

# Neutron Optics and Shielding Group Engineering Days 2015

Phil Bentley

European Spallation Source

3rd June, 2015

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# NOSG Goals

- Signal to noise ratio. Signal = optics & guides; noise = shielding & backgrounds
- To provide technical support to instrument projects to achieve beam requirements<sup>1</sup>
- To maximise instrument performance and minimise costs (yes, this *is* possible)
- To provide centralised services for horizontal cuts across instruments, avoiding duplication of effort and maintaining standards
- To make the ESS instrumentation environment radiologically safe<sup>2</sup>
  - ALARA = “As Low As Reasonably Achievable”

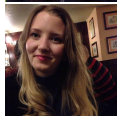
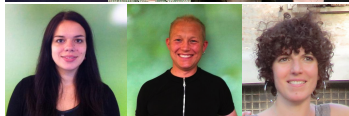
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<sup>1</sup>Creates interfaces with safety, waste; for ESS exceeds safety margins

<sup>2</sup>Has physics, legal, and procedural facets

# Neutron Optics and Shielding Group

- Phil Bentley
- Doug DiJulio
- Damian Martin Rodriguez
- Carolin Zendler
- Ann Terry
- Nataliia Cherkashyna
- Carsten Cooper Jensen
- Valentina Santoro
- Stuart Ansell
- Students:
  - Ellen Brydevall
  - John Stenander
  - Hanna Björgvinsdottir





# Large Parameter Space

- NOSG processes are designed to simplify everyone's lives
- High dimensionality is what we do best

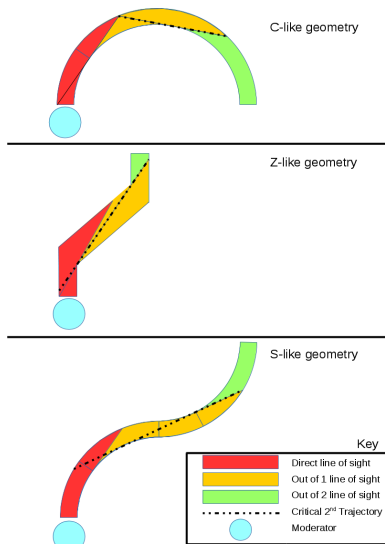


- Optics and shielding are intertwined
- Separating them frequently creates problems (background issues)
- Using them together can save money, increase  $S : N$  performance



# Optics Process

- Document the beam *and background* requirements
- No point simulating beams until you know what you want to get out
- Once you have requirements, there are many ways of deploying a beam, Phase 1 needs options.
- e.g. 1: Curved; 2: Straight; 3: Total cost-optimised (benders reduce total shielding cost, line of sight lost earlier = thinner shielding)



These are not necessarily horizontal

# Integrated Plan for Optics & Shielding

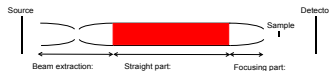
Optics		% Load	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Requirements	100		█											
Optics Baseline Study	50		█	█										
Optics Option 2 Study	50			█	█	█								
Optics Option 3 Study	50				█	█	█	█						
Options Selection	100									█	◆			
Optics Concept Ready														

Shielding		% Load	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Shielding Geometry	100		█											
Initial Simulations	50		█	█										
Model Improvement	100			█	█	█								
Final Simulation of BG	50					█	█							
Integration	50							█	█					
Cost-Benefit Analysis	50									█				
Conceptual Design Report	100										█			
Toll Gate Review													◆	

Key	
Preparation	█
Optics	█
Shielding	█
Reporting	█

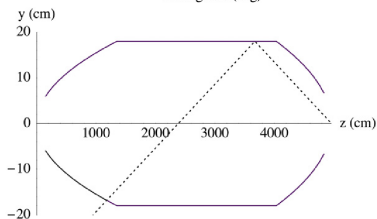
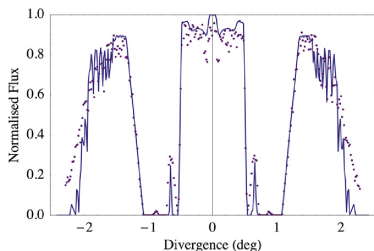
# “Standard” Guide — Ballistic with Conic Sections

- Specify  $\lambda$ , div, beam size
- Tells you baseline focussing geometry immediately
- ...and the straight/curved part in the middle ( $R$ ,  $w$ ,  $\lambda$ ,  $m$ )
- ...and phase space mapping at start



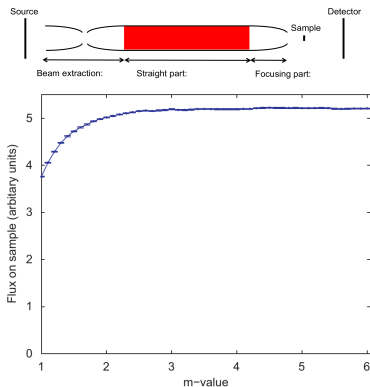
# Divergence Minima

- Trace backwards to identify defects
- Ellipses are *not* immune
- Reduced neutron intensity due to large grazing angles
- May be higher orders than shown here
- Optimise the angles and geometry out of your  $\lambda$  band



