PSI Center for Neutron and Muon Sciences

Radiation Safety Assessment

Overview Including Technical Solutions

Artur Glavic (PSI)
Estia iSRR – Lund, 2026-06-17

Overview

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EUROPEAN SPALLATION SOURCE

Document Type	Analysis Report
Document Number	ESS-3836635
Date	9th February 2021
Revision	2
State	Released
Confidentiality Level	Internal
Page	1 (9)

ESTIA- H1 and H2 design scenarios

	Name	Role/Title
Owner	Jos Cooper	Estia Project Lead
Reviewer	Arno Hiess Joffrey Germa Valentina Santoro	Head of Scientific Activities Division Radiation Protection Engineer Neutronics Scientist
Approver	Andrew Jackson Günter Muhrer Sigrid Kozielski	Head of Neutron Instruments Division ESS Shielding Coordinator Radiation Protection Group Leader

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Document Type	Design Description
Document Number	ESS-0432926
Date	Apr 13, 2026
Revision	4
State	Released
Confidentiality Level	Internal
Page	1 (57)

ESTIA - Radiation Safety Analysis

	Name	Role/Title
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Reviewer	Alan Takibayev Yvonne Hinrichsen	Scientist, Target Division Radiation Protection Group
Approver	Andrew Jackson Günter Muhrer Per Roos	Group Leader for Large Scale Structures ESS Group leader Radiation Protection Group Leader for Radiation Protection ESS

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Document Type	Report
Document Number	ESS-6014372
Date	Apr 13, 2026
Revision	1
State	Released
Confidentiality Level	Internal
Page	1 (25)

COMPREHENSIVE RADIATION SAFETY ASSESSMENT OF ESTIA

	Name	Role/Title
Owner	Fabian Valenzuela Lundkvist	Safety Engineer, ESH&S Division
Reviewers	Joshaniel Cooper	Lead Instrument Scientist of ESTIA
	Ana Cintas	Radiation Protection Expert, ESH&S Division
	Alan Takibayev	Spallation Physics Scientist, Target Division
Approvers	Andrew Jackson	Head of LSS Division
	Per Roos	Group leader, Radiation Protection Group
	Günter Muhrer	Group Leader for ESS Spallation Physics, Target Division

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Document Type	Verification Report
Document Number	ESS-6056497
Date	May 11, 20266
Revision	1
State	Released
Confidentiality Level	Internal
Page	1 (4)

ESTIA SHIELDING VERIFICATION REPORT

	Name	Role/Title
Owner	Joshaniel Cooper	ESTIA project lead, LSS
Reviewer	Ana Cintas	Radiation Protection Expert
Approver	Per Roos	Group Leader, Radiation Protection

H1/H2 Scenarios

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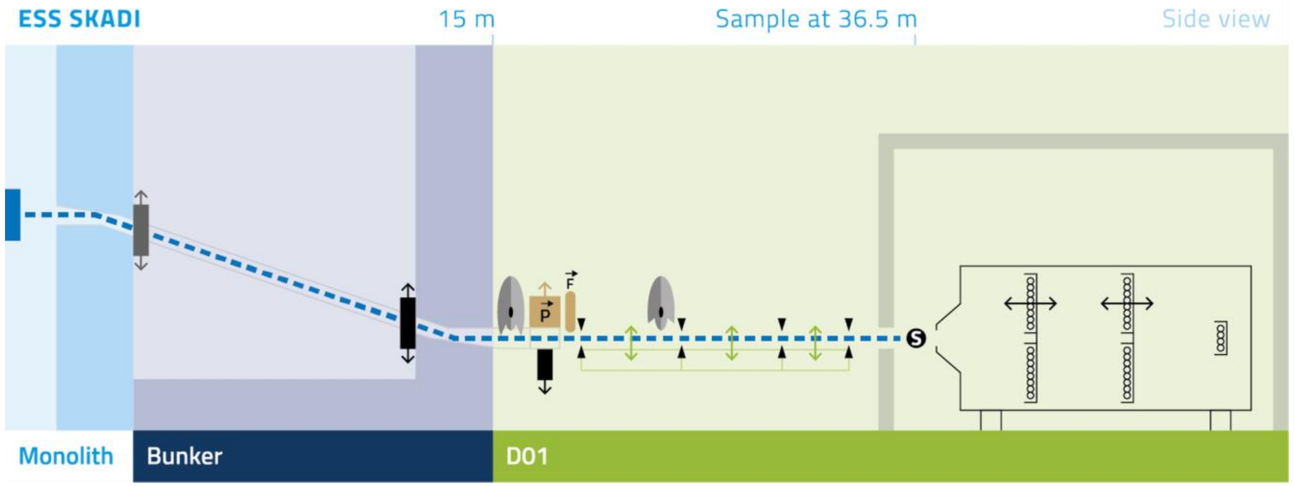
From simulation:
Maximum neutron current before shutter: 3.3×10^9 n/s (6% of LOKI)
Maximum neutron current at sample position : 2.1×10^9 n/s

Document Type Analysis Report
Document Number ESS-3836635
Date 9th February 2021
Revision 2
State Released

