System Acceptance Review meeting for BIFROST

BIFROST Cave
=ESS.NSS.H01.BIFRO.U01

PRESENTED BY ALAN TAKIBAYEV

2025-09-03

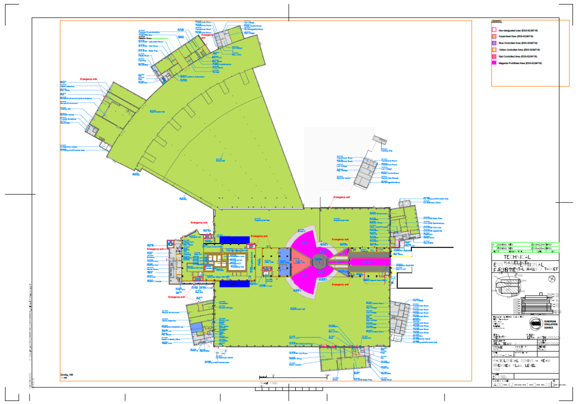
SHIELDING DESIGN REQUIREMENTS

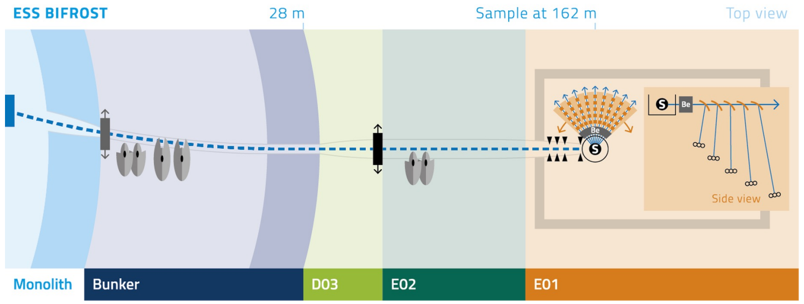
ESS-0057612 Rev 13 [2024/07/12]
Area Classification Design Requirements Document for D,E&G Buildings

ESS-0239718 Rev 14 [2024/09/05]
ESS Handbook for Radiation Protection Chapter 2: General Radiation Protection Rules

ESS-1108220 Rev 01 [2020/02/25]
Guideline and Rules for Instrument Shielding Design

ESS-0019931 Rev 07 [2024/12/05]
ESS Procedure for Designing Shielding for Safety





	Non-designated area	Designated radiation areas				
		Definition				
Criteria/Area classification	White Non-designated area	Green Supervised Area	Blue Controlled Area	Yellow Controlled Area	Red Controlled Area	Magenta Prohibited Area
Potential annual effective dose	<1 mSv	<6 mSv	>6 mSv	>6 mSv	>6 mSv	-
Ambient equivalent dose rate	Permanent: 100 µSv/year Non-permanent: 0.5 µSv/h	<3 µSv/h	<25 µSv/h	<2.5 mSv/h	<100 mSv/h	>100 mSv/h

of ESS, to ensure that the overall dose constraints are met. As a result, instruments are required to demonstrate compliance at TG3 with the following limits for their worst-case H1 scenarios and H2 events with a likelihood above one per year:

1. All instruments must design their cave and guide shielding so that the calculated area-averaged dose rates of all shielding surfaces, excluding the cave roof, are less than 0.5 µSv/hour. The averages must be performed separately for each of the four walls of the instrument cave, and for each 10m-long section of the guide shielding.
2. In order to comply with ESS-0001786 [2], the dose rate on the outer surface of the instrument shall not exceed 3 µSv/hour. To test for compliance, the calculated dose rate needs to be averaged over a 20×20 cm^2 area and multiplied by the appropriate safety factor.

Besides, for the other H2 events (i.e. H2 with a likelihood below one per year), the dose received by each individual per event shall not exceed 1 mSv.

6.3. Creation of local blue controlled radiation areas

Instruments may designate parts of their caves and other areas (e.g. part or all of the cave roof) as blue controlled radiation areas while the beam shutter is open. This will increase the maximum permissible continuous dose rate to 25 µSv/hour in those areas. The same safety factors apply. In order to do so, access to these areas must be controlled by suitable protective and administrative measures to be approved by the Radiation Protection Group.