# Optimum Coating

- High- $m$  coatings are not necessary in the middle section
- Certainly  $m \leq 2$  provides good performance, and standardisation for large fraction of guide

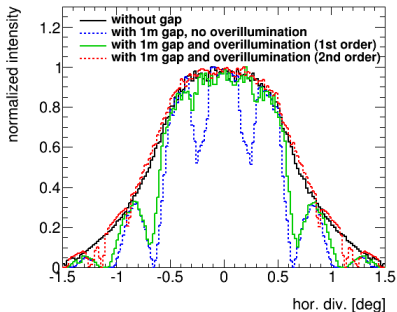
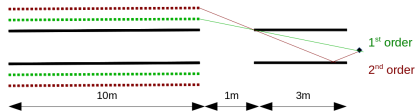


**Fig. 4.** Effect on flux at the sample position for varying  $m$ -values of the middle section of a 150 m parabolic guide. The guide geometry was optimised for high-divergence  $\pm 2^\circ$  cold neutrons using  $m=3$ .

Klenø *et al*, NIMA 696 (2012), 75

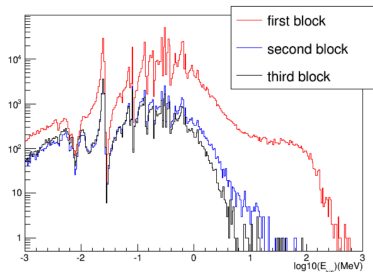
# Gaps & Overillumination

- One or two places in the guide expect gaps (choppers), misalignment (floor transitions)
- NOSG will help the instrument team to mitigate the impact on the instrument
- Important for data quality and stability of system



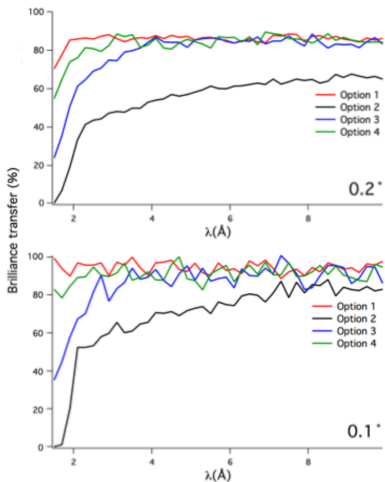
# Multiple Line of Sight

- 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



# Optics Criteria

- Performance
- Cost
- Risk
- Schedule
- Robustness (passive tolerance of misalignment)



- Review 2014 — the process was used to identify >20 M Euro potential savings<sup>3</sup>
  - Many proposals have interesting optics, that are technically advanced, and occasionally challenging with undeveloped cost-benefit analyses
  - Integrated and centralised methodology has potential of reducing budgeted cost of instrument projects
  - Cost-benefit analysis is done in close partnership with instrument teams, removing complexity and increasing robustness
  - Many gains in line-of-sight optimisation: reduced cost on shielding, shutters, choppers

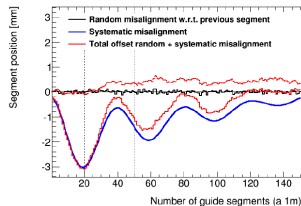
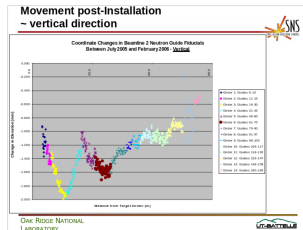
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<sup>3</sup>Detailed report available on request

# Key Optics Risk: Misalignment

# Systematic Misalignment

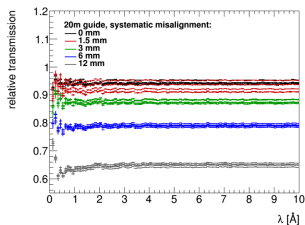
- Based on SNS Data from K Herwig's project
- Damped cosine function using data from CF
- Based on these data we have a *quantified* risk of misalignment of instruments
- This is part of the Phase 1 study & documentation for each instrument
- NOSG can help you do this



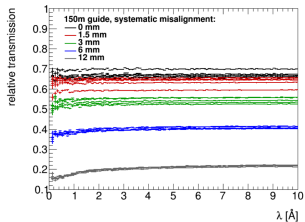
(c) 3 mm

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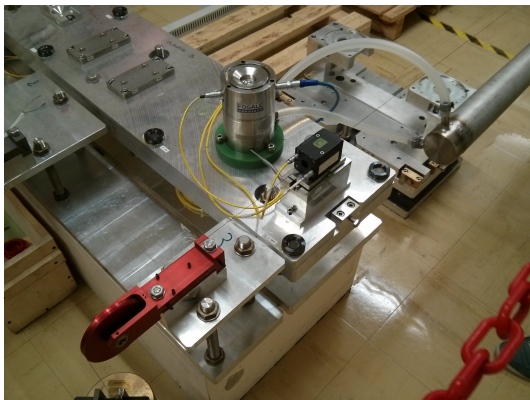
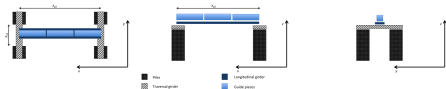
(a) 20 m guide, 20 segments



