Standard Shielding Project
Neutronics

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30^{th} January, 2019

Neutronics Requirements

Prioritisation of requirements:

1. Meeting safety requirement of 3 μSv/h contact dose externally - this is a legal requirement
2. Minimising waste and activation as per ALARA principle - this is best practice
3. Instrument backgrounds - this is a low priority issue and will be mitigated in the caves[1]

[1] The viability of this mitigation strategy is not part of the project scope

Transforming Neutronics Requirements into Methodology

In order of priority:

1. Meeting safety requirement of 3 μSv/h contact dose externally - this is a legal requirement
   - Adjust shielding thickness appropriately until requirement is met.
2. Minimising waste and activation as per ALARA principle - this is best practice
   - No heavy concrete
   - Boron-rich inner layers, and steel inner layers
   - CaCO concrete aggregates
3. Instrument backgrounds - this is a low priority issue and will be mitigated in the caves[2]
   - Collimator blocks and expansion zones (empty chopper pits) - these also reduce cost downstream! (more on that soon)
   - Chopper pits designed as expansion zones (reduce cost downstream)
   - Boron-rich inner layer to reduce albedo back-shine

[2] The viability of this mitigation strategy is not part of the project scope

Problem Breakdown

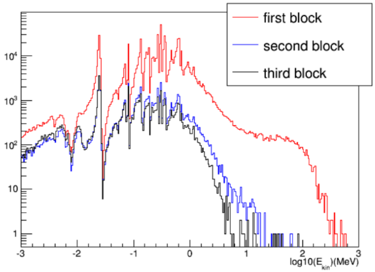
What does the shielding look like in the following scenarios:

- Out of line of sight of the source
- Around a chopper out of line of sight of the source
- Within line of sight of the source, with fast neutron wall loading $\propto 1/R^3$
- Around a chopper within line of sight of the source

Line of Sight Variable

Line of Sight

- Losing line of sight if possible saves cost
- Certainly helps with background
- Diminishing returns after $2\times$ LOS
- Twice line of sight is recommended strategy for cost and background
- Instrument project should look at at least one option



V. Santoro *et al*

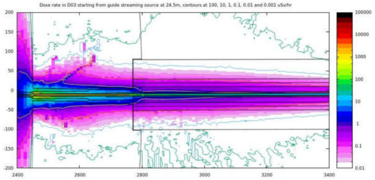
Line of Sight

Pre-2019 assumption, until more evidence exists:

- Within line of sight heavy shielding is needed (e.g. bunker)
- Heavy shielding is instrument-specific
  - Depends on beam dimensions
  - Depends on beam geometry, collimation etc
- Out of line of sight requirements are comparable to ILL

Assumptions Were Correct

- ESS-0511506 shows that this assumption is valid
- *Fig. Right:* shows horizontal slice through BIFROST, bunker wall on left
- Out of line of sight, the dominant source of radiation is prompt gamma from the neutron guides

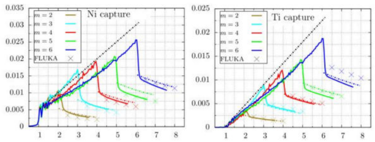


R. Kolevatov, ESS-0511506

Out of Line of Sight: Prompt Gamma

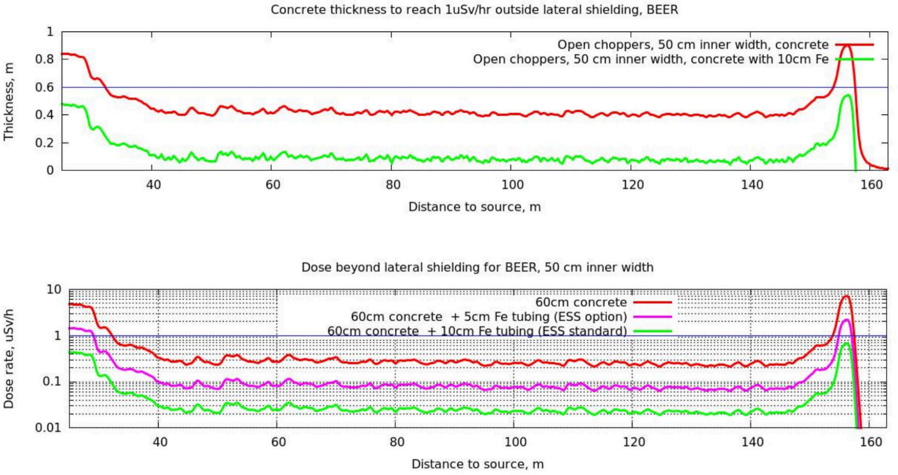
Prompt Gamma Emission Probability vs *m*

