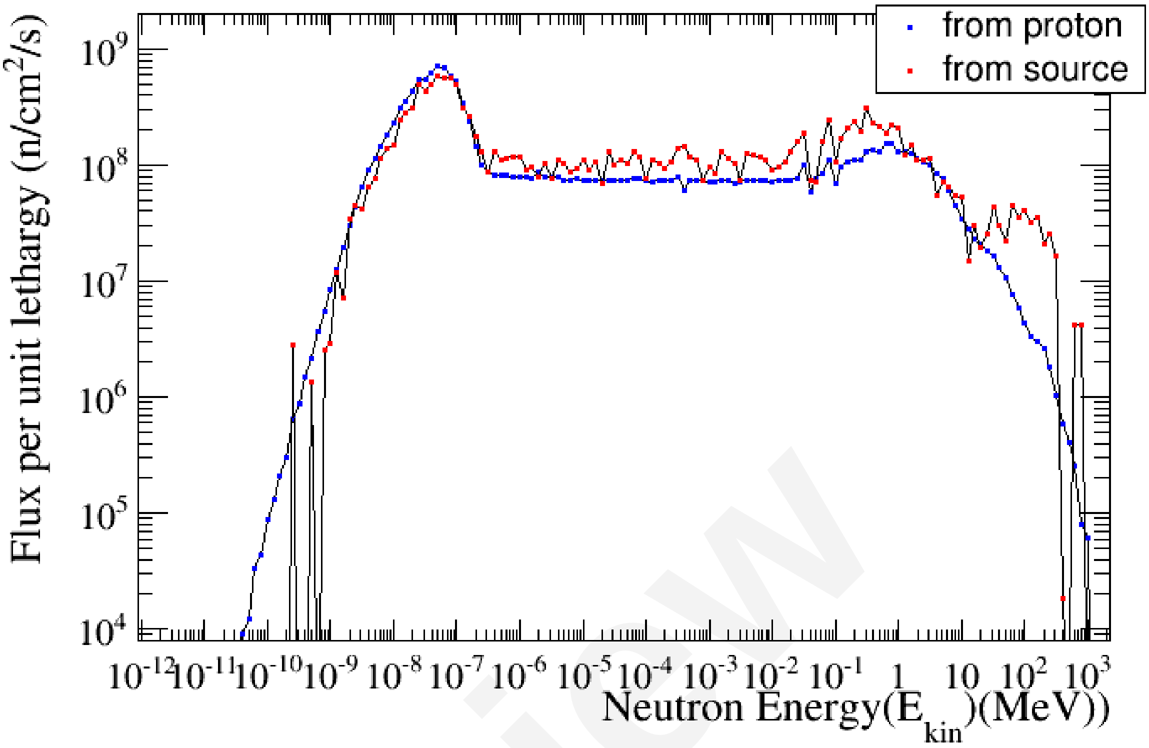


Fig. 5. Neutron energy spectrum in unit of lethargy at the exit of the monolith (5.5 m from the moderator). In blue the simulation has started from the proton beam, in red from the source term located at the entrance of the NMX beam line (2m from the moderator).

11. CALCULATIONS

9.1 Dose map inside the bunker.

We need to estimate the amount of the radiation escaping the service feed through located in the bunker roof. To have knowledge the amount of radiation entering the feed through we calculate the neutron dose map inside the bunker. This radiation dose map has been computed using the conversion factor from flux to dose from [4].

