

# INSTRUMENT SAFETY READINESS REVIEW

## DREAM RADIATION SHIELDING CALCULATIONS

26.03.2026 | TSITOHAINA RANDRIAMALALA

# OVERVIEW

## Documentation



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### DREAM: H1 AND H2 SCENARIOS FOR RADIATION SHIELDING

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- Biological shielding components
- H1/H2 scenarios definition
- Shielding strategy description



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### DREAM - Radiation Safety Report

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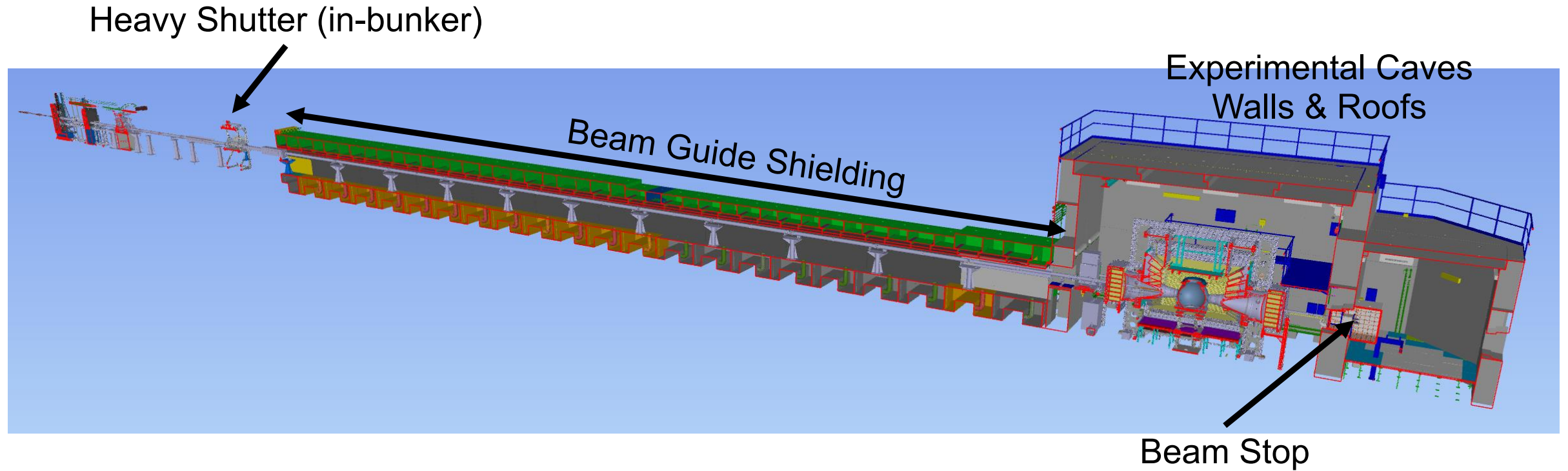
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- Report on the neutronic calculations
- Demonstrate compliance with radiation safety limits

# OVERVIEW

## Biological Shielding Components



# HAZARDS SCENARIO

#	Cause	Event	Effect
H1.1	Unspecified bulky sample environment	MOB hit on a bulky aluminium piece of sample environment	Aluminium prompt gamma generated at the sample position
H1.2	Empty sample	MOB dumped onto the beam stop	Prompt gammas generated at the beam stop and fast neutrons scattered back into the experimental cave
H1.3	Strong neutron scattered sample	About 0.3% of MOB isotropically scattered from the sample	High activation at the inner surface of the walls of experimental cave
H1.4	Neutron guide	MOB propagating in the last focusing section	Hard gammas generated from the beam guide coating and substrate

#	Cause	Event	Effect
H2.1	All choppers parked in open position	AOB dumped onto the heavy shutter	The radiation dose rate downstream beam to the heavy shutter is less than 3 mSv/h.
H2.2	All choppers and heavy shutter parked in open position	AOB transported along the entire guide	Hard gammas generated along the entire guide, highest current of fast neutrons streaming outside the bunker area, highest prompt- gammas generated at the beam stop and highest flux of fast neutrons scattered back into the experimental cave
H2.3	Cadmium sheet at the sample position	The entire MOB neutrons converted into photons at the sample position	Highest radiation dose rate generated at the sample position

- ESS accelerator operating at 5MW and proton beam energy of 2 GeV
- Thermal neutron flux/current:
  - **Accidental Open Beam (AOB):** 1E+10 n/cm<sup>2</sup>/second upstream beam of the heavy shutter
  - **Maximum flux Operation Beam (MOB):** 6E+9 n/second at sample position
- Fast neutron flux: 3E+7 n/cm<sup>2</sup>/second

# SHIELDING STRATEGY

#	Cause	Event	Effect
H1.1	Unspecified bulky sample environment	MOB hit on a bulky aluminium piece of sample environment	Aluminium prompt gamma generated at the sample position
H1.2	Empty sample	MOB dumped onto the beam stop	Prompt gammas generated at the beam stop and fast neutrons scattered back into the experimental cave
H1.3	Strong neutron scattered sample	About 0.3% of MOB isotropically scattered from the sample	High activation at the inner surface of the walls of experimental cave
H1.4	Neutron guide	MOB propagating in the last focusing section	Hard gammas generated from the beam guide coating and substrate

Cave Walls Activation

#	Cause	Event	Effect
H2.1	All choppers parked in open position	AOB dumped onto the heavy shutter	The radiation dose rate downstream beam to the heavy shutter is less than 3 mSv/h
H2.2	All choppers and heavy shutter parked in open position	AOB transported along the entire guide	Hard gammas generated along the entire guide, highest current of fast neutrons streaming outside the bunker area, highest prompt-gammas generated at the beam stop and highest flux of fast neutrons scattered back into the experimental cave
H2.3	Cadmium sheet at the sample position	The entire MOB neutrons converted into photons at the sample position	Highest radiation dose rate generated at the sample position

Heavy Shutter

Beam Guide Shielding & Beam Stop

Experimental Cave

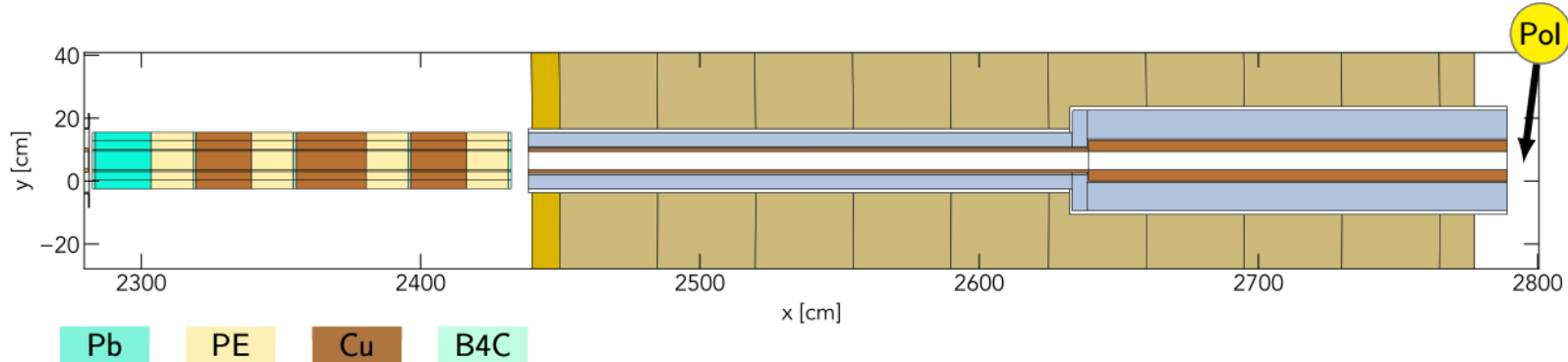
# RADIATION SHIELDING

# NEUTRONIC CALCULATIONS

- Optimization of the shielding components based on Monte Carlo simulations using PHITS
- Acceptance criteria ( radiation dose rates limits ):
  - *Supervised area* : 1.5  $\mu\text{Sv/h}$  (incl. safety factor of 2)
  - *Controlled area* (experimental cave roof) : 12.5  $\mu\text{Sv/h}$  (incl. safety factor of 2)
  - Outer surface dose: 0.5  $\mu\text{Sv/h}$