- ESS-0511500 has a brilliant analysis from Rodion
- *Fig. Right:* shows Ni and Ti probability of neutron capture for various *m*
- Using MCSTAS models from the instruments, he was able to estimate the minimum shielding specifications for several instruments just for the prompt gamma
- Neutron doses are negligible in these areas, assuming other contributions are meeting the requirements.
- Lets look at the specifications for each instrument



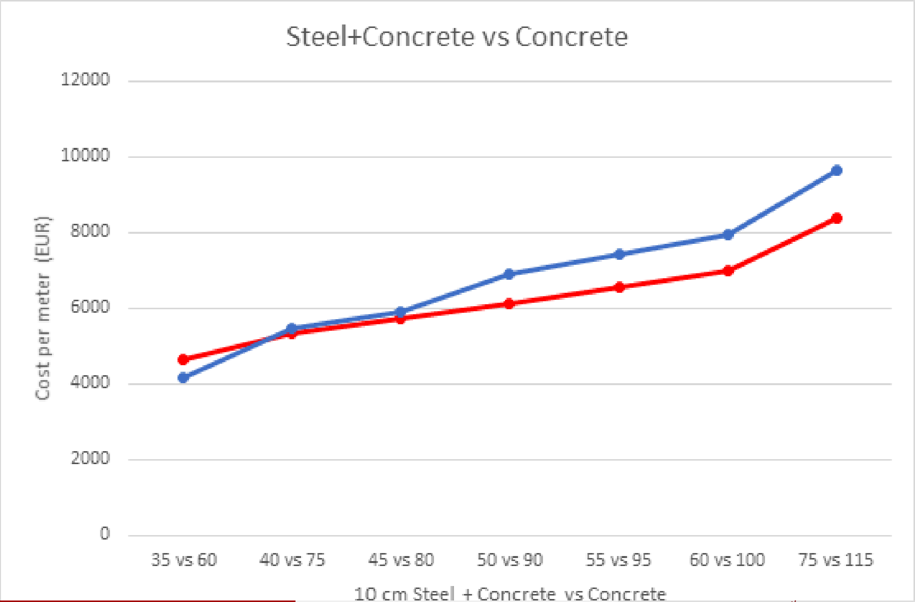