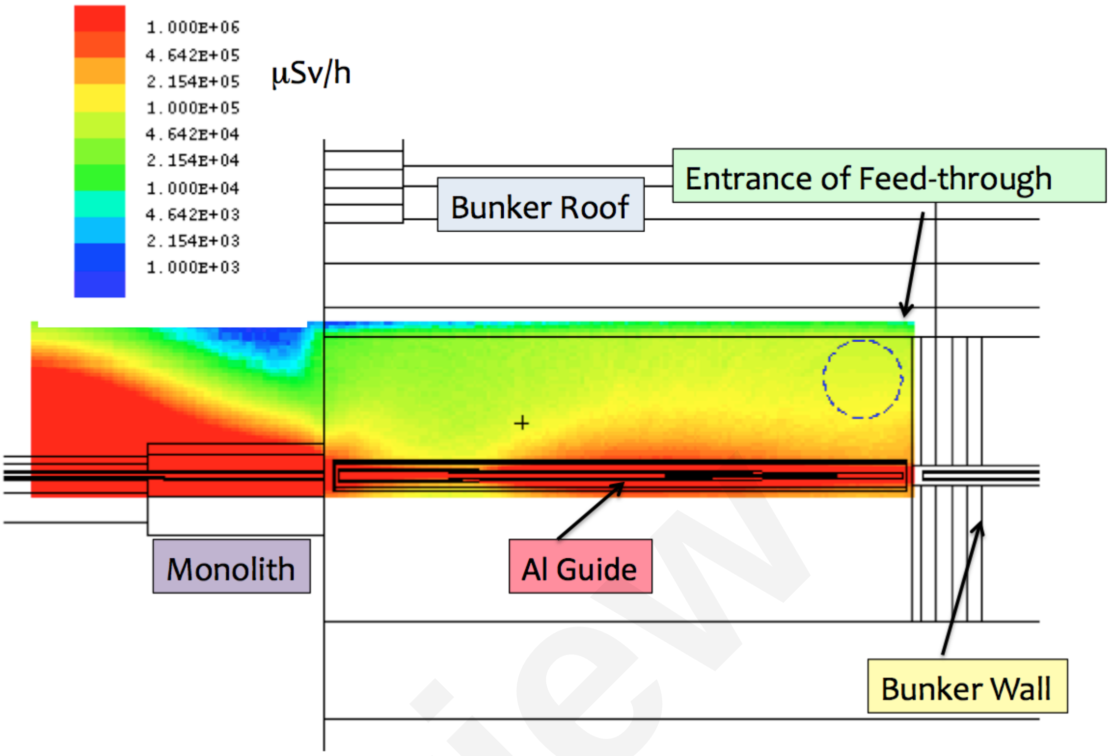
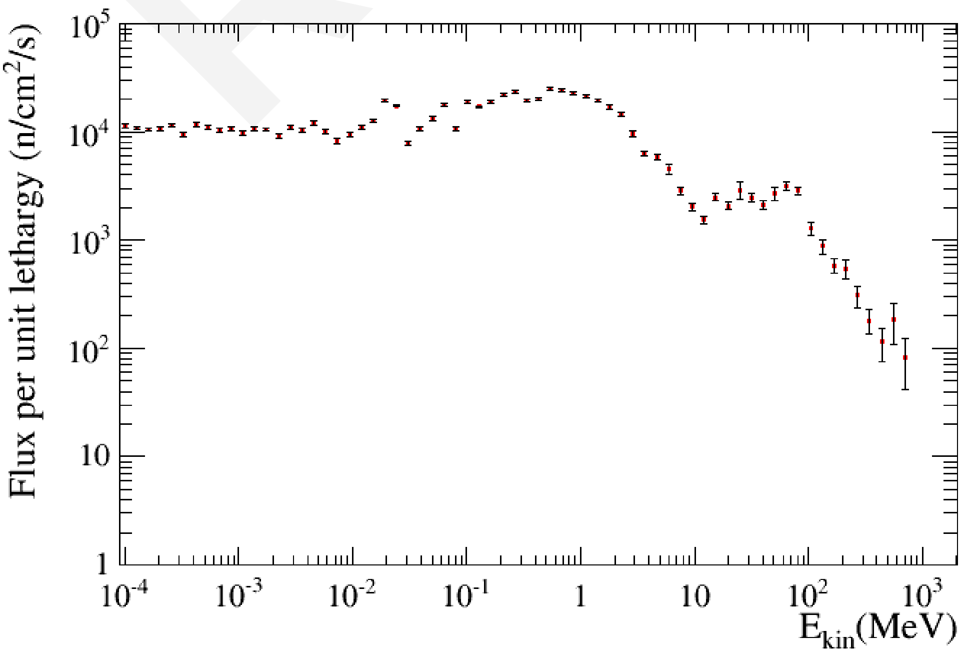