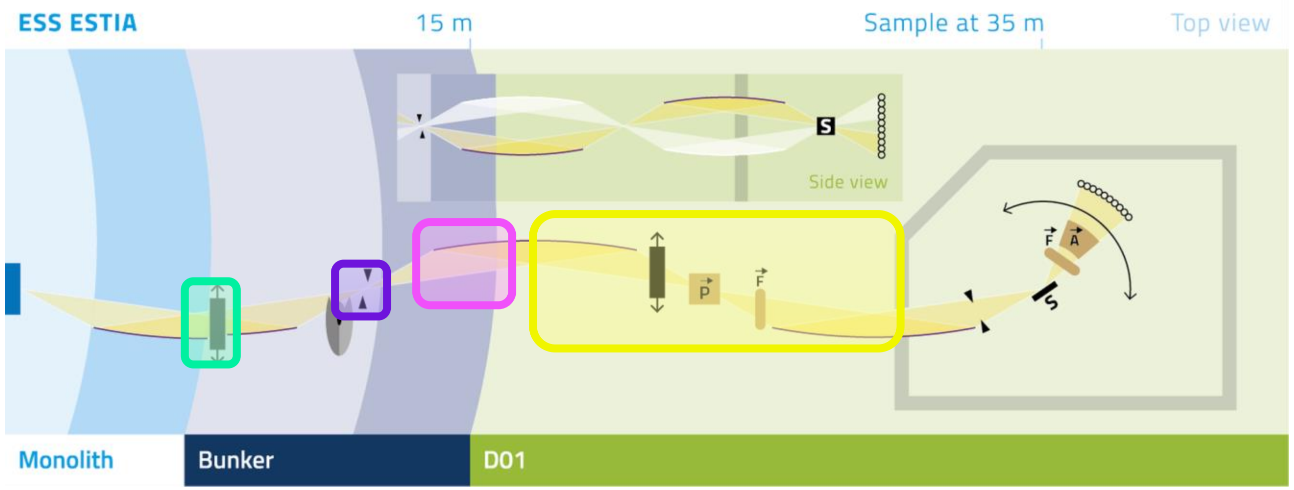
#	Cause / Instrument state	Access to areas
H1-1	Standard operation with full beam	outside boundary
H1-2	Instrument shutter closed	experimental cave; middle-focus
H1-3	100% incoherent neutron scattering at sample position	outside boundary
H1-4	Cd/Gd containing sample substrates	outside boundary
H1-5	100% incoherent scattering at middle focus	outside boundary
H1-6	Beam fully blocked by boron containing mask at the middle focus	outside boundary
H2-1	Cd sheet blocking full beam at sample position	outside boundary

Radiation Safety Analysis – Estia is Different

Typical "short" ESS beamline:



Estia beamline layout:



- 4-sided neutron guide with small variation in cross-section
- T0-chopper or LoS avoidance in bunker
- Penetration through bunker wall within steel vessel, only guide cross-section open
- Guides requiring shielding outside of bunker

- Large 80x200mm² opening in insert

- Precision optics, requiring large cut-out in bunker wall that needs to be compensated

- Small choke point used for compensation, especially against high energy neutrons

- Low number of reflections and flux while integrating shielding in guide
  ➔ No outer shielding required

Radiation Safety Analysis

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4. ACCEPTENCE CRITERIA

4.1. Component optimization for shielding characteristics

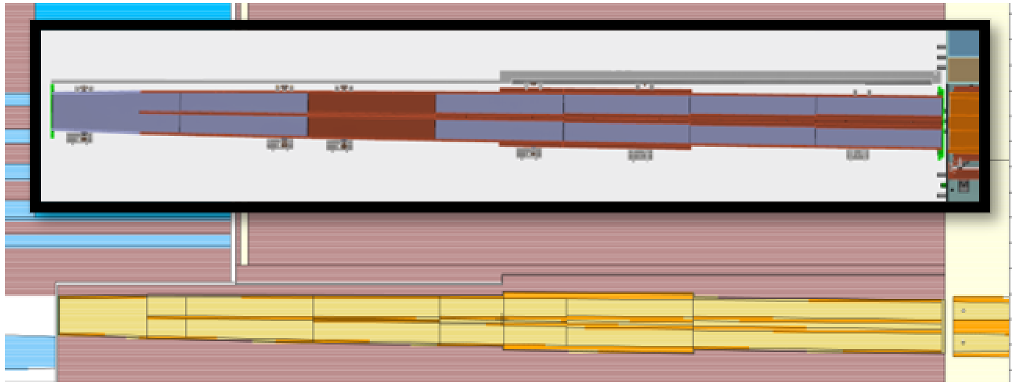
Following the ALARA principle we did not only assess the safety of the shielding but made comparisons of the effectiveness of specific crucial components. The items were considered optimal if they provide measurable improvement over alternatives without significant extra design effort or construction cost.

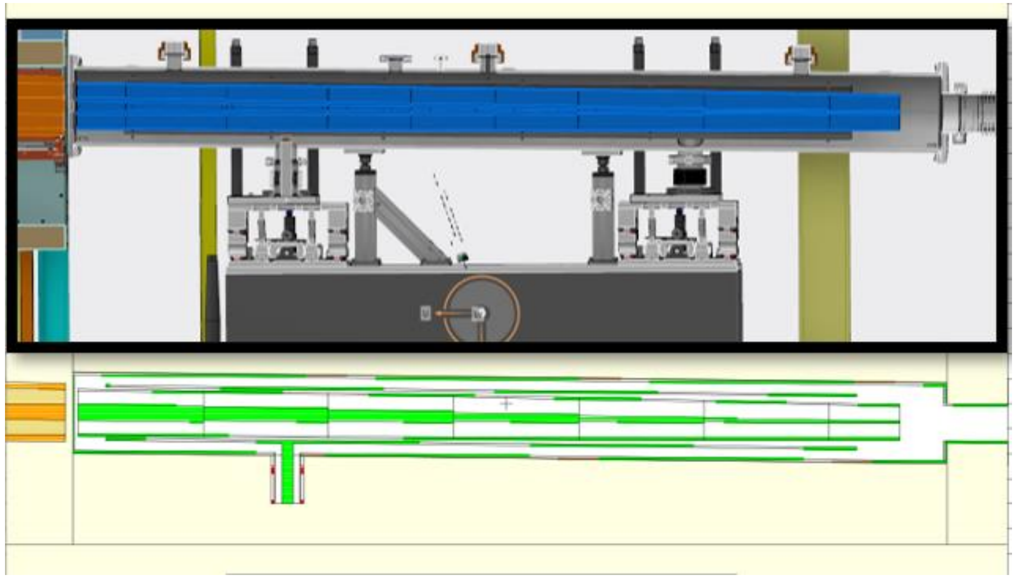
In addition, the acceptance criteria reported in the ESS document ESS-1108220 “Guideline and rules for instrument shielding design were taken into consideration:

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 [20], 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, which in this case is 2 [21].

