Ground Level Enhancement Event Monitor (GLEEM)

– New prospects for ground level neutron monitoring

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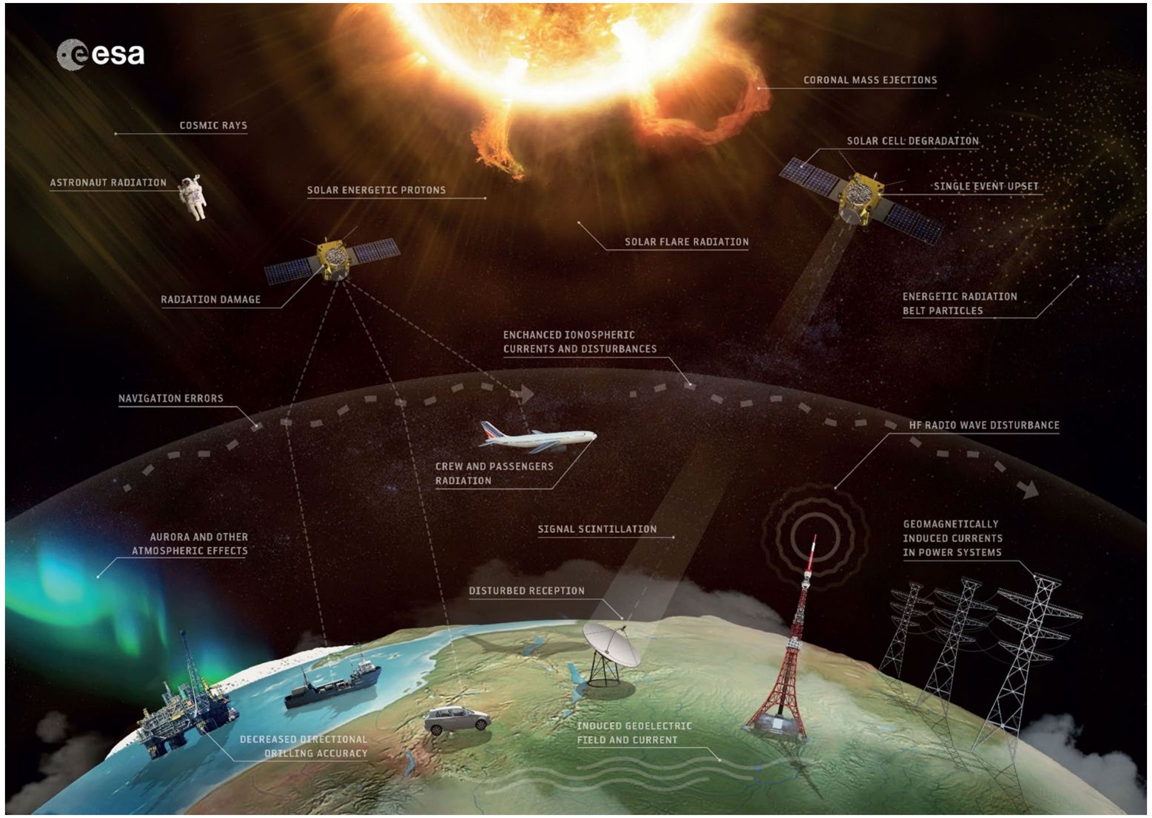
UK Nuclear Academics Meeting 2023, Synergies in Nuclear-relevant research 1, 6/9/23

Context

- Improve UK space weather monitoring and prediction capabilities
- £20 million, four-year Space Weather Instrumentation, Measurement, Modelling and Risk (SWIMMR) programme
- Significant risks to critical global infrastructures: listed UK's National Risk Register



Above: Space weather refers to the environmental conditions in space as influenced by solar activity.
Credit: ESA/Science Office, CC BY-SA 3.0 IGO

SWIMMR S5 structure

Design Phase (S

£175k 2

1. Develop a det
transport model

Implementation

£1.856M 1

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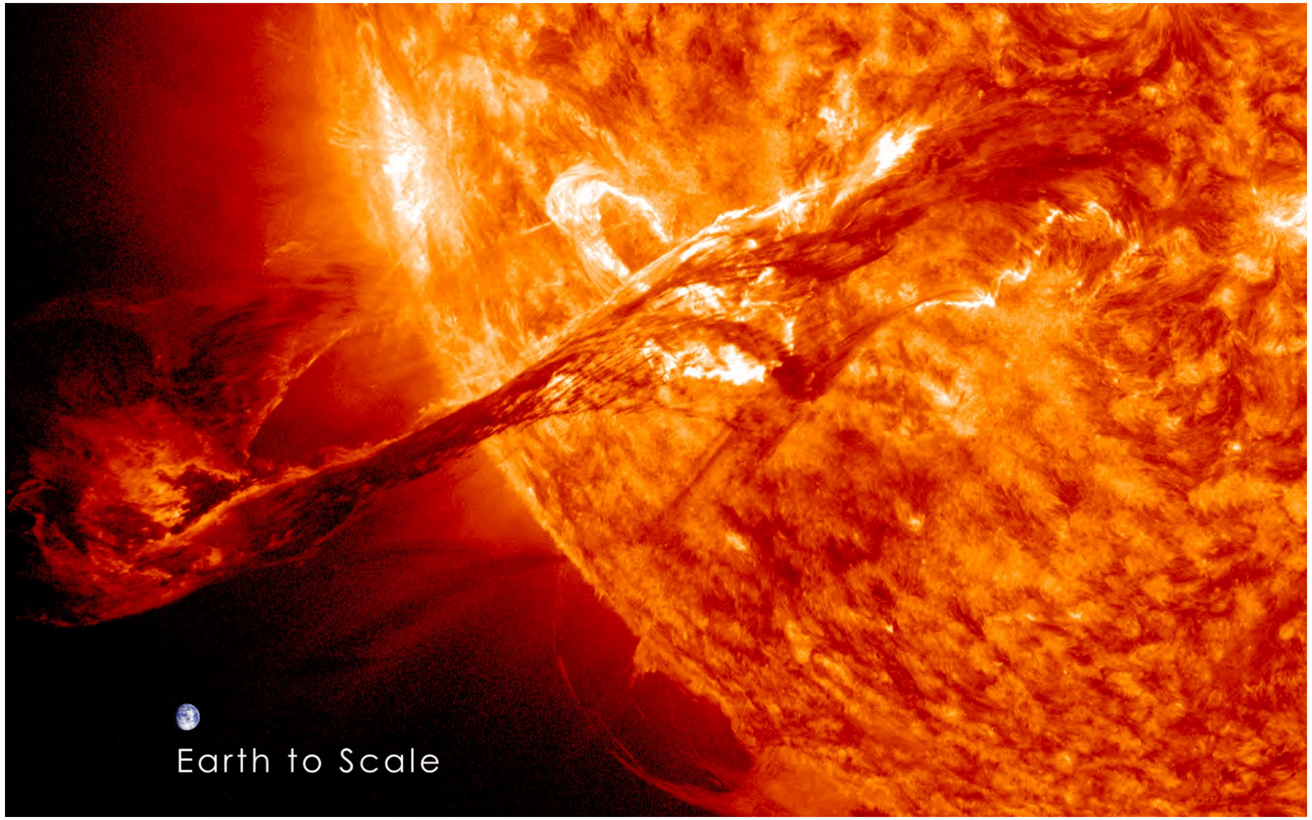
Right: The Met Office Space Weather Operations Centre (MOSWOC) 2015. Source: https://blog.metoffice.gov.uk/

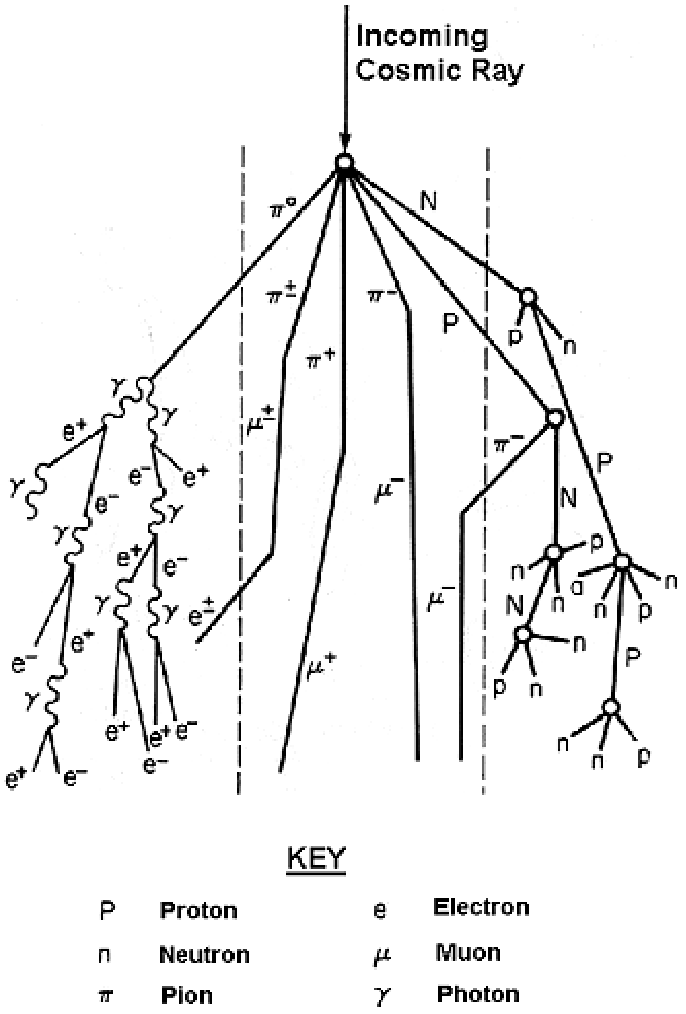
Overview

- Context, structure and aims
- Principles and status
- Methods
- Results
- Conclusions and future work