R. Kolevatov, ESS-0511500

Prompt Gamma Shielding: Beer

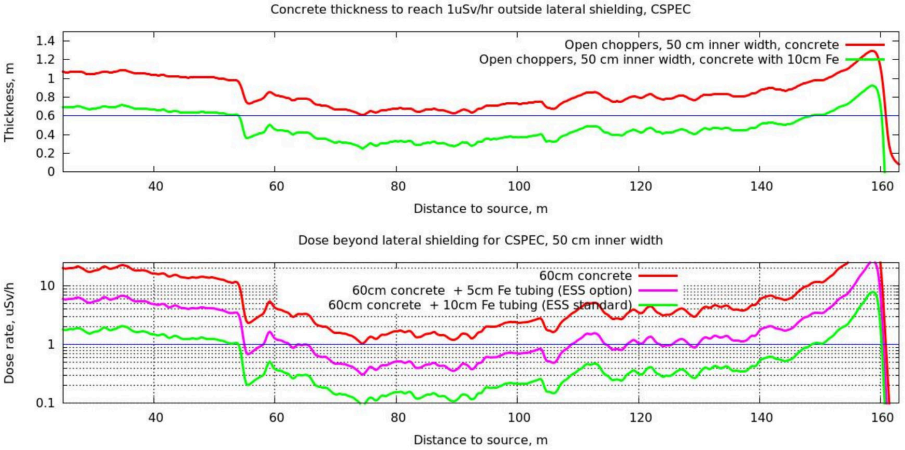


R. Kolevatov, ESS-0511500

Steel layer is always cheaper

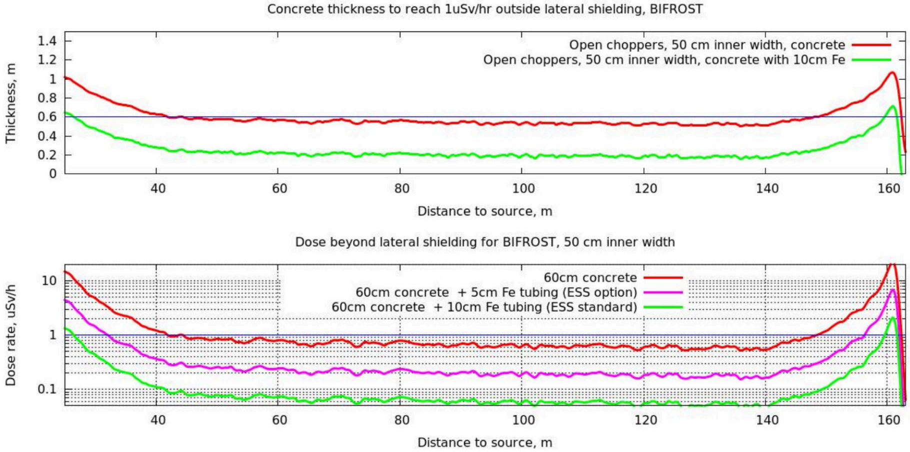


Prompt Gamma Shielding: CSPEC



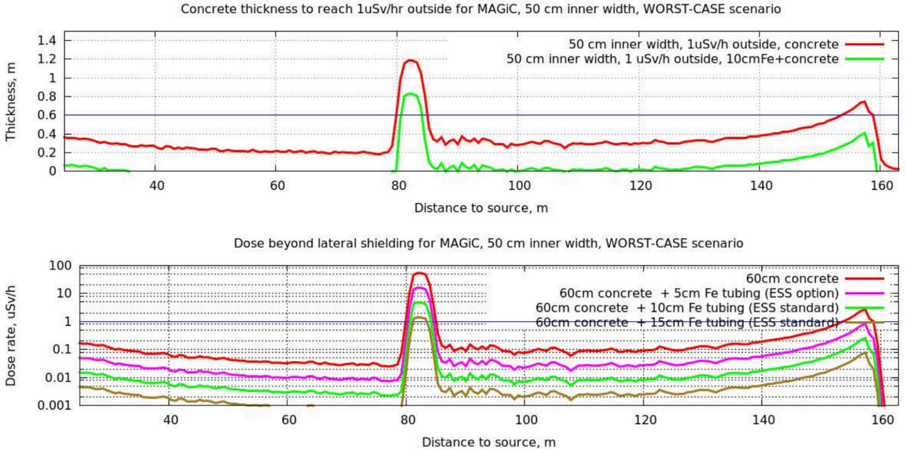
R. Kolevatov, ESS-0511500

Prompt Gamma Shielding: BIFROST



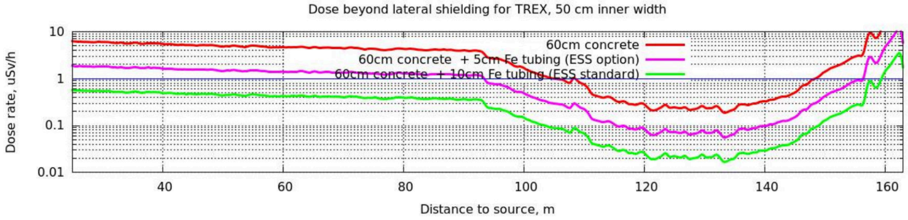
R. Kolevatov, ESS-0511500

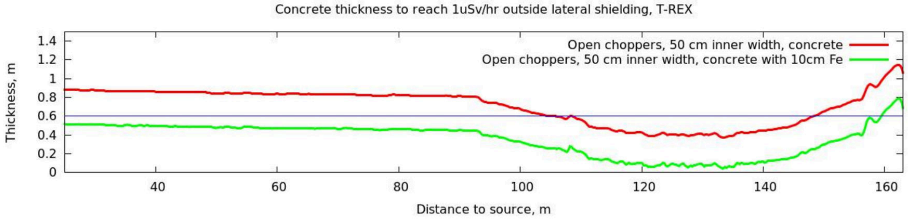
Prompt Gamma Shielding: MAGIC



