Neutron moderators and biological shielding

W. Schreyer

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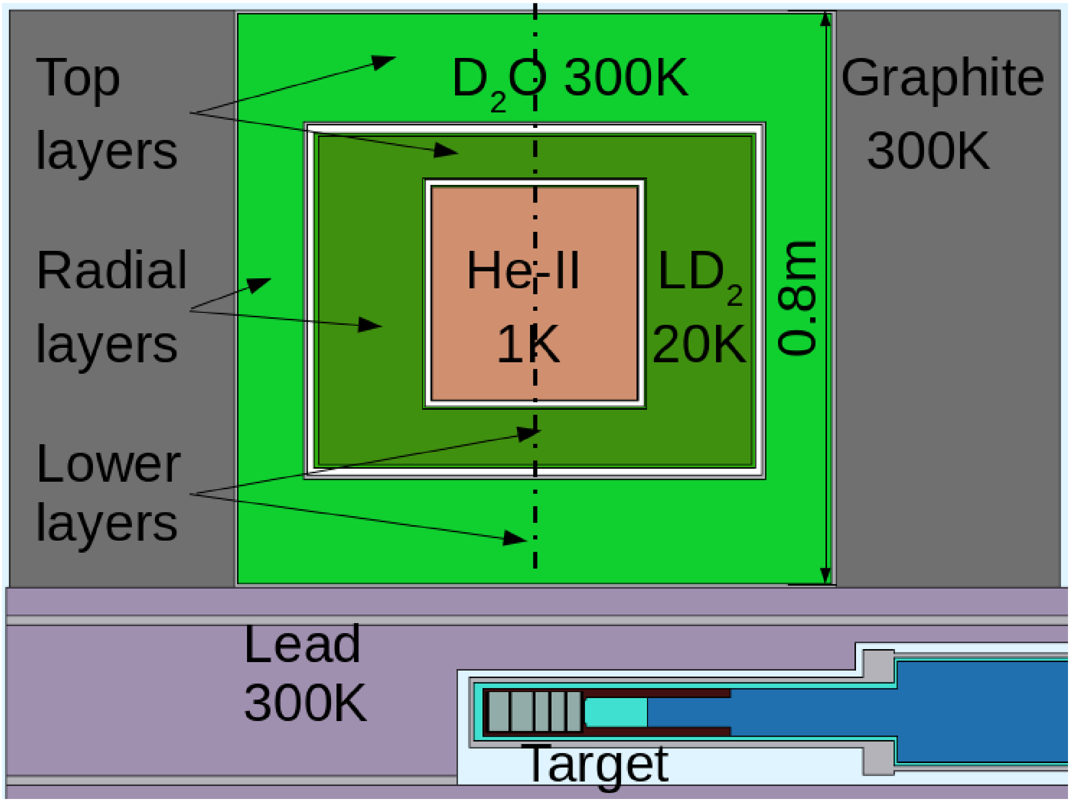
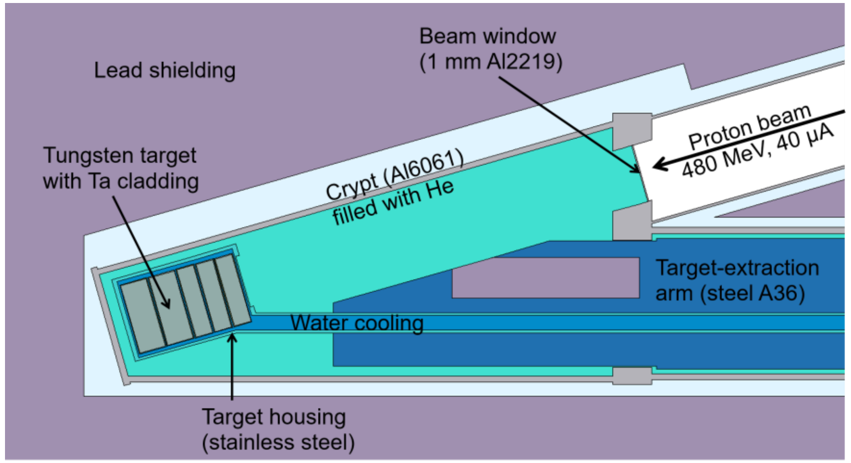
Optimization parameters



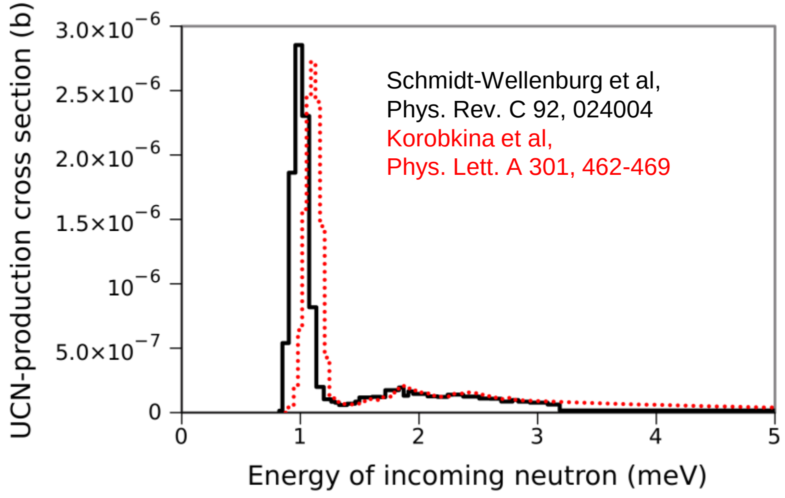
Side view of basic concept: concentric cylinders

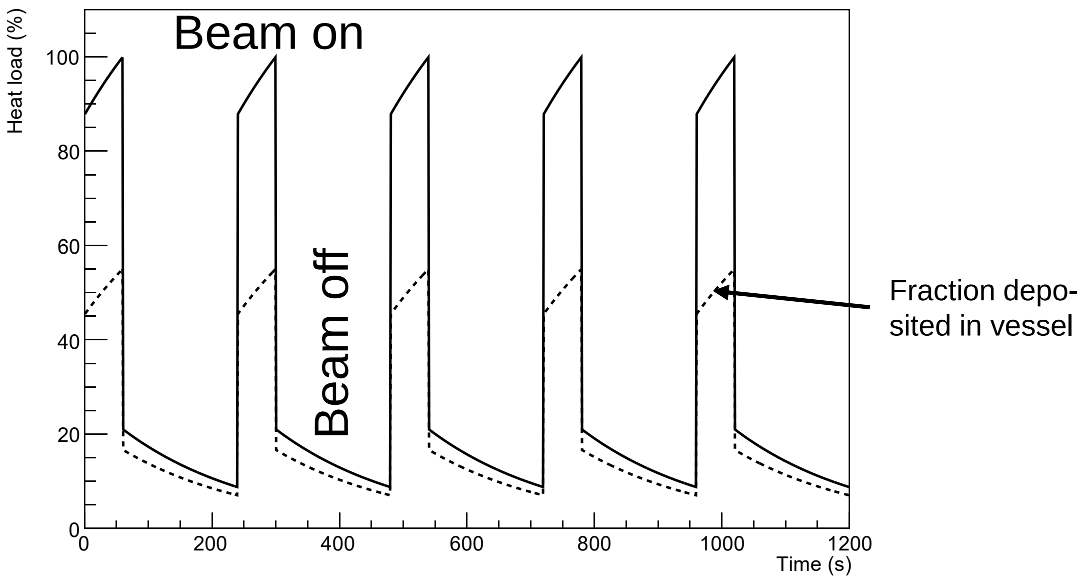
- Choice of moderators/reflectors (Pb, D_2O, LD_2, C)
- Volume/thickness of moderators
- Wall thickness of vessels