Principles of the ground level neutron monitoring

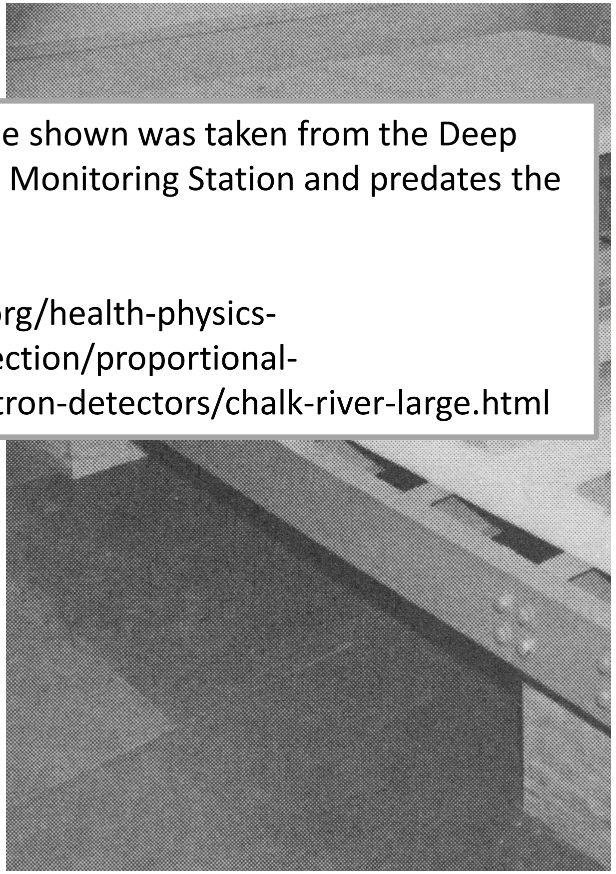
- Deduce primary cosmic particles
- Hard solar energetic particles (SEP), energies >300 MeV
- Ground level enhancements (GLE)
- Early warning of GLEs
- Input data for models



Above: Cosmic ray spallation Source: Bütikofer, R., 2018

Status (and standard, NM-64)

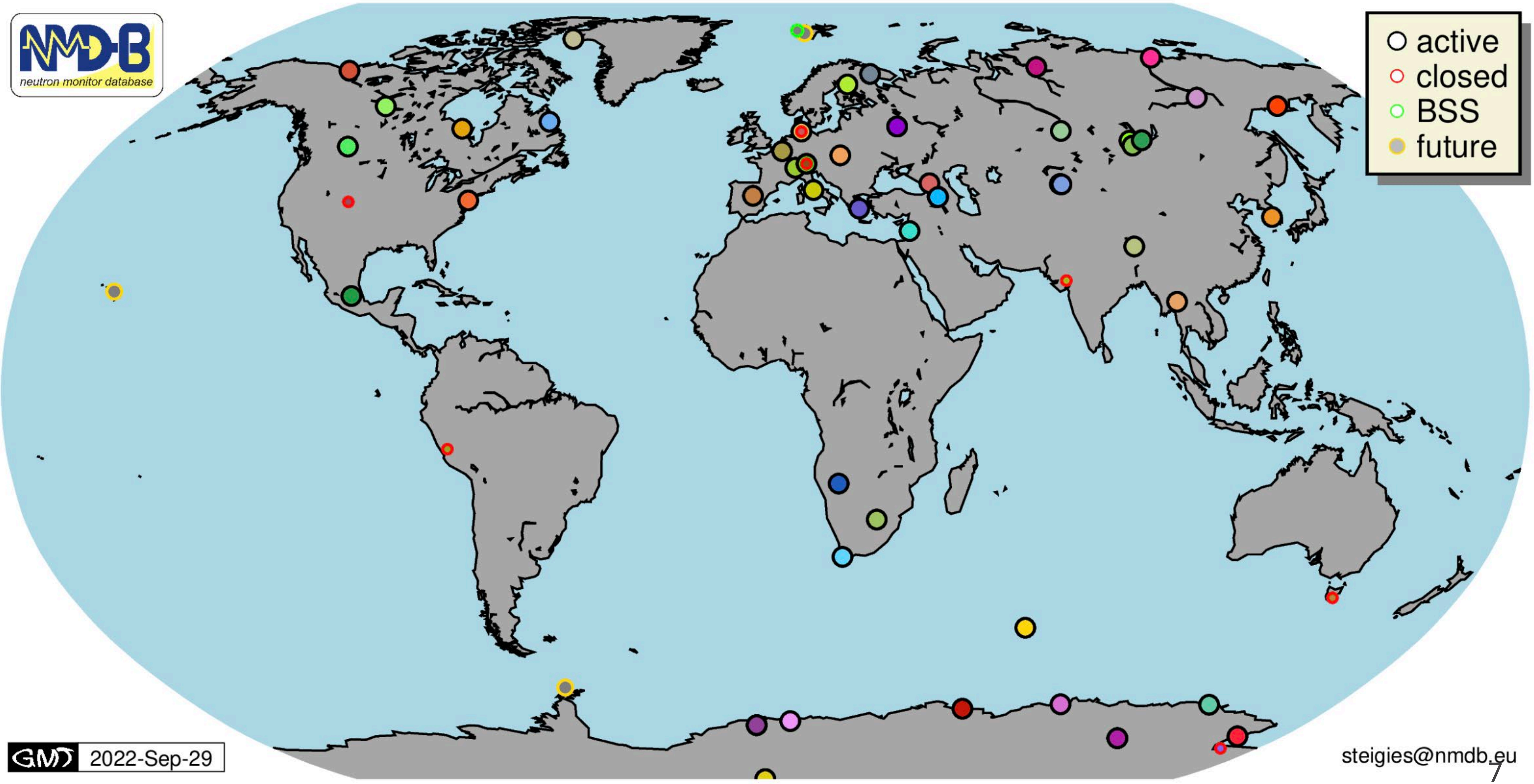
- Predominantly record secondary neutrons
  - 1. Production
  - 2. Moderation
  - 3. Detection
- Boron trifluoride (BF_3), Chalk River BP-28
- Size and mass
  - 6-NM-64 L 2.3 x W 3.2 x H 0.5 m
  - 18-NM-64 ~36 tons



Right: The tube shown was taken from the Deep River Neutron Monitoring Station and predates the NM-64/BP-28

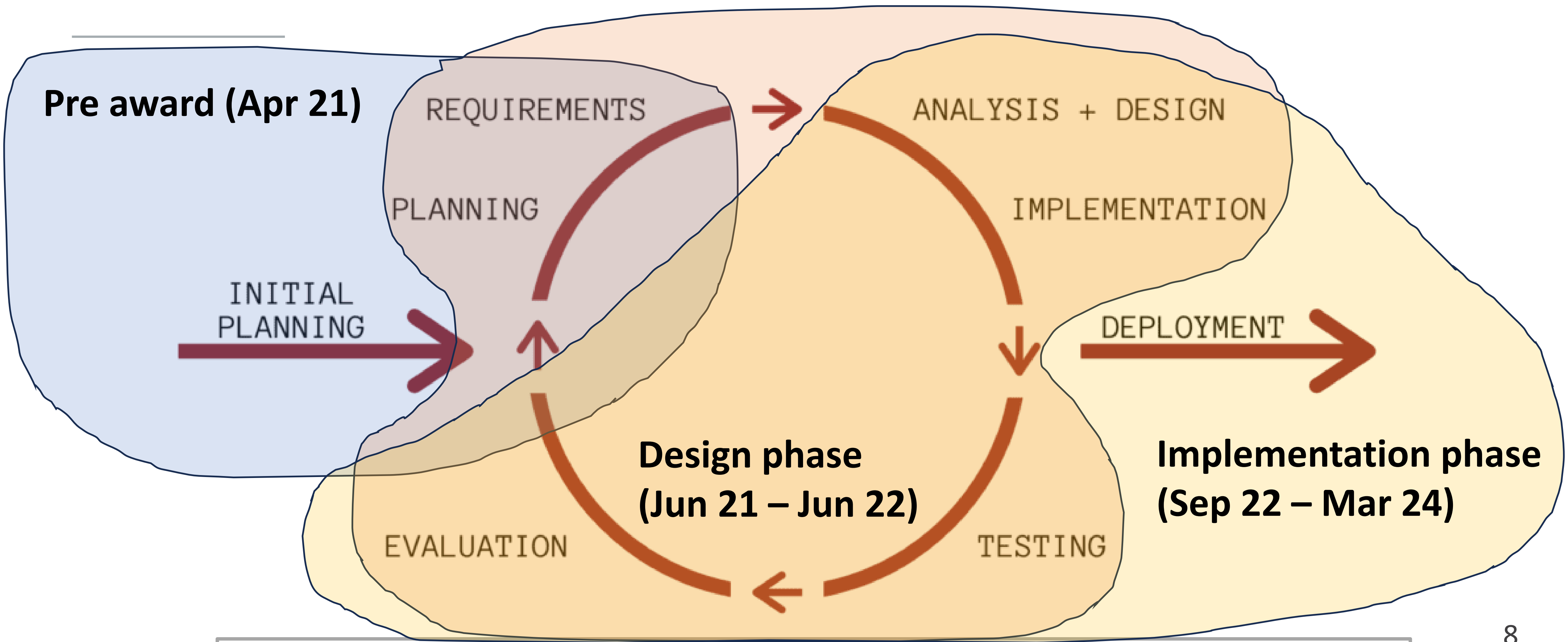
https://orau.org/health-physics-museum/collection/proportional-counters/neutron-detectors/chalk-river-large.html

