Overall Shielding Strategy for Instruments

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European Spallation Source

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Unique ESS Long-Term Challenges

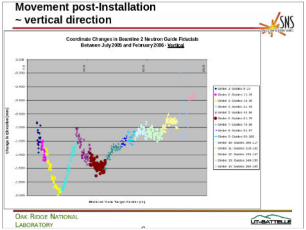
- Alignment, because:
  - Floor load capacity is low (20T/m^2, compared to 30-60 T/m^2 at other spallation sources)
  - On average, ESS guides are long ($\geq$ 150 m) due to optimisation for the source pulse structure
  - Thermal stability is $\pm$ 2°C ($\Longrightarrow$ around 160 μm variations with 2 m supports, 20μm/°C)
- Background, because:
  - Long pulse spallation source
  - No source heavy shutters[1] to use for diagnosis[2]
  - 5 MW source, 5$\times$ greater beam power than existing facilities[3]
  - Relatively (and in some cases absolutely) reduced thickness target shielding compared to other spallation sources facilities[3]
- Moderator brightness assessment, because:
  - Moderators will be regularly replaced on a 2 year cycle
  - Each instrument views a different perspective of the overall system

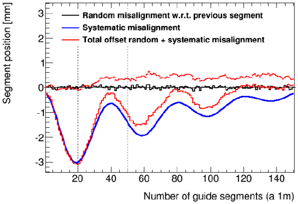
Response to Unique ESS Challenges

- Alignment
  - Dedicated staff to handle as built models, monitor instrument performance, plan for maintenance (probably need 3-5 staff)
- Background
  - Dedicated staff supporting for continuous R&D on background minimisation throughout facility lifetime, supporting future instruments, upgrades and interventions, along with the safety, activation etc.
- Moderator brightness
  - Above staff support dedicated spallation physics team
  - Feed back real time performance monitoring and diagnostics of source

Systematic Misalignment

- Based on SNS Data from K Herwig's project
- Damped cosine function using data from CF
- Based on these data we have a *quantified* risk of misalignment of instruments
- This is part of the Phase 1 study & documentation for each instrument





(c) 3 mm

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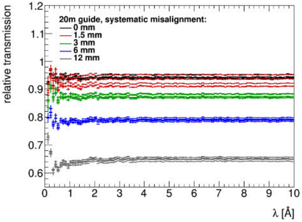
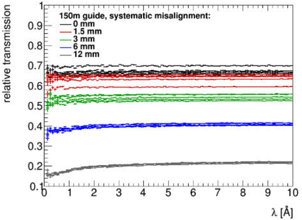


(a) 20 m guide, 20 segments



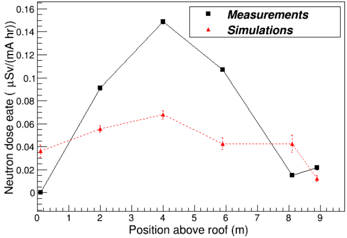
(b) 150 m guide, 150 segments

Fact Finding Mission — 2012-2013

- Input from SNS
- Input from PSI
- Input from ISIS

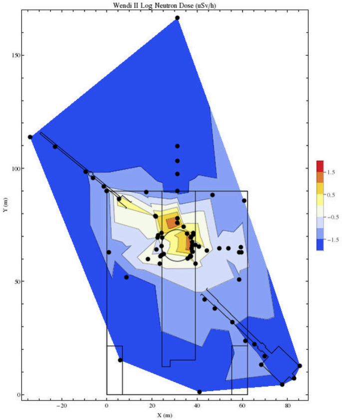
PSI Measurements

- High energy component streaming through target
- Dose rate meets safety requirements
- Pulsed source instrument would be $\times 100$ above requirements



SNS Measurements

- Hotspot above harp (mitigated at ESS)
- Earthquake streaming is critical



Main Lessons

- If we rely purely on concrete and steel, then fast neutron streaming is likely to be an issue
- Instruments will all need to have a substantial cave, or suffer from background issues
- Albedo transport down the guides (and between instruments) has to be minimised
- Assumptions used at reactor sources do not hold for pulsed spallation sources (*i.e.* copying reactor design concepts can result in considerable background issues