Top view of spallation target

Optimization goal



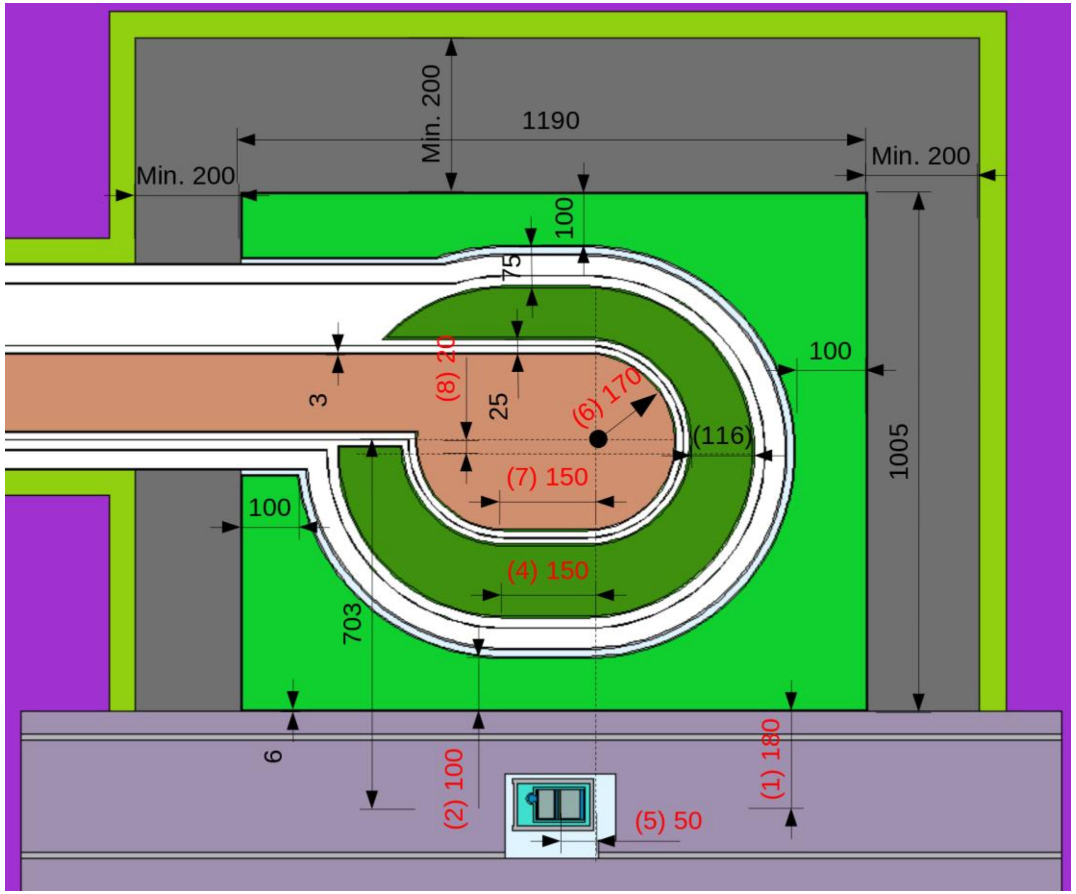


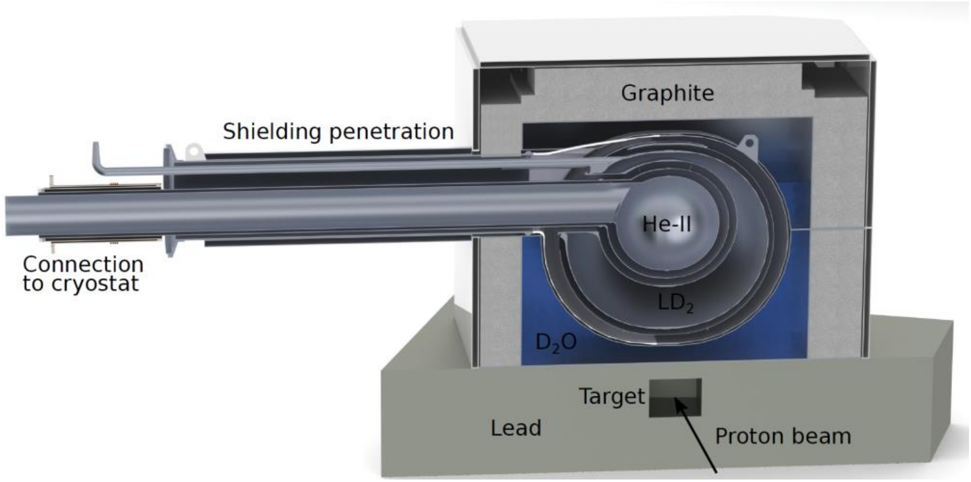
Heat load during typical irradiation profile

Maximize UCN density ρ in typical experiment

- Density estimator $\rho = \frac{P\tau}{V}$
- Production P and heat load Q from MCNP simulation
- Model for temperature/storage lifetime:
  (pumping speed, Kapitza resistance, Gorter-Mellink heat transport, …)
  $$\tau^{-1} = {\tau_{\mathrm{He}}}^{-1} + {\tau_{\mathrm{wall}}}^{-1} + {\tau_{\beta}}^{-1}$$
  $$\tau_{\mathrm{He}} = 500{\sim}1500\ \mathrm{s} \cdot \left(\frac{Q}{1\ W}\right)^{-1.5\sim-1.0}$$
- Volume of whole system:
  $$V = V_{\mathrm{source}} + V_{\mathrm{guide}} + V_{\mathrm{nEDM}}$$

Multi-parameter optimization

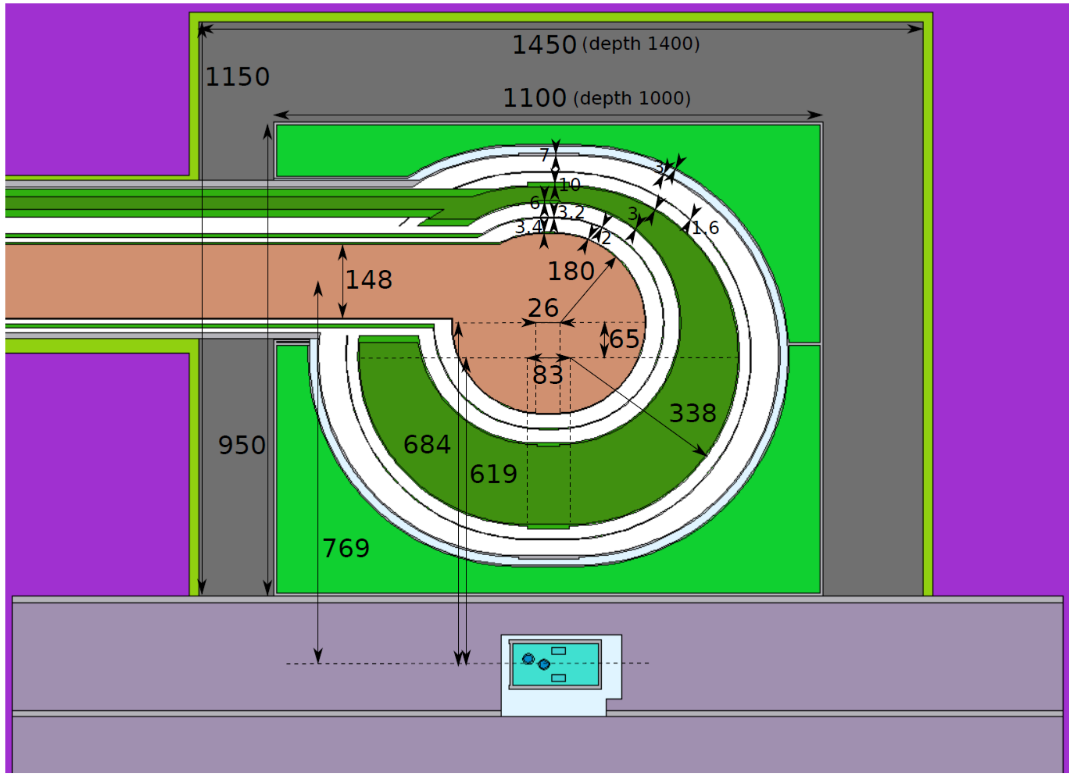




- Further refined model
- Fixed amount of LD_2 (125 L)
- Optimized 8 parameters for wide range of assumptions

Assumption	Range
τ_{wall}	60 s – 100 s
τ_β	880 s
B	500 s – 1500 s
a	-1.5 – -1.0
$V_{\mathrm{guides}} + V_{\mathrm{EDM}}$	100 L – 200 L