3.2.5. Particle transport code calculations

The assigned shielding expert will perform particle transport code calculations under the following boundary conditions:

- Particle transport codes to be used:
  - Publically released version of MCNP(X)
  - Publically released version of Fluka
  - Publically released version of MARS
  - Publically released version of PHITS.
- Activation/Burn-up codes to be used:
  - See the *ESS Procedure for activation calculations* (ESS-0051491) [8].
- Cross-section libraries
  - ENDF 8.1 or lower depending on availability and applicability
  - Other libraries, upon approval by the SDC.
- Flux to dose conversation factors
  - As shown in Chapter 4.
  - A safety factor of 2 shall be applied to all particle transport code calculations, if the calculations are compared with the legal or ESS established dose limits. However, no safety factor needs to be applied if the calculations are compared with the dose constraints (e.g. dose to public, ESS dose constraint for annual dose to worker).
  - The dose requirements stated in [4] shall not be exceeded anywhere in the investigated workspace.

Responsible:
Assigned shielding expert
Particle transport code calculations

Output/product: The assigned shielding expert will present the results of the assessment to the customer and start the review and approval process.

SUMMARY OF BIFROST CAVE NEUTRONIC SIMULATIONS

ESS-1417912 Rev 03 [2025/07/08]

H1 and H2 Scenarios for the Radiation Shielding of BIFROST

Event ID	Event description
H1-1	Unspecified bulky sample environment. The MOB is incident on a bulky piece of sample environment with more than 2 cm of aluminium in the beam.
H1-2	Oxford 15 T magnet. The MOB is incident on an Oxford 15 T magnet or an ILL Orange cryostat.
H1-3	Beam stop. The MOB is dumped in the designated beam stop (B_4C and polyethylene sandwich)
H1-4	A large single crystal is placed at the sample position. Intense Bragg peaks (0.3 % of the full beam) (MOB) are scattered towards the walls and the roof of the cave from the sample position.
H1-5	Full beam into the get lost tube. Dumping the MOB into the get lost tube walls.
H1-6	Full beam into beam attenuator. Dumping the MOB into the beam attenuators at the BW chopper position achieves near perfect boron absorption.
H1-7	Guide coating gammas. MOB propagating in the last focusing section.
H1-8	User measures 1x1x1 cm3 La_2NiO_4. A very large sample with absorbing nickel and lanthanum produces prompt gammas, inside an orange cryostat
H1-9	Sample with much hydrogen or disorder. 10 % of the MOB is scattered in 4pi.

Event ID	Event description
H2-1	Choppers are parked in fully open position. The Accidentally Unchopped Beam (AUB) is dumped onto the beam stop.
H2-2	Cd sheet in the sample position. The entire MOB is dumped in Cd at the sample position.
H2-3	4pi scatterer at the sample position. Placing a 100 % effective incoherent scatterer of the MOB at the sample position.
H2-4	Dumping the AUB into the instrument shutter.
H2-5	Dumping the AUB beam into a parked BW chopper disc.
H2-6	Bunker choppers are closed. Dumping the AUB beam into the parked focussing/pulse-shaping chopper disc (closed), creating boron gammas in the bunker.
H2-7	Dumping the MOB into the B_4C lined beryllium vacuum vessel, creates boron gammas.
H2-8	The MOB is absorbed by the slit blades (B_4C) 3.1 m (or less) upstream of the sample position (inside the cave).

ESS-2495661 Rev 02 [2025/07/11]

BIFROST Cave Shielding Neutronics Simulations

H1-4	The Bragg peak contribution to the dose rate is well below 0.1 μSv/h.
H1-7	Guide coating photons are added to other safety scenarios.
H2-1	The cave is sufficient to shield from the unchopped beam (AUB) on the beamstop to below 1.5 μSv/h. An excess of radiation due to neutron streaming through the labyrinths and chicanes is mitigated by borated lining.
H2-2	The dose rate from Cd capture does not exceed 1.5 μSv/h at the walls and 12.5 μSv/h on the roof.
H2-3	The cave is sufficient to shield from the 100% efficient isotropic scatterer to below 1.5 μSv/h. An excess of radiation due to neutron streaming through the labyrinths and chicanes is mitigated by borated lining.
H2-8	The dose rate from divergence jaws is more than 2 orders of magnitude below 1.5 μSv/h.

Status Report

SAT BIFROST Cave

- ESS-5774902
- **NIT-226: Gaps closer to sample position have had shims added. 4 gaps of between 10-20 mm have been measured between roof beams and will be noted with an NIT.**
- NIT-227: Not all handrails installed.
- **NIT-264: Borated lining unfinished.**
- **NIT-228: Unfinished installations.**
- NIT-248: Only on temporary power.
- NIT-263: Yes – in cave, no – north side.
- NIT-229: Handrails on E01 shielding blocks installed and bolts torque check.