Special situation for Estia above guide, see later discussion

Shielding Solutions – Beam Extraction



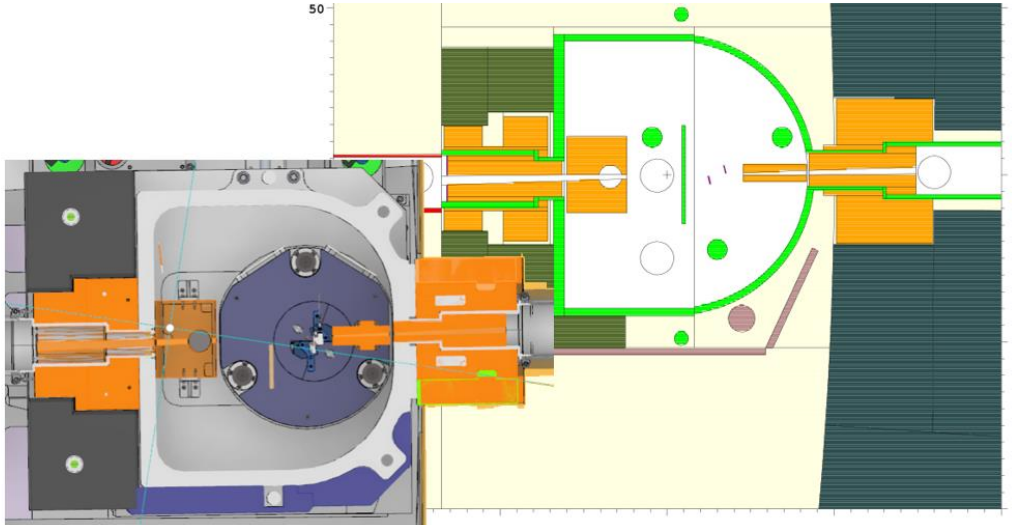


- Neutron feeder and BBG feature heavy collimation plates that split the large opening into two separate channels

➔ Supports breaking line-of-sight towards Virtual Source and reduces size and view of monolith opening.

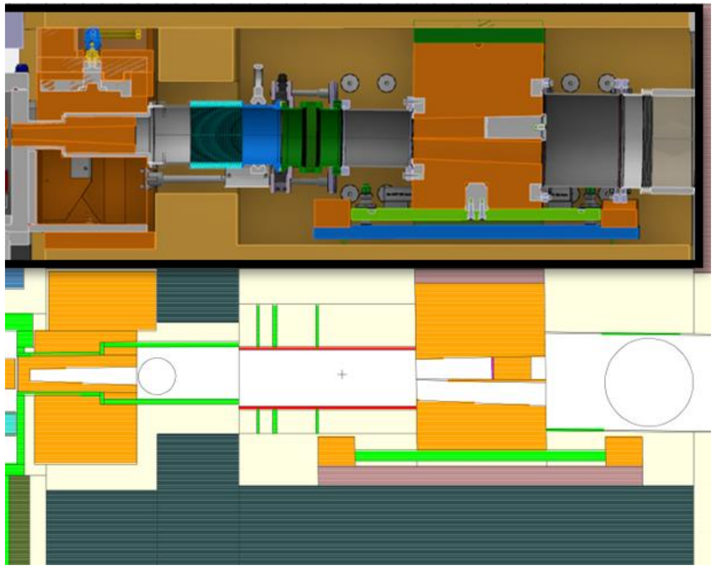
(Installation verified in NBOA SAT **ESS-5919359**)

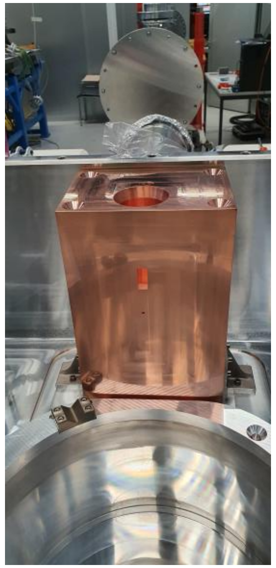
Shielding Solutions – Choke Points

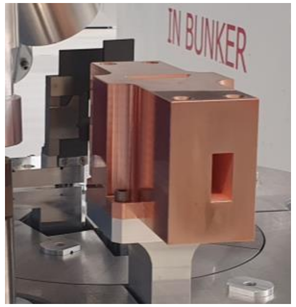


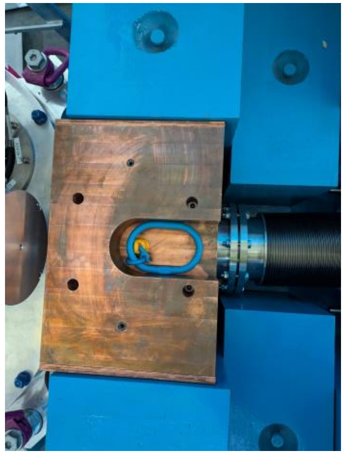
- Choke point around Virtual Source is used with multiple heavy collimation elements (copper) that compensate for missing bunker wall volume
- After each collimator a space allows scattered neutrons to escape to avoid albedo transport (streaming)

➔ Effective suppression of fast neutrons leaving the bunker and reduction of beamline background.