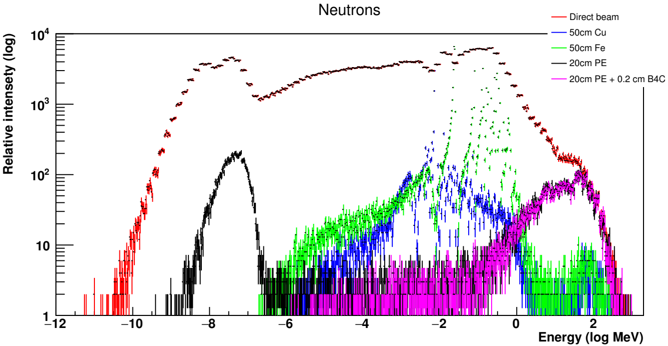
Requirements

- "The world's leading neutron source"
- Interpreted by almost all instruments as exceeding current world leading signal-to-noise by factor of 10 [4]
- Typical numbers:
  - $10^{-6} - 10^{-7}$ elastic line to background on inelastic spectrometers
  - 6-8 decades on log-log plot for SANS & Reflectometry
  - 10^4 Bragg-peak to background on diffraction

Shielding Strategy

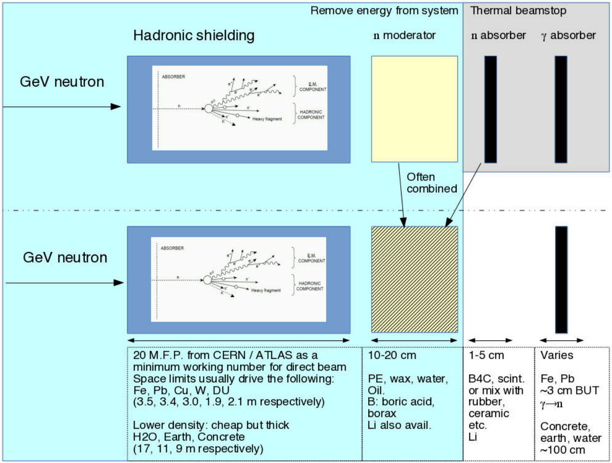
(With a small note: Gunter Muhrer is the shielding coordinator, and signs off on shielding as meeting the safety and licensing requirements).

Hadronic Shielding Materials



C. Cooper-Jensen *et al*, in preparation

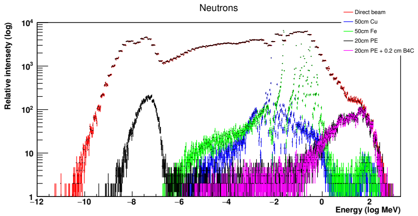
High Energy Shielding Concept



Elements borrowed from ATLAS/CERN and mathsconcepts.com

Copper Guide Substrates

- Steel transmits keV-MeV neutrons
- Normally we would stop these with plastic
- Sometimes gamma dose is too high for plastic (e.g. next to supermirrors)
- Solution: replace iron-based substrate with copper



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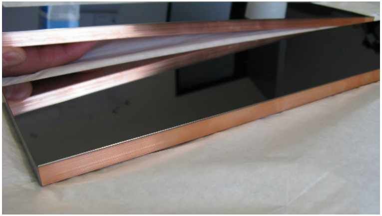
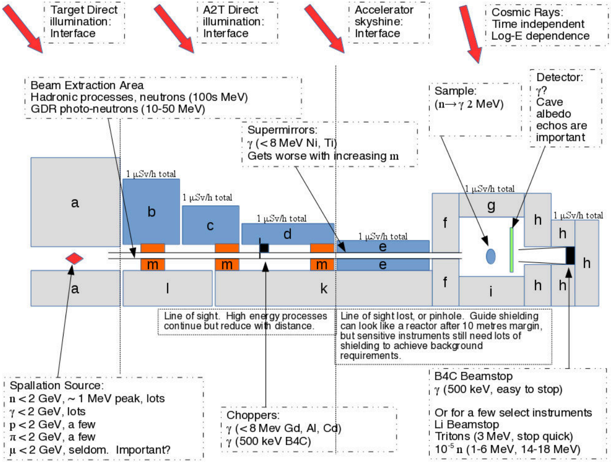
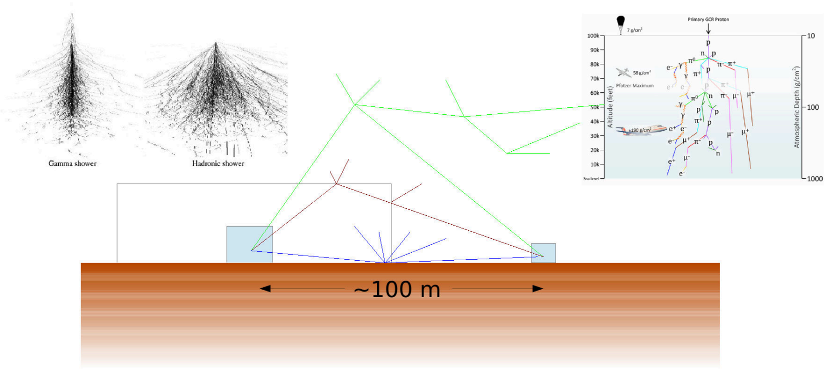