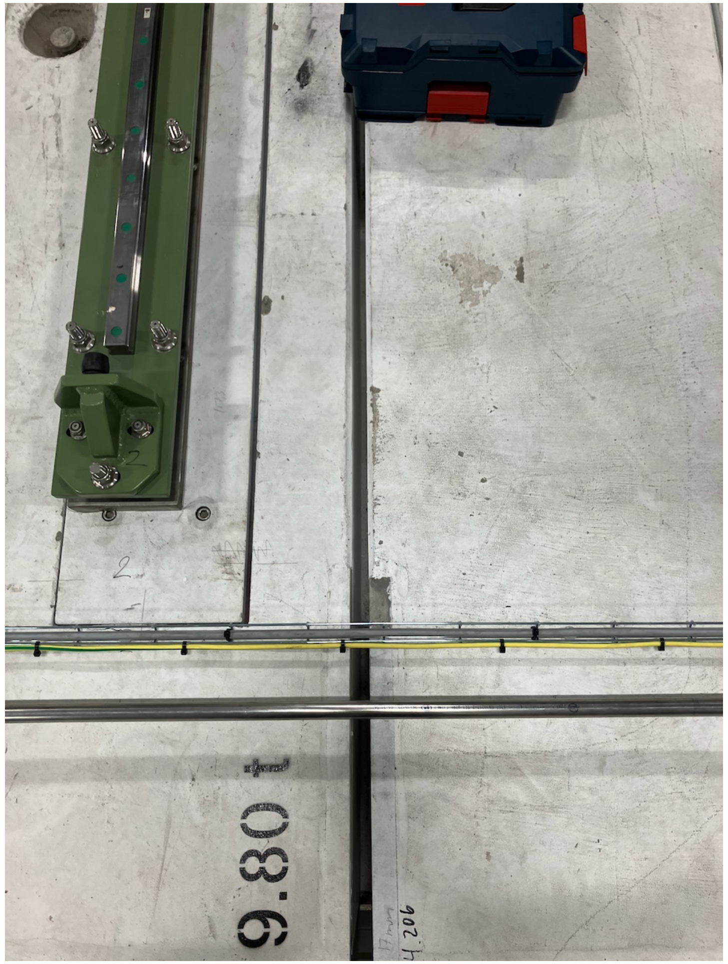
Test case		Pass/Fail	Note
1.	Less than 10 mm gap between the roof beams or compliance with x10 rule (100 mm dogleg)	Fail	NIT-226
2.	Less than 10 mm gap between the roof beams and cave wall or compliance with x10 rule (580 mm dogleg)	Pass	
3.	Less than 10 mm gap between the upper labyrinth pre-cast blocks	Pass	
4.	Less than 10 mm gap between the lower labyrinth pre-cast blocks	Pass	
5.	Cave installed within 30 mm of stated nominal position	Pass	
6.	Nuts torqued correctly on handrails on cave roof	Fail	NIT-227
7.	Screws torqued correctly on sample platform base	Pass	
8.	Screws torqued correctly on handrails on sample platform	Pass	
9.	Screws torqued correctly on elevated access stairs	Pass	
10.	Lower labyrinth entrance width: 1.6 m	Pass	
11.	Elevated labyrinth entrance width: 1.4 m	Pass	
12.	Borated polyethylene lining installed in lower cave labyrinth	Pass	
13.	Borated polyethylene lining installed in upper cave labyrinth	Pass	
14.	Two concrete service covers installed outside cave	Pass	NIT-264
15.	Three lead service covers installed outside cave	Fail	NIT-228
16.	Maximum 25 mm gap between the concrete part of the hatch and the cave roof in closed position	Pass	
17.	Maximum 25 mm gap between the stainless steel base of the hatch and the concrete roof	Pass	
18.	Hatch motion engages all limit switches after reinstallation	Pass	
19.	Hatch moves smoothly from closed to open position after reinstallation	Pass	NIT-248
20.	Permeability of materials used within 2.7 m of the sample position are less than 2.0	Pass	
21.	Density of concrete samples is greater than 2320 kg/m^3	Pass	
22.	All floor tiles are in place and those within the cave are screwed down	Fail	NIT-263
23.	All nuts torqued correctly on clamps securing the tank rotation	Pass	
24.	Beam stop is assembled as per drawings and sits within cave wall	Pass	
25.	Sample platform translate and engages limit switch	Pass	
26.	Handrails on E01 shielding blocks installed and bolts torque check	Fail	NIT-229
27.	Cave hatch cannot be moved without PSS Permit	Pass	
28.	Cave hatch engages PSS switches when in closed position	Pass	