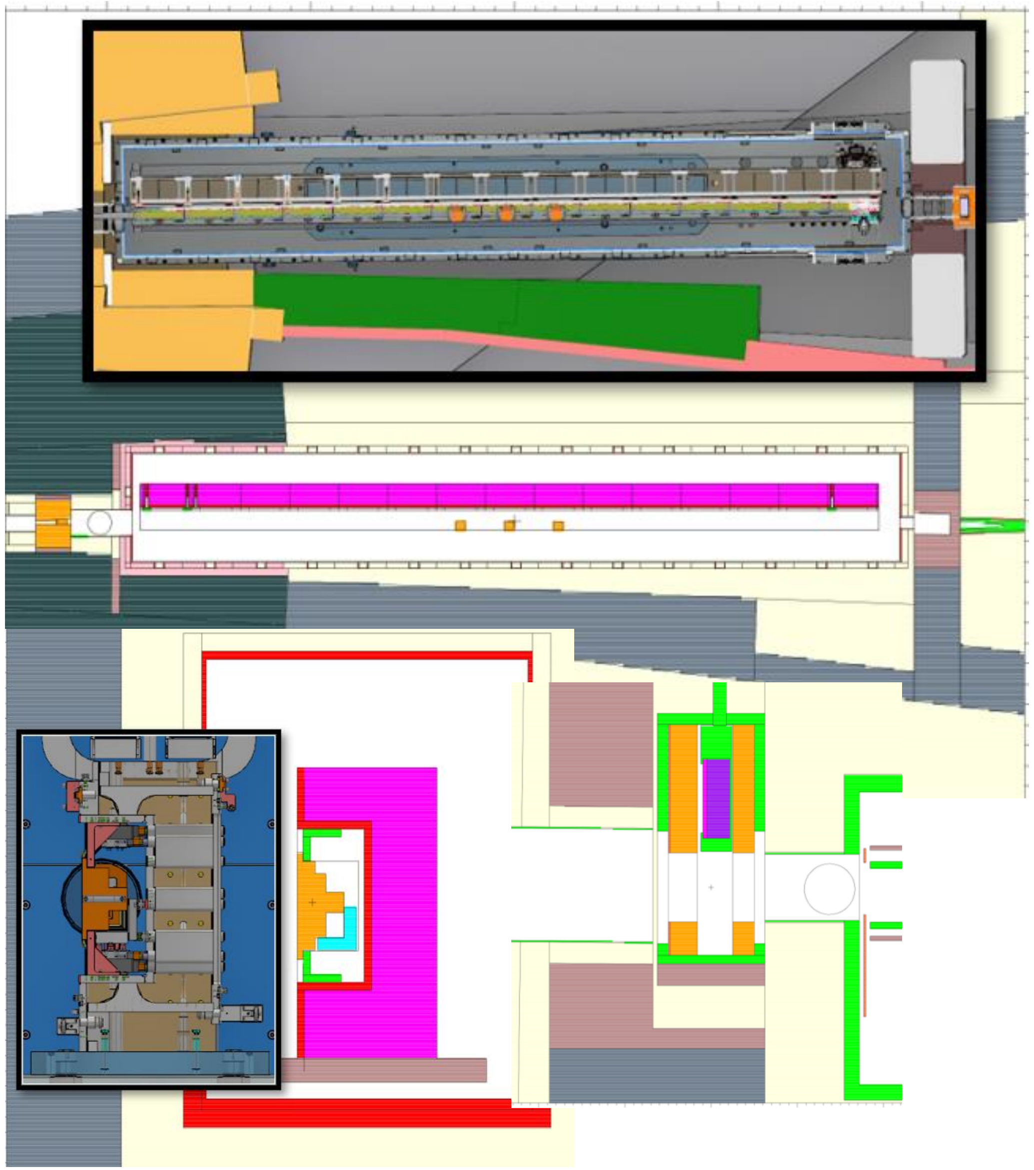






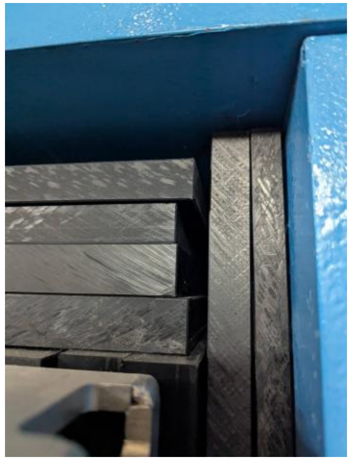
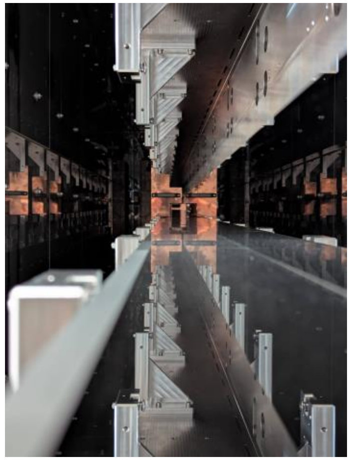
(Inspection reports Chopper/BWI: **ESS-5912344/ESS-5912345**)