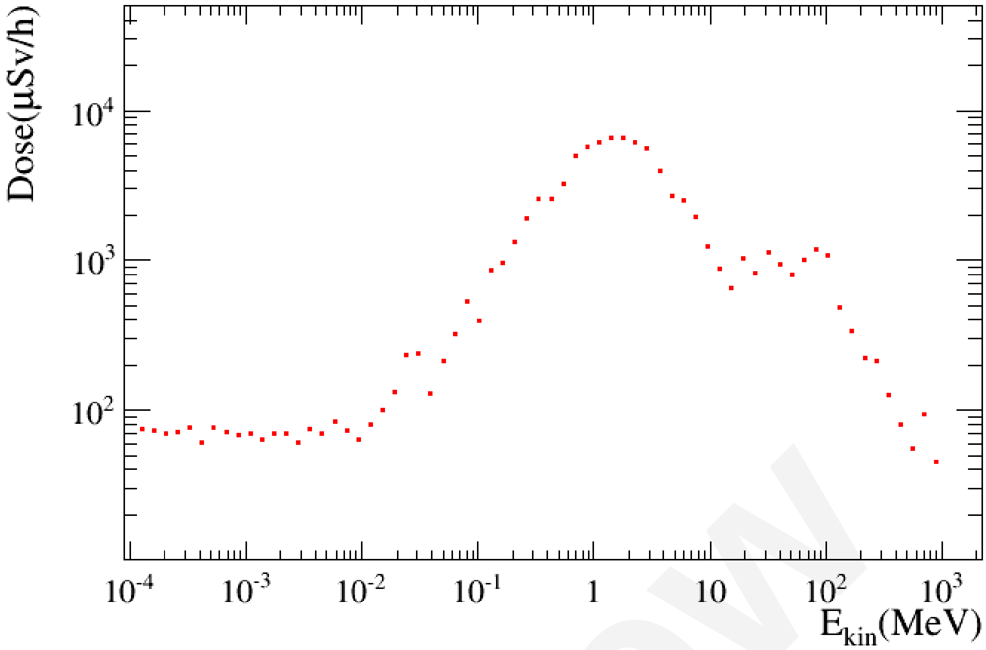