# HEAVY SHUTTER

## Input Geometry



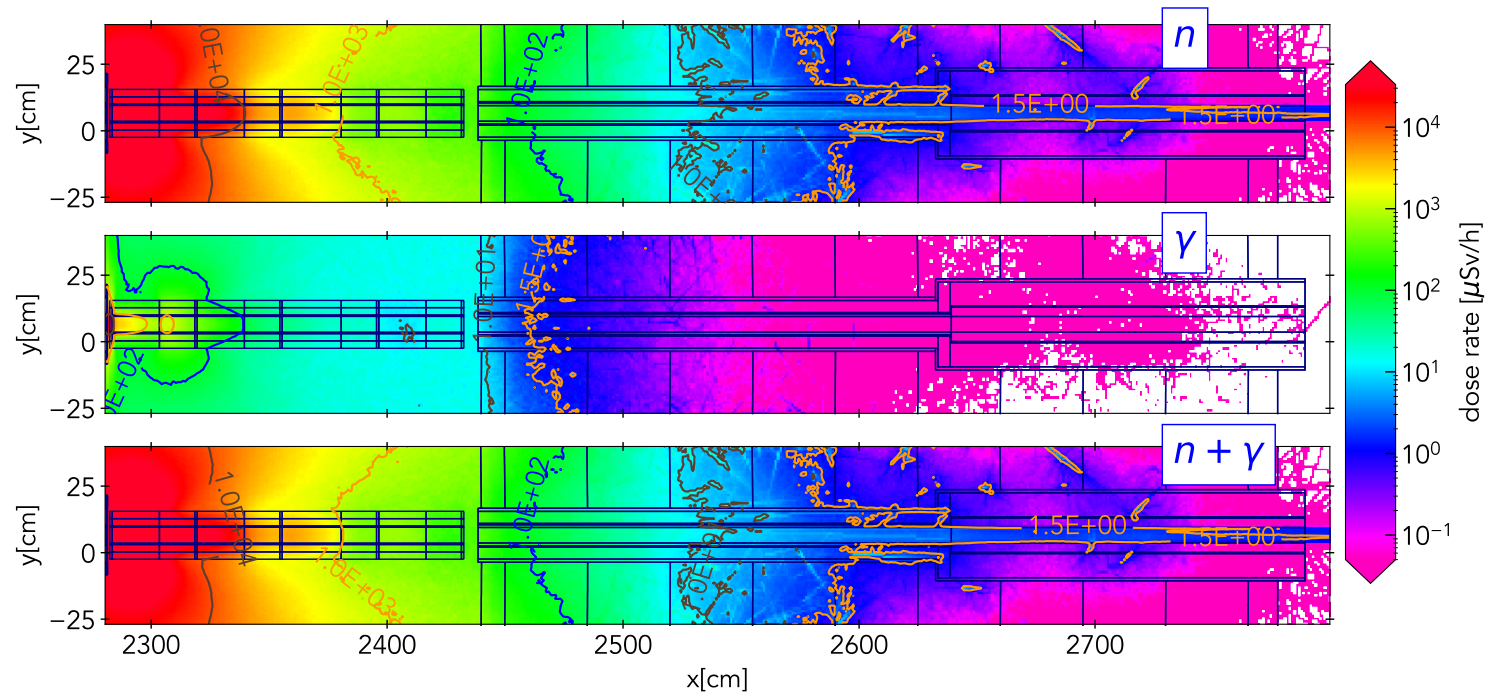
- Heavy shutter dimension (L × W × H) = 150 cm × 18 cm × 18 cm

## Acceptance criteria

- Heavy shutter ensures safe access to the outside bunker region during operation.
- Position of Interest (Pol) : *supervised area*
- Dose rate limit at Pol : <math><1.5 \mu\text{Sv/h}</math> from *H2.2 simulation*

# HEAVY SHUTTER

## Radiation Dose Map

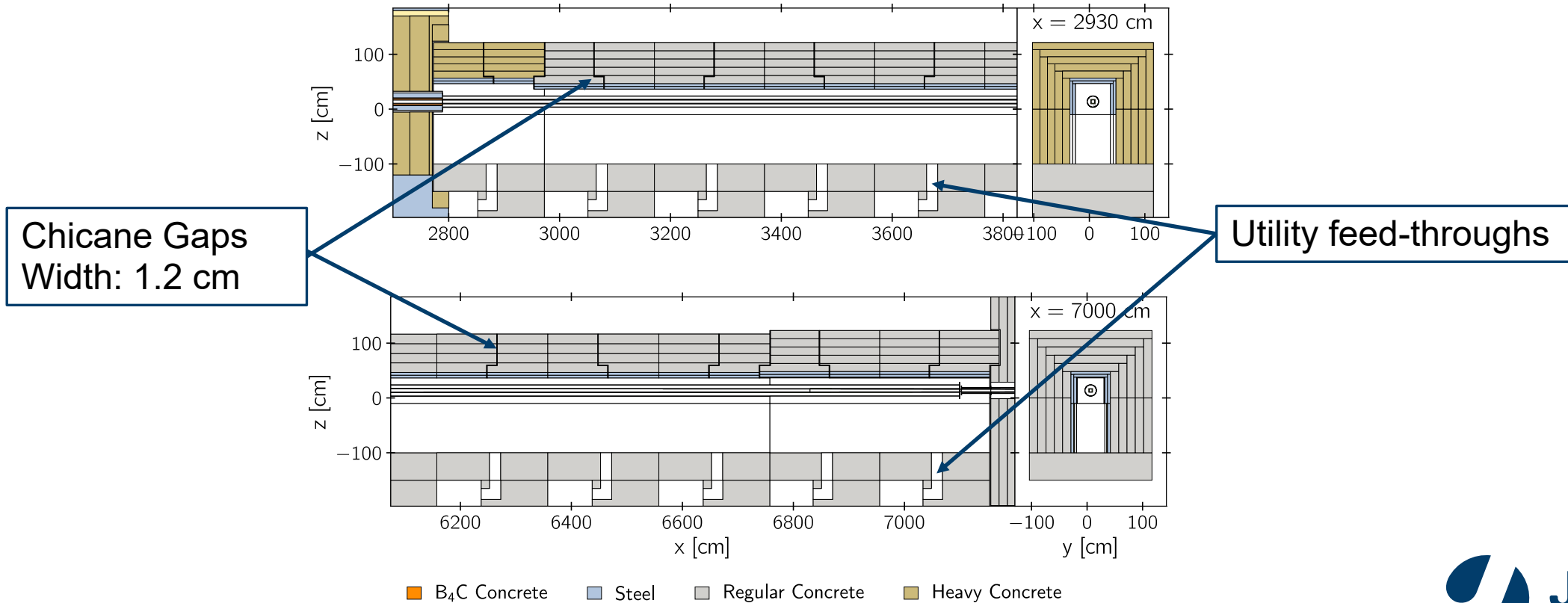


Dose rate measured at PoI - *H2.2 simulation*:  
 $1.12 \pm 0.10 \mu\text{Sv/h}$  ( over 6 cm  $\times$  6 cm the beam guide cross section )

# NEUTRON BEAM GUIDE SHIELDING

## Shielding Geometry

- Multi-layer shielding configuration: *B<sub>4</sub>C-concrete* + *Steel* + *Concrete*
- Includes potential radiation leakage paths: *gaps* and *feed-throughs*