R. Kolevatov, ESS-0511500

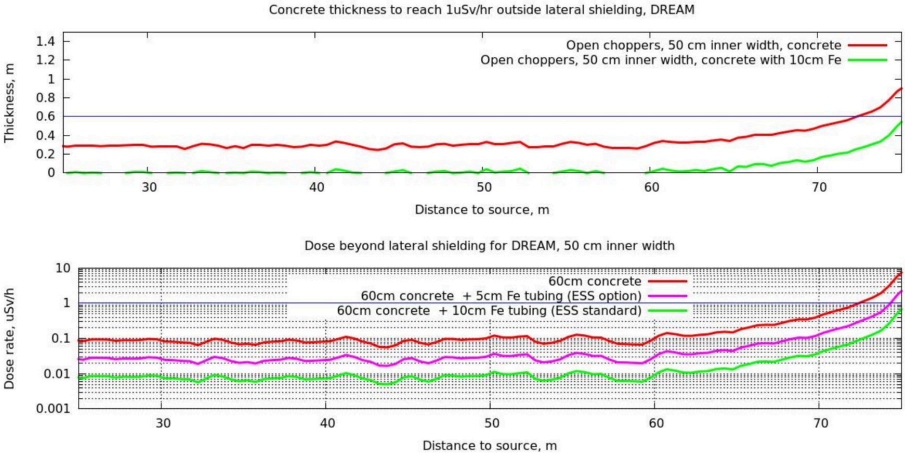
Prompt Gamma Shielding: TREX





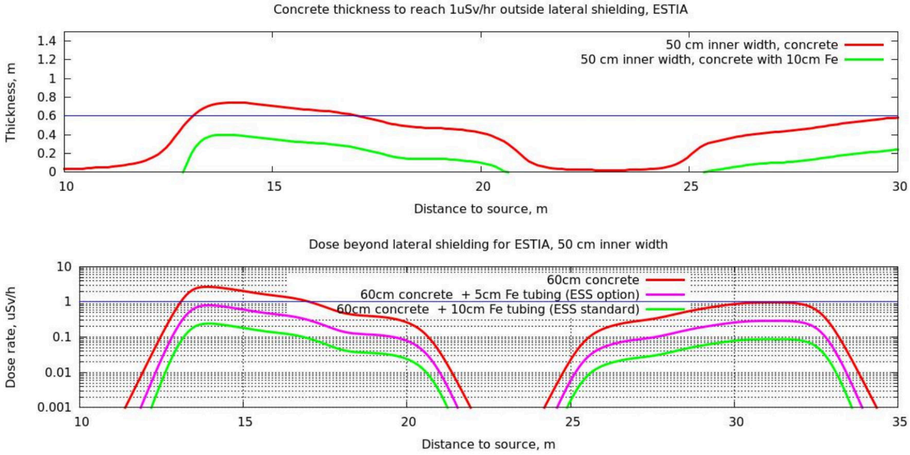
R. Kolevatov, ESS-0511500

Prompt Gamma Shielding: DREAM



R. Kolevatov, ESS-0511500

Prompt Gamma Shielding: ESTIA



R. Kolevatov, ESS-0511500

Within Line of Sight: Fast Neutrons - ODIN

Guide Geometry for ODIN

- ESS-0511504 contains F. Grünauer's thorough work on ODIN
- *Fig. Right:* shows geometry of chopper pit and guide