Above: Construction of a 6-counter NM
Source: Carmichael, H., 1968, Annal of



NMDB
neutron monitor database
active
closed
BSS
future
2022-Sep-29
steigies@nmdb.eu

Methods (overview)

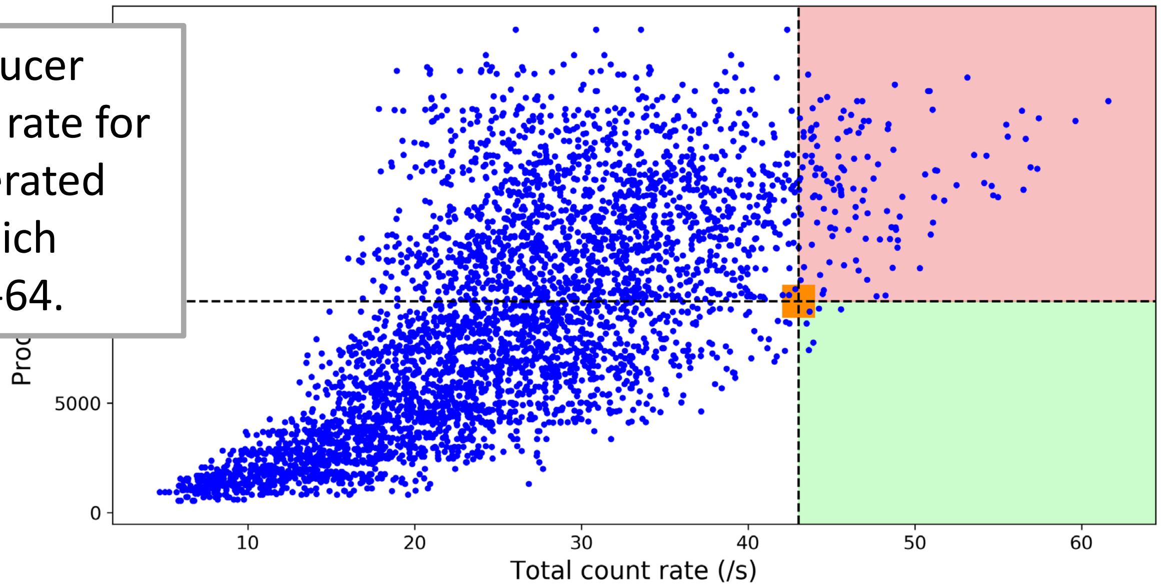


Above: Generic process model. Source: https://flexagon.com/blog/7-software-development-models-you-should-know/

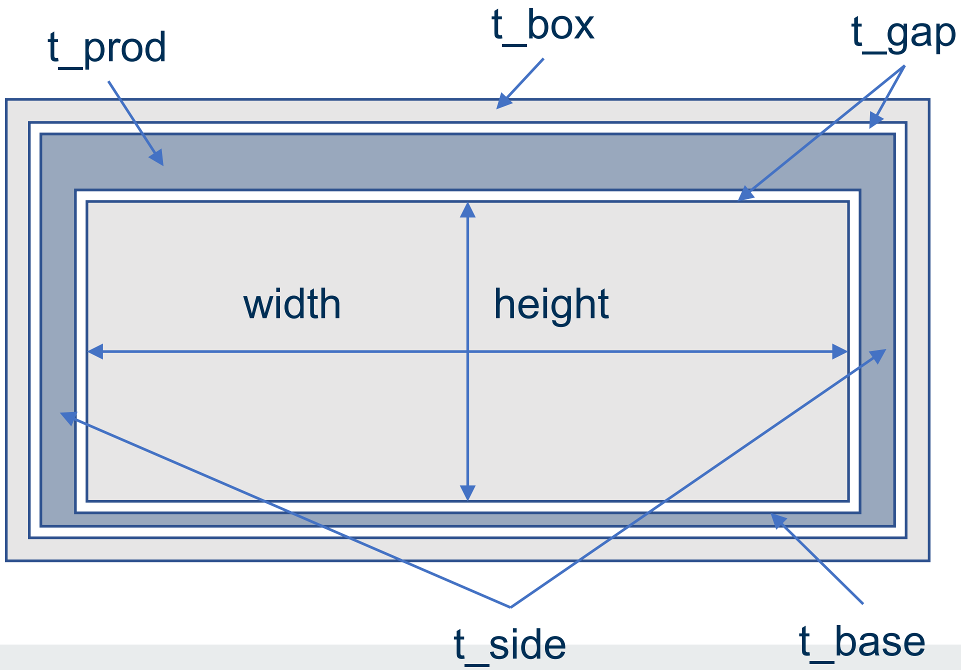
Methods (overview)

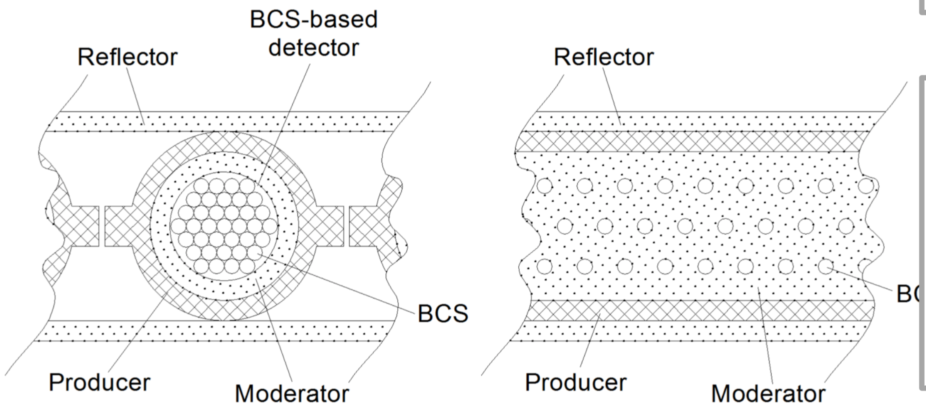
- ☑ Define models
- ☑ Evaluate detectors
- ☑ Modelling design optimisation
- ☑ Validate experimental
- ☑ Engineered solution
- Deploy and integrate

Top right: Producer mass vs. count rate for randomly generated geometries which mimic the NM-64.



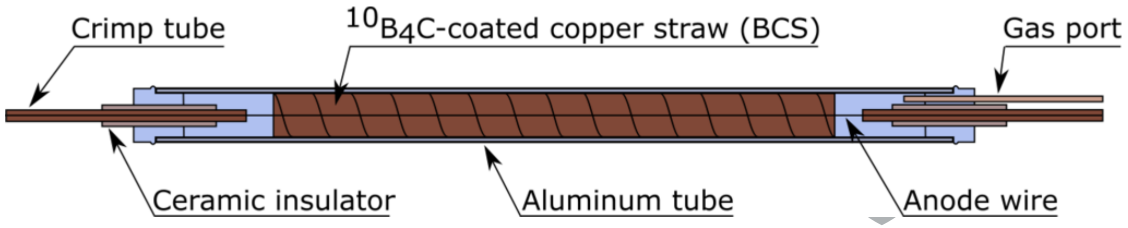
Bottom right: Slab parameter optimisation of bulk material and sensor locations within the slab.