(b) 150 m guide, 150 segments

# Alignment Risk Mitigation

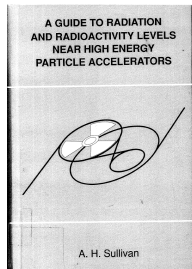
- Optical bench prototype project started Q1 2015, concluding Q2-Q3 2015
- Long instruments will be monitored with hydrostatic alignment metering
- Hydrostatic = water + capacitance meters
- Realignment strategy developing, either:
  - using motors on demand
  - planned interval, manual



# Shielding

# Body of Knowledge

- Essential reading is Sullivan “A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators”
- Also: Baranov *et al*, “Estimation of Radiation Background, Impact on Detectors, Activation and Shielding Optimization in ATLAS”
- Note that neither of these are reactor documents!



Estimation of Radiation Background,  
Impact on Detectors, Activation and  
Shielding Optimization in ATLAS



Atlas Radiation Background Task Force Summary Document

Reported by

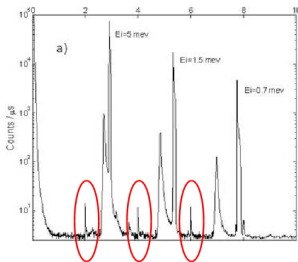
S. Baranov<sup>1</sup>, M. Benatar<sup>2</sup>, J. Dancoski<sup>3</sup>,  
V. Hedberg<sup>4</sup>, A. Nisari<sup>5</sup> and M. Shupe<sup>6</sup>

1. SLAC National Accelerator Laboratory  
2. SLAC National Accelerator Laboratory  
3. SLAC National Accelerator Laboratory  
4. SLAC National Accelerator Laboratory  
5. SLAC National Accelerator Laboratory  
6. SLAC National Accelerator Laboratory

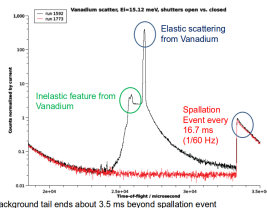
# Shielding Concept Development

# Background Requirements

- SNS Data: 0.9-3.5 n/min per meter of tube ( $\approx 4 \times 10^{-4} \text{ n m}^{-2} \text{ s}^{-1}$ ).
- $\sim 100\times$  too high
- Instrument proposals:  $10^{-6}$ – $10^{-8}$
- JPARC Data: similar ratios
- PSI: continuous, so different issues
- ISIS: World leaders in signal-to-noise until ESS is built(!)
- SNS-TS2 will certainly learn from TS1



HYSPEC data summed over all detectors

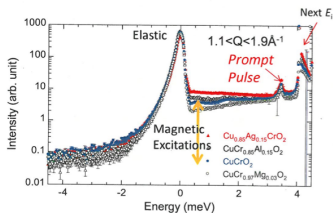
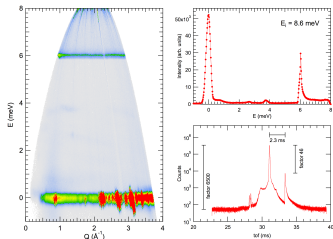


Background tail ends about 3.5 ms beyond spallation event

LET (ISIS), HYSPEC (SNS)

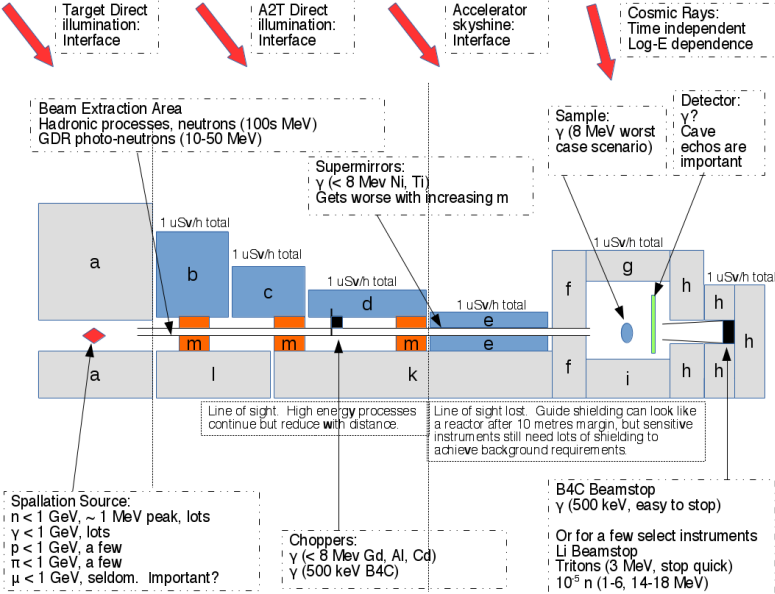
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CNCS (SNS) and Amateras (JPARC)