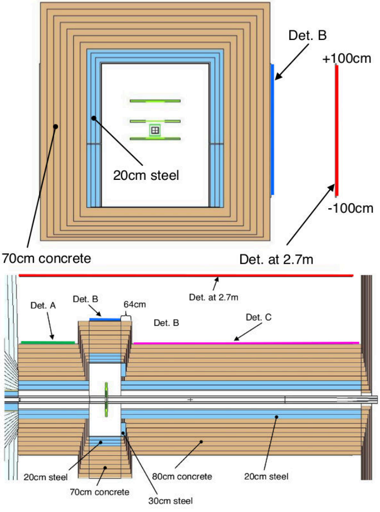


Fig. 233: Horizontal cut through the Monte Carlo model of the guide shielding

F. Grünauer ESS-0511504

Guide Results for ODIN

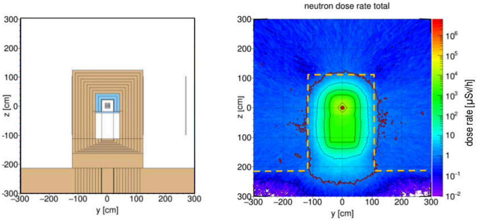


Fig. 246: Vertical neutron dose rate distribution through the guide shielding perpendicular to the beam axis (40m from the focal point). The red line is the 1μSv/h border.

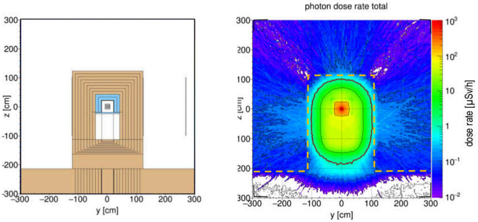


Fig. 247: Vertical generated gamma dose rate distribution through the guide shielding perpendicular to

Top Down Results for ODIN

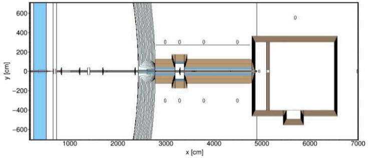


Fig. 240: Horizontal area through the Monte Carlo model of the ODIN instrument for which the radiation distribution is shown in the following image

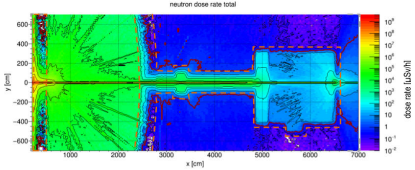
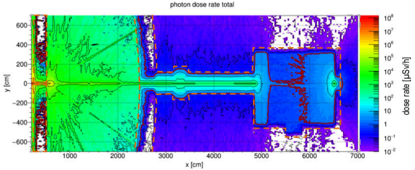


Fig. 241: Total neutron dose rate distribution in the horizontal area. The red line is the 1µSv/h border.



Side Results for ODIN

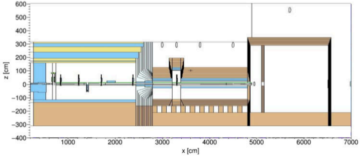


Fig. 243: Vertical area through the Monte Carlo model of the ODIN instrument for which the radiation distribution is shown in the following image

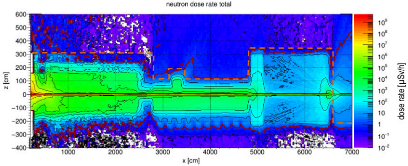
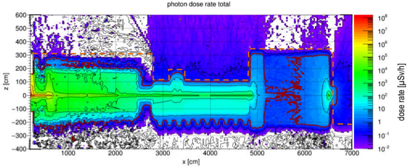


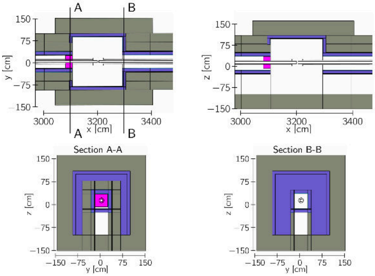
Fig. 244: Total neutron dose rate distribution in the vertical area. The red line is the 1μSv/h border.



Within Line of Sight: Fast Neutrons - TREX

Chopper Pit and Guide Geometry

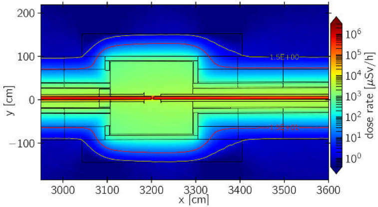
- ESS-0511498 shows a thorough analysis of TREX beamline
- Final geometry *right*: Top view, side view, front sec A, front sec B
- Collimator block (copper) *reduces cost as well as background*.



