Shielding Requirements and Backgrounds

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European Spallation Source

3rd May, 2017

Safety Requirements

Legal Requirements

- ESS-0001786 defines radiation areas
- Supervised areas:
  - $< 3\ \mu$Sv/h
  - Likely accidents are H2 (1-100 yr events)
  - All other events are included in the dose budget!

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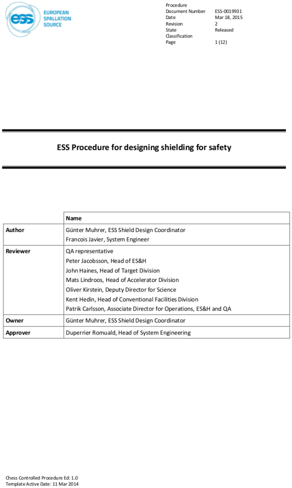
Summary Report	
Document Number	ESS-0001786
Date	Dec 7, 2015
Revision	3
State	Released

Definition of Supervised and Controlled Radiation Areas

	Name
Author	Günter Muhrer, ESS Shield Design Coordinator François Javier, System Engineering
Reviewer	Peter Jacobsson, Head of ES&H Eric Pitcher, Head of Target Division Mats Lindroos, Head of Accelerator Division Shane Kennedy, Deputy Director for Science Kent Hedin, Head of Conventional Facilities Division John Haines, Associate Director for ES&H, QA and Operations
Owner	Günter Muhrer
Approver	Roland Garoby, Technical Director

Safety Procedure

- ESS-0019931 defines process we must use
- By hand: 3× safety margin (1 μSv/h), with detailed review
- Non-approved codes ignored (but still useful!)
- Approved codes: 2× safety margin (1.5 μSv/h)



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Procedure	
Document Number	ESS-0019931
Date	Mar 18, 2015
Revision	2
State	Released
Classification	
Page	1 (12)

ESS Procedure for designing shielding for safety

	Name
Author	Günter Muhrer, ESS Shield Design Coordinator Francois Javier, System Engineer
Reviewer	QA representative Peter Jacobsson, Head of ES&H John Haines, Head of Target Division Mats Lindroos, Head of Accelerator Division Oliver Kirstein, Deputy Director for Science Kent Hedin, Head of Conventional Facilities Division Patrik Carlsson, Associate Director for Operations, ES&H and QA
Owner	Günter Muhrer, ESS Shield Design Coordinator
Approver	Duperrier Romuald, Head of System Engineering

Chess Controlled Procedure Ed: 1.0
Template Active Date: 11 Mar 2014

Approved Transport Codes

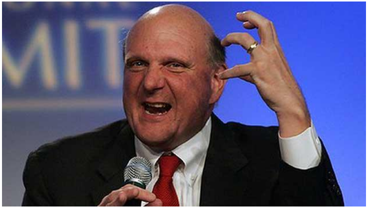
- MCNP(X)
- FLUKA — low E?
- MARS — low E?

Approved Activation Codes

- Cinder
- Orihet
- Monteburn
- Cinder is preferred
- The others can only be used in case of Cinder license problems

Licensing Problems

- MCNP(X) is
  - Paid license
  - A birth location lottery
- The other codes can have drawbacks:
  - Not approved (e.g. GEANT4, PHITS)
  - Questions about accuracy at low energy (e.g. FLUKA, MARS)



What do we do?

- Your team expert didn't win the birth location lottery
- You are not alone!
- Many staff at ESS, even in NOSG, will never gain full use of MCNP

What do we do?