Shielding Solutions – Selene 1 Area



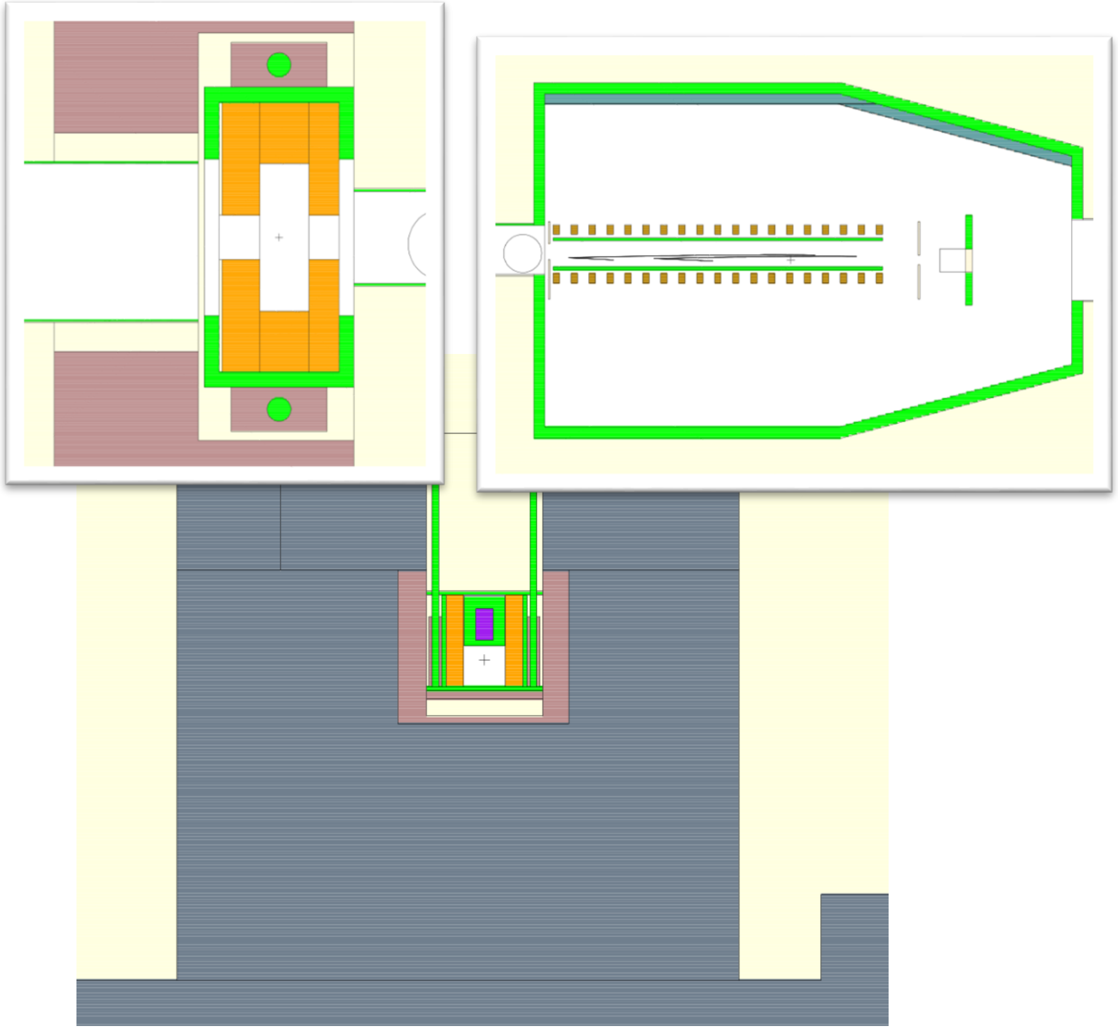
- Residual gaps between vacuum tank and bunker wall are filled with HDPE shielding.
- Establish a bunker-side access area around Selene 1, separated with a wall that includes the instrument shutter
- Potential direct view into the bunker is blocked by 3 extra copper blocks within the guide vacuum
- Borated mineral cast in support structure

➔ Allow full access to all areas downstream of the wall and further reduce instrument background.

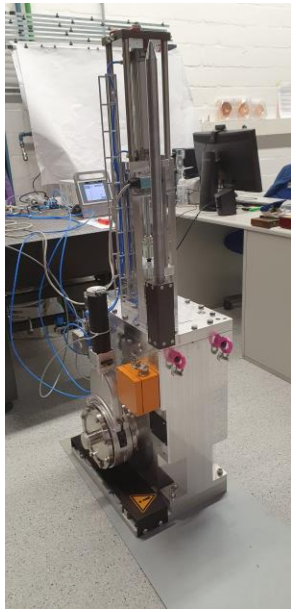



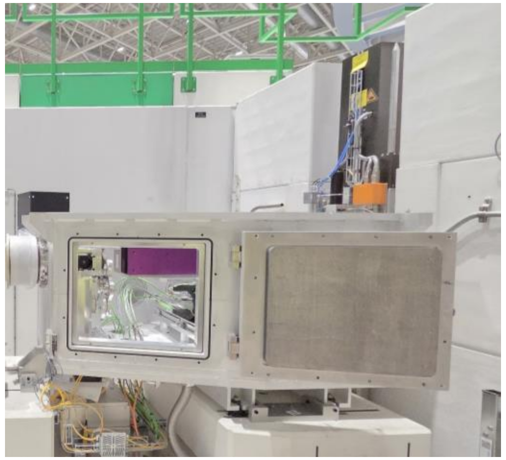

(Inspection report SG1: **ESS-5912346**)