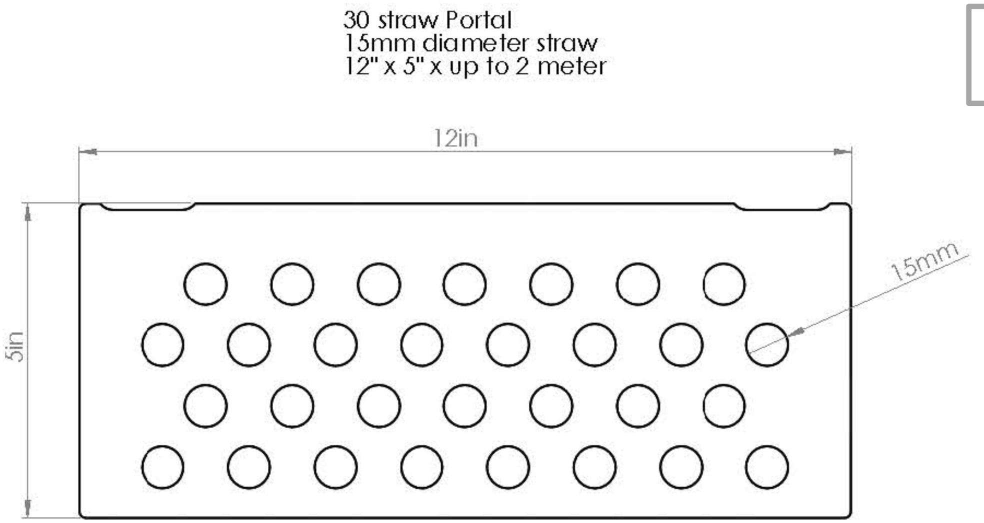


Bottom left: Evaluated both existing and concept designs via simulation with BF3, ^{3}He and BCS detector solutions.

Methods – Boron coated straws (BCS)