- Do shielding calculations by handbook, as per ESS-0019931
- In the equilibrium region, 1.5 μSv/h $\approx$ 1.0 μSv/h — you don't save much money
- Get someone to check the results with *any* relevant simulation package, even if it is "not approved"
- This check is also needed for MCNP, if you care about physics and backgrounds
- Options:
  - ESS has limited bandwidth for GEANT4, CombLayer & MCNP
  - Activation calcs can be fairly quick
  - High energy & astronomy community has *many* GEANT4, FLUKA & MARS people
  - JPARC community has several PHITS experts (Niita *et al*)

Core Physics

Fast Neutron Albedo

- Roughly half the beam is scattered back

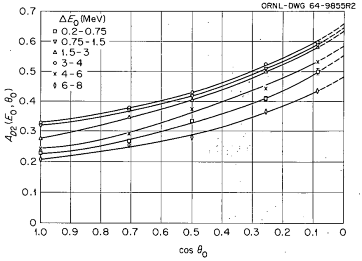


Fig. 4.3. Total Single-Collision Dose Albedo as a Function of cos θ_0 and ΔE_0 for Fast Neutrons (>0.2 MeV) Reflected from Concrete. (From Maerker and Muckenthaler, ref. 1.)

W. E. Selph, ORNL-RSIC-21 (DASA-1892-2)

Fast Neutron Albedo

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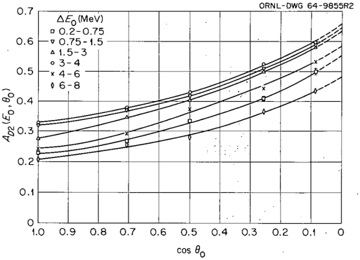

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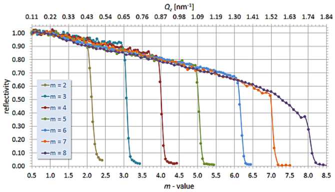
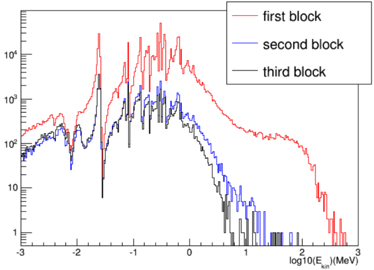


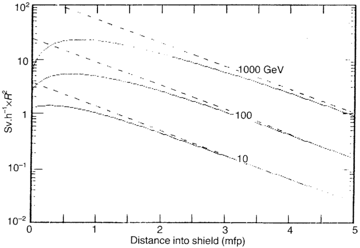
Multiple Line of Sight

- 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



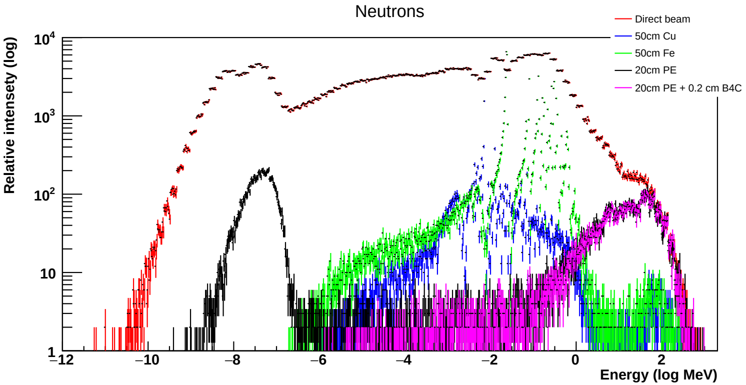
Secondary Particle Equilibrium

- Data corrected for $1/R^2$
- High energy particles create more particles
- Need 3 MFP to reach “neutron scattering” world
- Adding shielding might make a problem worse!
- This is why big empty spaces work (e.g. bunker)
- Guessing can be difficult, we need to simulate



A. H. Sullivan, ISBN 1 870965 183 (1992), p. 39

Hadronic Shielding Materials

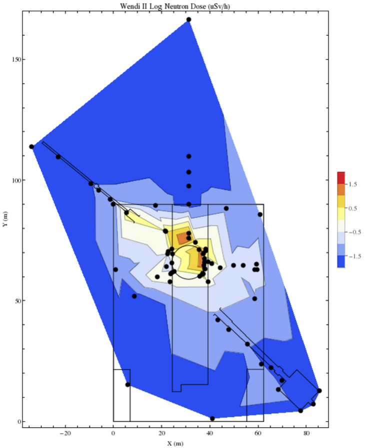


C. Cooper-Jensen *et al*, in preparation

Survey of SNS

Three brightest *n* sources:

- Harp / A2T source — mitigated by interface with Tom Shea (Accelerator)
- Monolith interfaces — earthquake gap between target & bunker!
- Basis shielding — mitigated by margin of error on the LOS.