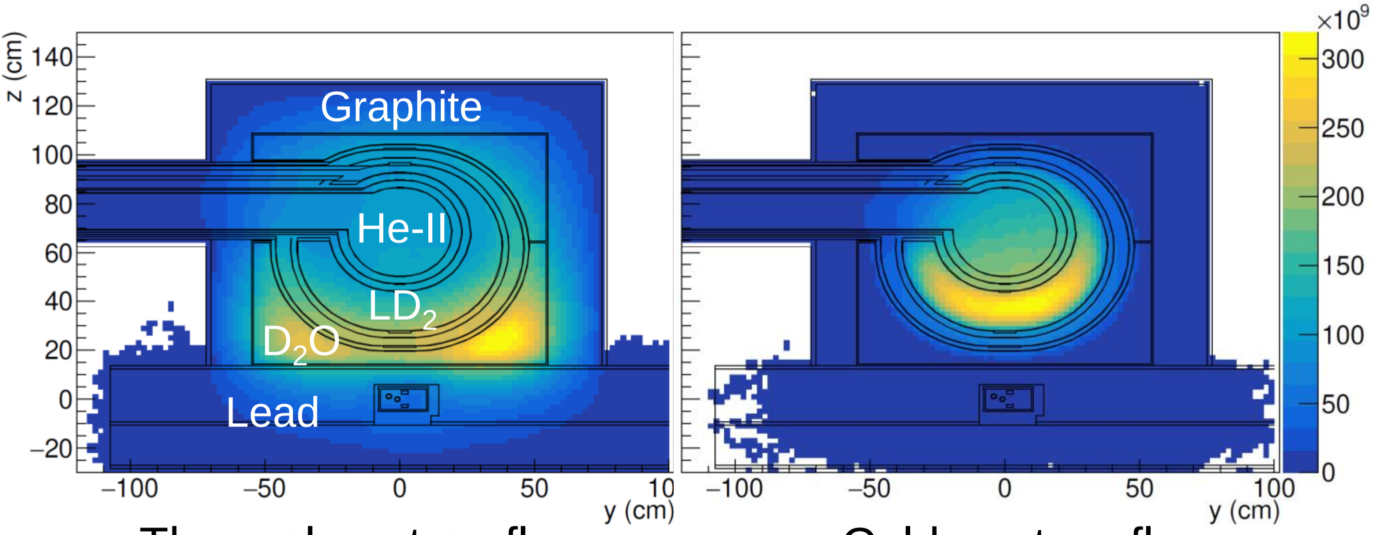
Results

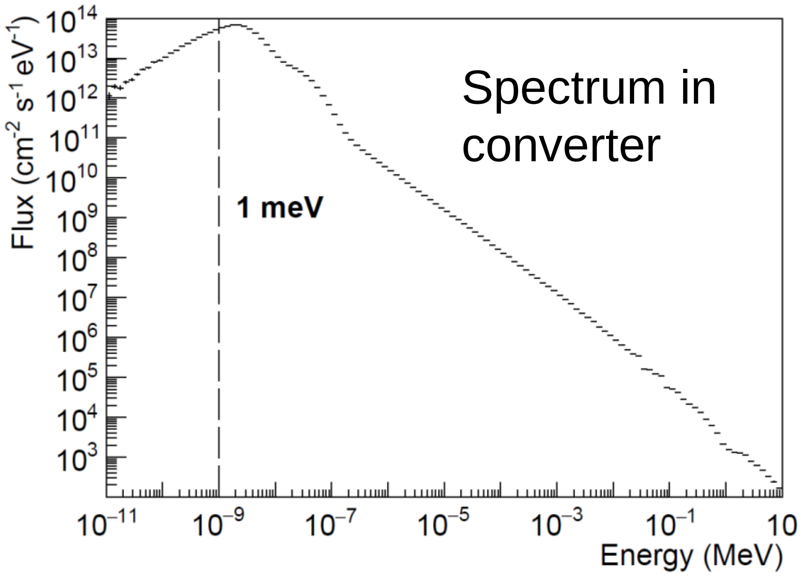


Detailed engineering model

- Minimized wall thicknesses with ANSYS
- Minimized cost for D_2O (430 + 200 L) and graphite (reused)
- Optimized position above target
- **UCN production: 1.4·10^7 to 1.6·10^7 UCN/s**
- **Max. heat load: 8.1 W @ 1.1 K**
- 27 L He-II converter (+ ~50 L in guide)
- 125 L LD_2, max. heat load 63 W @ 20 K
- Storage lifetime in source: ~30 s
- Recently published: 10.1016/j.nima.2020.163525

Most important parameters





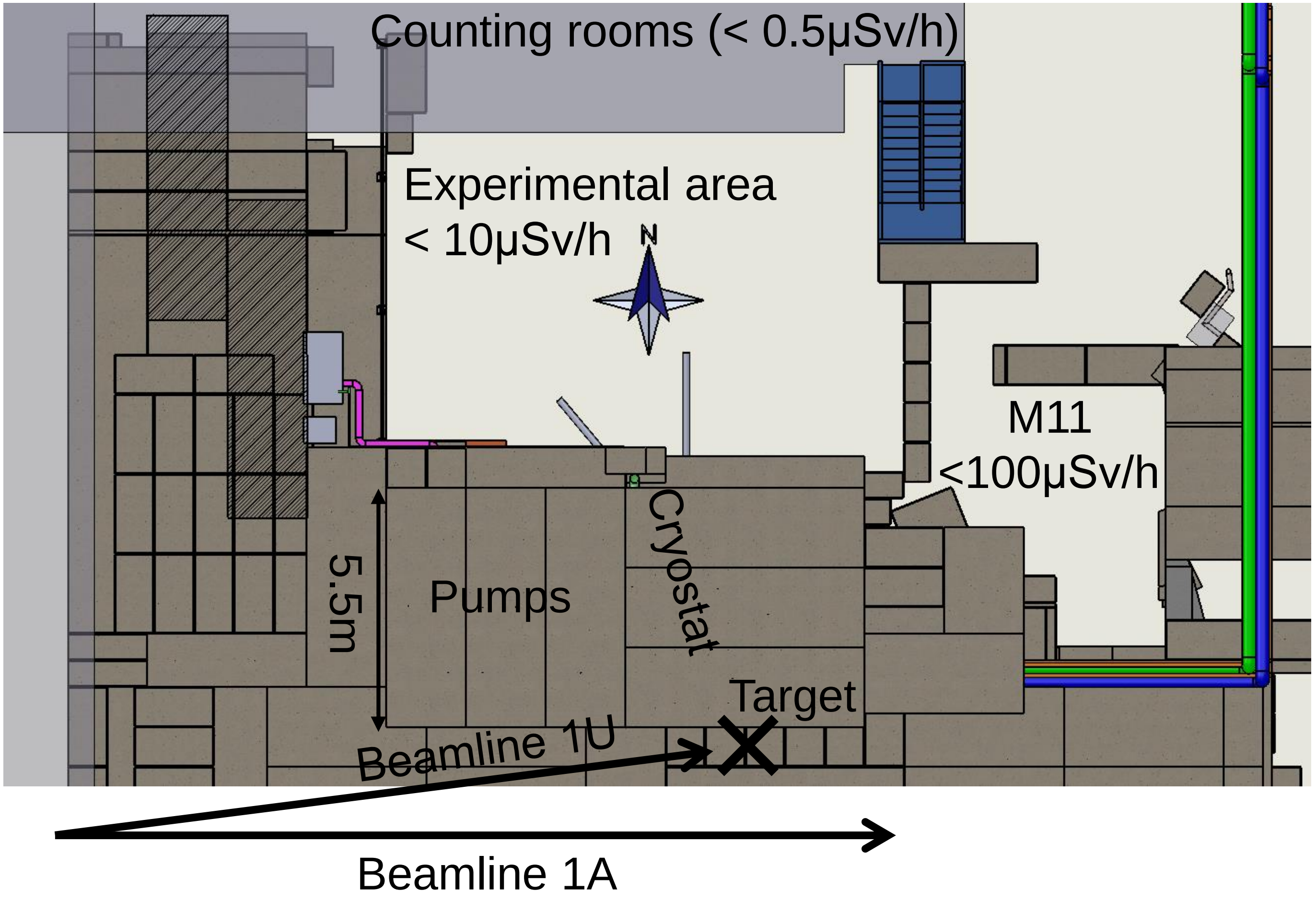
Impact on UCN density

- Cold moderator: (compared to LD_2)
  - sD_2O (optimized): -62 %
  - LH_2 (optimized): -67 %
  - Add 15L LD_2 (optimized): +5 %
- Converter vessel: (compared to 2mm Al6061)
  - Beryllium: +90 %
  - AlBeMet/MgAl: +40 %
  - Reduce thickness 1 mm: +25 %
- Moderator vessels:
  - Reduce thickness 1 mm: +5 %
  - Reduce spacing 10 mm: +5 %
- LD_2 purity: (compared to 100% para-D_2)
  - 33 % Ortho-D_2: -7 %
  - Add 1 % hydrogen: -4 %
- Bismuth neutron filter:
  - +25 %, but +200% heat load on LD_2 &10x radioactivity

Biological shielding

Moderator engineering – see next talk

Requirements



- Reduce prompt radiation below limits
- Quick access to cryostat, while beamline 1A operating
  - Exclusion area access controls
  - Minimize residual radiation < 65 μSv/h for maintenance at cryostat lid
  - Safety procedures for confined spaces
- Beam losses in beamlines 1A or 1U:
  - < 50 mSv/h in any accessible area
- Minimize shielding, maximize experimental area
- Include space to bury target at end of life