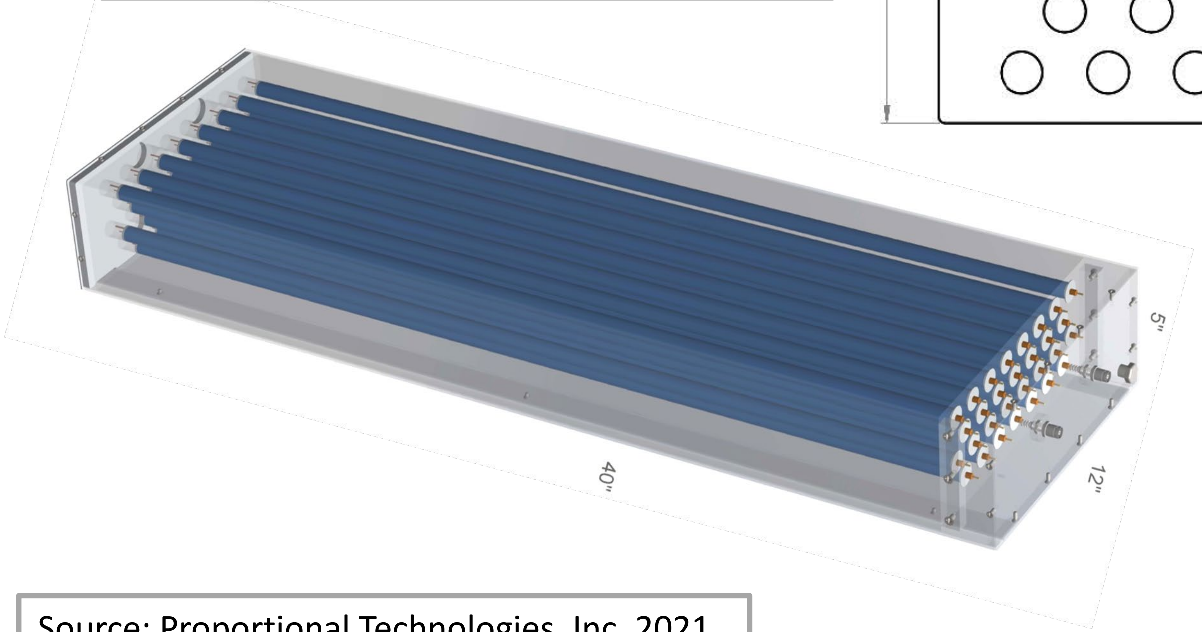


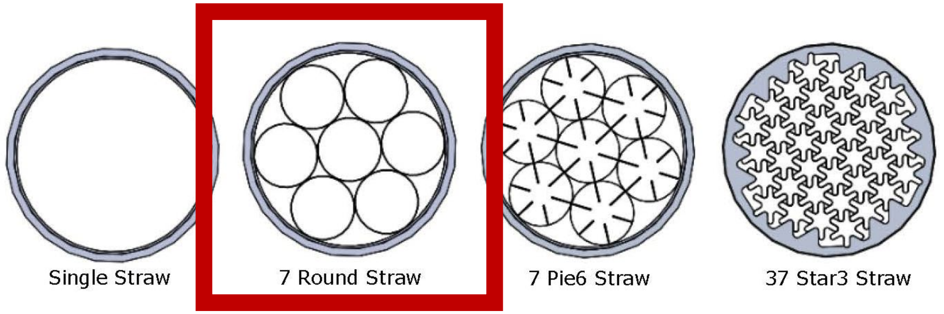
Cross-section of a BCS



Proportional Technologies, Inc
Innovations in Nuclear Imaging

PTI-110 Boron coated straw (BCS) portal module

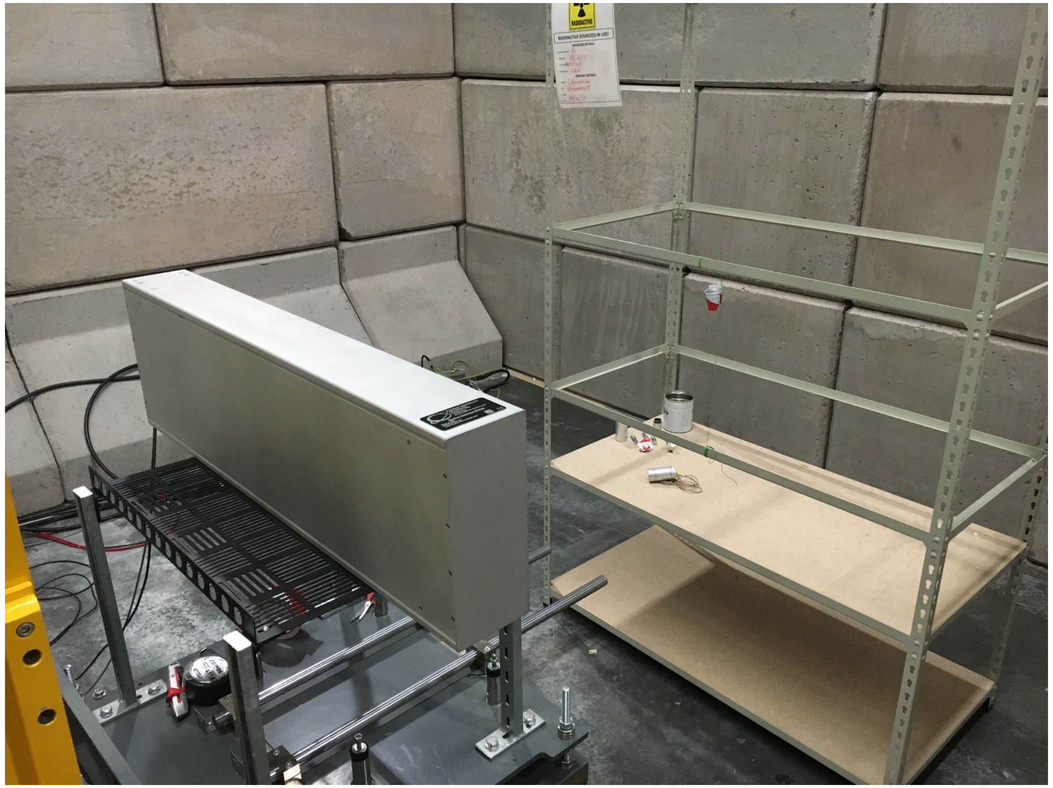




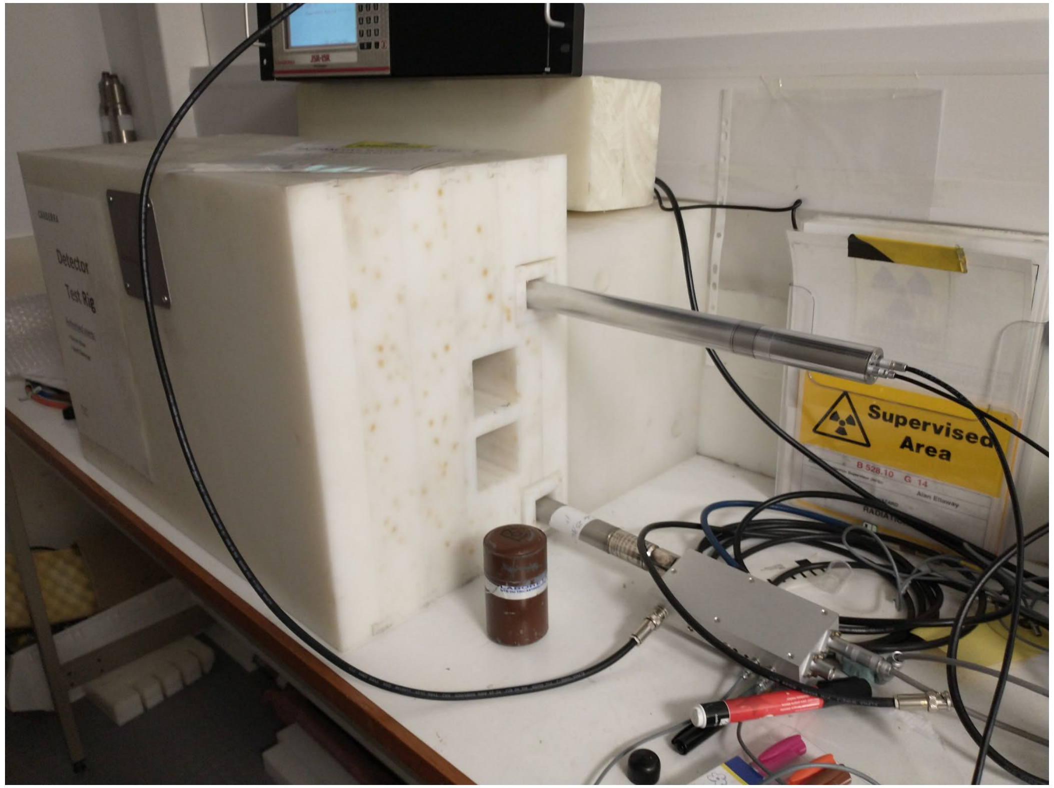
PTI-204 1" BCS detector configurations

Source: Proportional Technologies, Inc. 2021

Methods – Experimental setups

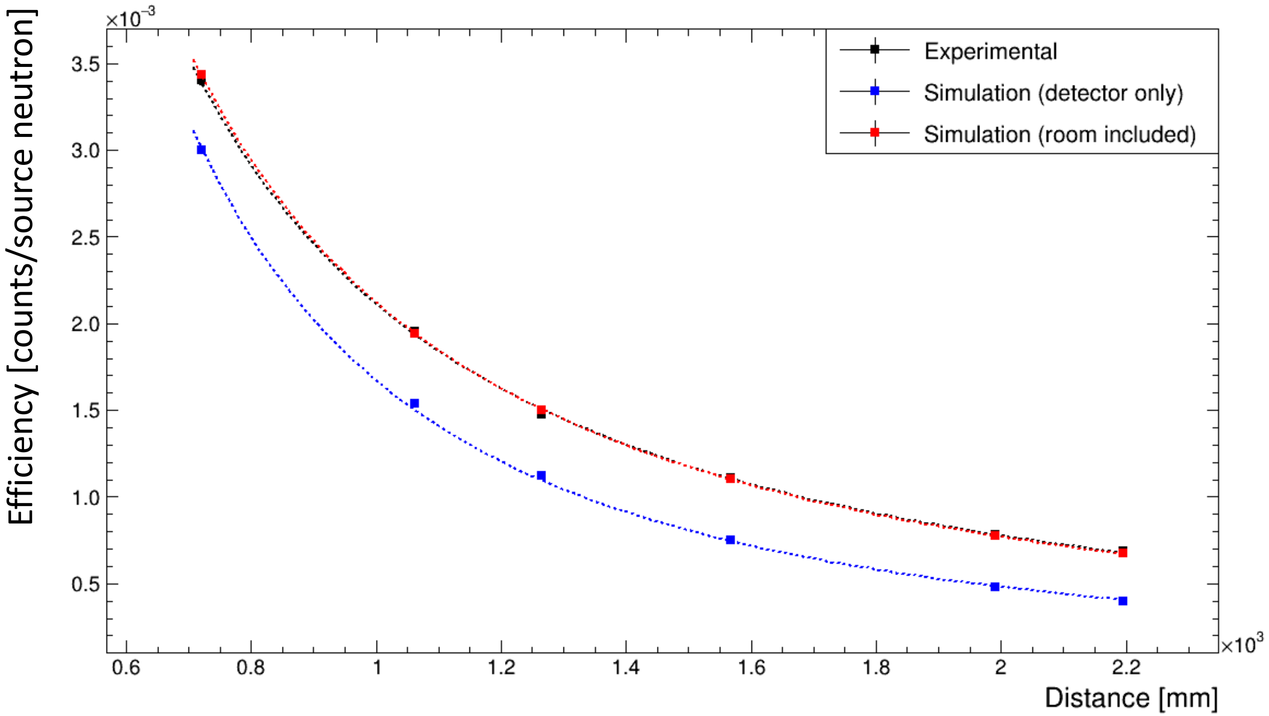


PTI-110 absolute efficiency to Cf-252 as a function of separation & height above the gnd

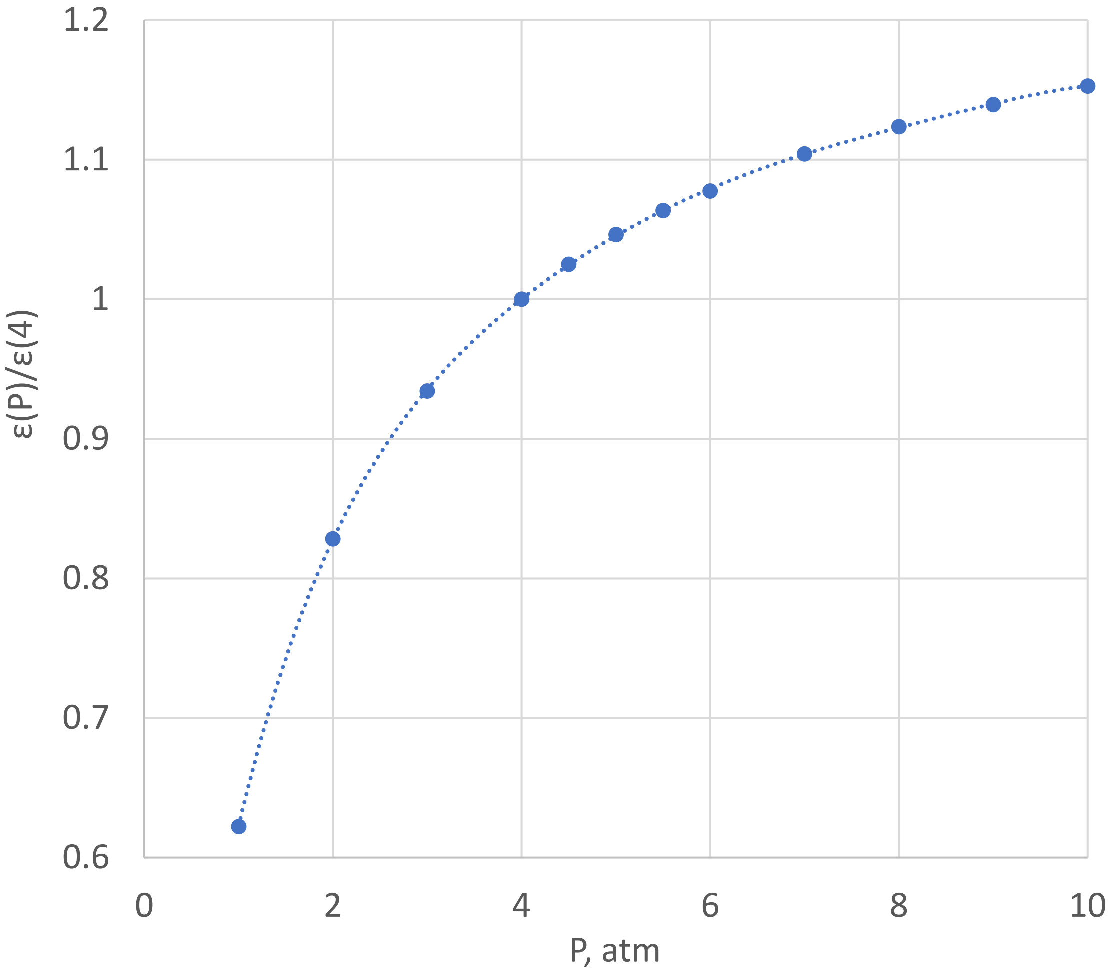


Experimental comparison of PTI-204 with 7.5 atm He-3 tubes, scaled to 4 atm.

Results



Measured and modelled efficiency plots for the PTI-110 slab as a function of source to detector separation. Includes room return and efficiency factor[1].