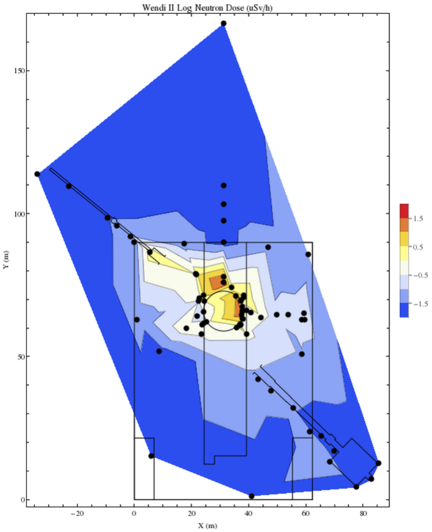
DiJulio *et al*, Journal of Physics: Conference Series 746 (2016) 012033

Survey of SNS

Other interesting facts:

- The accelerator is quiet
- POWGEN straight beamline is OK
- BASIS thin shielding is OK out of line of sight

We thought we might see a safe but significant number of fast neutrons there, but we didn't.



Background Requirements

Requirements

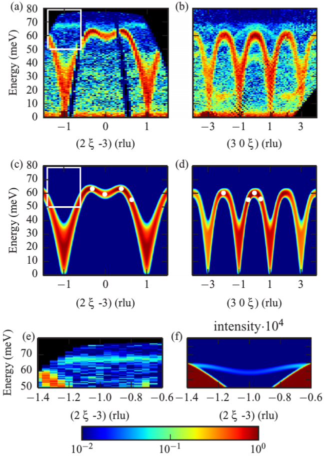
- "The world's leading neutron source"
- Interpreted by almost all instruments as exceeding current world leading signal-to-noise by factor of 10 [1]
- Typical numbers:
  - $10^{-6} - 10^{-7}$ elastic line to background on inelastic spectrometers
  - 6-8 decades on log-log plot for SANS & Reflectometry
  - 10^{4} Bragg-peak to background on diffraction

[1] NOSG Handbook, ESS-0039408

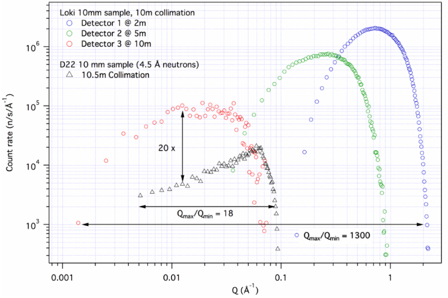
The Problem

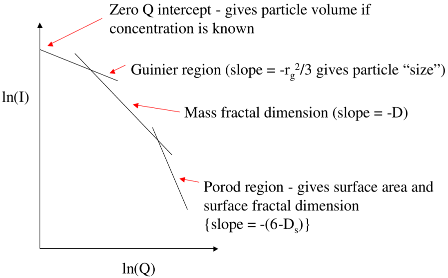
- Background limited science is frequently on a log scale.
- Weak scattering
- Small samples
- “New horizons in science”...
- The instruments are still radiologically safe