# NEUTRON BEAM GUIDE SHIELDING

## Thicknesses of Layers

*Table 6-1 Thicknesses of the beam guide shielding layers for different regions. Units are in millimetres.*

Region		Upper Part				Lower Part		
Start	End	B4C Cement	Steel	Heavy Concrete	Regular Concrete	B4C Cement	Steel	Regular Concrete
27726	29726	-	100	650/675 <sup>a</sup>	-	-	-	650
29726	51572	-	100	-	750	-	50	750
51572	67575	-	100	-	700	-	50	700
67575	71575	15	100	-	750	15	50	750

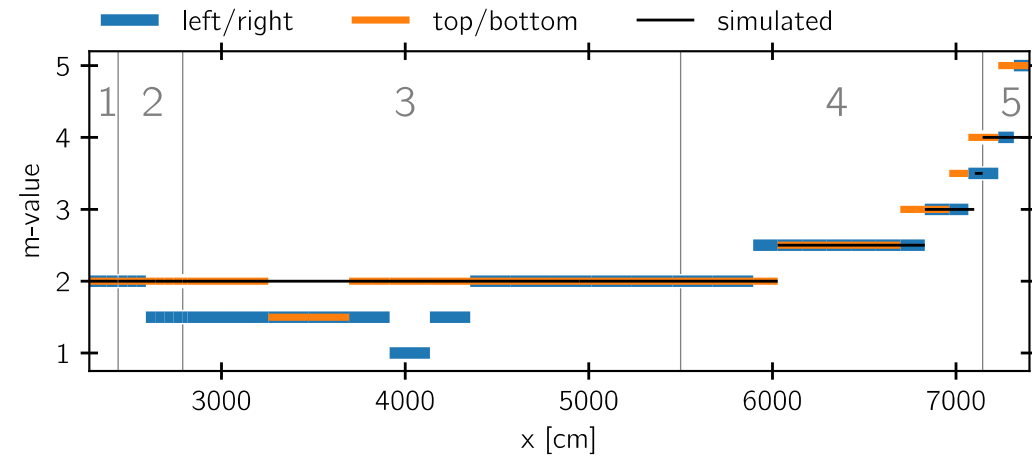
<sup>a</sup> Top/Side

# NEUTRON BEAM GUIDE SHIELDING

## Neutron Guide

Conservative supermirror configuration:

- Slightly higher m-values considered

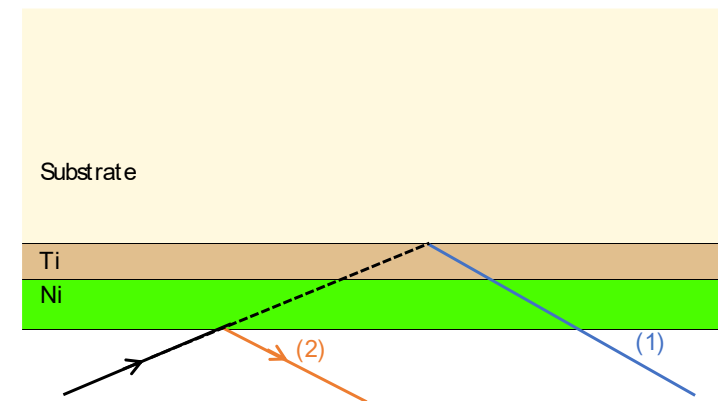
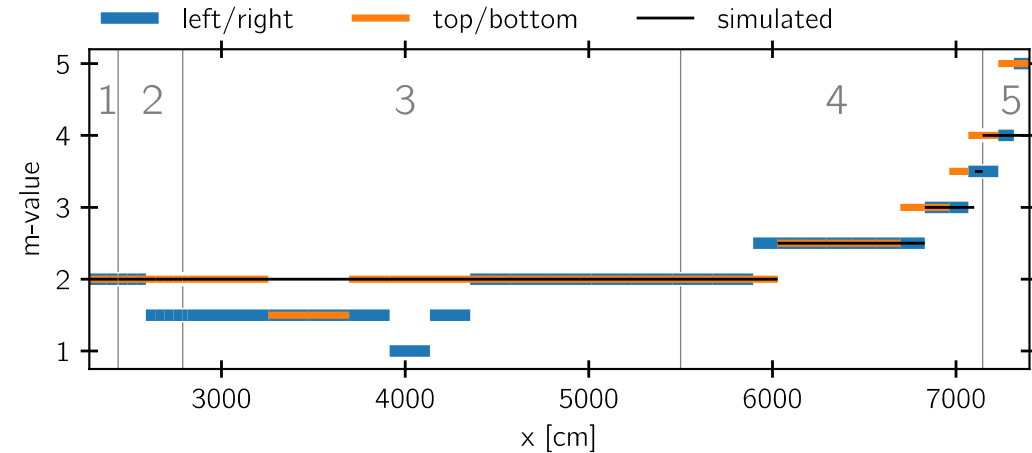


# NEUTRON BEAM GUIDE SHIELDING

## Neutron Guide

Conservative supermirror configuration:

- Slightly higher m-values considered
- Ni/Ti bilayer model
- Two distinct reflection configurations evaluated

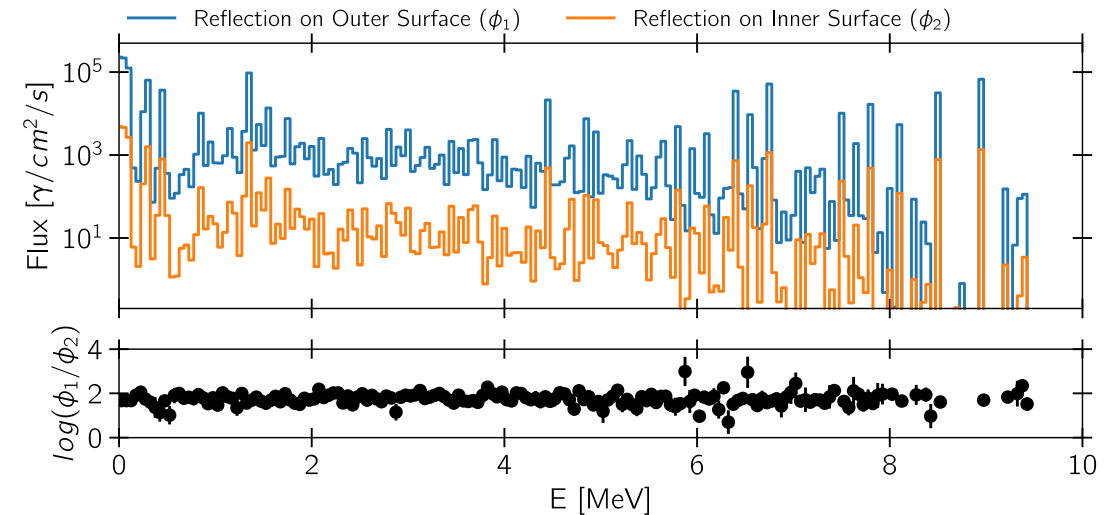
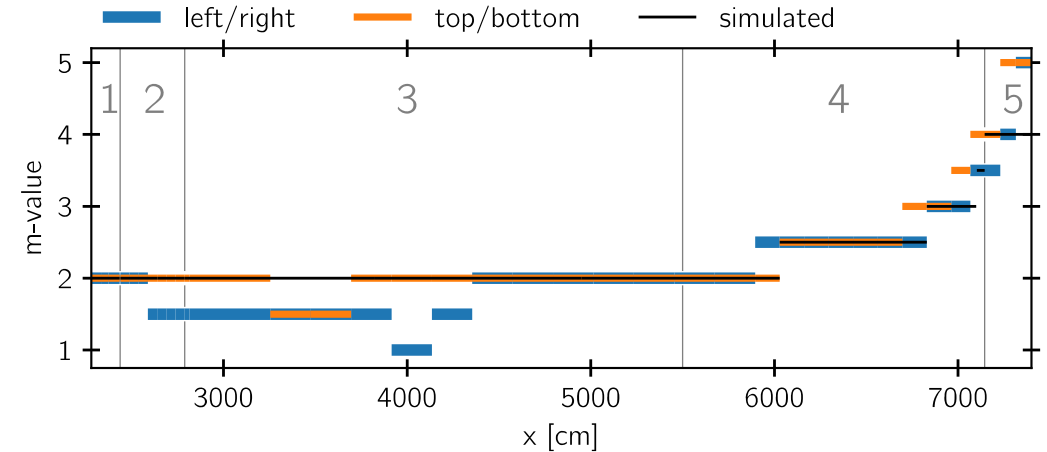