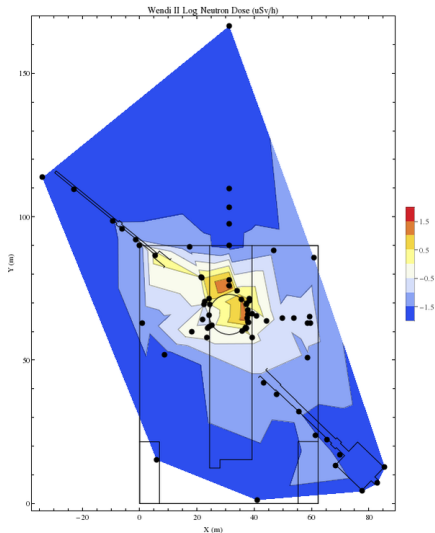
# Internal & External Radiation Sources



# Survey of SNS

Three brightest  $n$  sources:

- Harp / A2T source — mitigated by interface with Tom Shea (Accelerator)
- Monolith source — mitigated by Bunker Project, interface Rob-Target
- Basis source — mitigated by margin of error on the LOS. ESS adds 10 metres of heavy shielding beyond LOS point (this is not a serious issue)

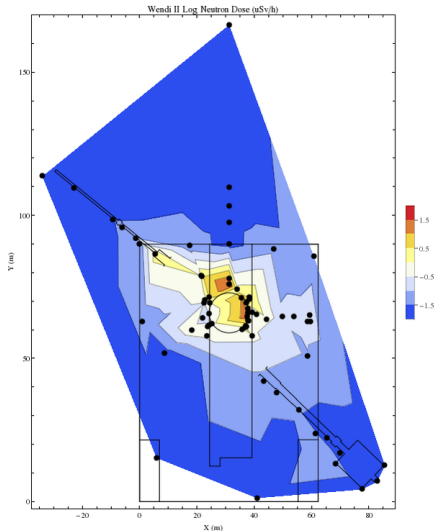


# Survey of SNS

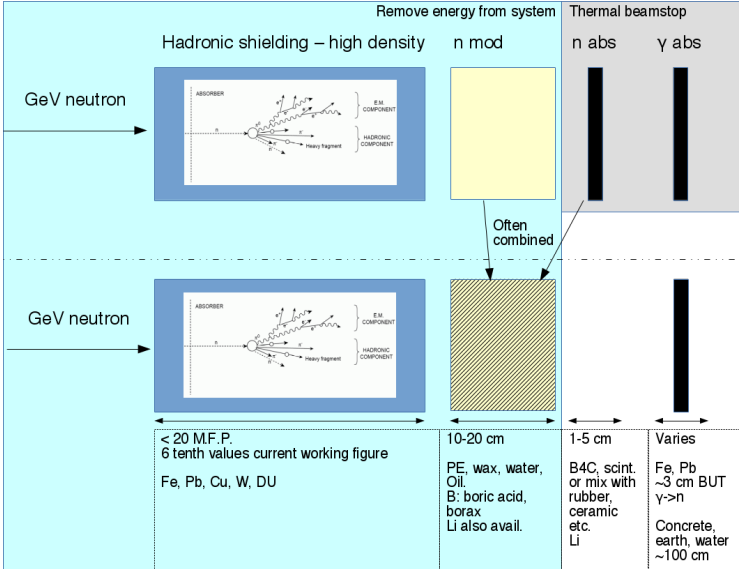
Other interesting facts:

- 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.