Spectroscopy

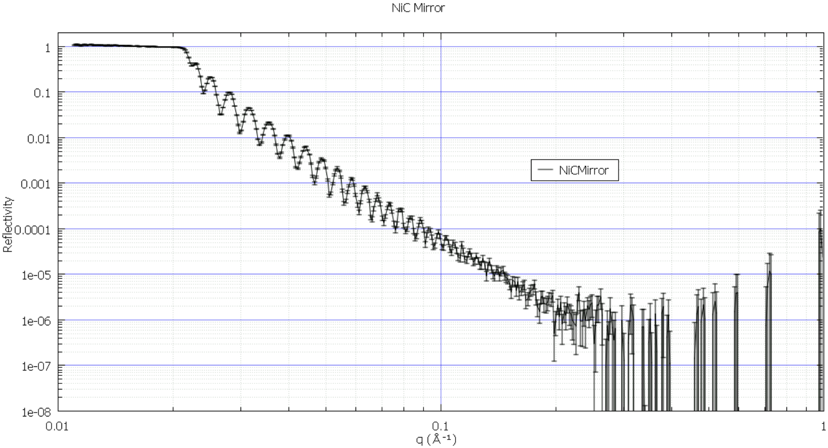


SANS

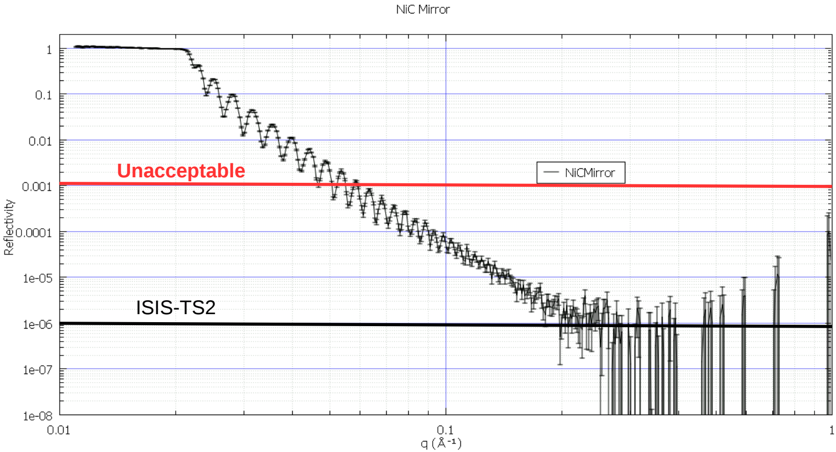

Loki 10mm sample, 10m collimation
Detector 1 @ 2m
Detector 2 @ 5m
Detector 3 @ 10m
D22 10 mm sample (4.5 Å neutrons)
10.5m Collimation
20 x
Q_{max}/Q_{min} = 18
Q_{max}/Q_{min} = 1300
10^6
10^5
10^4
10^3
Count rate (n/s/Å^{-1})
0.001
0.01
0.1
1
Q (Å^{-1})


Zero Q intercept - gives particle volume if concentration is known
Guinier region (slope = $-r_g^2/3$ gives particle “size”)
Mass fractal dimension (slope = -D)
Porod region - gives surface area and surface fractal dimension {slope = $-(6-D_s)$}
ln(I)
ln(Q)

Reflectometry — 10^{-6} is Possible

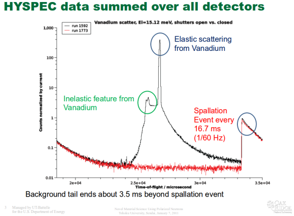


Reflectometry — 10^{-3} Doesn't Cut It

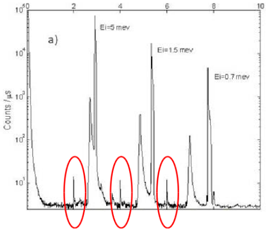


Background Requirements

- SNS CNCS and HYSPEC: BG$\approx$ 11-30 n s^{-1} whole detector).
- BG:S $\approx 10^{-3}$
- $\sim 100\times$ too high
- Instrument proposals: 10^{-6}–10^{-8} n m^{-2} s^{-1}
- TS2 and LET internal backgrounds are so low you even see TS1 background