# NEUTRON BEAM GUIDE SHIELDING

## Neutron Guide

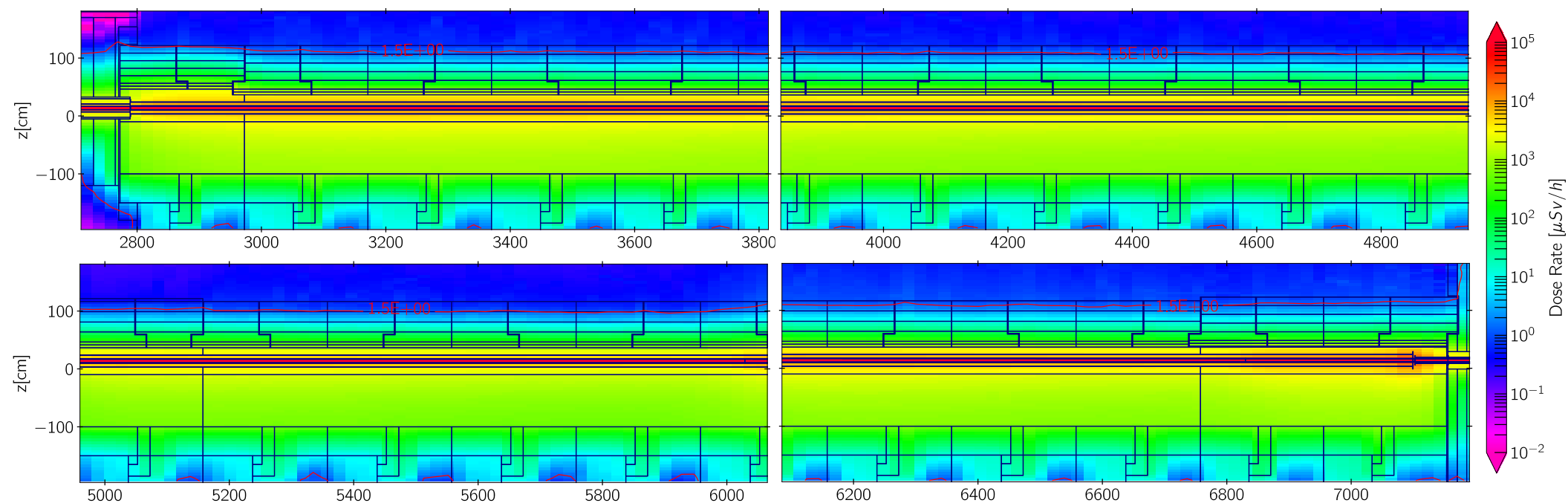
Conservative supermirror configuration:

- Slightly higher m-values considered
- Ni/Ti bilayer model
- Two distinct reflection configurations evaluated
- Outer-surface reflection leads to increased  $\gamma$ -ray production



# NEUTRON BEAM GUIDE SHIELDING

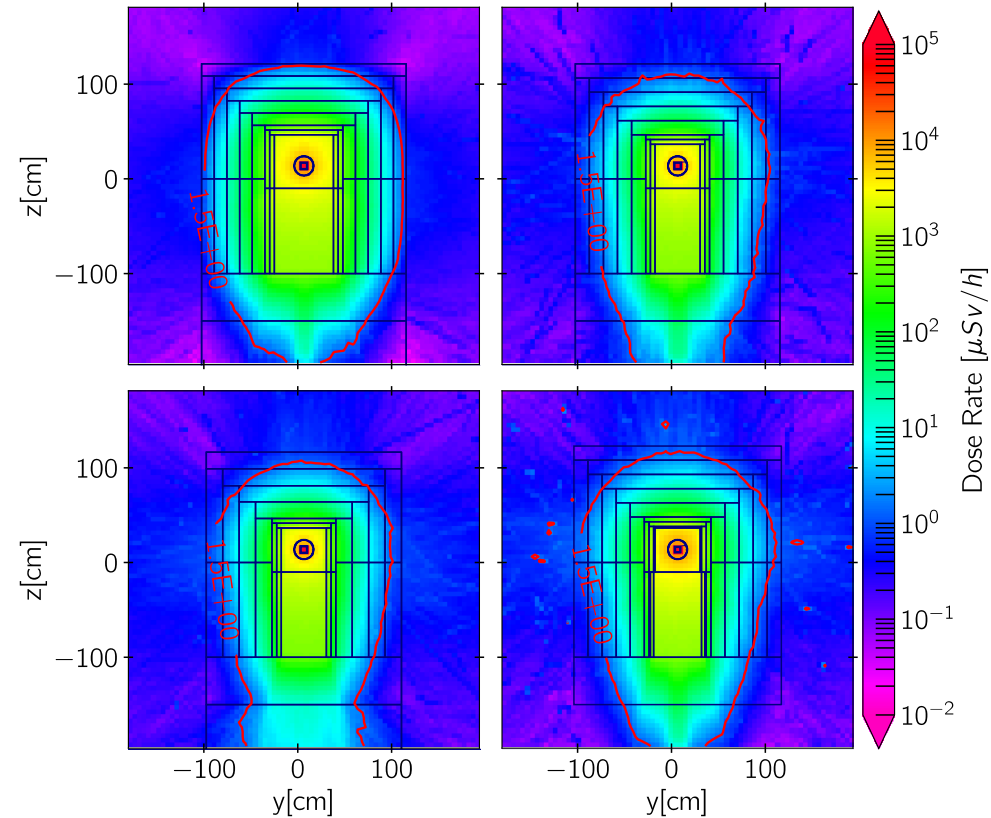
## Radiation Dose Rate Distributions



- Radiation dose map from *H2.2 simulation*
- $1.5 \mu\text{Sv/h}$  (red isoline) does not exceed the physical boundary of the shielding structure

# NEUTRON BEAM GUIDE SHIELDING

## Radiation Dose Rate Distributions



- Radiation dose map from *H2.2 simulation*
- $1.5 \mu\text{Sv/h}$  (red isoline) does not exceed the physical boundary of the shielding structure

# NEUTRON BEAM GUIDE SHIELDING

## Outer Surface Dose Rate

*Table 6-6 Dose rate for 10 m long sections on the outer right surface of the beam guide shielding. Values in brackets are relative errors.*

Region [mm]		Dose Rate [ $\mu\text{Sv/h}$ ]				Total (%)
Start	End	Bad Neutrons		Good Neutrons		
		Neutron	Photon	Neutron	Photon	
27700	37700	0.24 (2.60)	0.07 (2.47)	0.00 (0.00)	0.10 (2.43)	0.41 (4.33)
37700	47700	0.22 (3.91)	0.07 (2.64)	0.00 (0.00)	0.12 (2.21)	0.41 (5.21)
47700	57700	0.25 (2.73)	0.08 (2.18)	0.00 (0.00)	0.10 (2.16)	0.43 (4.11)
57700	67700	0.26 (2.71)	0.10 (1.82)	0.00 (0.00)	0.08 (2.15)	0.44 (3.90)
61650	71650	0.20 (3.12)	0.08 (2.00)	0.00 (0.00)	0.11 (2.52)	0.39 (4.48)