Shielding Solutions – Shutter Area and Middle-Focus



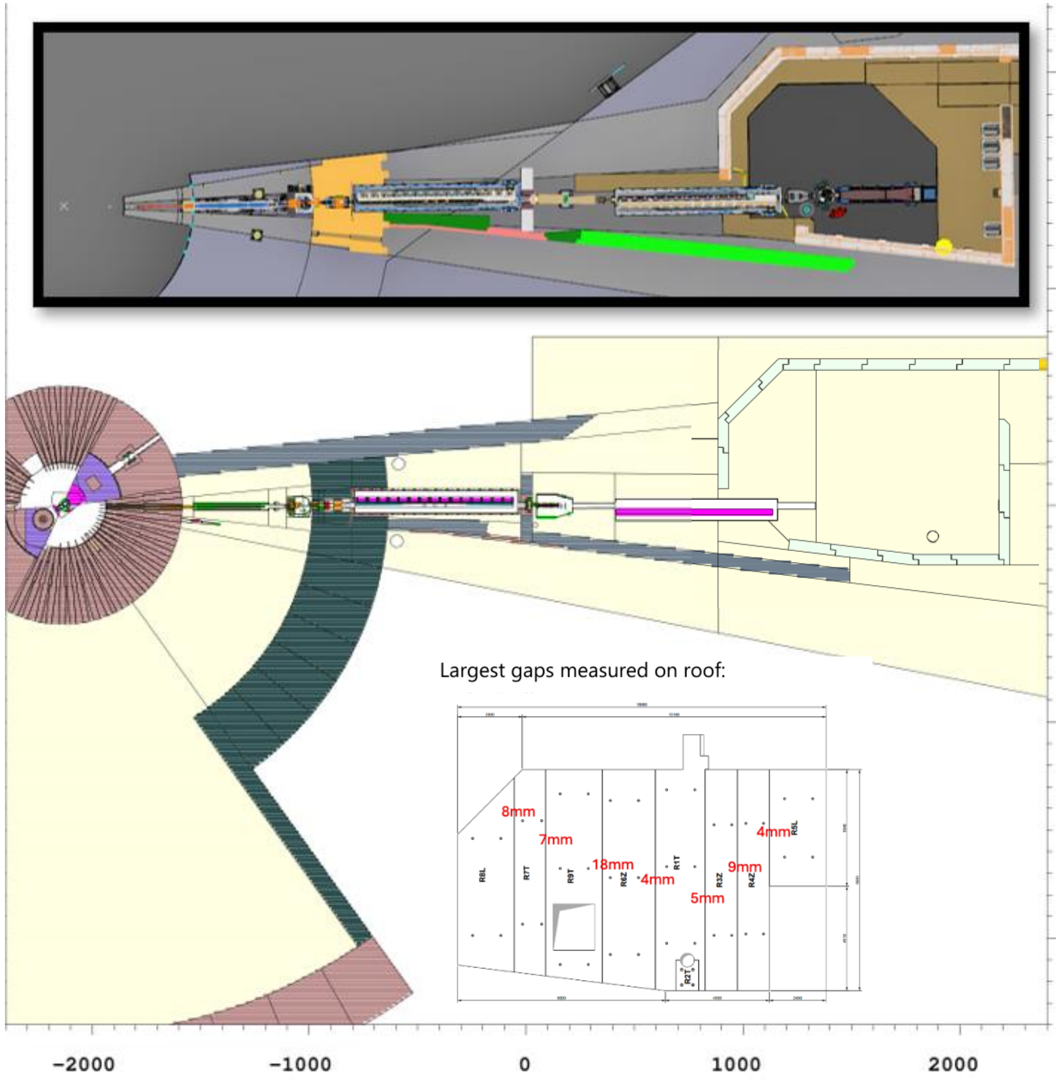
- As only cold neutrons need to be blocked, simple B4C with lead and copper blocking gammas is sufficient
- Shutter operates fail-safe within vacuum using pneumatic cylinder and bellow against gravity + vacuum force
- Middle-Focus houses neutron polarizer and mask changer, for gammas produced there the vacuum chamber includes lead lining



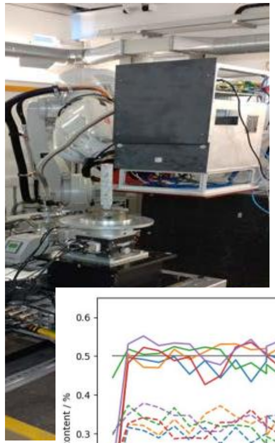


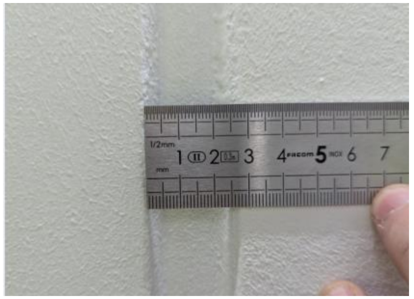
(Shutter inspection report: **ESS-5492754**)

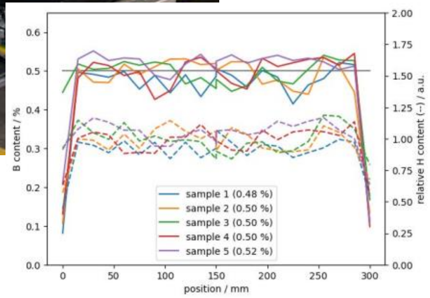
Shielding Solutions – Experimental Cave



- Downstream of the shutter, the experimental cave is primarily mitigating secondary radiation from interaction of the beam with specific sample materials.
- The walls and ceiling are normal concrete with small boron content to reduce gammas from scattered neutrons and instrument background.



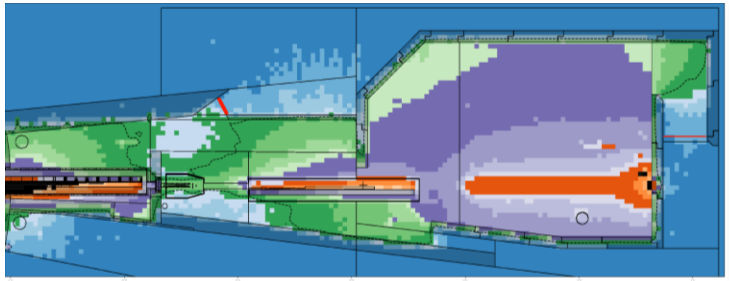




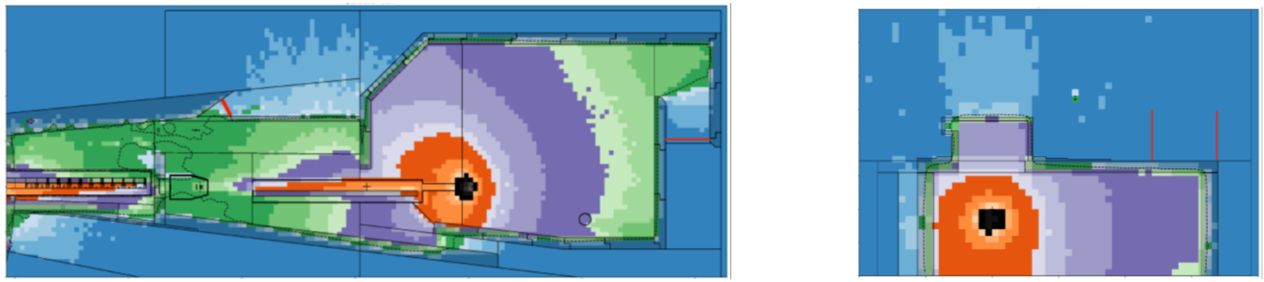
(Boron distribution verification: **ESS-6045167**
Cave inspection/SAT report: **ESS-5980377/ESS-5967162**)