Access Plan Overview
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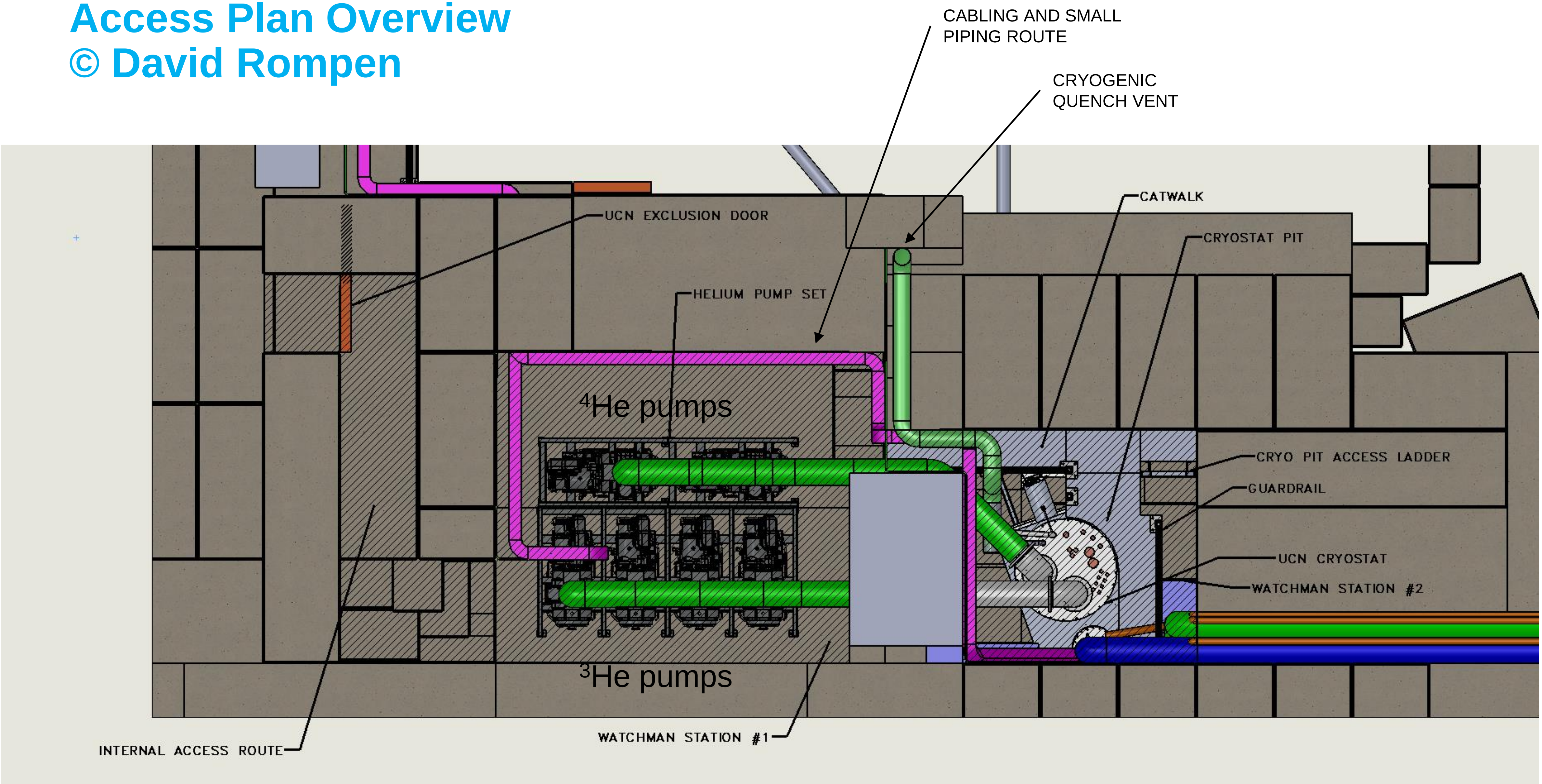

Proposed UCN Shielding Pyramid Overview
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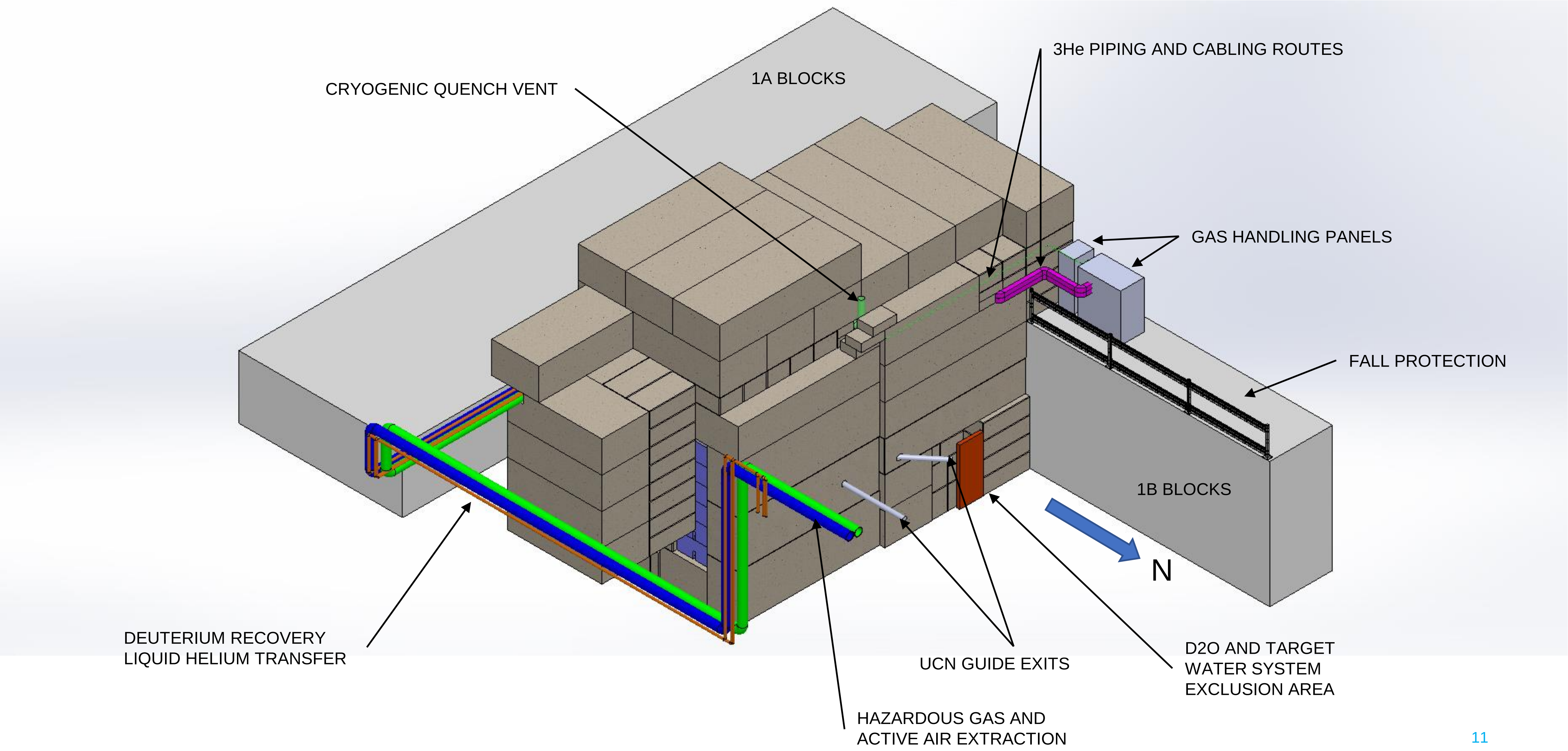
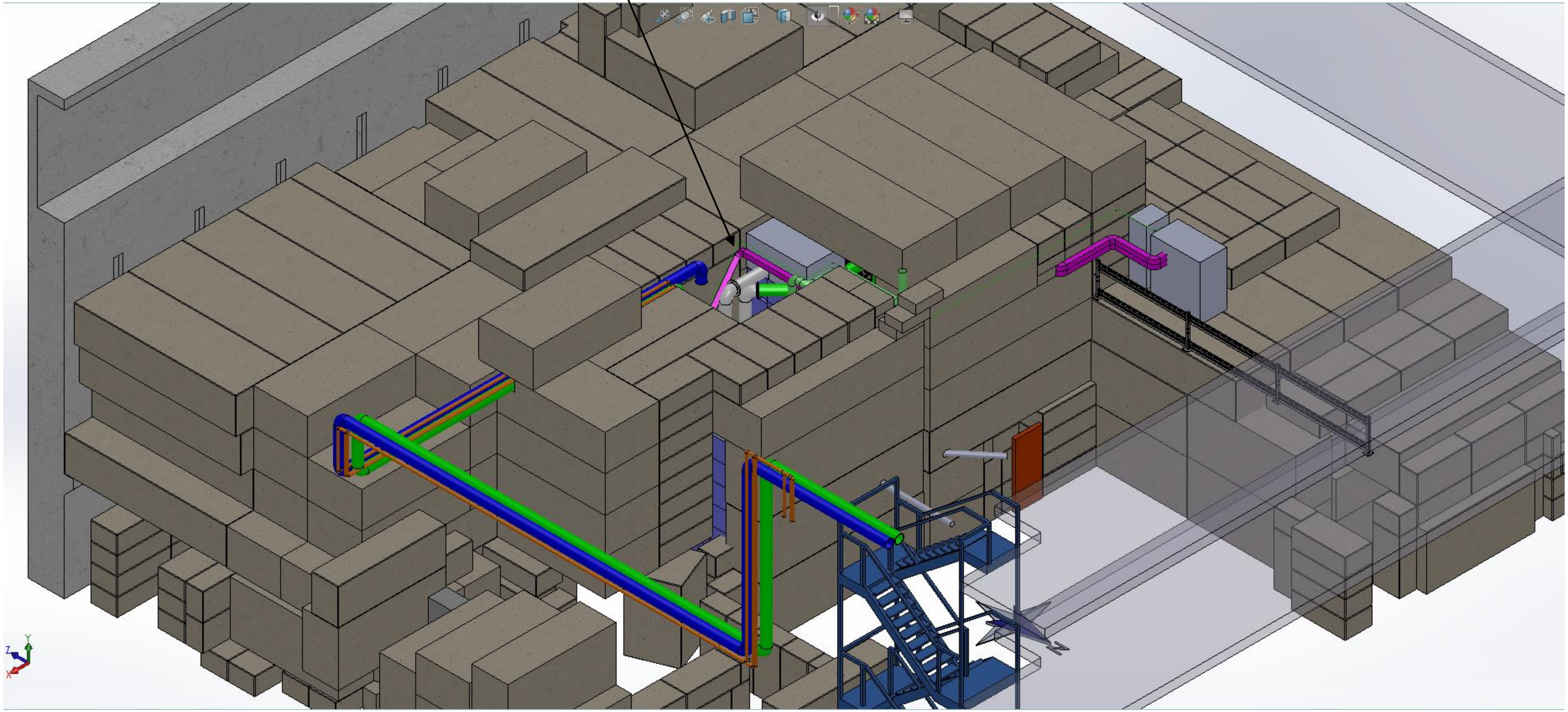