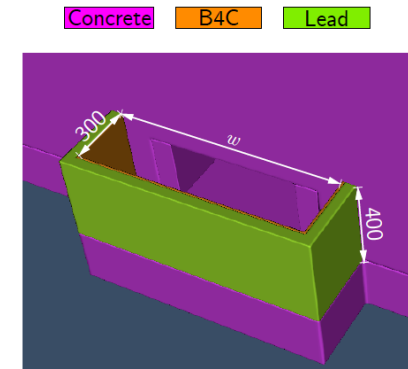
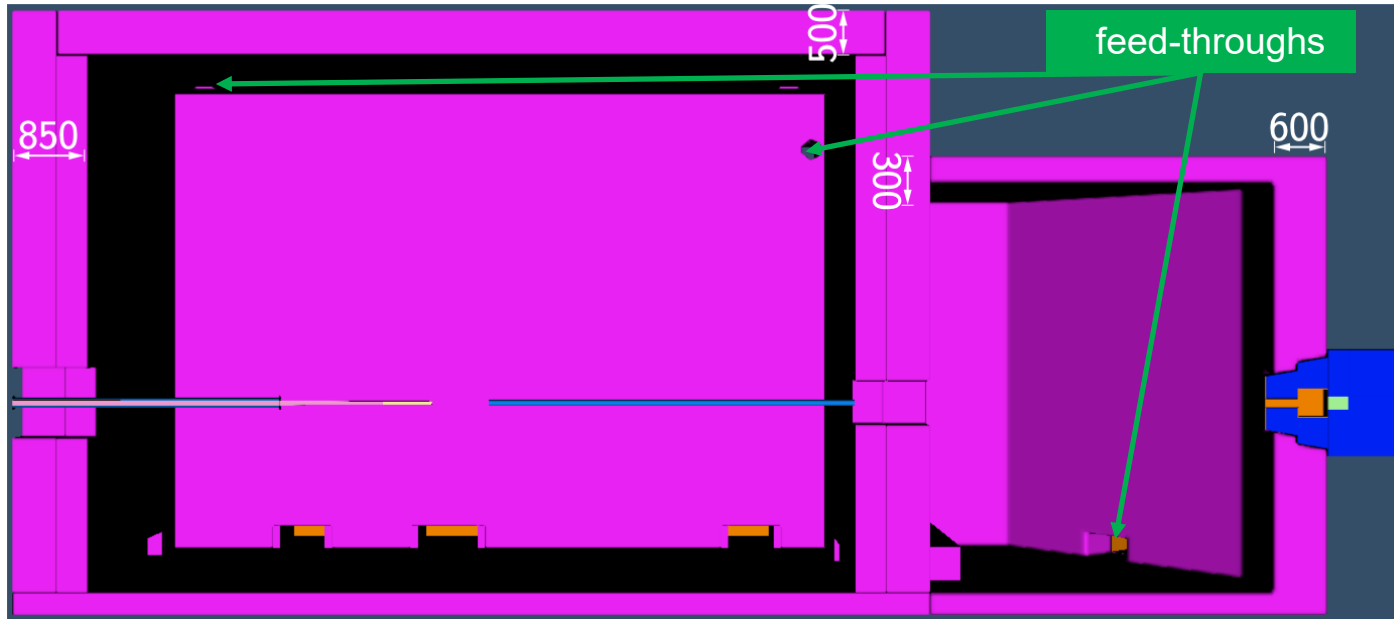
Good neutrons:  $E \leq 330 \text{ meV}$   
 Bad neutrons:  $E > 330 \text{ meV}$

**< 0.5  $\mu\text{Sv/h}$**

# EXPERIMENTAL CAVES

## Input Geometry

Cut view of the caves with walls and roofs dimensions in mm



Ground feed-through shielding:

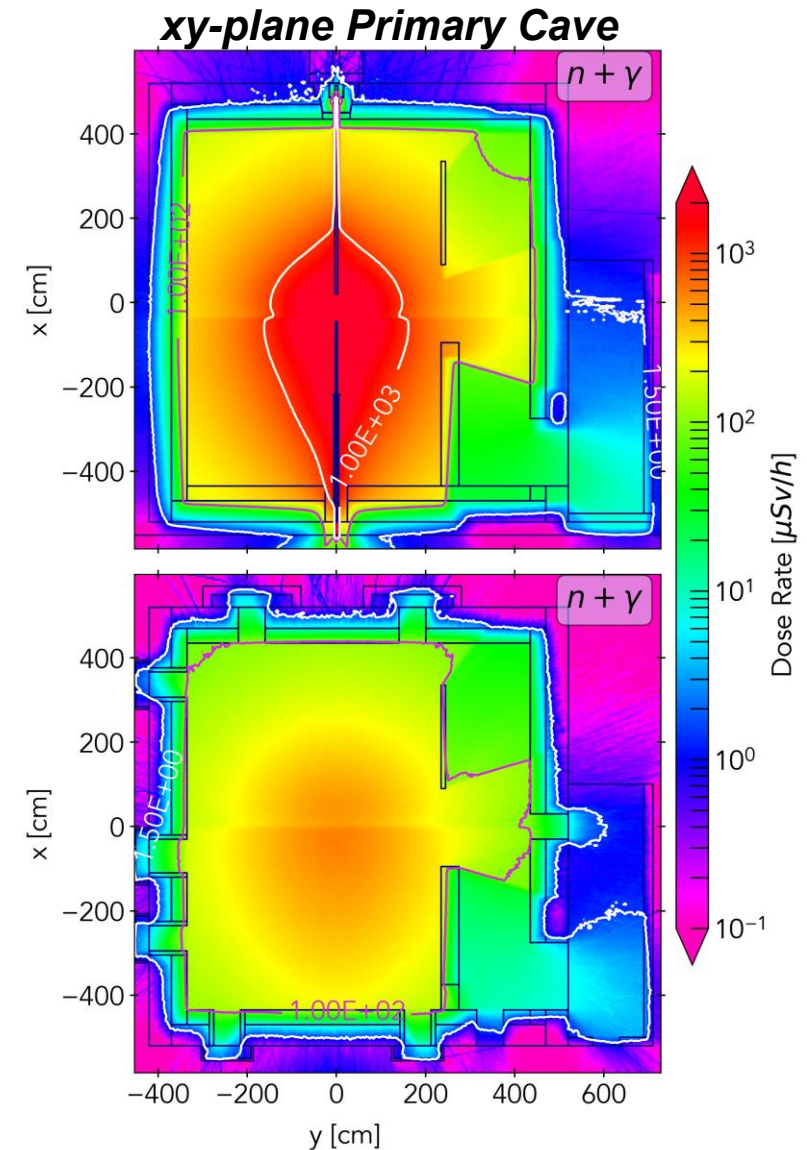
- 50 mm Pb layer
- 10 mm B4C lining

Primary & secondary caves were simulated separately

# EXPERIMENTAL CAVES

## Radiation Dose Rate Distribution

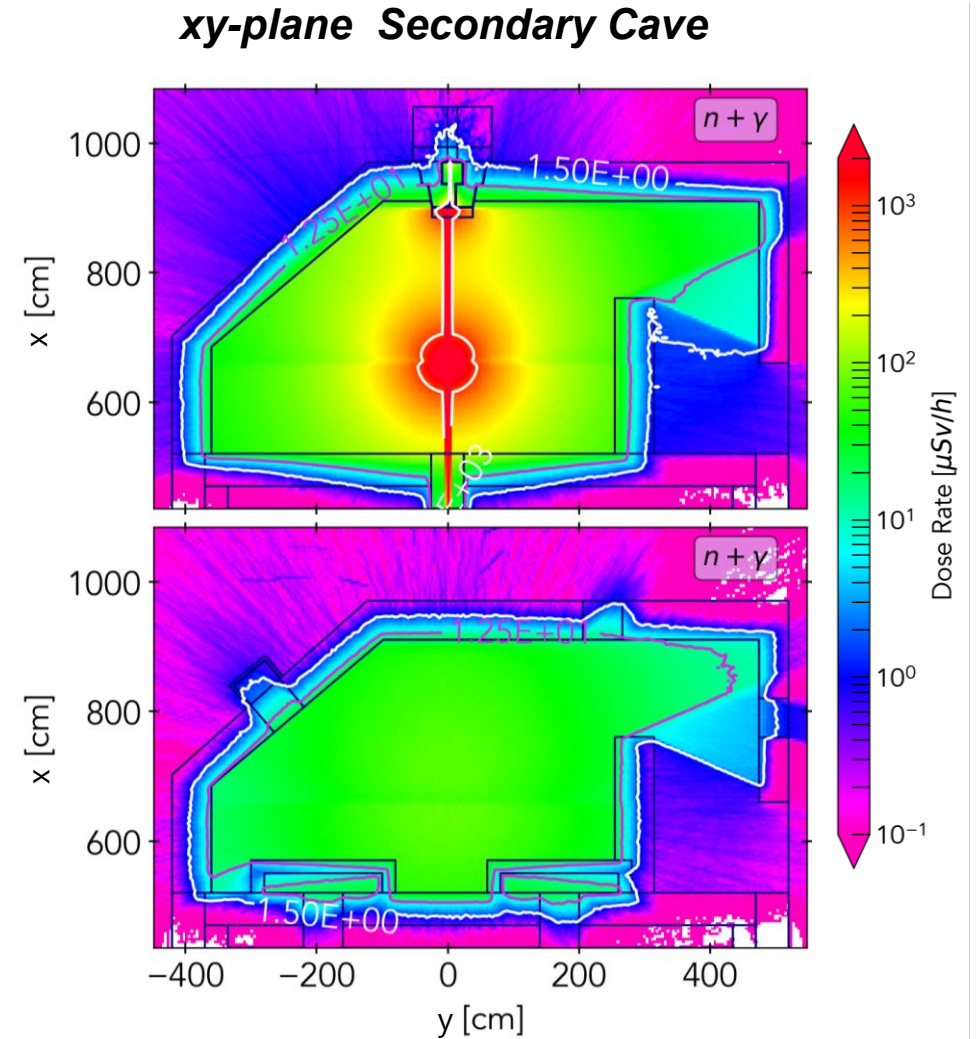
- Radiation dose map - *H2.3 simulation*
  - Upper: at the roof feed-through level
  - Lower: at the sample plane
- Dose rate  $< 1.5 \mu\text{Sv/h}$  beyond the walls (*supervised area*)



# EXPERIMENTAL CAVES

## Radiation Dose Rate Distribution

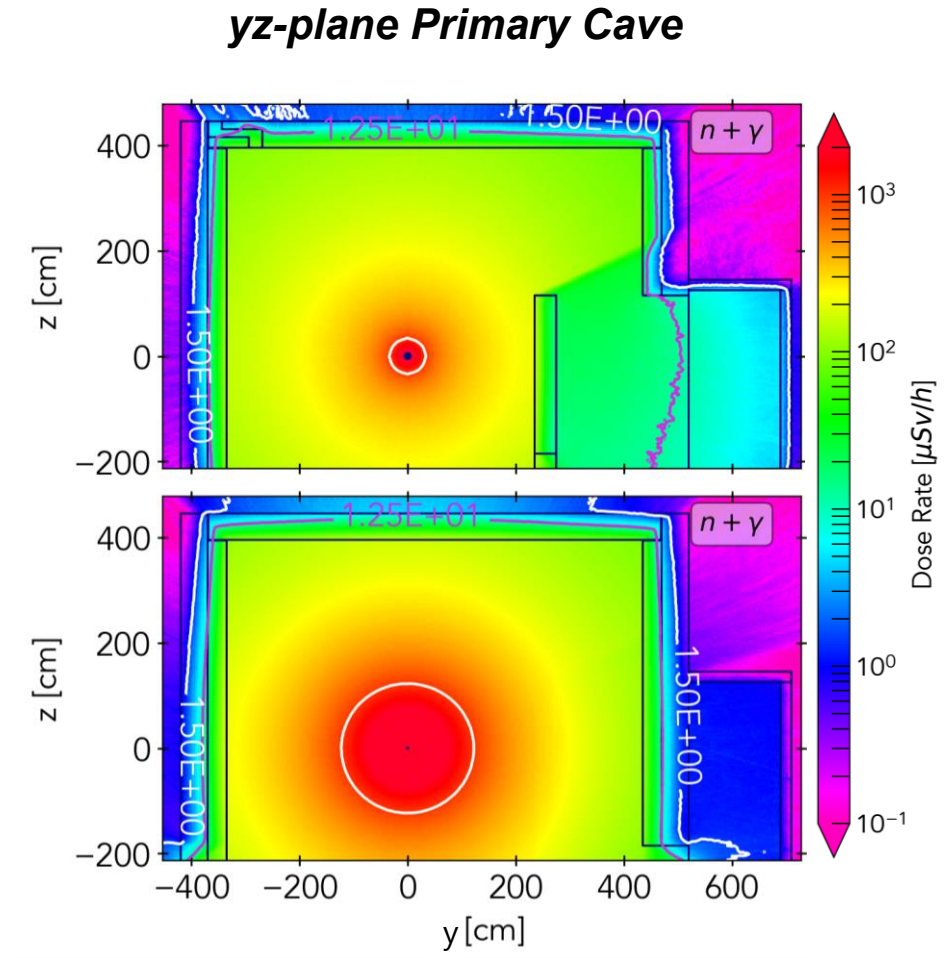
- Radiation dose map - *H2.3 simulation*
  - Upper: at the roof feed-through level
  - Lower: at the sample plane
- Dose rate  $< 1.5 \mu\text{Sv/h}$  beyond the walls (*supervised area*)



# EXPERIMENTAL CAVES

## Radiation Dose Rate Distribution

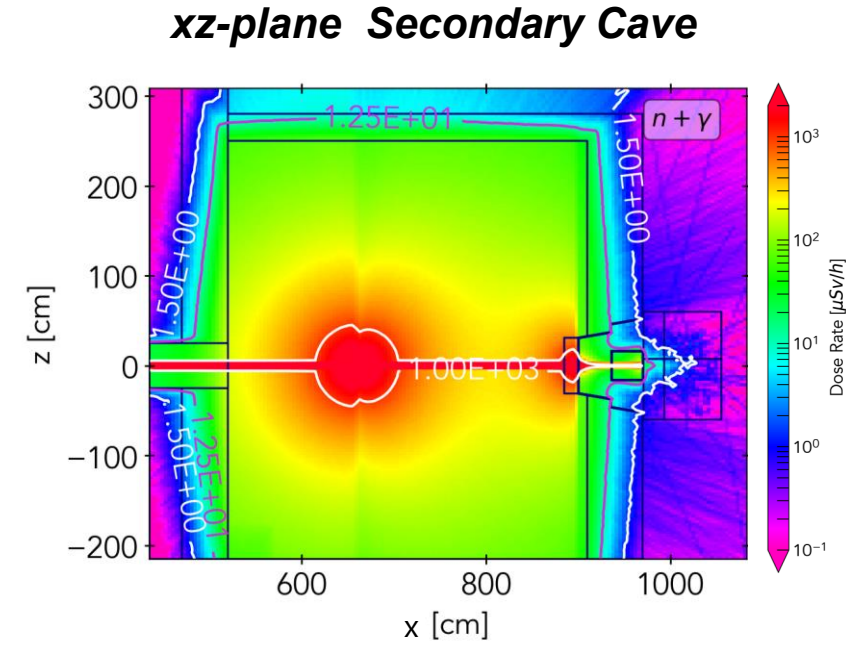
- Radiation dose map - *H2.3 simulation*
  - Upper: at the roof feed-through level
  - Lower: at the sample plane
- Dose rate  $< 1.5 \mu\text{Sv/h}$  beyond the walls (*supervised area*)
- Dose rate  $< 12.5 \mu\text{Sv/h}$  above the roof (*controlled area*)