Relative efficiency vs. pressure based on the average of the Inner and Outer shapes, normalised to 4 atm. Calculated using sensitivity scaling rules for ^3He vs pressure, updated from INMM45, S. Croft et. al, 2004

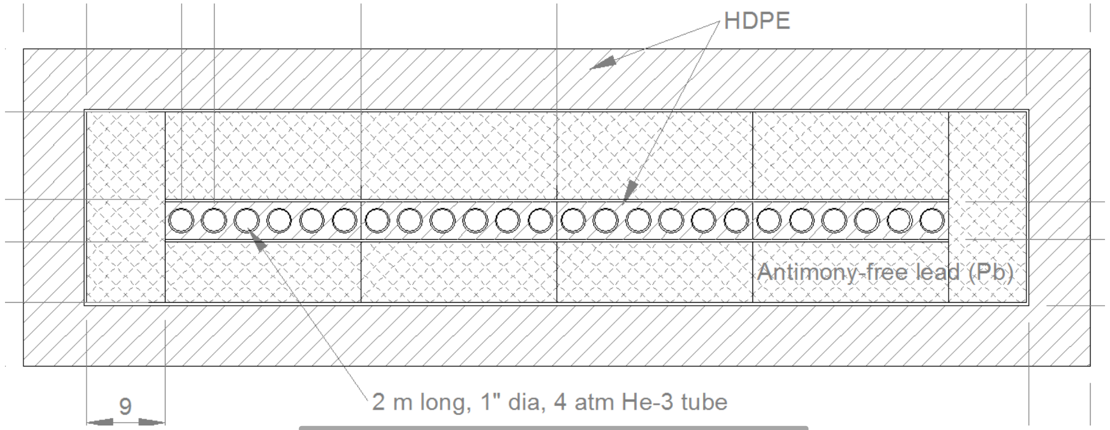
Conclusions

- PTI-110
  - Experimentally evaluated via 252Cf as a function of distance
  - Determined detection efficiency and supported validation of our models
  - Unit failed before further testing
- PTI-204
  - Evaluated against 7 atm ^3He tube
  - ~1/3 the efficiency of a 4-atm ^3He tube (using gas fill pressure scaling laws)
  - ~1/5 the cost of a 4-atm ^3He tube
  - $3-4k / 2 m PTI-204 (Apr '22) vs. $16-20k / 2 m ^3He (Oct '22)
  - Detection efficiency cost difference: ~0.6
  - BUT… an instrument 3x bigger
- BCS require further development for extended operational use vs. ^3He detectors which have decades of service operation and long MTBF

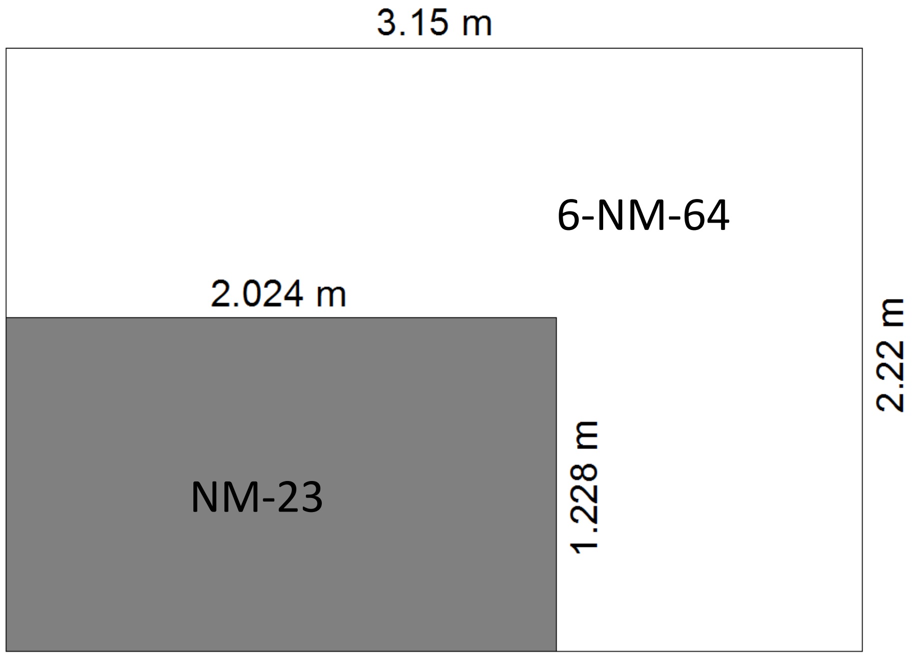
Conclusions and future work

- Confidence in our MCNP models
- A ^3He-based engineered design: 64% smaller footprint; 80% smaller volume; 55% less mass; ~50% cheaper (6-NM-64 benchmark)
- Long count results utilising an analogue (the Canberra N50L) to the final design in agreement with calculations and existing monitors
- Interrogate our CR flux model, high energy physics modelled poorly in MCNP
- Experimental validations using the ISIS spallation source
- Data ingest (Met Office, Surrey Space Centre, NMDB)
- Site deployment (est. Dec '23)

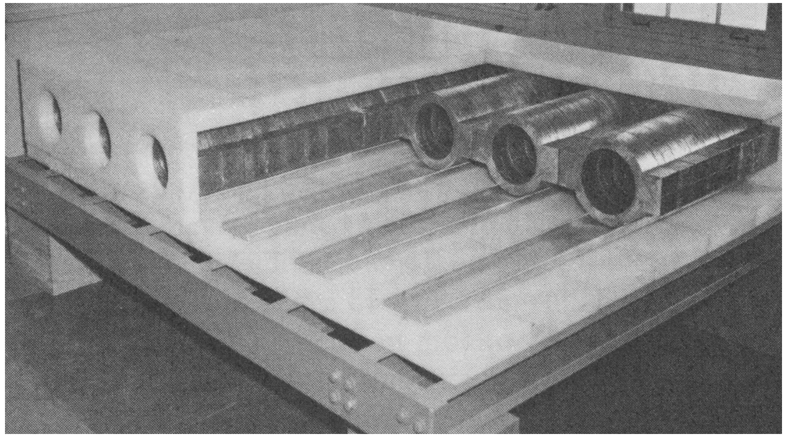
Our design vs. 6-NM-64



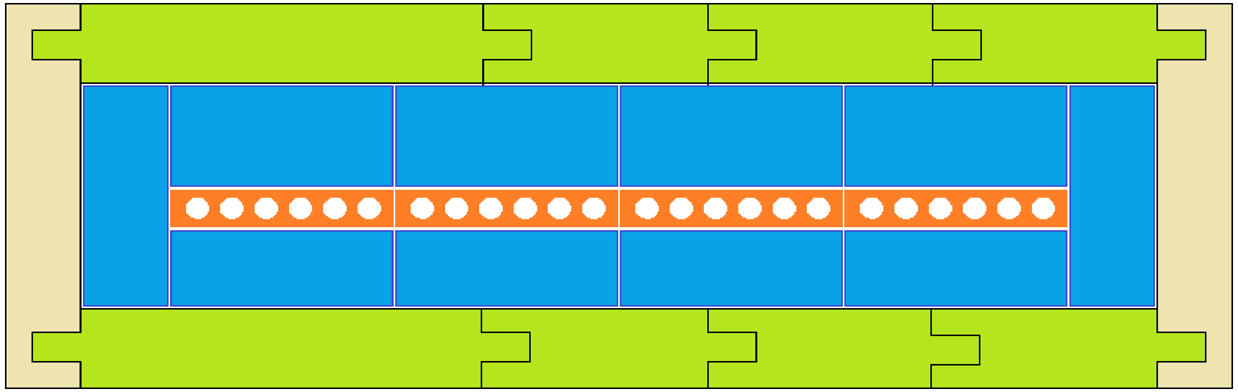
Proposed concept design.



Above: Footprint size comparison of the new neutron monitor design with a 6 tube NM-64.



Above: 6-counter NM-64 neutron monitor
Source: Carmichael, H., 1968, Annal of the IQSY



Engineered design.