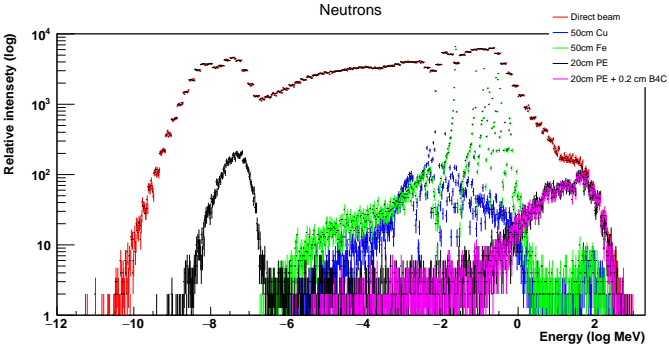


# High Energy Shielding Concept

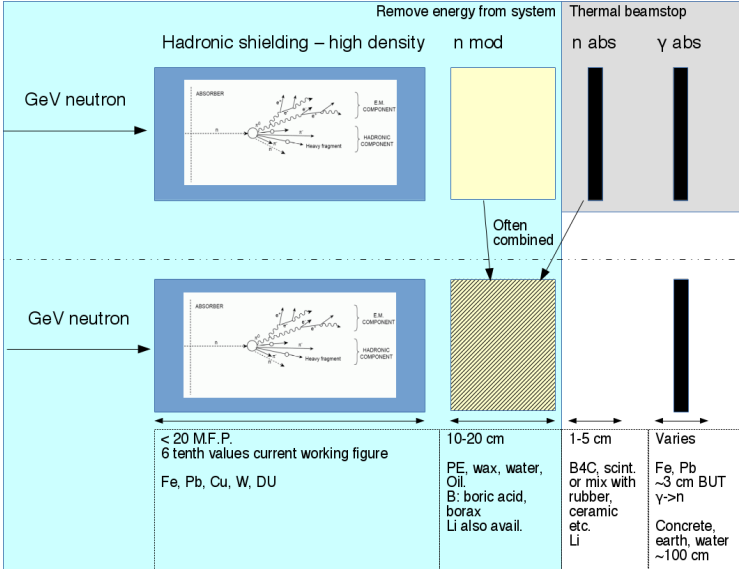


Elements borrowed from ATLAS/CERN and mathsconcepts.com

# Hadronic Shielding Materials

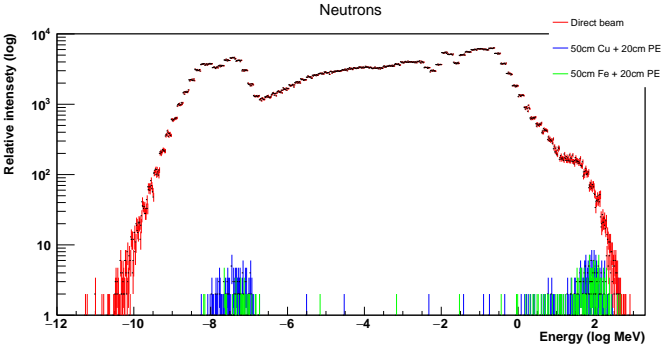


# High Energy Shielding Concept



Elements borrowed from ATLAS/CERN and mathsconcepts.com

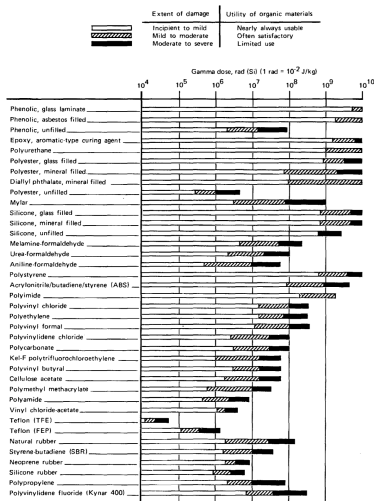
# Hadronic Shielding Materials



NASA has studied plastics extensively in radiation fields.

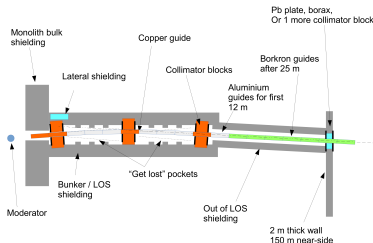
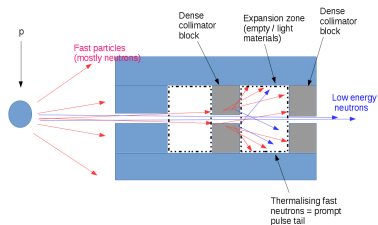
Safe plastics currently:

- Polyurethane
- Polystyrene
- Polyethylene
- Polyimide (e.g. Kapton), particularly near choppers and other warm components
- Thermoset polyimides are attractive
- Epoxy (rad-hard / qualified)



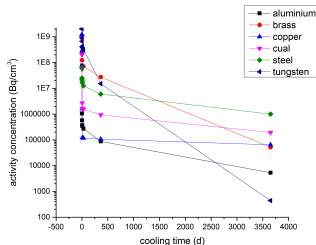
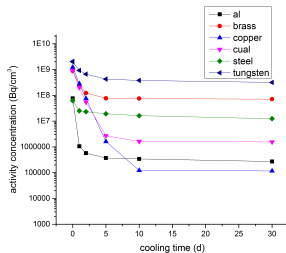
# Beamline Concept

- Space is actually as important as shielding
- Need fast particles to escape out of beamline into bunker
- Pockets still need to be optimised (H, B materials)
- Still need to engineer chopper activation, radiation on electronics etc



# Radiation Safety Engineering for Servicing

- Need access to dense area before 3 days? Mild steel + B-plastics.
- Can wait for 3 days? Copper is better.
- We will optimise the access / shielding properties
- NOSG—Chopper Group—Target Division interface



Many thanks to Zsafia Kokai, Target Div.