Swiss Neutronics - ESS collaboration (in preparation)

Internal & External Radiation Sources



Skyshine



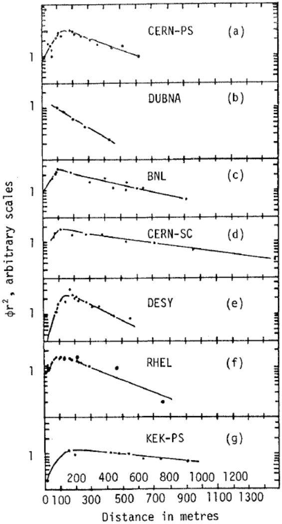
Gamma shower
Hadronic shower
~100 m
Primary GCR Proton
Pfotzer Maximum
Altitude (feet)
Atmospheric Depth (g/cm²)
Sea Level

Skyshine

- Peak at $\sim$100 metres for many accelerators
- Comes from *everywhere* that high-energy particles escape

$\phi(r) =$
$\frac{aQ}{4\pi r^2}\left[1 - \exp\left(\frac{-r}{\mu}\right)\right]\exp\left(\frac{-r}{\lambda}\right)$

- $a \approx 2.8$; $\mu \approx 56$ m; $\lambda \approx$ 100's m



Stevenson & Thomas, Health Physics 46 (1984), p115

Skyshine

- Peak at 100 metres for many accelerators
- Comes from *everywhere* that high-energy particles escape

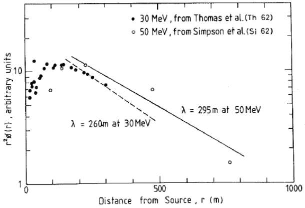
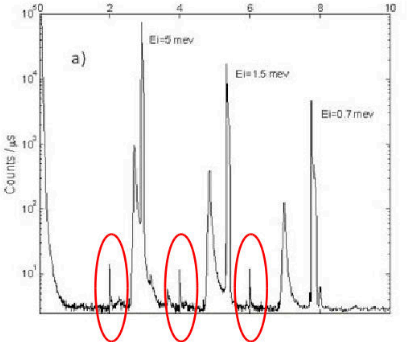


FIG. 8. Comparison of the effective absorption length for 30 and 50 MeV with data from the Rutherford Laboratory Proton Linear Accelerator (Th62; Si62).

Stevenson & Thomas, Health Physics 46 (1984), p115

Skyshine

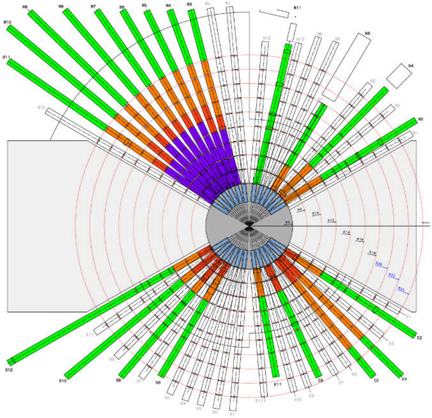
- Almost certainly what we see on LET from TS1
- This is *significant* for ESS
- Naive instrument design would give 10^{-4} background from this component alone
- To get 10^{-6} background we *need* instrument caves



Many thanks to Rob Bewley for this excellent picture

Integration Challenges

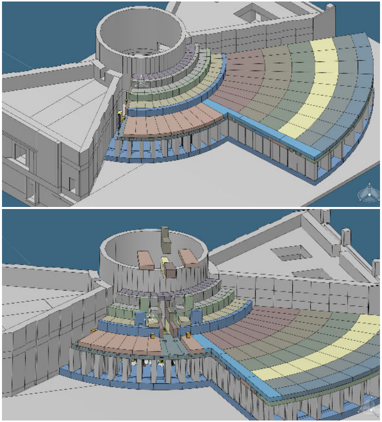
- Typical ESS layouts present integration challenges
- Non-green zones have more than nominal required 1.5 metres of lateral shielding
- Simplify engineering and reduce shielding risks — common bunker solution in overlap zones