Proposed UCN Shielding Pyramid Overview (© David Rompen)

EXPOSED CRYOSTAT PIT ACCESS



Proposed UCN Shielding Pyramid Overview
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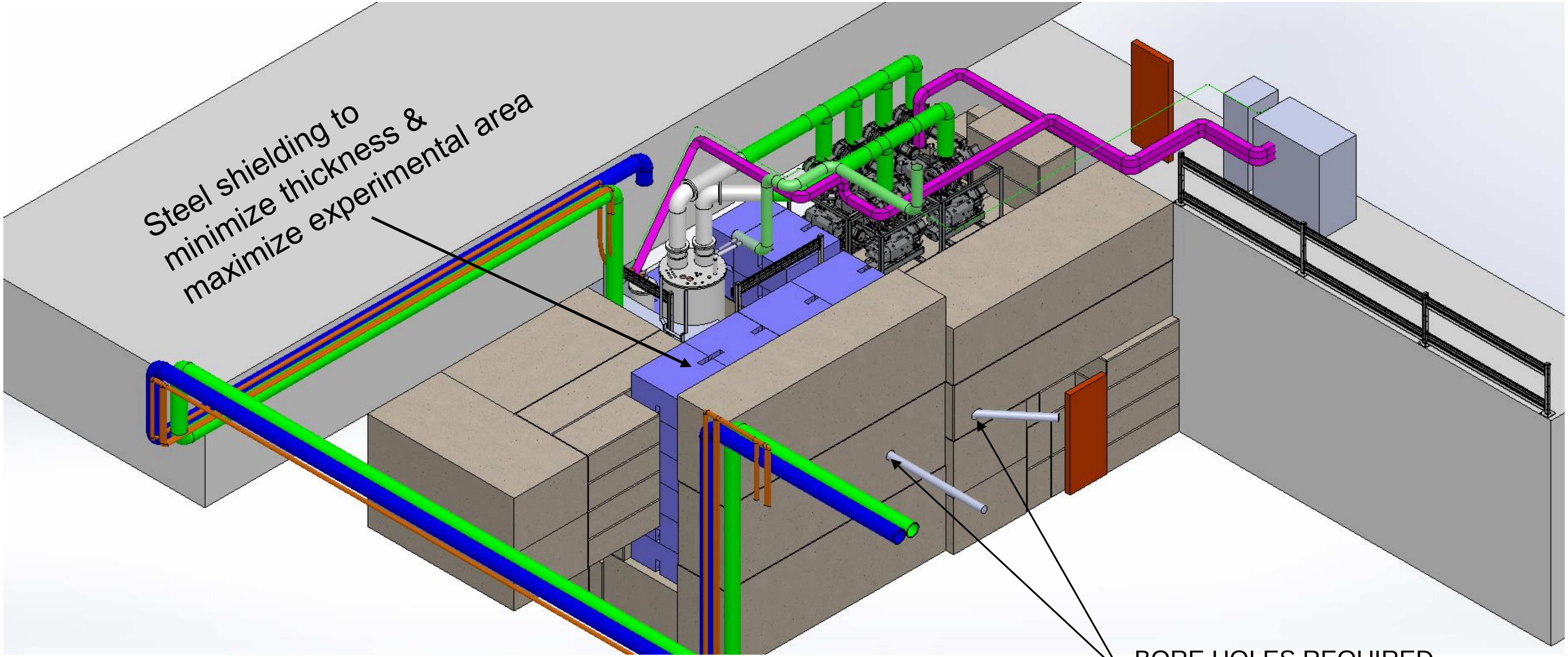

BORE HOLES REQUIRED
8" DIAMETER

Potential temporary shielding allowing source installation while beamline 1A operating

Inner shielding
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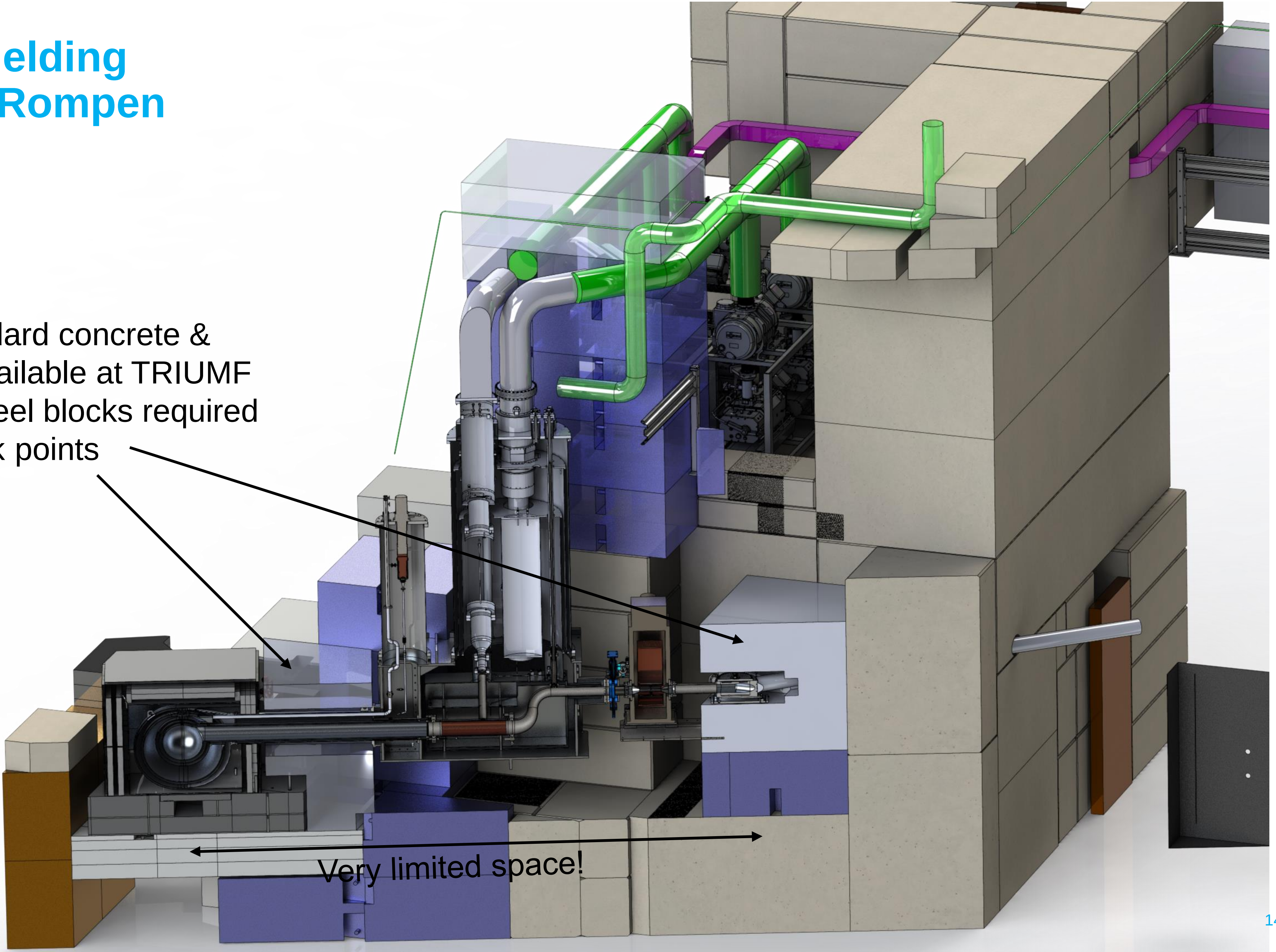
- Sufficient standard concrete & steel blocks available at TRIUMF
- Few custom steel blocks required for critical weak points