Thank you

Ground Level Enhancement Event Monitor - GLEEM

Funded by:

Science and Technology Facilities Council

In partnership with:

Met Office

Collaborators:

UK Atomic Energy Authority

Hybrid Instruments

MIRION TECHNOLOGIES

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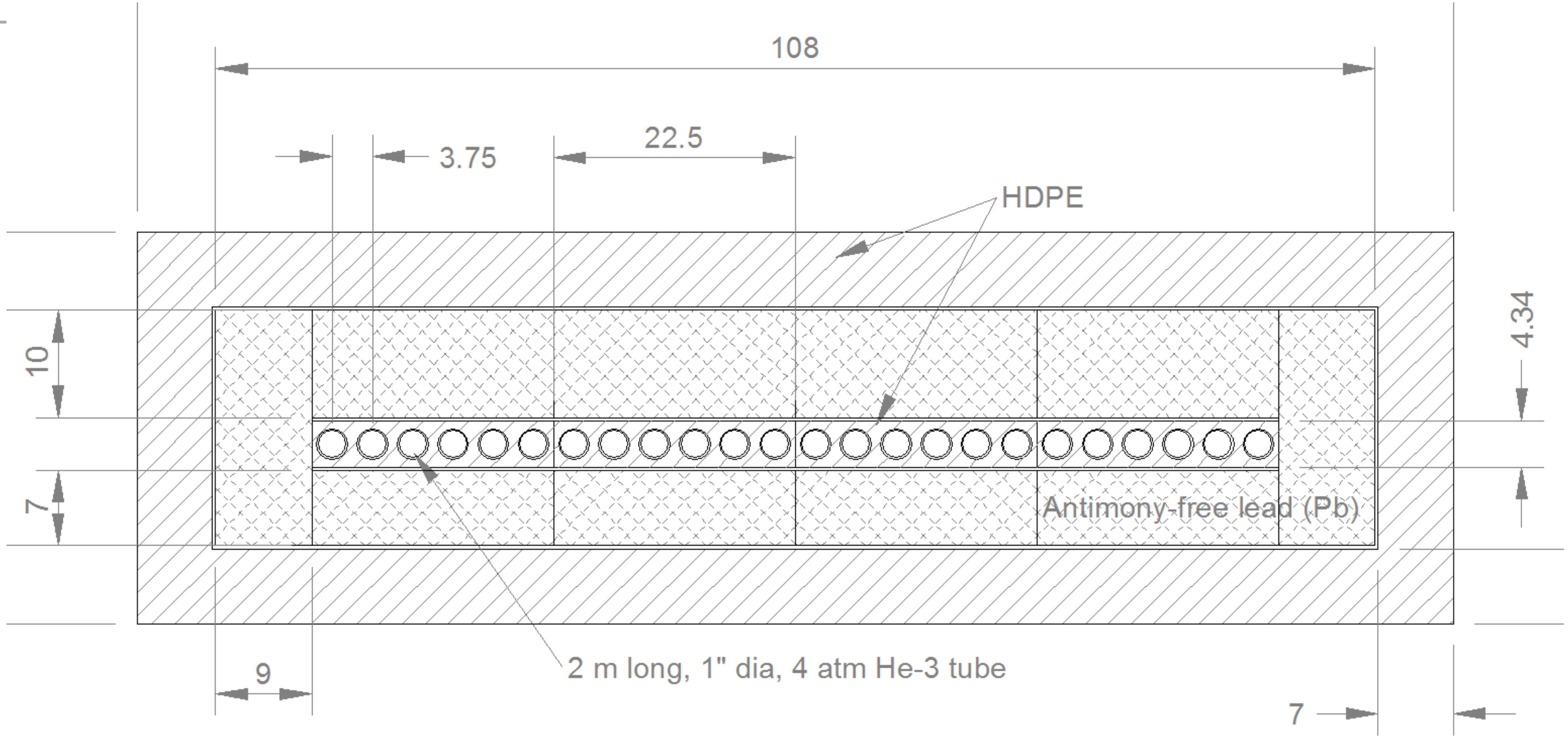
Aims of SWIMMR S5

- Develop *"networkable instruments for ground-level neutron monitoring"*
- Deliver operational instruments to the UK Metrological Office
- Cheaper, compact, comparable results
- *"Major increase in monitoring worldwide...*
- *Enhance existing global capabilities..."*

Right: The Met Office Space Weather Operations Centre (MOSWOC) 2015. Source: https://blog.metoffice.gov.uk/

Design overview

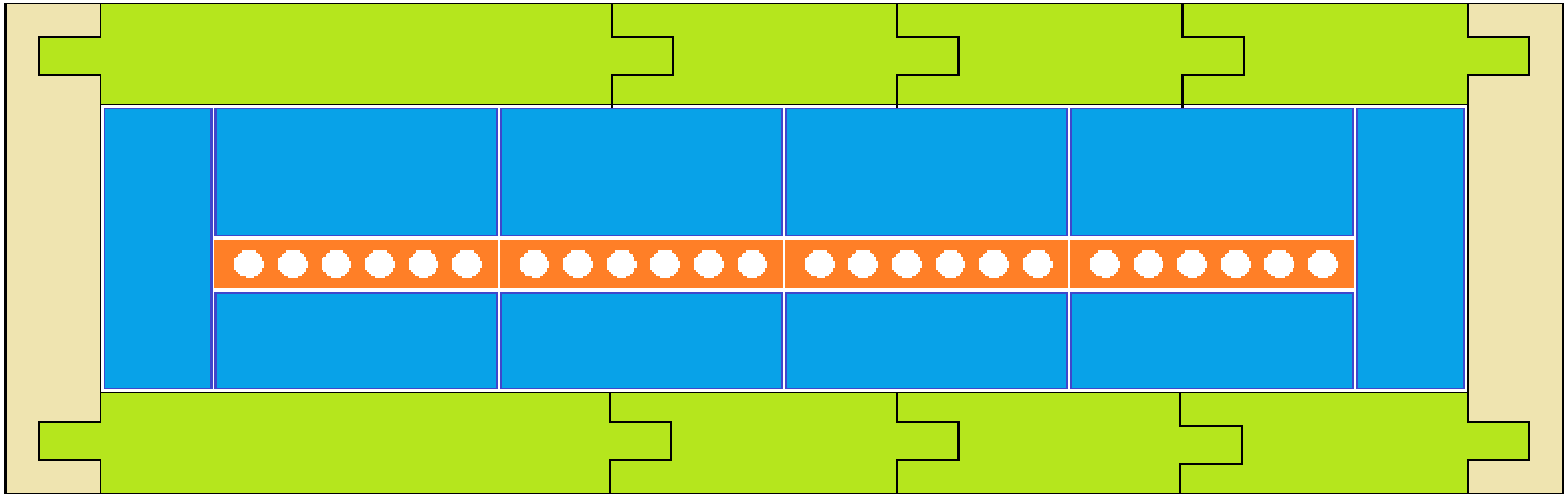
Concept design



Above: Cross-sectional geometry of new ground-level neutron monitor based on ^{3}He counters.

Engineered design

- ^{3}He solution
- Compatible with 1” dia BCS
- Matched 6-NM-64
- New functionality
- COTS components‡
- Reduced size and cost

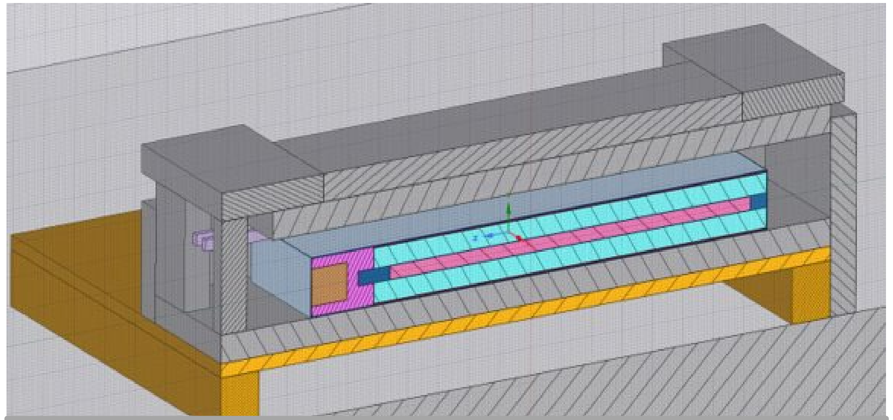


Pilot long counts

N50L pilot

- N50L passive neutron monitor
  - Mirion Technologies (Canberra UK) Ltd.
  - Encased in Pb and HDPE
  - Count rates recorded over several weeks
  - Air pressure logged for pressure corrections

Above: Photograph of the partial construction of the lead producer layer. The lead was assembled on all six sides of the N50L module.