Tsito Randriamalala, ESS-0511498

Chopper Pit Results

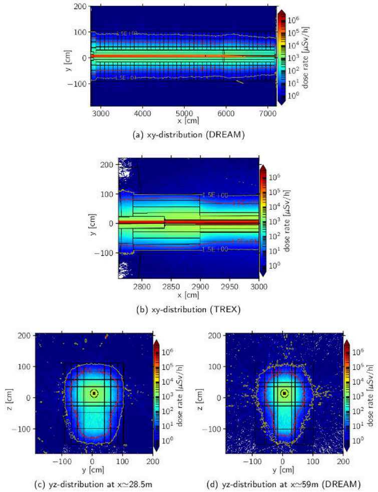
- Final geometry *right*: meets requirements



Tsito Randriamalala, ESS-0511508

Guide Results

- Final geometry *right*: meets requirements



(a) xy-distribution (DREAM)

(b) xy-distribution (TREX)

(c) yz-distribution at x≃28.5m

(d) yz-distribution at x≃59m (DREAM)

Tsito Randriamalala, ESS-0511508

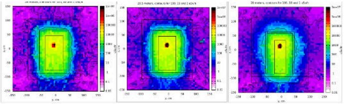
Within Line of Sight: Fast Neutrons - HEIMDAL

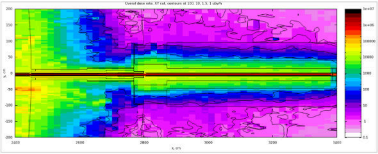
Heimdal Results

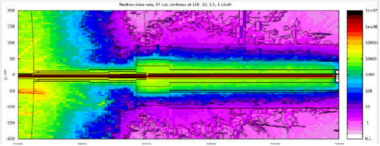
- ESS-0511510 shows analysis of the HEIMDAL beamline
- The geometry is the same as the others with the boron-steel-concrete sandwich structure

Heimdal Results

- Graphs show overall dose rate and neutron contribution
- Photon contribution is negligible.







R. Kolevatov, ESS-0511510

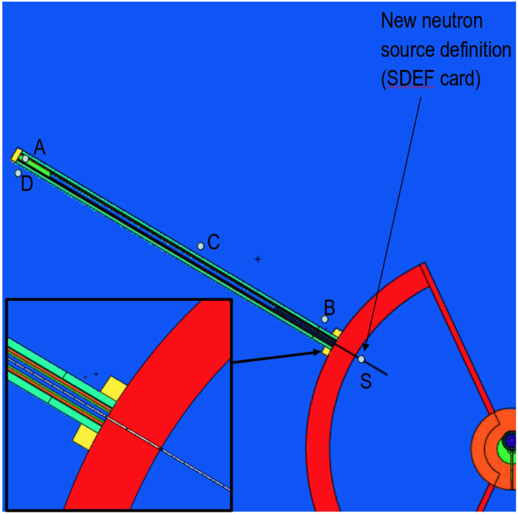
Within Line of Sight: Fast Neutrons - Magic

Magic Results

- Previous work from Uwe Filges (PSI) presented at IKON 2-3 years ago

Magic Results

cross section inside shielding: 50 cm x 50cm



Shielding around guide:

10 cm borated concrete
10 cm standard steel
50 cm standard concrete

Source – tally S: 13.8 Sv/h

@77m - tally A: 8.8 mSv/h

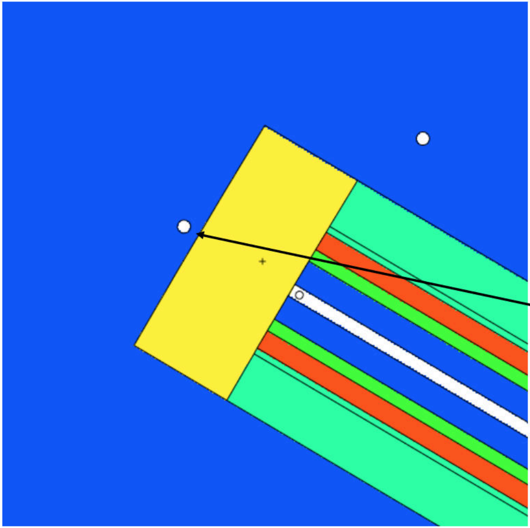
fast neutron flux: 4.7E4 n/cm^2/s

@30m – outside guide shielding
tally B: 3.4 μSv/h

@50m ouside guide shielding
tally C: 1.9 μSv/h

@77m ouside guide shielding
tally D: 1.1 μSv/h

Magic Results



U. Filges

Remember:
@77m center of beam: 8.8 mSv/h neutron dose rate

Beam dump consists of 50 cm heavy concrete (4.9 g/cm^3)

Concrete includes 5 % B_4C

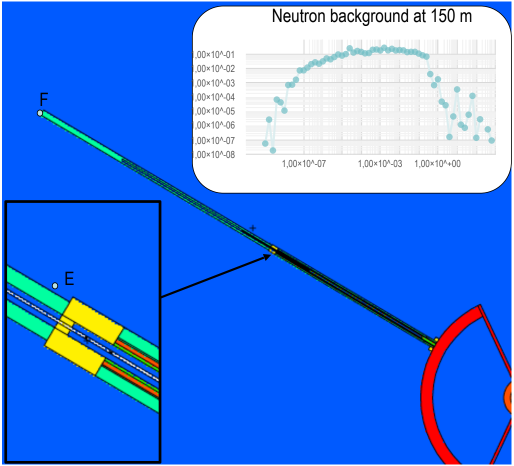
Behind beam dump:
n-dose rate : 1.6 µSv/h
g-dose rate : < 0.1 µSv/h

30 $n/s/cm^2$

Detector size: d=6 cm

Magic Results

150m Guide Shielding



Shielding around guide behind 77m:

- 2m heavy concrete with vacuum tube belt
- 75m standard concrete (0.5 m thickness)

neutrons

Source – tally S: 13.8 Sv/h

@80m ouside guide shielding
tally E: 1.3 μSv/h

@150m inside guide shielding
tally F: 0.2 μSv/h
4.2 n/s/cm^2

Summary of Thicknesses

Magic Results

INSTRUMENT		30	40	60	80	100	120	140	150	160
SCPEC	Steel	75	75	70	50	45	50	55	60	100
	No Steel	115	115	115	95	80	95	92	100	130
	Common Design	75	75	75	50	50	50	60	60	100
				§						
BIFROST	Steel	65	40	35	35	35	35	35	40	75
	No Steel	100	65	60	60	60	60	60	75	110
	Common Design	65	50	40	40	40	40	40	40	80
MAGIC	Steel	70	70	70	50	50	50	50	50	80
	No Steel	x	x	x	x	x	x	x	x	x
	Common Design	70	70	70	70	50	50	50	50	80
T-REX	Steel	See below			50	50	40	15	40	80
	No Steel				90	90	70	50	70	120
	Common Design				50	50	50	50	50	80
DREAM	Steel	See below			60					
	No Steel				90					
	Common Design									
ODIN	Steel (30cm)	60	60	60						
	No Steel	x	x	x						
	Common Design	x	x	x						
HEIMDAL	Steel (25cm)	50	50	50	50	50	EXPANSION ZONE			
	No Steel	x	x	x	x	x	x	x	x	x
	Common Design	x	x	x	x	x	x	x	x	x
		2cm B4C – 10 cm of steel – 2cm B4C – 60 cm of concrete								

Acknowledgements

- We gratefully include the work of:
  - Rodion Kolevatov - IFE, Norway
  - Tsito Randriamalala - FZJ, Germany
  - Florian Grünauer - Physics Consulting, Germany
  - Uwe Filges - PSI, Switzerland
- Also thanks for input from:
  - Valentina Santoro (ESS)
  - Nataliia Cherkashyna (ESS)
  - Doug DiJulio (ESS)
  - Emmanouela Rantsiou (PSI)
  - Erik Iverson (SNS, USA)
  - Stuart Ansell (MAX-IV)
  - Richard Hall-Wilton (ESS)
  - Kalliopi Kanaki (ESS)

Thank You

Thank you for your attention