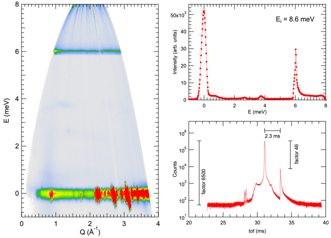
HYSPEC (SNS), 100$\times$ too high

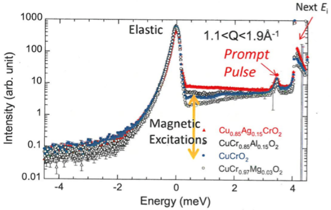


LET (ISIS) Acceptable

Background Requirements

- Similar problems on CNCS
- Similar problems at JPARC

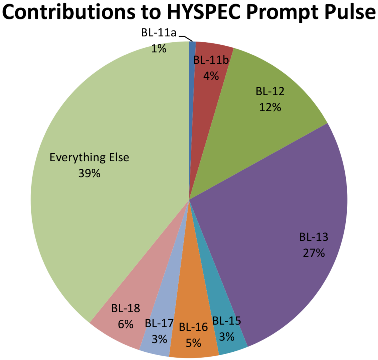




Amateras (JPARC)

HYSPEC Background Sources

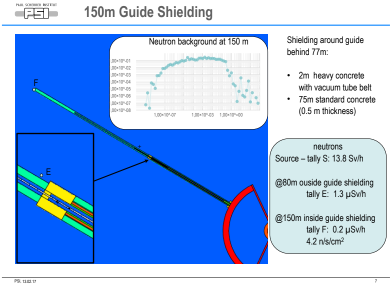
- Not trivial to debug backgrounds
- Even if you find sources, fixing them can be expensive
- Need to fix as much as possible during early design



M. Smith *et al*, ORNL/TM-2015/238

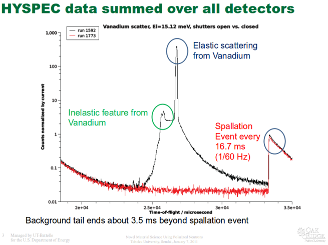
Cave Echo Estimate at 150 m

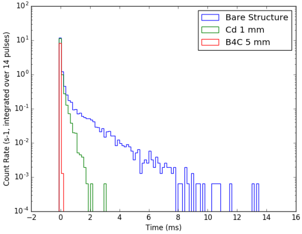
- MAGIC source (Uwe Filges) 4 neutrons /cm2 /s
- Fairly flat spectrum from keV to 1 MeV



ns Pulse (HYSPEC)

- 5 × 5 × 5 m^3 cave
- "Bare structure" tail matches time structure very well
- *No skyshine, A2T, target, bunker, crosstalk*
- Illustrates the fast suppression of boron, compared to cadmium

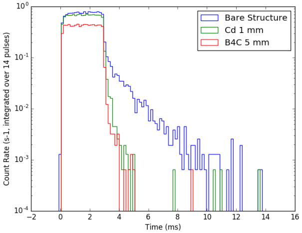




Simple model (MCNP+GEANT4+python script)

ESS Pulse (CSPEC,TREX)

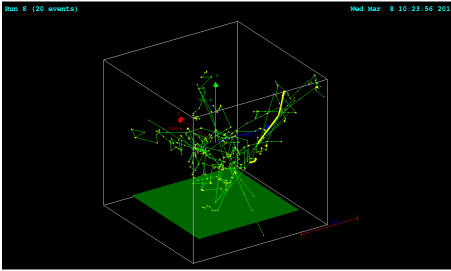
- $5 \times 5 \times 5\ m^3$ cave
- ~ 5 m^2 detector area
- $+$ TOF broadening (150 m flight)
- 1 n/s fast neutron count rate
- TREX has $\sim 5{\times}10^4$ n/s signal
- These numbers are consistent with 10^{-4}



Simple model (MCNP+GEANT4+python script)

Preliminary Skyshine Results

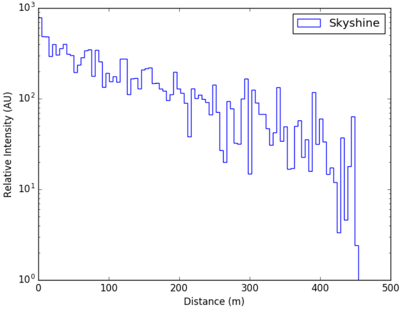
- Skyshine is a high energy phenomenon
- Fast neutrons escape into the sky, and scatter back down
- 100s of metres
- Cube on the right is 1 km $\times$ 1 km $\times$ 1 km