# EXPERIMENTAL CAVES

## Radiation Dose Rate Distribution

- Radiation dose map rate at the vertical plane of the beam ( $y=0$ ) - *H2.3 simulation*
- Dose rate  $< 1.5 \mu\text{Sv/h}$  beyond the walls (*supervised area*)
- Dose rate  $< 12.5 \mu\text{Sv/h}$  above the roof (*controlled area*)



# EXPERIMENTAL CAVES

## Outer Surface Dose Rate

*Table 7-5 Dose rate on the outer surface of the primary cave walls from H2.3 event simulation. Values in brackets are relative errors.*

Side	Dose Rate [ $\mu\text{Sv/h}$ ]		
	Neutron	Photon	Total
Front	0.020 (23.8)	0.211 (4.45)	0.231
Rear	0.041 (23.3)	0.280 (7.32)	0.321
Left	0.004 (45.8)	0.356 (8.38)	0.360
Right	0.048 (23.6)	0.295 (4.95)	0.343

< 0.5  $\mu\text{Sv/h}$

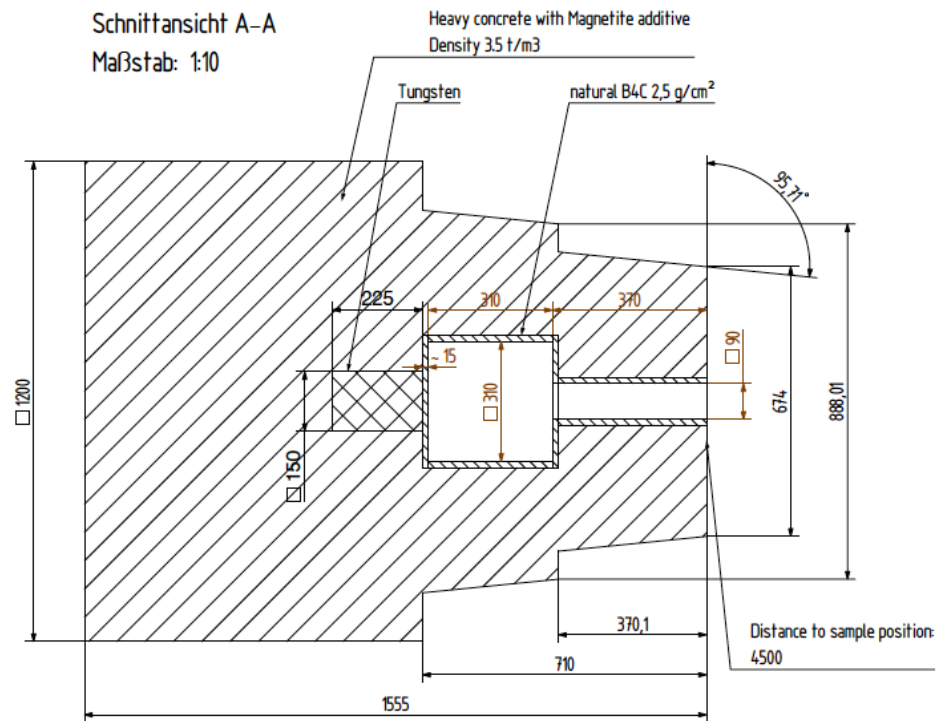
*Table 7-6 Dose rate on the outer surface of the secondary cave walls from H2.3 event simulation. Values in brackets are relative errors. Rear-Left wall is the wall between the rear and the left walls.*

Side	Dose Rate [ $\mu\text{Sv/h}$ ]		
	Neutron	Photon	Total
Rear-Left	0.020 (40.2)	0.418 (4.11)	0.437
Rear	0.009 (41.6)	0.312 (6.22)	0.322
Left	0.018 (43.3)	0.301 (3.16)	0.320
Right	0.007 (25.1)	0.233 (3.02)	0.240

< 0.5  $\mu\text{Sv/h}$

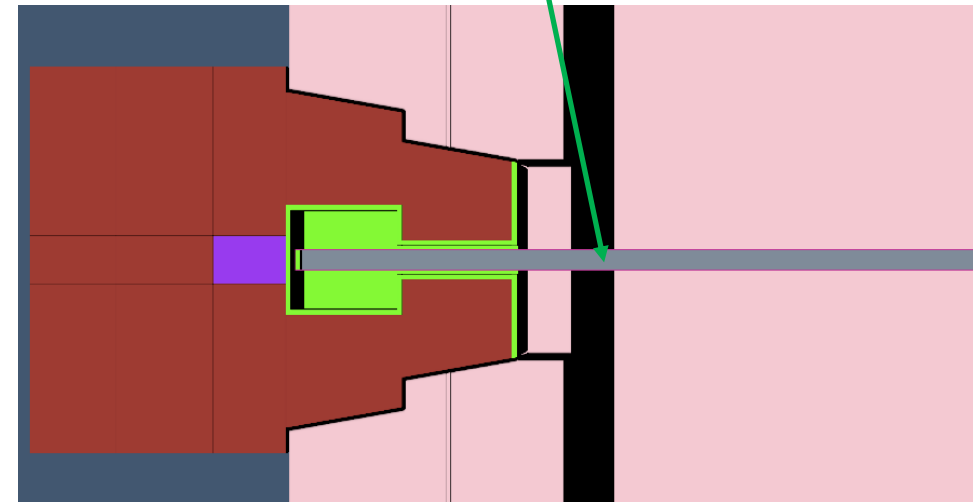
# BEAM STOP

## Input Geometry



Technical drawing with dimensions in mm

Aluminum get-lost beam tube coated  
with 0.1 mm B4C-epoxy resin

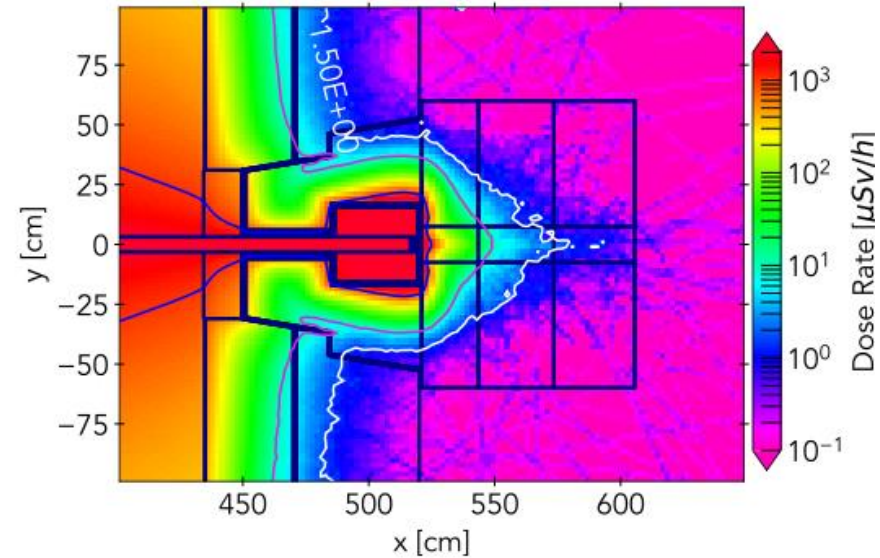


Simulated geometry model

# BEAM STOP

## Radiation Dose Rate

- Beam stop inserted in the primary cave rear wall
- Dose rate behind the beam stop less than  $1.5 \mu\text{Sv/h}$  – *H2.2 simulation*