Status

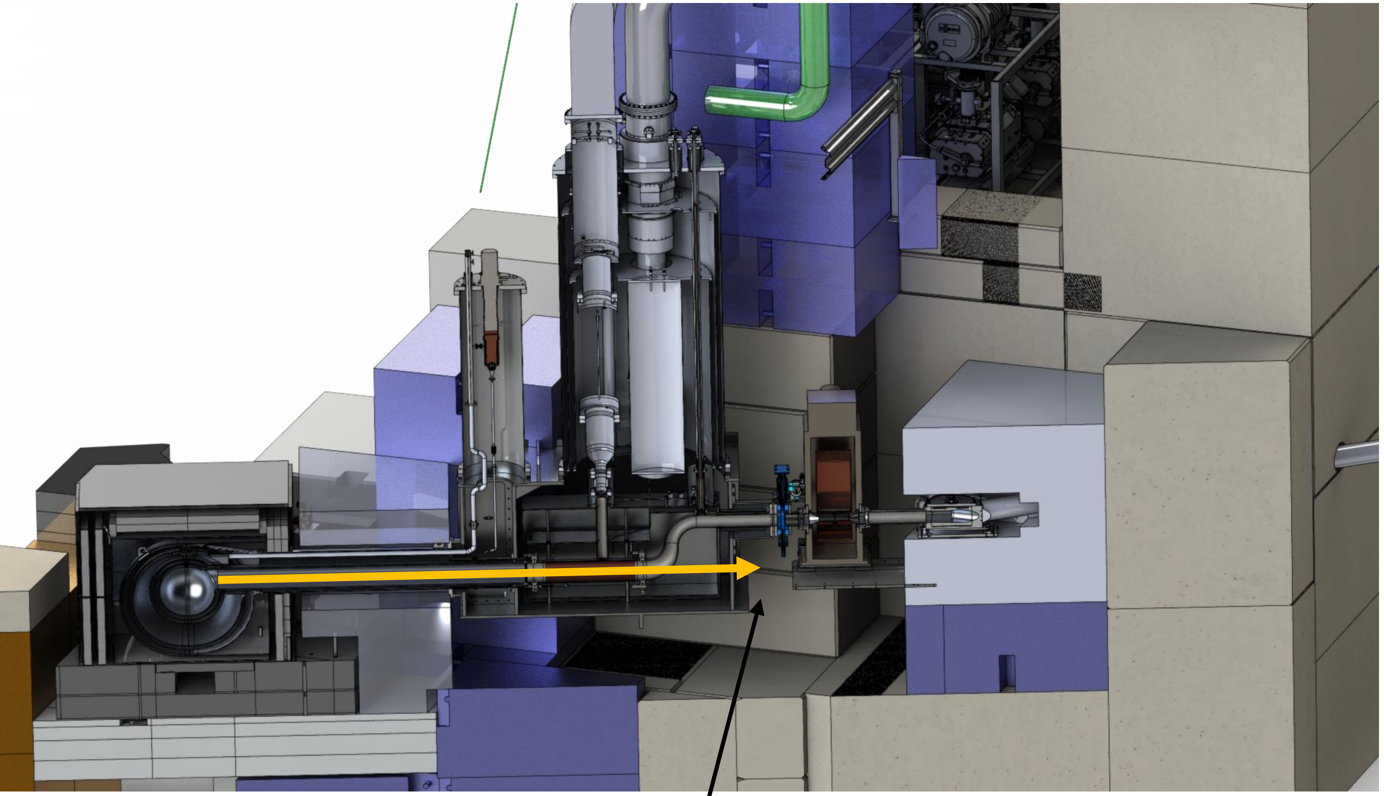
- 2018: Extensive simulations
  - show that concept adheres to dose limits in all scenarios,
  - produce dose-rate maps (see appendix), and
  - put requirements on radiation hardness of components.
- May 2019: TRIUMF review identifies no showstoppers
- Winter 2020: Dose estimates for
  - Cryostat maintenance
  - Moderator replacement

To do

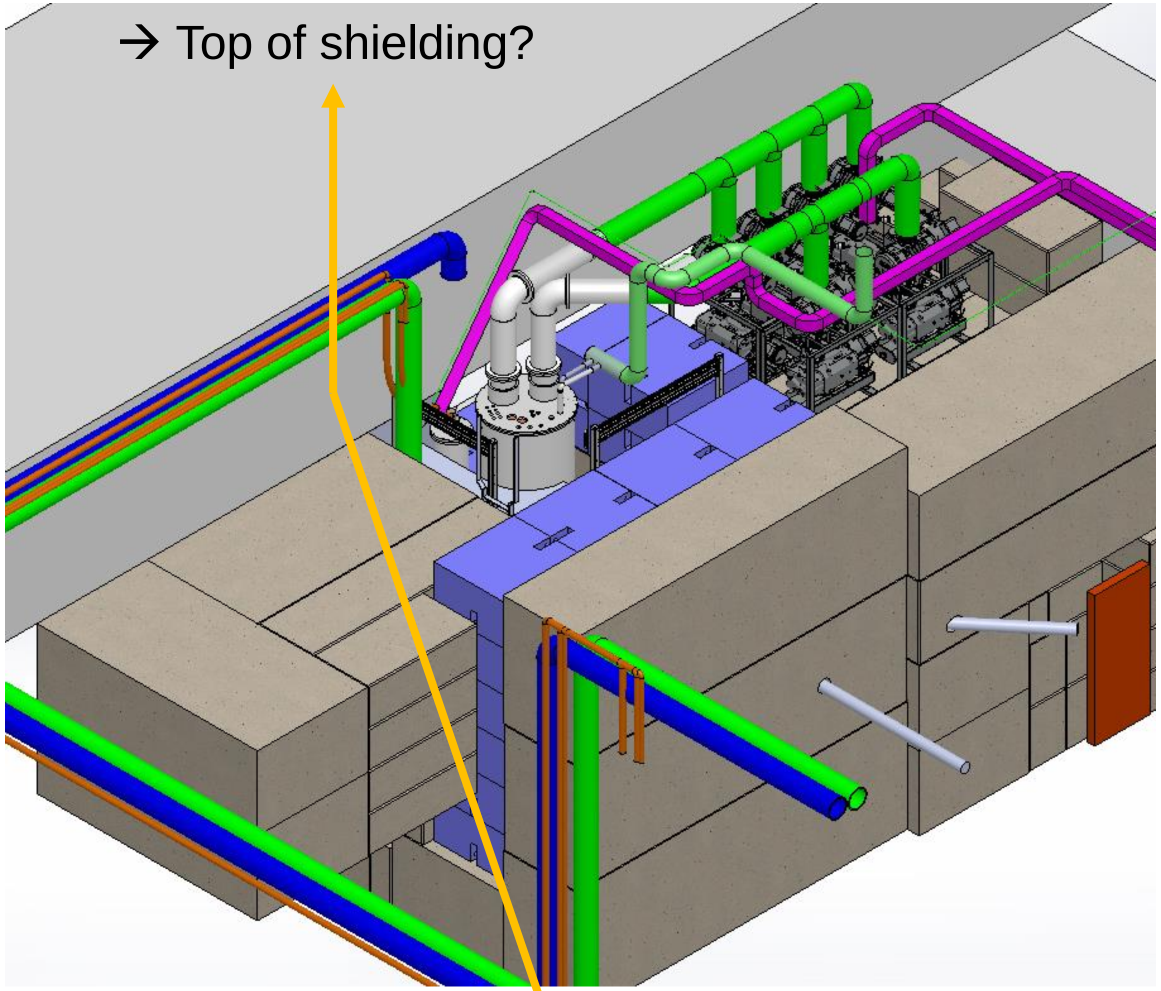
- Detailed design of D_2O & graphite moderators to finalize dimensions
- Design and order custom shielding
- Finalize procedures and safety precautions for
  - Access to exclusion areas/confined spaces
  - Moderator replacement
  - Target replacement
- Shutdown 2021: Test target replacement procedure

Moderators and partial shielding have to be installed during shutdown 2021 or project will be delayed by one year!

VCN



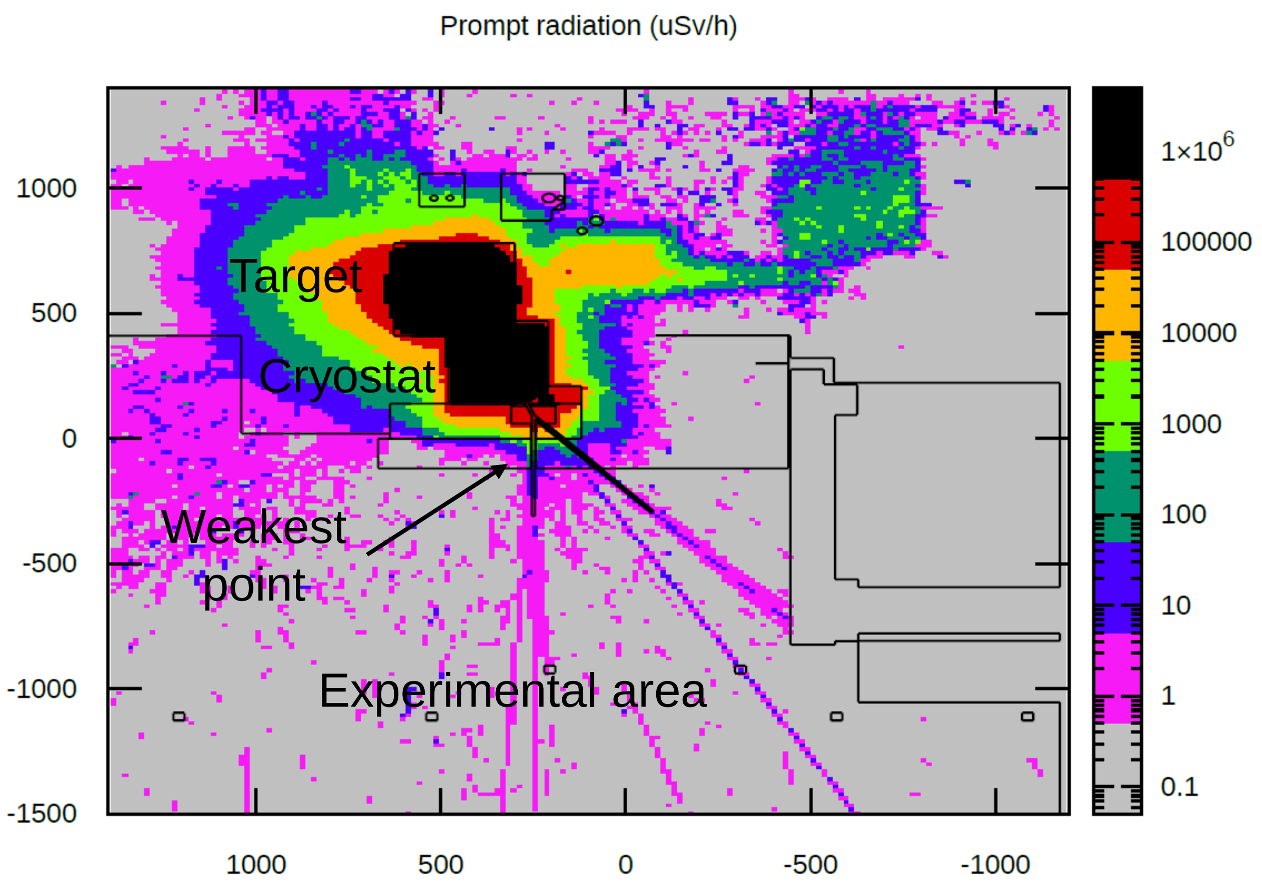
Add diagnostics port
No additional guides & penetrations