VERY PRELIMINARY results :)

Preliminary Skyshine Results

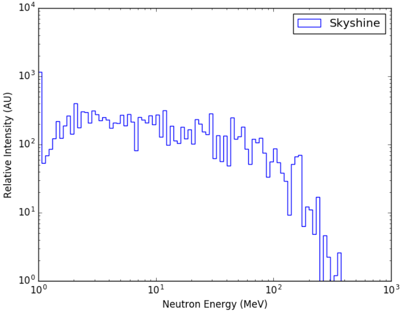
- Covers whole site



VERY PRELIMINARY results :)

Preliminary Skyshine Results

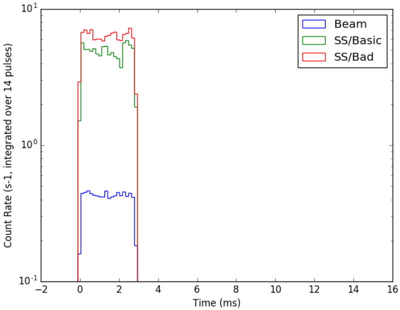
- Broad distribution of energies $\sim$ 100s MeV
- Skyshine signal is *large*: 10s n /m^2 /s



VERY PRELIMINARY results :)

Compare Skyshine to Beam

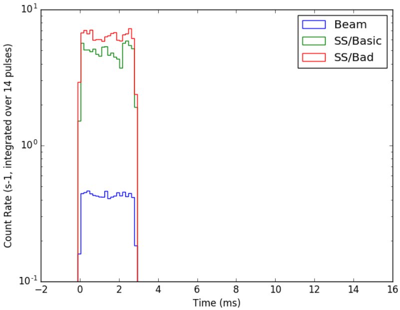
- Guide albedo source shown in blue
- Skyshine is the strongest fast neutron source.
- We are now perhaps approaching 10^3 signal to noise.
- Only considers accelerator source — no target, bunker, A2T contributions yet.



VERY PRELIMINARY results :)

This isn't all bad news

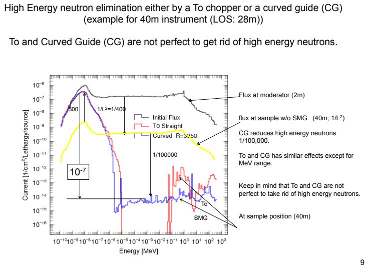
- NOSG is working on this for multiple instruments (after ICANS, i.e. 3rd April start).
- Instrument input is the *requirement* as this changes cost prioritisation
- 1 order of magnitude = 1 metre of concrete (or integral equiv)



VERY PRELIMINARY results :)

T0 Choppers and Curved Guides

- Curved guide superior to T0 chopper
- Performance is better, also steady state solution
- T0 choppers should be backup solution for later problems, or where there is no choice for straight guides



Masa Arai, IKON 2017 presentation

Acknowledgements

- Douglas DiJulio (ESS)
- Nataliia Cherkashyna (ESS)
- Damian Martin Rodriguez (ESS)
- Carsten Cooper-Jensen (ESS)
- Valentina Santoro (ESS)
- Carolin Zendler (IFE)
- Stuart Ansell (ESS)
- Uwe Filges (PSI)
- Rob Bewley (ISIS)
- Rob Dalgliesh (ISIS)
- Emmanouela Rantsiou (PSI)
- Richard Hall-Wilton (ESS)
- Ken Herwig (SNS)
- Jack Carpenter (ORNL)
- Georg Ehlers (SNS)
- Geoffrey Greene (SNS)
- Masa Arai (ESS)
- Eric Iverson (SNS)
- Franz Gallmeier (SNS)

Thank You

Thank you for your attention