Shielding – Calculation Results

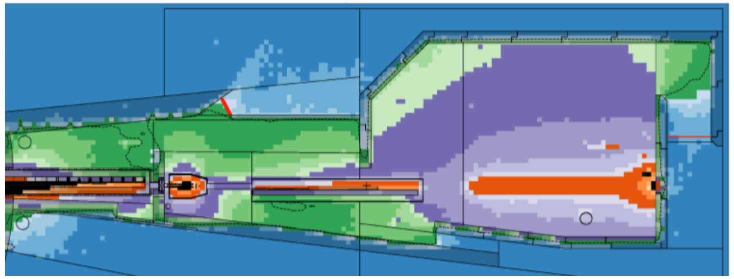
H1-1 Open Beam - Unpolarized



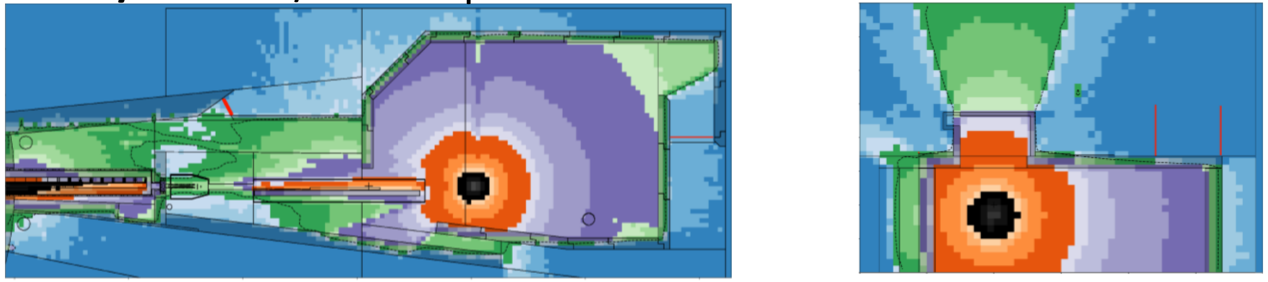
H1-3 Water Sample



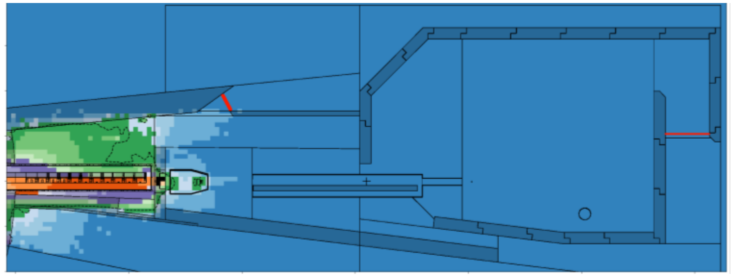
H1-1 Open Beam - Polarized



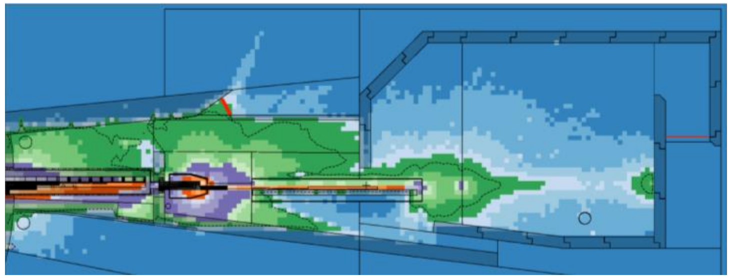
H1-4/H2-1 Cd/Gd Sample



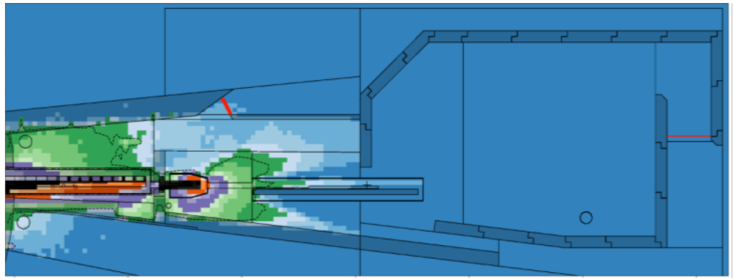
H1-2 Shutter Closed

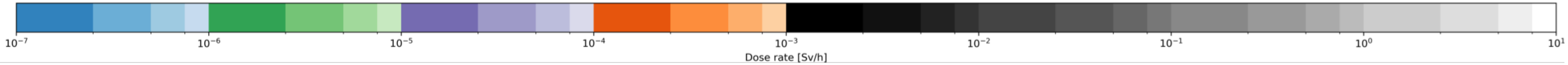


H1-5 Vanadium at Middle-Focus



H1-6 Boron Mask at Middle-Focus





Deviation from Guidelines for Instrument Shielding Design

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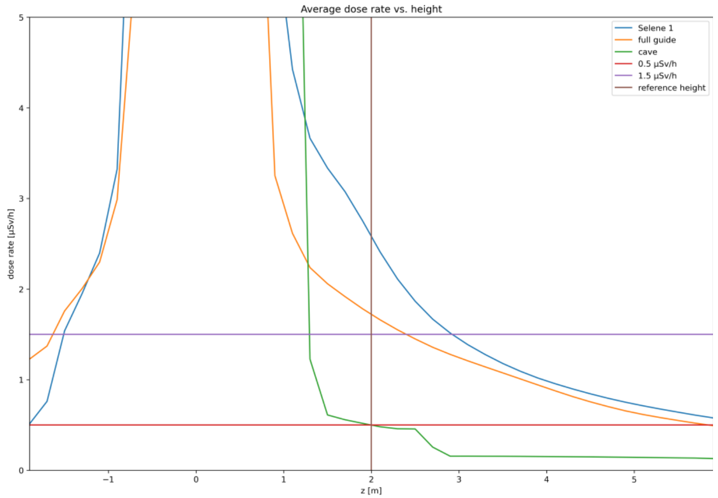
- For the area above the neutron guide, Estia exceeds the recommended 0.5 µSv/h average value due to the missing guide shielding
- All relevant dose from Estia is gamma radiation from the guide
- The evaluation that this recommendation is based on (ESS-1108220) finds only minimum impact from the Estia instrument to the relevant locations
- An exception of this limit was therefore granted

Table 3 **Calculated instrument contributions at the reference points**

Ref. Point	Total	LOKI	FREIA	ESTIA	SKADI	VESPA	DREAM	ODIN	NMX	BEER	CSPEC	BIFROST	MIRACLES	MAGIC	T-REX	HEIMDAL	Test BL
1	18.4					0.1	0.1	0.0	0.0	0.8	2.4	7.7	5.8	0.5	0.5	0.3	0.2
2	31.9					0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.6	2.0	21.4	7.6	0.2
3	26.0					0.1	0.0	0.0	0.0	0.4	1.1	3.8	16.6	2.4	1.0	0.5	0.2
4	103.1					0.3	0.3	0.3	0.0	2.0	4.2	11.2	52.4	16.8	10.1	4.5	1.0
5	8.3			0.0	0.0	0.3	5.3	2.1						0.1	0.1	0.0	0.3
6	8.4			0.0	0.0	0.3	5.4	2.1						0.1	0.1	0.0	0.3
7	7.4			0.0	0.1	0.3	4.6	1.6						0.1	0.1	0.1	0.5
8	27.4			0.2	0.3	1.6	12.3	7.7	1.0	0.3				0.6	0.6	0.3	2.4
9	4.8	0.7	0.9			0.7	0.2	0.2						0.2	0.2	0.2	1.5