# Benchmarking

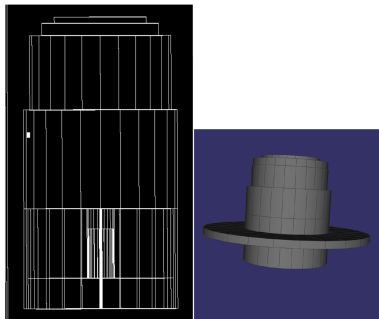
# Measurements of PSI Target

- Wendi-2 meter ( $^3\text{He}$ , PE, W, to 5 GeV)
- Standard “rem-ball” survey meter (to MeV)
- Measured at various positions around target using crane



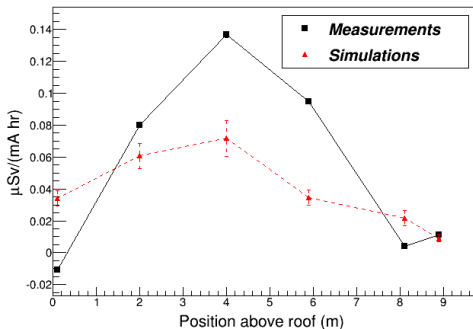
# GEANT4 Model of PSI Target

- PSI target monolith modelled in GEANT4
- Forced cylindrical symmetry to speed up simulation (numerically identical once normalised)



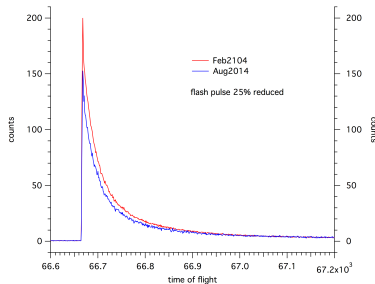
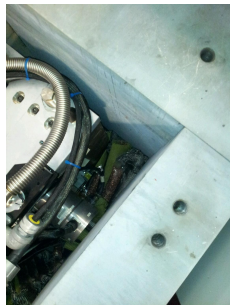
# Benchmarking Code: PSI Target

- PSI target monolith modelled in GEANT4
- Compared with measured data
- Good agreement between simulation and measurement
- Note: *linear y-axis*



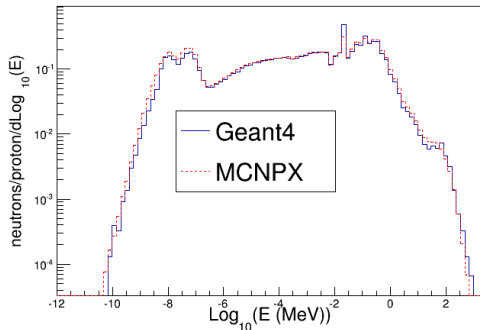
# Validation of Shielding Concept

- CNCS spacing in shielding is too big
- Initial tests of adding bags of copper beads in *some key areas* in chopper pits
- Initial trials at CNCS resulted in 25% reduction — bigger work now planned.
- Experience at JPARC similar (Mr Suzuki's copper collimator, priv. comm. Masa Arai)



# Cross-Checking Models

- ESS TDR target monolith modelled in GEANT4 (Doug) and MCNP (Konstantin Batkov, Target Division)
- Modelling in excellent agreement
- Validation of both guide and shielding models is part of NOSG Phase 1 & 2 processes



DiJulio, Batkov *et al*



# Copper Substrate Guides

- Save money, increase  $S : N$  performance
- ESS — Swiss Neutronics project
- Much better at stopping kev-MeV neutrons than carbon steel.
- High thermal conductivity
- Fast activation cooldown (3 days)



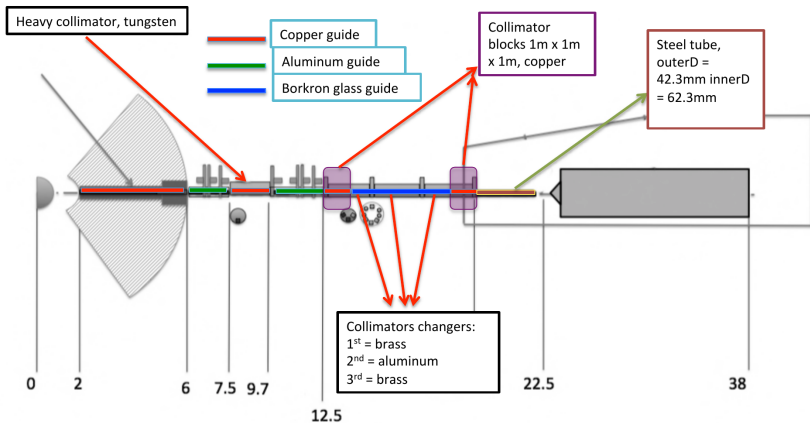
# Neutron Source Concrete

- High boron content
- High hydrogen content
- Structurally similar to “regular” concrete
- Alternate high density concrete without Fe ore
  - Avoids Fe windows
  - Potential cost savings overall