Fig.6 Radiation dose map inside the bunker. A dxtran sphere[1] is located at the entrance of the feed-through in the bunker wall as can be seen from the figure. In the simulation, the monolith, the neutron guide, the vacuum pipe, the bunker wall and bunker roof have been modelled.



(a)



(b)

Fig.7 (a) Neutron energy spectrum at the entrance of the feed-through. The neutron below 10^{-4} MeV are not considered in this calculation. (b) Neutron dose at the the entrance of the feed-through, the integrated dose corresponds to 81 mSv/h.

The radiation dose map is shown in Figure 6. The radiation around the entrance of the feed through is of the range of 60 -80 mSv/h. As additional check that the amount of radiation going in the utilities-feed through is right we calculate the spectrum at the entrance using an f5 tally [1]. The corresponding neutron spectrum and dose are shown in Figure 7(a) and 7(b). The total integrated dose for the spectrum shown in Figure 7(a) corresponds to 81 mSv/h, in agreement with the results of the dose mesh tally.

9.2 MCNP transport calculation for the feed through.

Figure 8 shows the radiation dose map for the utilities feed-through for neutrons and photons. The streaming path of the neutrons can be seen. A rough estimate for the dose at the exit is around 10 μSv/h for the neutrons (fig 8. (a)), while for the photons the radiation is well below 1 μSv/h (fig. 8 (b)).