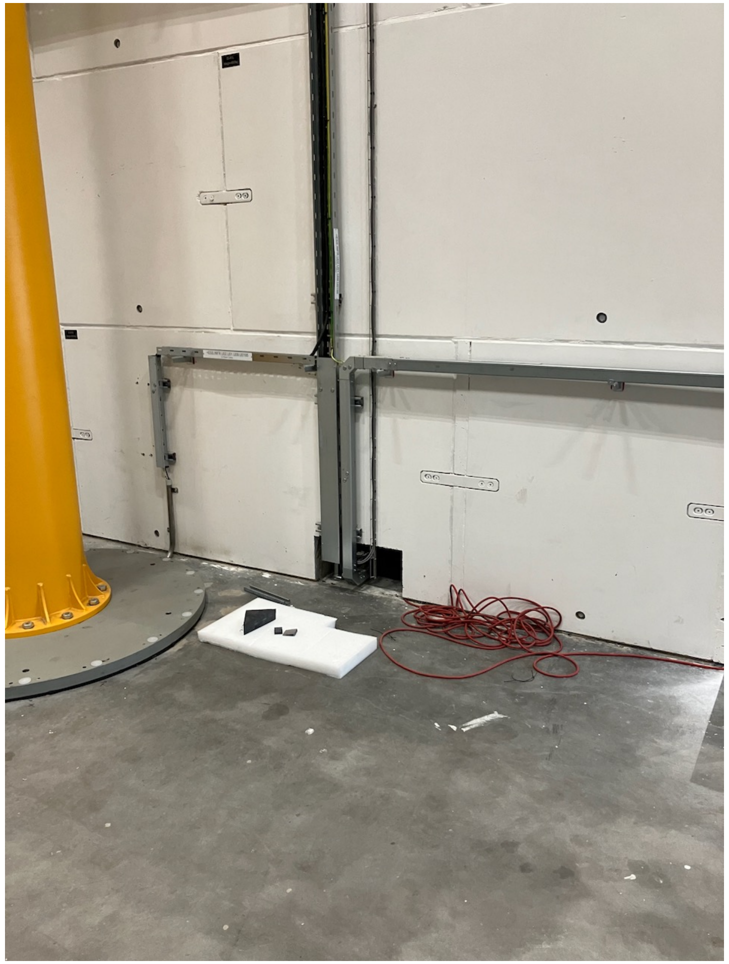
Status Report

SAT BIFROST Cave

Status Report

SAT BIFROST Cave





Hot Commissioning

SAT BIFROST Cave

System is not ready for hot commissioning—

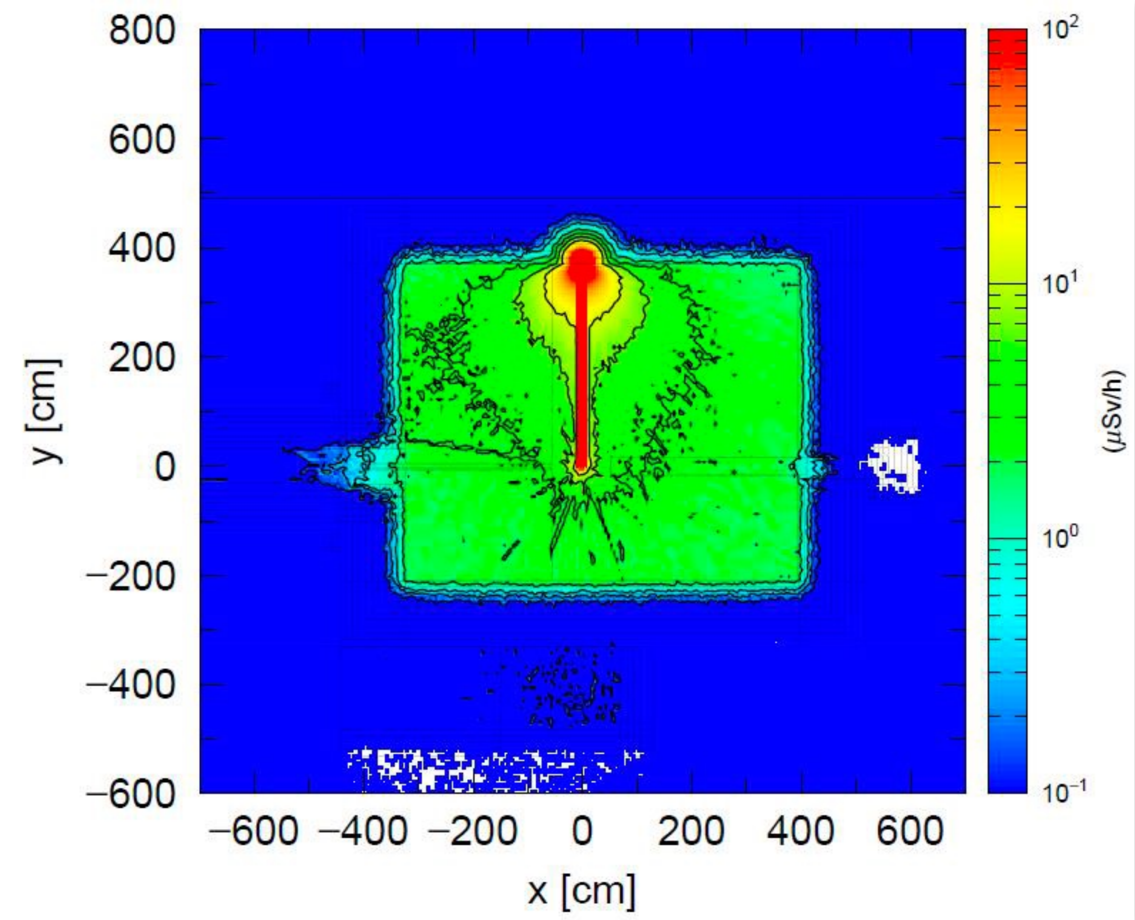
- SAT passed conditionally to be resolved before BOT.
- Estimated time: 2025 Nov.