# Shielding on Instruments

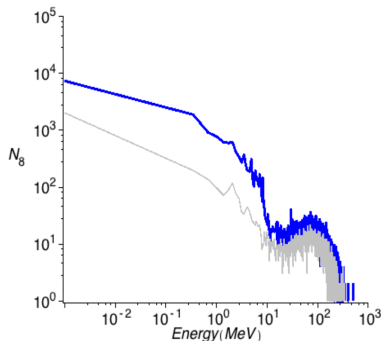
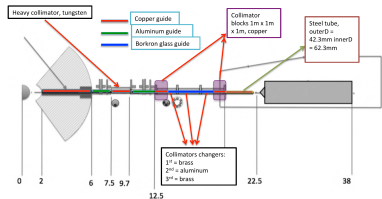
# Background Simulations — LOKI



N. Cherkashyna *et al*

# First Background Results — LOKI

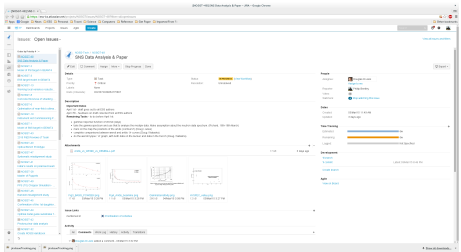
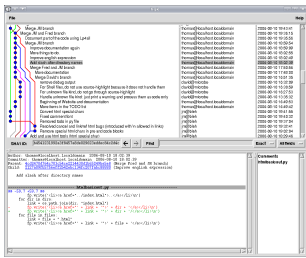
- Fast neutron spectrum entering the front wall of the detector cave
- At this stage, first heavy collimator  $\approx 10\times$  reduction
- Cave shielding is cheaper, the fast neutrons are dumped in the collimator and bunker



# Central Tools & Support

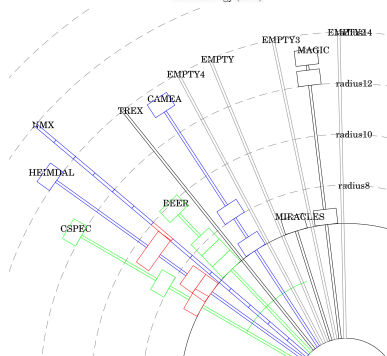
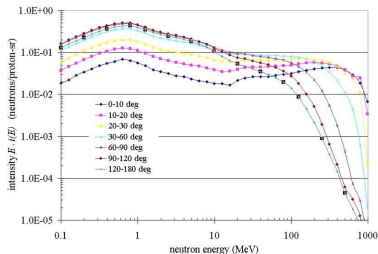
# Central Tools & Support

- Mercurial & git
- Agile — kanban — wiki, issue tracking with other tech groups, accelerator, target...
- Optimisers
- Support with VITESS / MCSTAS / GEANT4 / MCNP
- Validation of optics & shielding calculations



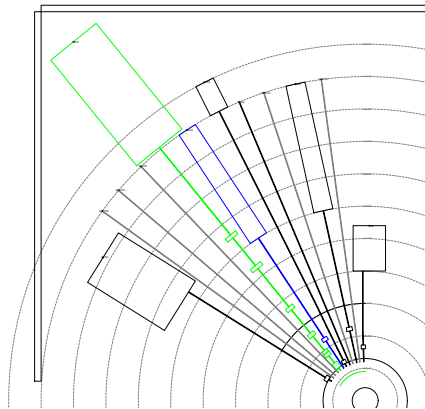
# Beam Port / Layout

- Each 12-port sector has  $(n - 1)! \approx 40,000,000$  possible instrument arrangements
- Variations in background sensitivity & cross-talk, moderator spectral brightness, A2T background, spallation background  $\propto \theta$
- Add in chopper overlaps, shutters, walls, vacuum vessels



# Master of Puppets

- Genetic algorithm-based solution
- Minimises background effects in previous slide
- Avoids mechanical interferences
- Uses standard methods to find solution
  - Tournament selection
  - logarithmic scoring
  - Standard GA parameters work very well
- Used in Phase 2 to allocate beamports



# Master of Puppets

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- Minimises background effects in previous slide
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- Uses standard methods to find solution
  - Tournament selection
  - logarithmic scoring
  - Standard GA parameters work very well
- Used in Phase 2 to allocate beamports



# Interfaces and Management

- Interfaces are identified
- Points of contact are assigned

Accelerator Skyshine	
NOSG Contact	External Contact
Nataliia Cherkashyna	Lali Tchelidze

Target Moderators, Beam Ports	
NOSG Contact	External Contact
Phil Bentley Doug DiJulio	Luca Zanini Konstantin Batkov

A2T Region	
NOSG Contact	External Contact
Phil Bentley Nataliia Cherkashyna	<del>Tom Shea</del> Lali Tchelidze (Accelerator)