10	4.8	0.8	0.9			0.7	0.2	0.2						0.2	0.2	0.2	1.5
11	34.0	3.8	0.0			0.5	0.3	0.4						0.0	0.0	28.0	1.0
12	38.4					0.6	0.8	0.7	16.3	8.7	3.9	3.0	1.6	0.3	0.8	0.4	1.3
13	15.2			0.3	0.3	0.5	1.7	1.3	3.7	2.4	1.2	1.0	0.6	0.2	0.4	0.2	1.2



COMPREHENSIVE RADIATION SAFETY ASSESSMENT OF ESTIA

7.1.2. H1 events

It should be noted that the third requirement in those listed above is not met, which is illustrated in Chapter 12 of [7]. However, during workflow *R-0194363* [21], this discrepancy was accepted by the Large Scale Structures Division.

Radiation Safety Assessment

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ESTIA SHIELDING VERIFICATION REPORT

6. CONCLUSIONS

All components of shielding for the ESTIA instrument are required for the shielding of the instrument both with the shutter closed as well as open based on the radiation shielding calculations [2]. The radiation protection function of the shielding for the ESTIA Instrument has been verified by Radiation Protection.

COMPREHENSIVE RADIATION SAFETY ASSESSMENT OF ESTIA

8. CONCLUSIONS

This report concludes that the applied safety provisions are satisfactory with respect to radiation safety in ESTIA. Identified deviations (see Section 7.1.2) from the requirements are accepted by the Large Scale Structures division.

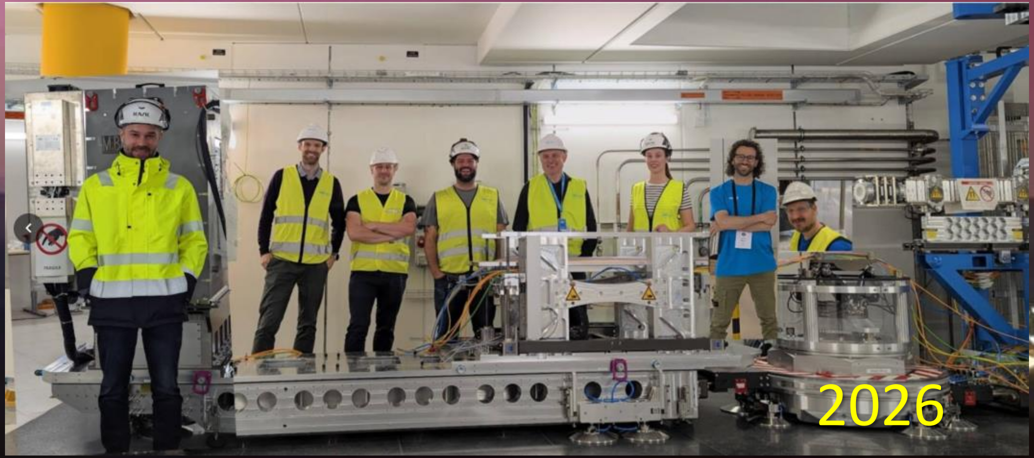
The calculations have been performed with an assumed 5 MW proton beam which is the highest possible beam power. Consequently, the conclusions drawn from the calculations are valid for any beam power.

Thank you for your attention!

Small Sample Polarized Reflectometer

Estia

ESS EUROPEAN SPALLATION SOURCE Instrument



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