ESS Spallation Physics Group activities for hot commissioning—

- Support the instrument team with shielding-related issues if requested.
- Scientific support if requested.

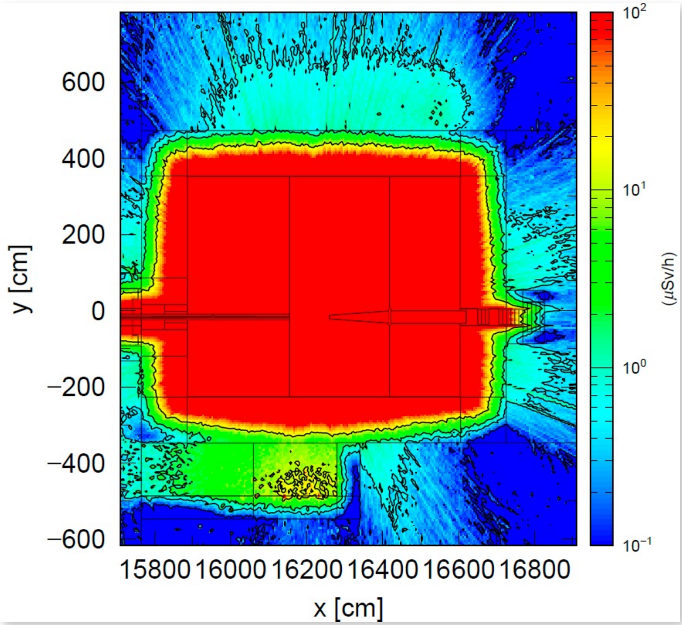
H1-4 BRAGG PEAKS

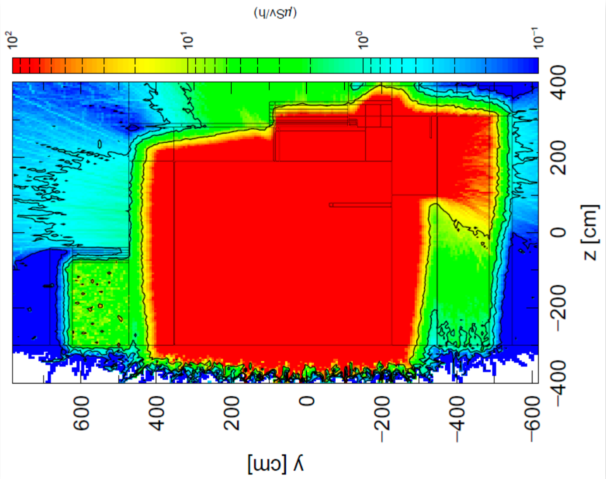
ESS-2495661 Rev 02 [2025/07/11]
BIFROST Cave Shielding Neutronics Simulations