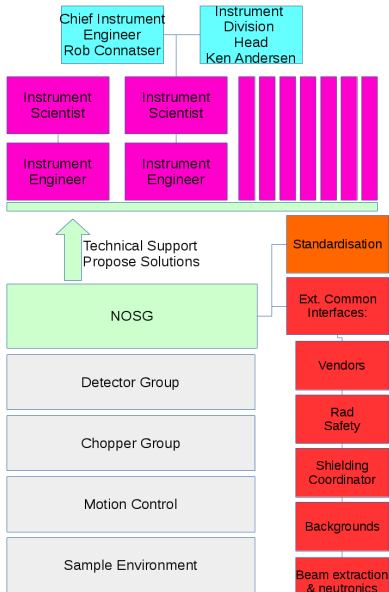
Target Direct Illumination	
NOSG Contact	External Contact
Nataliia Cherkashyna	Konstantin Batkov

# Interface Management: Instruments

Project	IK Optics	Optics Contact	IK Shielding	Shielding Contact
BEER	?	Damian Martin Rodriguez	?	Nataliia Cherkashyna
SKADI	?	Carolyn Zendler	?	Nataliia Cherkashyna
DREAM	?	Carolyn Zendler	?	Valentina Santoro
ESTIA	Y	Damian Martin Rodriguez	Y	Doug DiJulio
CSPEC	?	Carolyn Zendler	?	Valentina Santoro
FREIA	?	Carolyn Zendler	?	Doug DiJulio
HEIMDAL	?	Damian Martin Rodriguez	?	Stuart Ansell
CAMEA	?	Damian Martin Rodriguez	?	Doug DiJulio
NMX	N	Damian Martin Rodriguez	?	Valentina Santoro
LOKI	N	Carolyn Zendler	?	Nataliia Cherkashyna
ODIN	Y	Phil Bentley	Y	Stuart Ansell
Bunker	N/A	Phil Bentley	Y	Stuart Ansell
Optical Bench	N	Damian Martin Rodriguez	N	TBC

# Instrument Project Interface

- ESS instrument construction is a strong matrix structure
- NOSG:
  - Supplies technical expertise on optics and instrument shielding
  - Proposes solutions to Instrument Projects
  - Handles standardisation
  - Interacts with common interfaces



NOSG processes mandate NOSG staff involvement in:

- Design work, option criteria & selection (most of this talk!)
- Procurement documentation & preparation
- Vendor selection & criteria
- Factory acceptance testing
- Installation team
- Commissioning team

This is essential for quality of instruments.

# Future work, Planning Etc.

- Clearer picture of background sources and magnitudes at ESS
  - Skyshine, both linac and target
  - Direct target wall illumination
  - Spallation background down guides
- Significant development in bunker materials & geometry
- 5 instruments Phase 1
- 2-3 instruments Phase 2
- NOSG handbook
- Hot comm. & ops plan



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Reviewers: G Muller, O Kirstein  
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**NOSG Handbook**

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**DRAFT**



# Transition to Operations & Operational Plan

- Transition to operations and operational plan currently under development (existing plans are top-down)
- Comes from SNS, PSI, ISIS advice
- Staffing levels:
  - Approx. 1 optics person per 5-7 beamlines (3 total)
  - Approx. 1 shielding person per 5-7 beamlines (3 total)
  - 2 system development experts (1 shielding, 1 optics)
  - Supermirror expert
  - Other competences within the scope of the group when arising during operations (e.g.  $^3\text{He}$ , test beamline(s), monochromators)

Note that the above numbers have a certain degree of overlap across responsibilities

# Conclusions

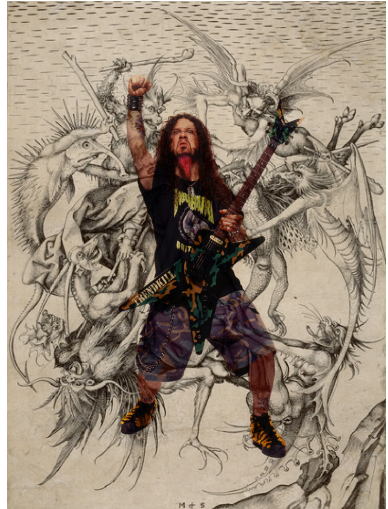
- Group has the required technical skills and base knowledge
- Key technologies identified, implemented, or on-track
- Methodology has been benchmarked and proven in critical tests
- Tools are in place to provide cutting-edge technical support to ESS instrument projects



# Conclusions

NOSG support in this process results in systems that are:

- Lower cost
- More reliable
- Simpler
- Proven and benchmarked



# Update NOSG Processes

- Maybe your ideas are better than ours
- We do this with a considerable measure of humility

# Update NOSG Processes

- Maybe your ideas are better than ours
- We do this with a considerable measure of humility
- Your technological distinctiveness will be added to our own



# Thank You



Thank You For Your Attention