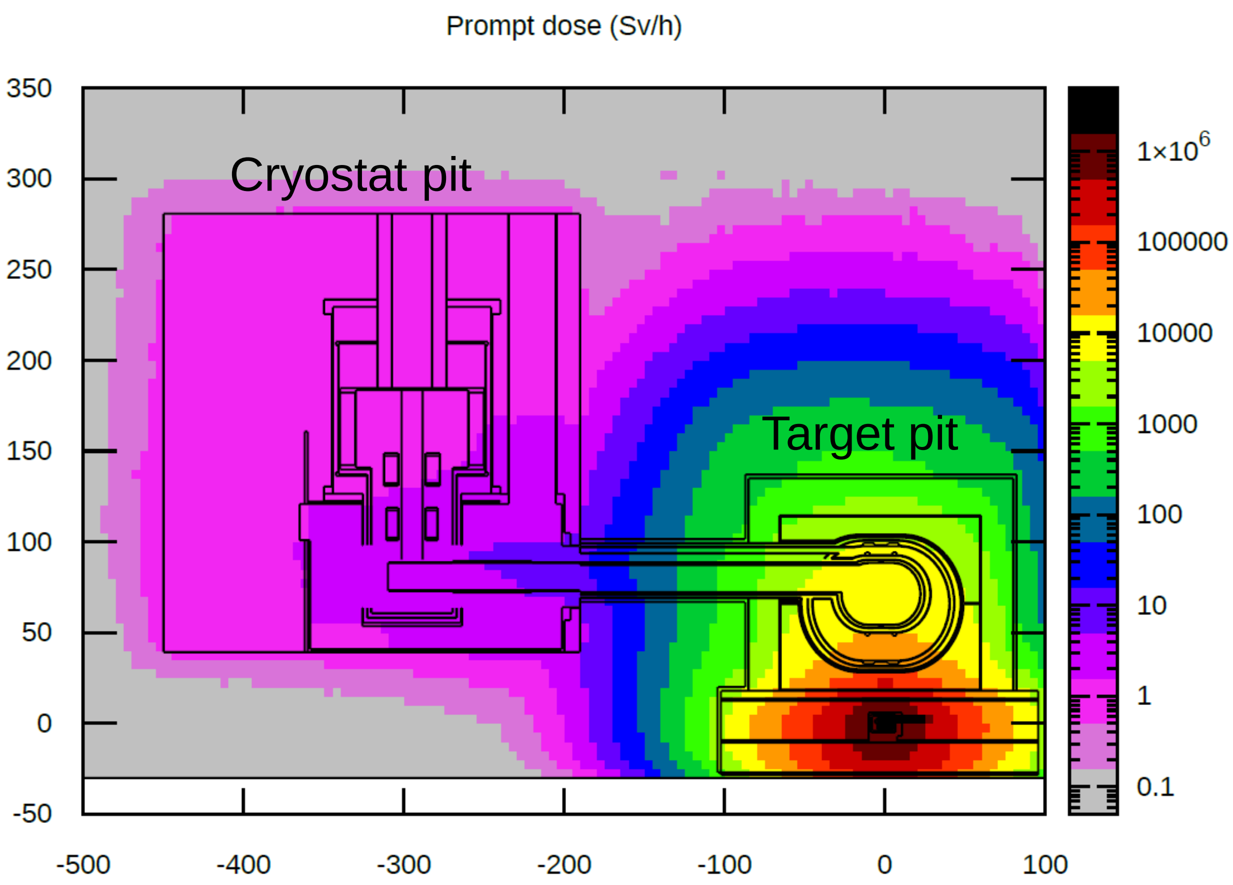
→ M11 area?

Dedicated VCN line (~5x5 cm^2):
Line of sight onto cold LD_2 moderator
No impact on UCN performance
Shielding penetrations needed

Prompt radiation



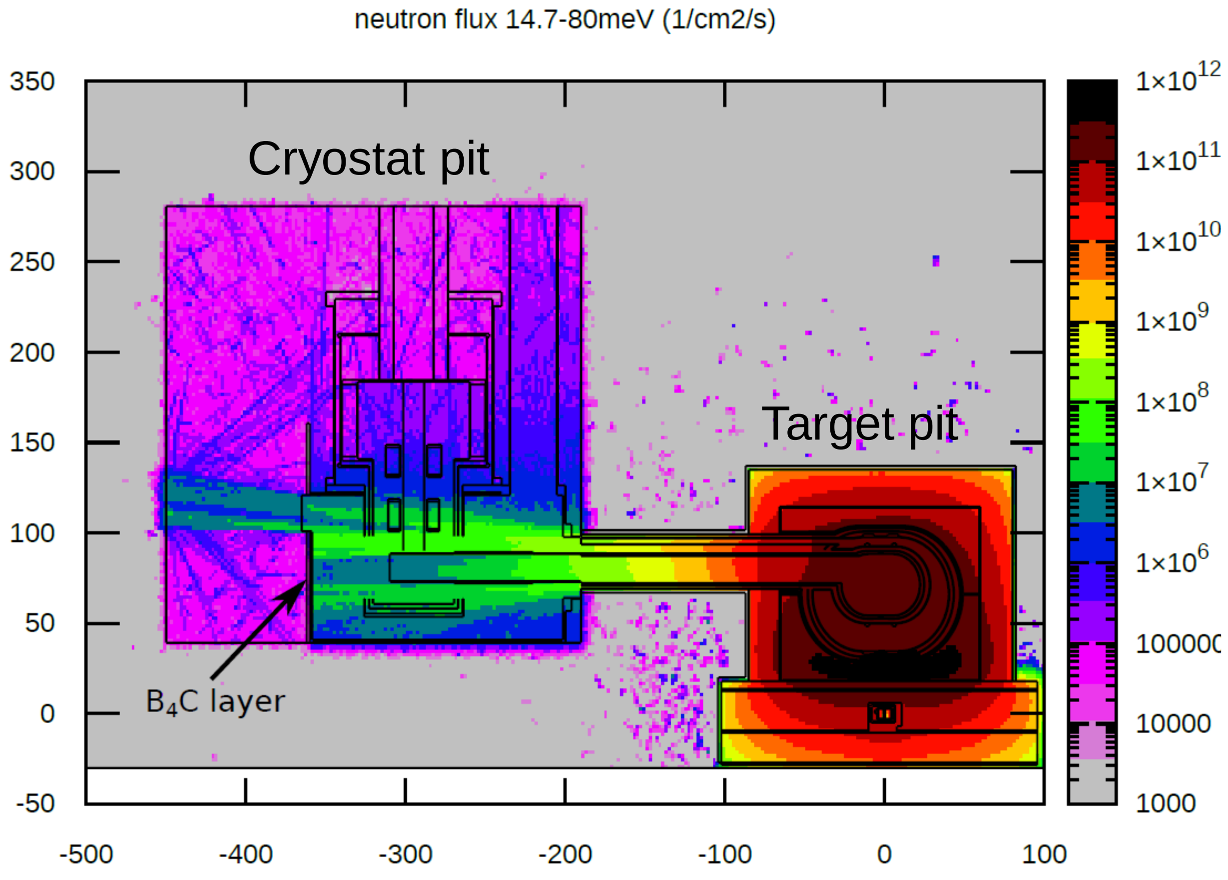
Prompt dose rate (µSv/h)