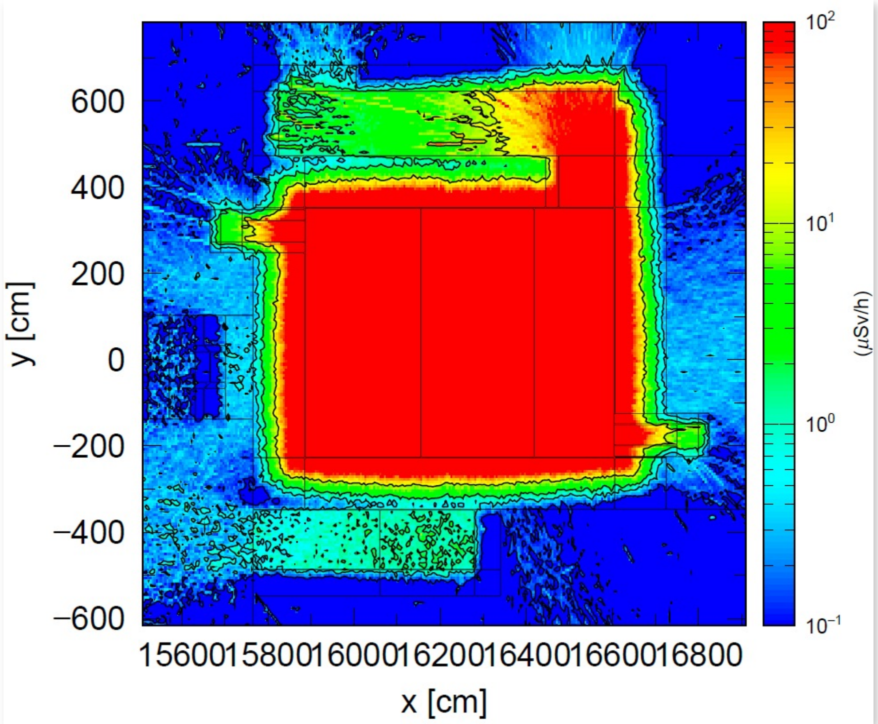


H2-2 CD CAPTURE

ESS-2495661 Rev 02 [2025/07/11]
BIFROST Cave Shielding Neutronics Simulations

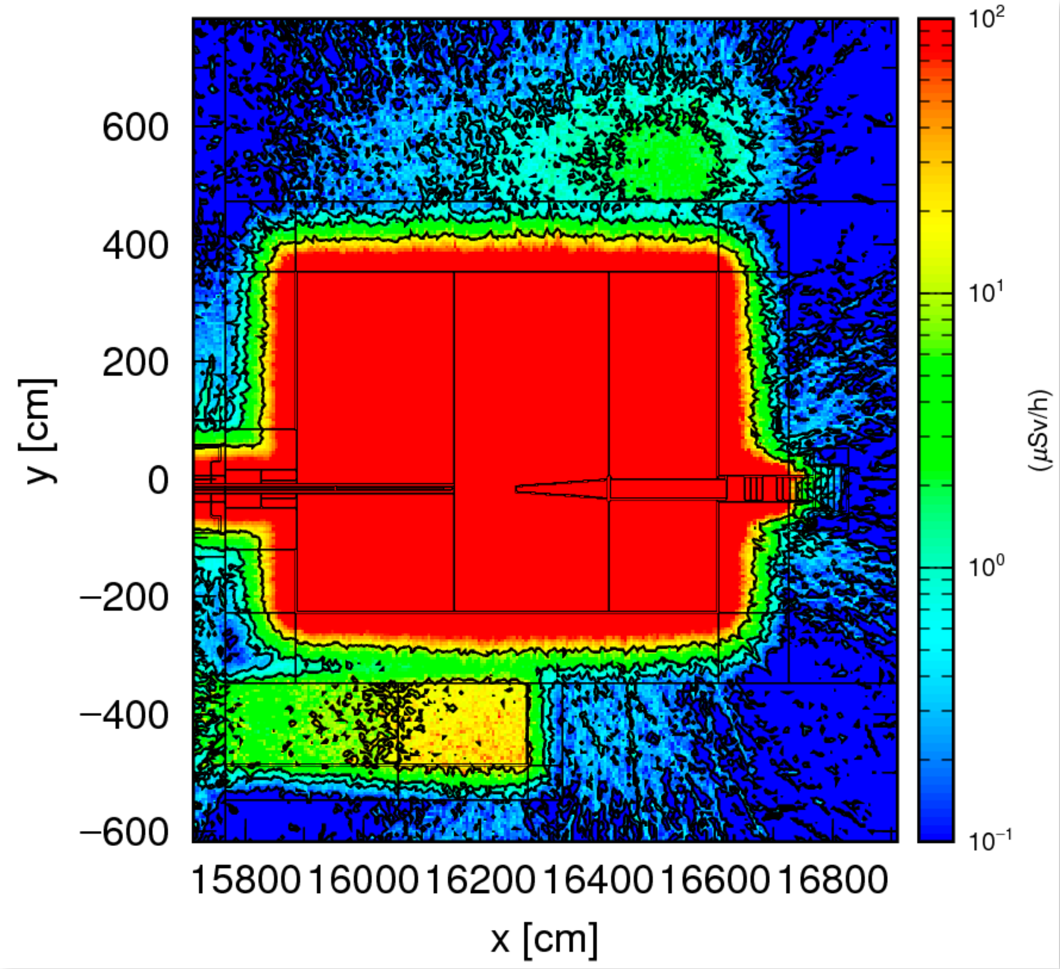






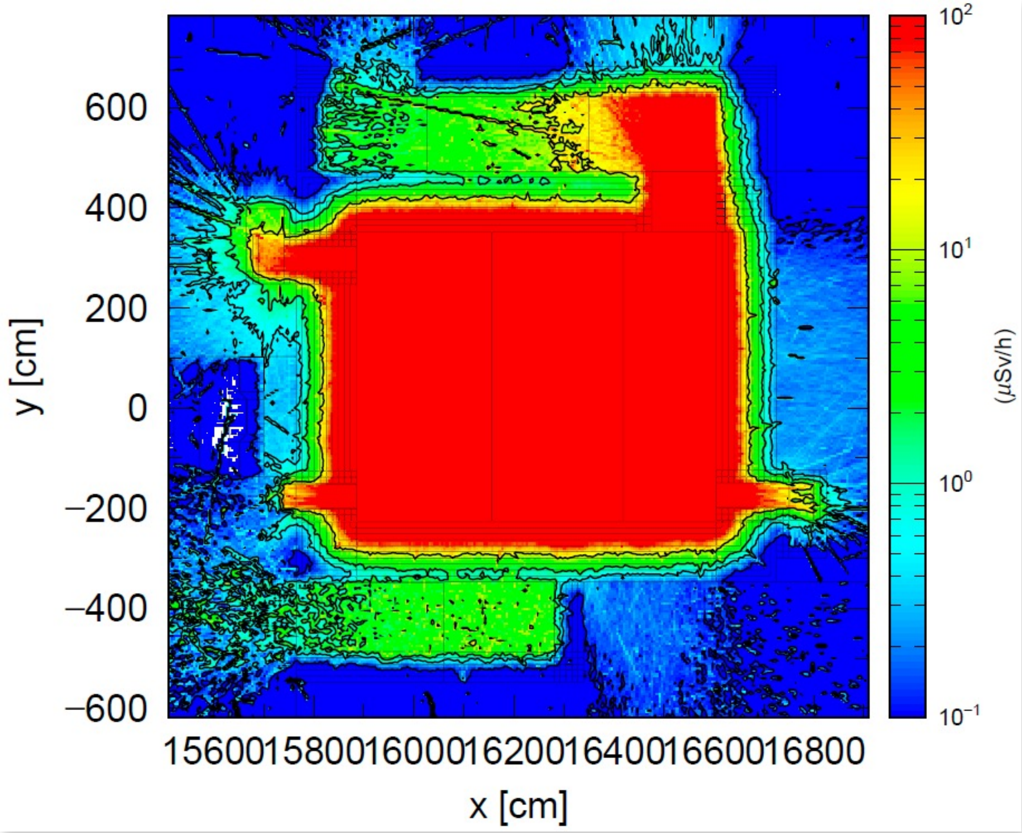
H2-1 UNCHOPPED BEAM ON BEAMSTOP

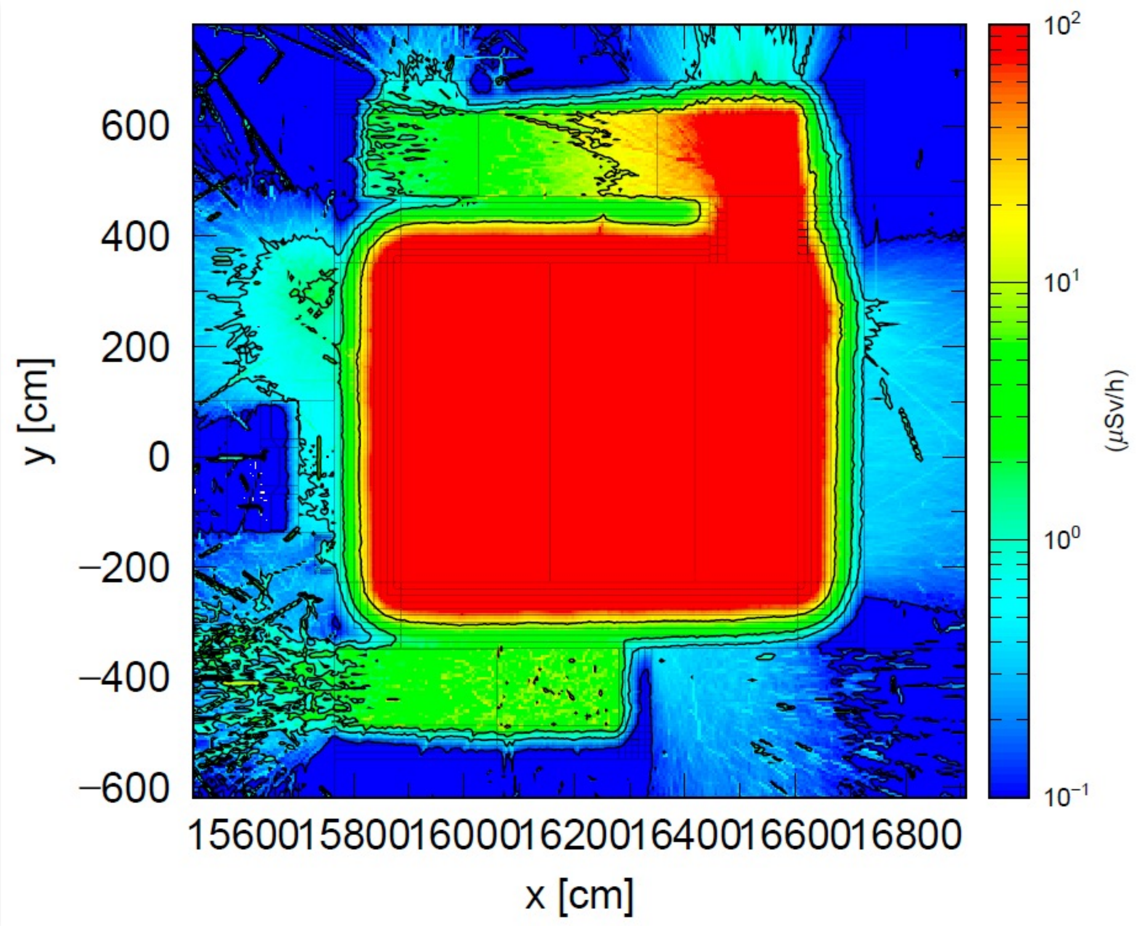
ESS-2495661 Rev 02 [2025/07/11]
BIFROST Cave Shielding Neutronics Simulations



H2-3 100% EFFICIENT ISOTROPIC SCATTERER

ESS-2495661 Rev 02 [2025/07/11]
BIFROST Cave Shielding Neutronics Simulations





H2-8 CLOSED DIVERGENCE JAWS

ESS-2495661 Rev 02 [2025/07/11]

BIFROST Cave Shielding Neutronics Simulations

11.3. H2-8, Divergence jaws next to the cave wall are closed at MOB.

The jaws are positioned next to the front wall of the cave. They contribute to the dose rate outside due to gamma radiation resulting