*Table 7-7 Dose rate on the outer surface of the beam stop walls placed on the downstream beam to the primary cave rear wall, from H2.2 event simulation. Values in brackets are the relative errors.*

Side	Dose Rate [ $\mu\text{Sv/h}$ ]		
	Neutron	Photon	Total
Rear	0.182 (2.62)	0.008 (2.61)	0.190
Left	0.061 (4.22)	0.012 (2.11)	0.073
Right	0.061 (3.87)	0.011 (2.18)	0.073
Top	0.062 (4.11)	0.009 (2.12)	0.071

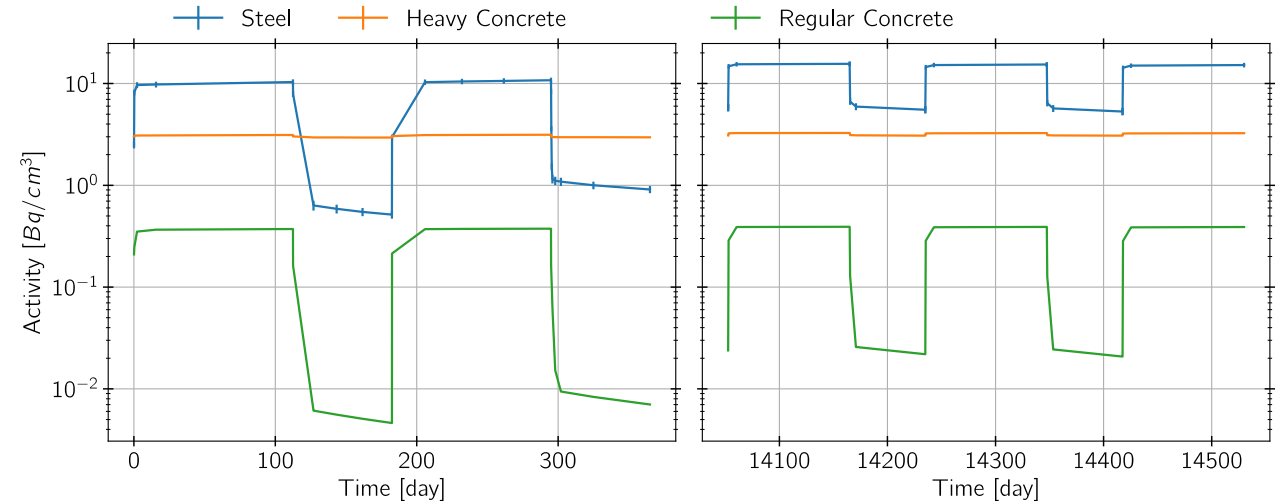
**< 0.5  $\mu\text{Sv/h}$**

# ACTIVATION SIMULATION & ANALYSIS

# ACTIVATION

## Activation Curve

- Activation simulations performed using DCHAIN-SP code
- Estimation of the activity build-up and the decay during and after operation
- For 40 years (ESS lifetime) :
  - 2 cycles of 2700 hours beam on and 1600 hours beam off
  - last cycle 2700 hours beam on



*Activity evolution of the materials of the beam guide shielding for (left) the two first and (right) the three last cycles.*

# ACTIVATION

## Radionuclides Production

- Activation simulations performed using DCHAIN-SP code

*Activity rate of the predominant radionuclides produced in the beam guide shielding structure*

Material	Bad Neutrons		Good Neutrons	
	Isotope	Activity Ratio (%)	Isotope	Activity Ratio (%)
Steel	Mn-56	67.38	Mn-56	60.27
	Fe-55	24.69	Fe-55	35.26
Heavy Concrete	K-40	66.78	K-40	98.52
	Fe-55	11.18		
Regular Concrete	Na-24	37.30	Na-24	40.34
	Al-28	33.36	Al-28	28.20
	Na-24m	18.65	Na-24m	20.18

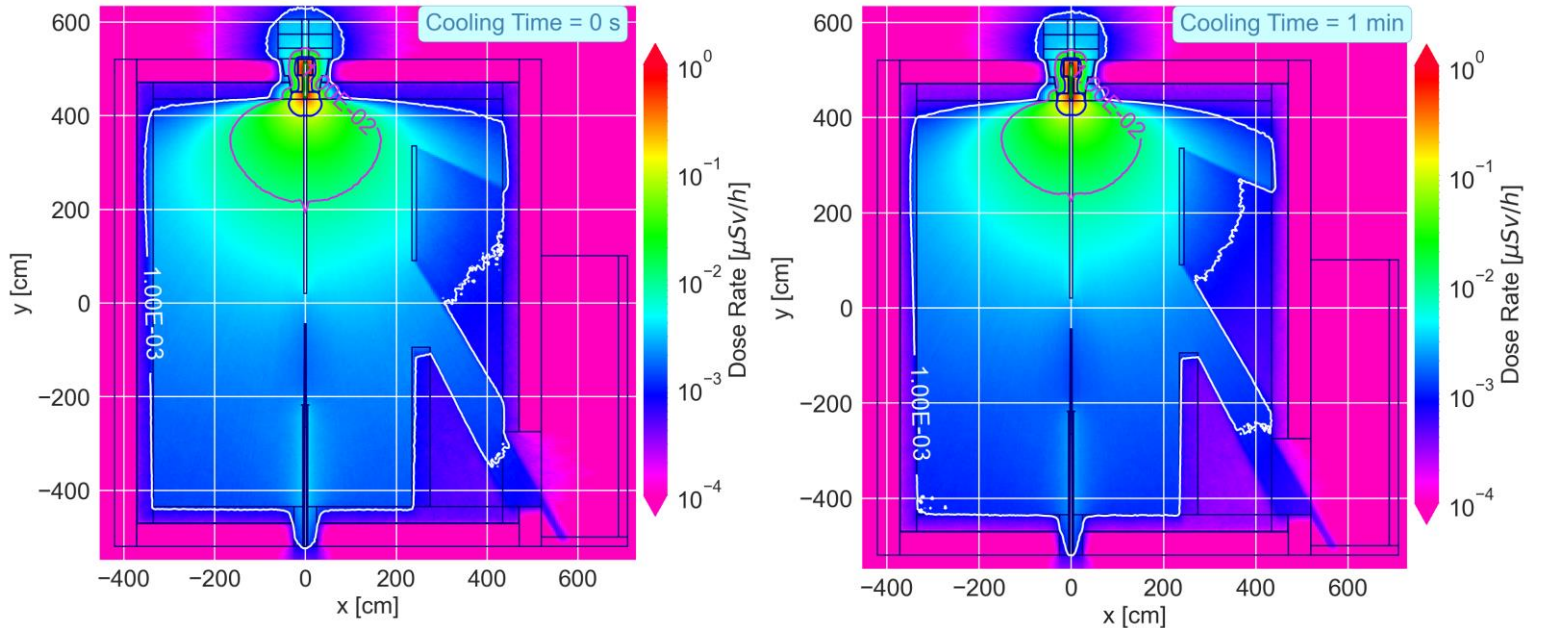
- Identification of radionuclides during and after the operation

# ACTIVATION

## Cave Accessibility

- Activation simulations performed using DCHAIN-SP code

- Estimation of delayed  $\gamma$ -ray yield following beam shutdown
- Residual dose extremely low after shutdown



*Dose maps of the decay photons induced by the activation after 0s and 1s beam shutdown.*

# CONCLUSION

- All shielding components have been validated through Monte Carlo simulations
- Worst-case scenarios have been assessed
- The DREAM shielding system fully complies with the ESS safety requirements.