9.3 Handbook calculation for the feed through.

The radiation dose at the end of the chicane has been also computed using an analytical calculation based on the following formulas from Sullivan [6]:

$$H_1 = H_0 / L_1^{\,2}$$

$$H_n = H_1 \times K^{n-1} \ \frac{A_1}{A_n} \cdot \left(\frac{\sqrt{A_2}}{L_2} \cdot \frac{\sqrt{A_3}}{L_3} \dots \frac{\sqrt{A_n}}{L_n} \right)^3$$

where H_0 is the radiation level at the entrance of the chicane, H_1 is the radiation level at the first leg of the chicane, A_n is the cross section area of the chicane and L_n is the length of the n-leg of the chicane (see Figure 4). K is a scatter coefficient, that for neutrons or secondary radiation from high energy particle interactions is estimated to be in the range 0.2 to 0.6. In this calculation K have been assumed to be 0.6.
If we take as initial value of H_0=81 mSv/h as computed from the dose map and f5 tally we estimate that the radiation level at the end of the chicane (H_5) is around 2μSv/h.

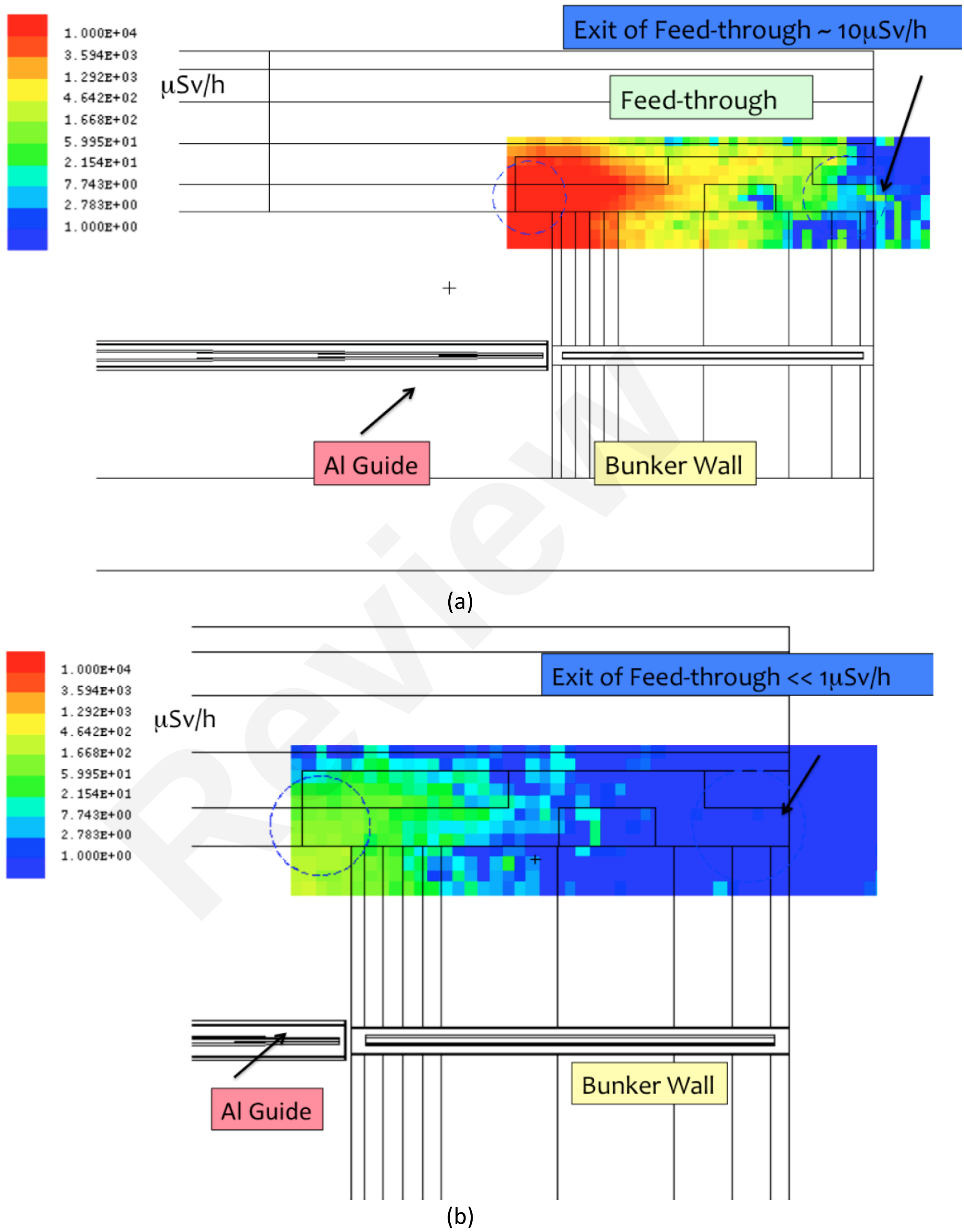


Fig.8 (a) Radiation dose map for neutrons inside the feed through. A dxtran sphere is located at the entrance of the feed-through and at the exit of the feed–through in the bunker wall. (a) Radiation dose map for photons inside the feed through.

9.4 Filling fraction for the feed through.

The MCNP6 simulations estimate a dose at the exit of the feed through that is roughly 10 μSv/h while the analytical calculation estimate is around to 2 μSv/h. Both results are slightly above the design criteria for the supervised zone with 1.5 μSv/h, for this reason we study a filling fraction for the feed through to meet the design criteria.

We simulated two different filling fraction one that would fill the 30% of the volume of the feed through and one that will fill 50% of the volume.

The results of these simulations are shown in Figure. 9 and show that a filling fraction of 30% is already enough to meet the requirements. In the simulation the importance of the neutron guide in the bunker wall has been set to 0, to allow that the radiation outside the bunker is only affected by the feed through in the bunker roof and not by the radiation in the neutron guide. The last contribution in fact is strongly related to the design of the neutron guide insert in the bunker wall and may change from instrument to instrument.