from neutron capture in boron. Given spectrum of gamma radiation, the dose rate outside shielding can be calculated as follows [9]:

$$\dot{H}(R,d) = \sum_{E} B_{\text{dose}}(E,\mu d)e^{-\mu(E)d}K(E)\Phi(E,R)$$

Here $\Phi(E,R)$ is a flux of photons with energy E at distance R. Other quantities which enter the expression are table values and can be found in literature [10], [11], [12]. $K(E)$ is flux to dose conversion factor, $\mu(E)$ – linear attenuation coefficient and $B_{\text{dose}}(E,\mu d)$ is buildup factor which takes into account contribution of secondaries arising from Compton scattering of source photons, fluorescence and electron-positron pairs creation and annihilation. Spectrum of prompt photon radiation can be found in [13].

E,keV	K(E)	photon/neuron	Dose rate a 120 cm from jaws, µSv/h	
			Unshielded	120 cm concrete
477,595	8,89E-03	0,937173	3314,985	2,58E-05
2296,63	2,69E-02	7,07E-06	0,075651	7,49E-06
2533,35	3,51E-02	1,09E-05	0,151723	2,51E-05
4444,03	4,82E-02	5,1E-05	0,97899	8,95E-04
4474,5	4,82E-02	5,89E-07	0,011296	1,04E-05
4711,18	4,82E-02	2,03E-05	0,389086	4,37E-04
6739,67	6,50E-02	1,48E-05	0,382524	9,20E-04
7006,75	6,70E-02	4,28E-05	1,14101	3,12E-03
8916,6	7,92E-02	1,01E-05	0,317602	1,32E-03
11447,75	1,09E-01	3,66E-06	0,158947	1,11E-03
		Total dose:	3318,592	0,007872

A table represents contribution of boron lines to the dose rate outside the cave. Beyond 120 cm concrete shielding the dose rate due to absorption in boron slits arises mainly from low probability (n,gamma) reactions. Still, the dose rate is more than 2 orders magnitude below the acceptable limit of 1.5µSv/hr.