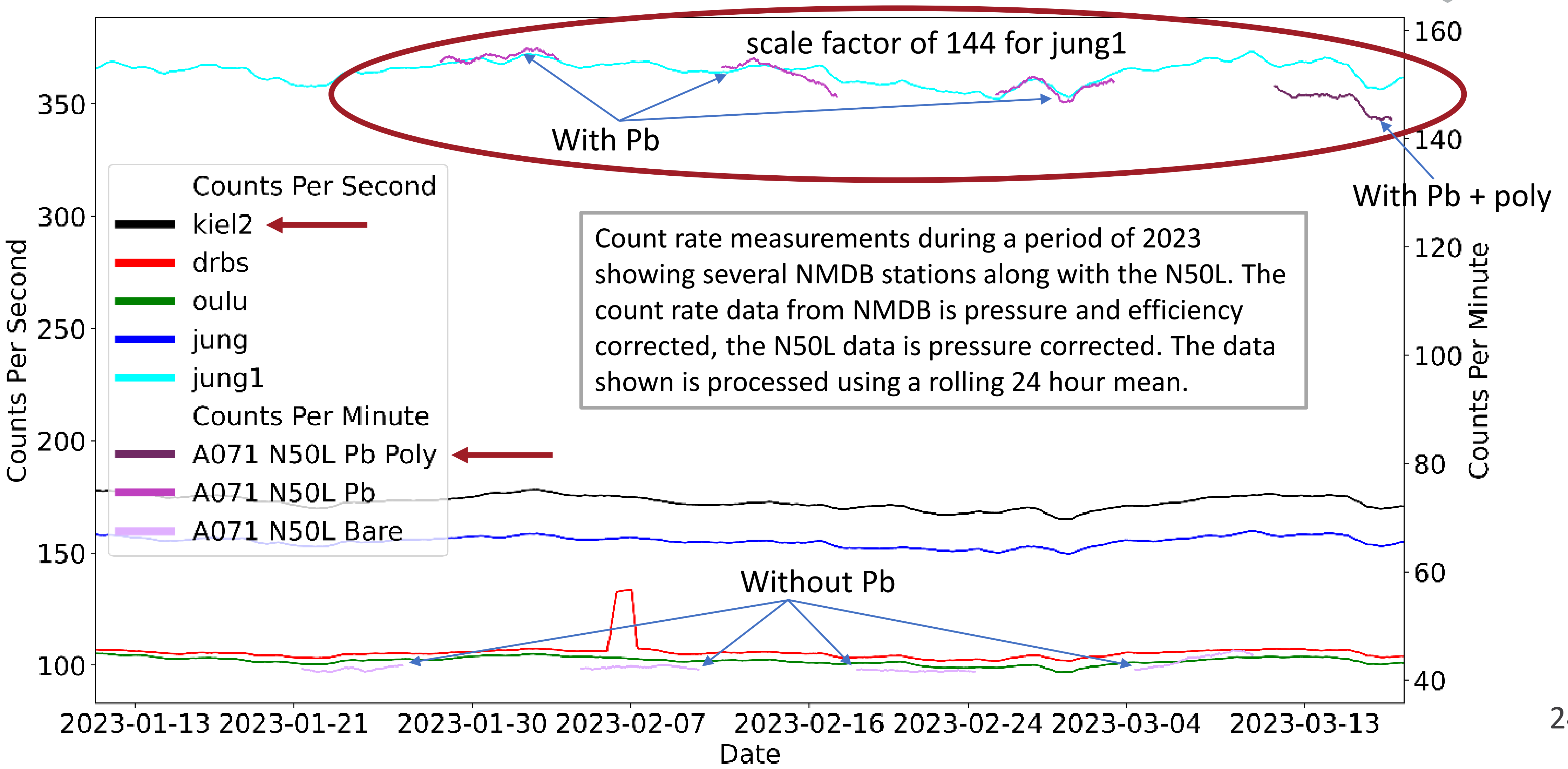
Above: CAD model of the Mirion N50L module surrounded by lead bricks atop a wooden pallet. This model is utilised for MCNPv6.2 simulations, for illustrative purposes a cutaway is shown.

Above: Photograph of the lead sarcophagus with partial construction of an outer reflector layer constructed of 50 mm thick high-density polyethylene.

Existing vs. pilot comparison

	Kiel2	DRBS	Oulu	Jung	Jung1	N50L
Latitude (°)	54.3399	50.0971	65.0544	46.55	46.55	54.029
Longitude (°)	10.1199	4.59003	25.4681	7.98	7.98	2.476
Altitude (m)	54.0	225.0	15.0	3570.0	3475.0	60
Geomagnetic Cutoff (GV)	2.36	3.18	0.8	4.45	4.5	2.31
Reference Air Pressure (mbar)	1006.7	986.6	1000.0	642.614	642.614	1002.3
Barometric Coefficient (%mbar)	0.721	0.739	0.74	0.72	0.72	0.922
Tubes	18 NM-64	9 BF3	9 BP28	18 NW IGY G15-34A	3 BP28	4 ^{3}He

Relative rate comparison



Scaling for proposed design

- N50L
  - 4 ^{3}He tubes, 0.71 m length
  - <u>150 cnts/min</u> or **2.5 cnts/s**
- Kiel
  - 18-NM-64, 3x bigger our 6-NM-64 benchmark
  - <u>180 cnts/s</u>
  - 180/3 **= 60 cnts/s**
- Proposed design
  - 24 tubes, 1.98 m length
  - 6x more tubes, 2.78x length of the N50L
  - The N50L is ~1/17th of the final design
  - N50L cnts/s * 18 = **~45 cnts/s**

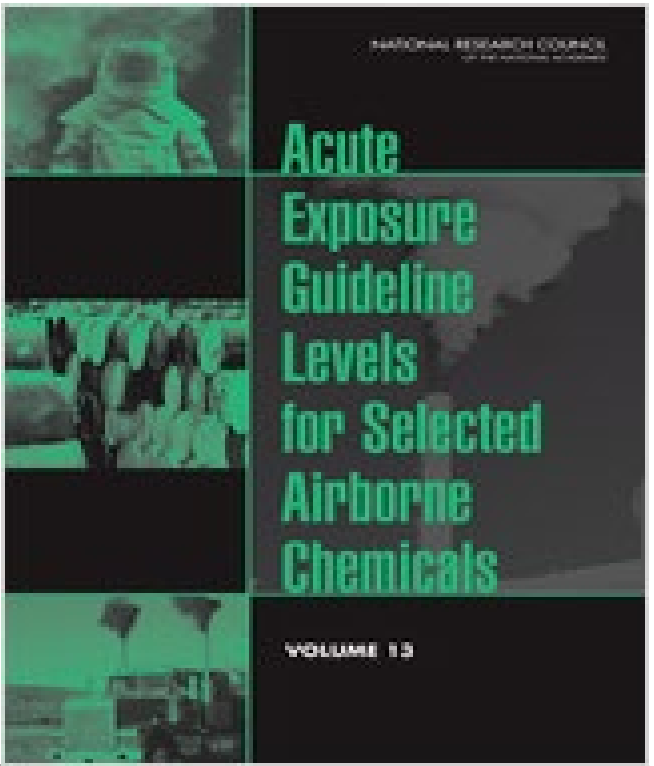
Detector choice

Toxicity

- AEGL-3(lethal) concentration
- 110 mg/m^3 in 10 minutes
- Recall BP-28 contains about 25 g
- Consider a room 5mWx10mLx2.5mH
- Uniformly dispersed = 200 mg/m^3

Centre: The tube shown was taken from the Deep River Neutron Monitoring Station and predates the NM-64/BP-28

https://orau.org/health-physics-museum/collection/proportional-counters/neutron-detectors/chalk-river-large.html



Acute Exposure Guideline Levels for Selected Airborne Chemicals: Vol. 13. Committee on Acute Exposure Guideline Levels; Committee on Toxicology; Board on Environmental Studies and Toxicology; Division on Earth and Life Studies; National Research Council. Washington (DC): National Academies Press (US); 2012 Dec 28.

MTBF: Do 3He PCs leak?

- Infantile failures happen in the factory
- GE RS confirm breakages can occur during shipment and as a result of handling accidents
- Canberra Industries used over 9000 ^{3}He PC's in waste assay and safeguards systems, with an average age of >10 y, and did not see any failures in-service
- What did occur:
  - Two Al-walled tubes got squashed on a shelf while in storage – but still worked afterwards
  - Two small portable systems got dropped down a flight of stairs and two tubes in each (i.e., 4) stopped working (anodes pinged)
  - One tube in a well counter was drilled into!
  - We have repurposed decade old tubes many times and they perform as new

- So, accidents can and do happen, which gives us pause over the use of BF_3, but we have never seen a ^{3}He tube leak in operation and fail its QA test.
- Roughly speaking then: 4/(10000x10) < 1/25,000 chance of failure per tube per year
  - So, a system with 24 tubes would be expected to have a tube failure in 1000 y of use on the average

Application requirements

- High & constant detection efficiency
- Simple gamma rejection
- Commercially viable
- Long-term stability
- Robustness for deployment
- Mitigable environmental influences

- Rules out anything with:
  - an efficiency less than close or better than BF_3
  - an efficiency that degrades over time
  - pulse shape discrimination requirement
  - prototype status and without an in-service record or long MTBF
  - a PMT or SiPM

Detectors considered

- BF3 filled proportional counters
- Boron-lined proportional counters
- ^{6}Li loaded glass fibre
- Light guides with ZnS scintillator and ^{6}LiF
- Crystalline neutron detectors, e.g. CLYC
- Scintillators doped with neutron capture materials
- Gamma-ray detectors surrounded by neutron capture material
- Semiconductor detectors with imbedded neutron capture materials
- Fission chambers
- Liquid scintillators for fast neutron detection
- Plastic scintillator for fast neutron detection
- High-pressure ^{4}He filled detectors for fast neutron detection
- Bubble detectors for fast neutron detection

Conclusions

- Both ^{3}He and BF_3 gas-filled cylindrical proportional counters are excellent technical solutions
- Our preference is for ^{3}He based on efficiency and toxicity
- The overall system cost is not dominated by the sensor cost and the difference in cost between ^{3}He and BF_3 per neutron detected is not the only factor of importance

SDP ILW Monitor. Courtesy Canberra/Mirion Technologies. This is an example of the demonstrated simplicity, versatility, and reliability to meet demanding applications.