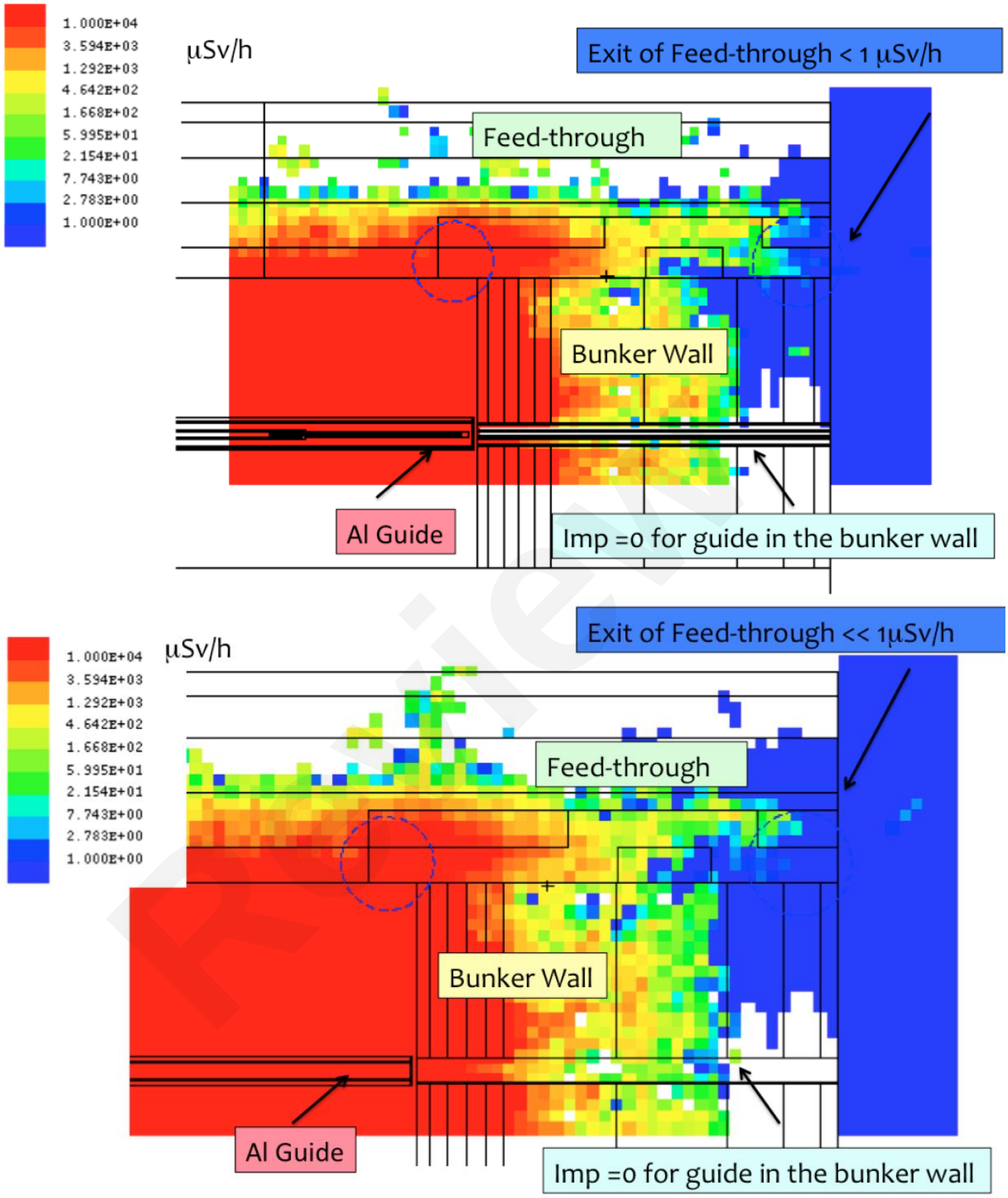


Fig.9 (a) Radiation dose map for neutrons inside the feed through with a filling fraction of 50%. (b) Radiation dose map for neutrons inside the feed through with a filling fraction of 30% .

12. CONCLUSIONS AND RECOMMENDATIONS

A MCNP6 simulation and an analytical calculations for the bunker utilities feed through in a worst case scenario with a straight metallic guide have been performed. The analytical calculation estimated the dose rate at the exit of the feed through to be 2 μSv/h. The MCNP6 simulations estimate is roughly 10 μSv/h. Since both results are slightly above the design criteria for the supervised zone with 1.5 μSv/h, we compute a filling fraction to meet the design criteria. The studies show that a 30% filling fraction is able to meet the required dose of 1.5 μSv/h.

13. GLOSSARY

Term	Definition

14. REFERENCES

[1] G. W. McKinney, F. B. Brown, et al, "MCNP 6.1.1 New Features Demonstrated", IEEE 2014 Nuclear Science Symposium, Seattle, Nov 8-15, LA-UR-14-23108 (2014).

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

[3] ESS-0087853

[4] ESS-0086538

[5] Muhrer G., ESS Procedure for designing shielding for safety, ESS-0019931

[6] A. H. Sullivan, A Guide to Radiation and Radioactivity Levels Near High Energy Particle accelerator, Nuclear Technological Institute, 25 September 2015, Versions nr.01

DOCUMENT REVISION HISTORY

Revision	Reason for and description of change	Author	Date
1	First issue	Valentina Santoro Stuart Ansell	<<2017-06-22>>
2	Second issue	Valentina Santoro	<<2017-06-22>>