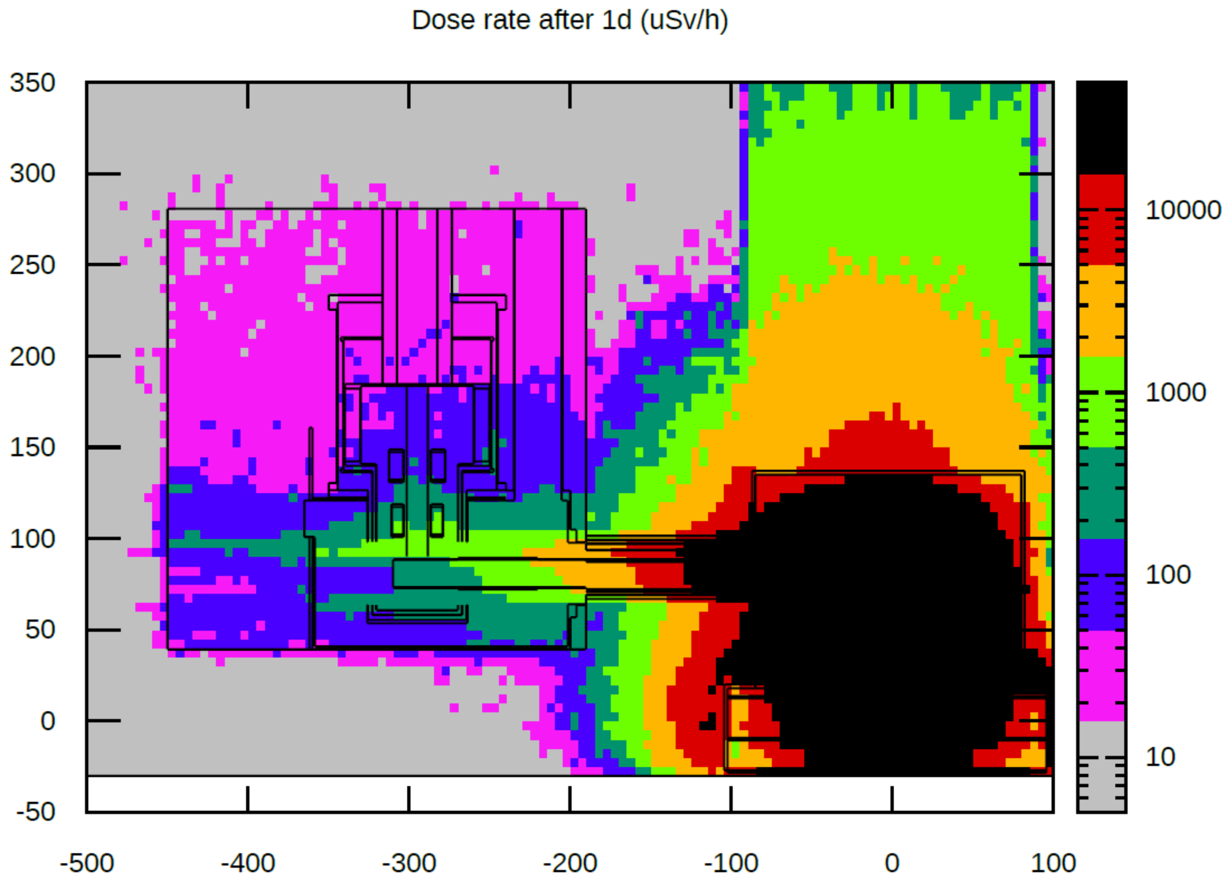
Prompt dose rate (**Sv/h**)

Extreme radiation environment in target pit

Activation and residual radiation

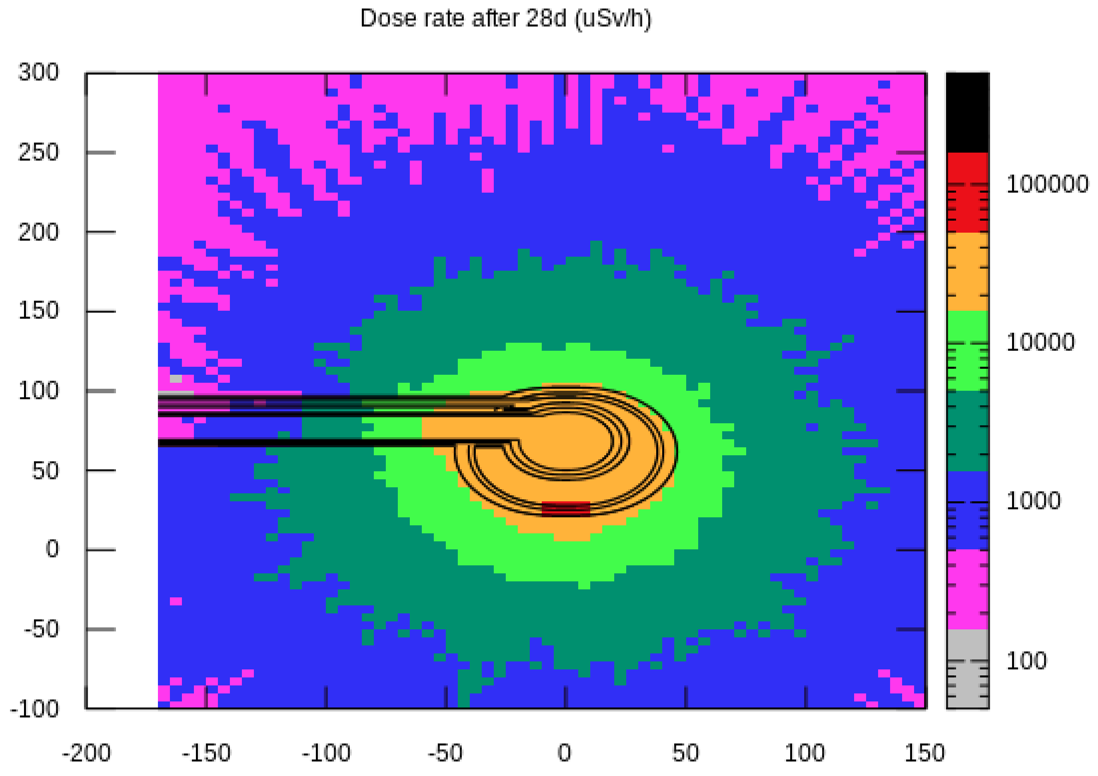


Thermal neutron flux in target and cryostat pits

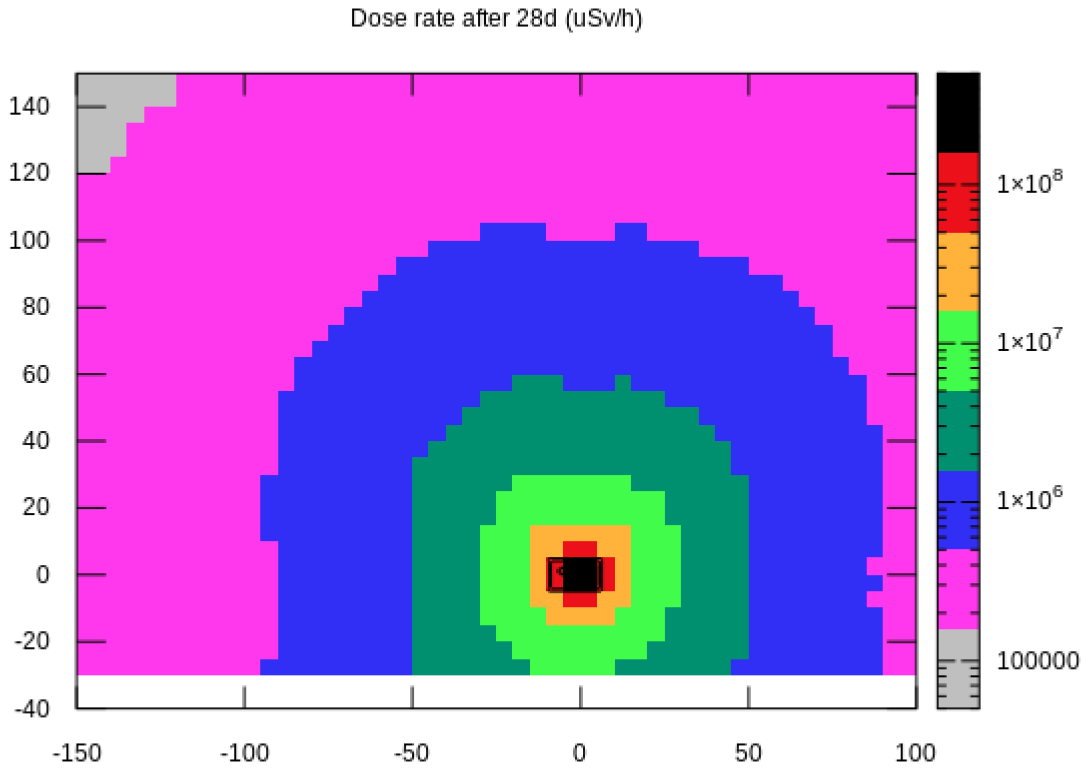


Residual dose rate (µSv/h) 24h after beam off
(cryostat lid accessible)

Target & moderator replacement after 20 years



Residual radiation from tail section
Already too hot to touch after 40 – 80 h irradiation



Residual radiation from target
15cm lead cask required for disposal