Old, illustrative figure, many thanks to Chopper group

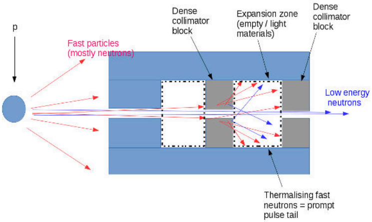
Early Bunker Project

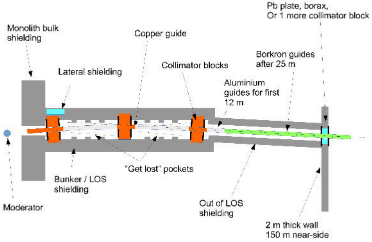
- 2014-2015: Identifying optimum materials and composition, researching those that do not exist and finding alternatives to those that are too expensive
- April 2015: Neutronics design phase begins



Beamline Concept

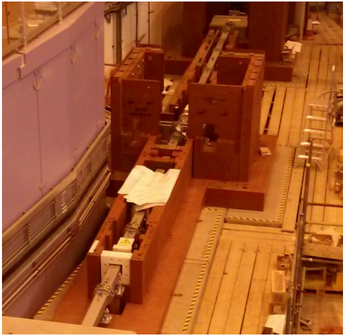
- It is essential to scatter out the high energy background component, via a series of dense scattering points and voids
- The old concept (right) was based on a filled bunker
- It has now been updated with a new concept based around largest possible voids (open bunker)





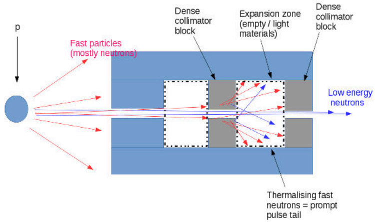
Beamline Concept

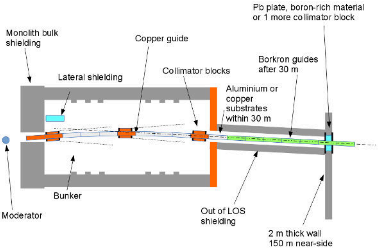
- Actual implementation at ISIS
- Note the steel collimators close to the guide



New Beamline Concept

- It's the same concept!
- It is essential to scatter out the high energy background component, via a series of dense scattering points and voids





ILL Water Bunker

- This is a reactor!
- We rejected this concept, because dealing with the water was considerable trouble

ILL Open Bunker

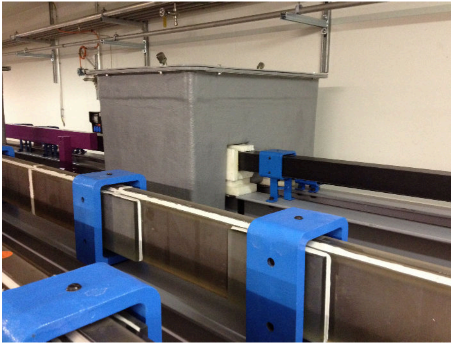
- This is a reactor!

PSI Open Bunker

- ESS bunker will in many ways look similar to this
- Note the water tank collimator blocks
- This concept needs additional source shielding and different collimation for a pulsed source

PSI Open Bunker Collimator Blocks

- Tanks of water with boric acid
- This concept needs additional source shielding and different collimation for a pulsed source
- ESS will use copper or tungsten strips

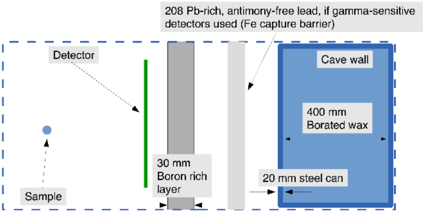


Borated Polyethylene Concrete

- Developed between ESS, Lund Univ, DTI
- Significantly enhanced suppression of 100 keV – 1 MeV neutrons
- *Direction independent* so ideal for instrument backgrounds
- Half the compression strength of regular concrete, but:
- Regular concrete needs structural reinforcement on ESS dimensions in any case

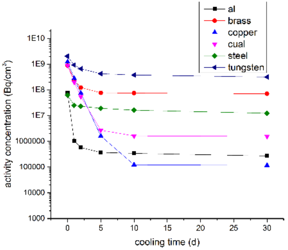
Instrument Caves

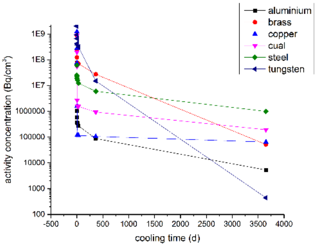
- Essential for meeting background requirements
- Borated wax cans (option 1) approved for fire safety
- Borated polyethylene concrete (option 2) in final stages
- (Some partners are not happy supplying wax cans!)



Radiation Safety Engineering for Servicing

- During phase 2 — activation engineering needs to be done
- Assess access areas / maintenance planning
- Swap out active components (Steels) for superior materials (Al, Cu) where feasible
- Affects operations budget and uptime significantly!





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