Technical Development of the NM-2023 Ground Level Neutron Monitor

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Background

A **Ground Level Enhancement (GLE)** is a significant increase in the count rate observed by ground-based cosmic ray (CR) detectors caused by energetic charged particles reaching the Earth's surface.

GLEs have the potential to **disrupt critical national infrastructure** such as the power grid, transport, satellite applications and communications, and safety critical electronic control systems.

SWIMMR S5 Project Aim[1]:

Design and implement **operational** Neutron Monitors (NMs) that are **cheaper**, more **compact**, capable of producing **comparable** results to the NM-64 design, and **networkable** for **deployment** at a Met Office site with **data ingest** by MOSWOC.

Initial Design Study

Several detector types were assessed: BCS, ^{3}He, BF_3

- **^{3}He proportional counters** were selected based on high efficiency, long stability, no toxicity and long mean time between failure.

System design parameters such as the **moderator/producer thickness** and **detector positions** were selected through a parameter optimisation modelling study performed by the UKAEA[2].

4-NM-2023 was estimated to produce comparable count rates to the 6-NM-64 with **64% smaller footprint**, **80% smaller volume** and **55% less mass[2]**.

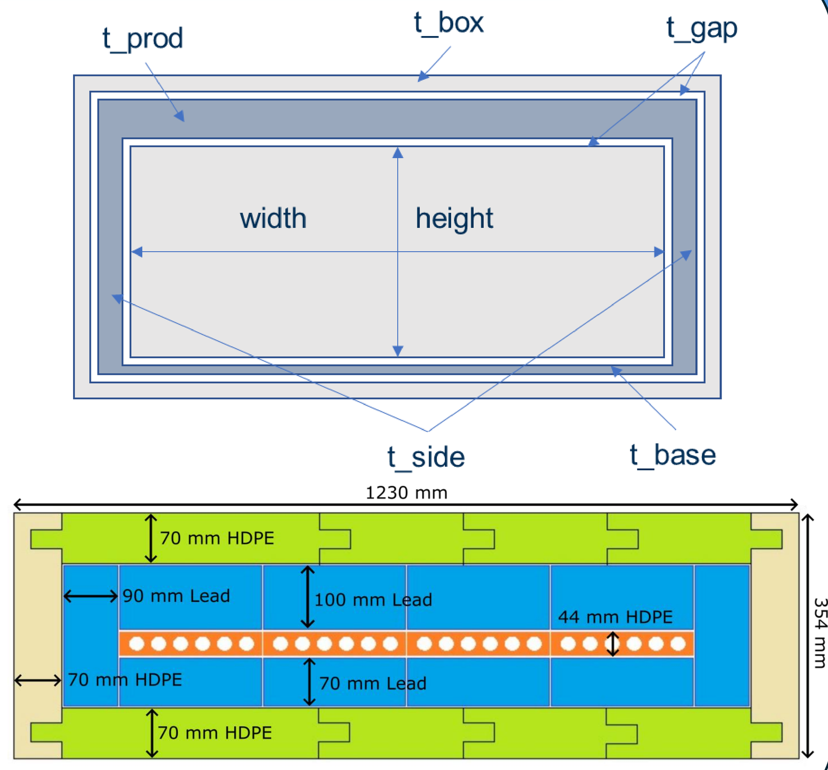

Figure 1: Design study parameters and resulting optimal thicknesses

Mechanical Design

4-NM-2023 consists of three concentric layers:

- Inner HDPE Moderator housing the ^{3}He tubes
  - **Thermalises neutrons** for detection
- Middle Lead Producer weighing ~5.2 t
  - Target to **generate spallation neutrons**
- Outer HDPE Reflector layer
  - Aids with moderation and **reflects background neutrons**

Monitor has external dimensions of **36 cm H, 123 cm W, 253 cm L** with a total mass of ~6.0 t

Components are **modular** such that the monitor can be arranged/upgraded into different sizes

- Enables creation of **1,2,3…-NM-2023 designs**

4-NM-2023 is housed within an **ISO container** which includes:

- **Pitched roof** to prevent snow buildup
- External Pressure/Temperature/Relative Humidity monitor (Vaisala WXT534)
- **4G antenna** for remote communication
- **HVAC** for improved temperature stability

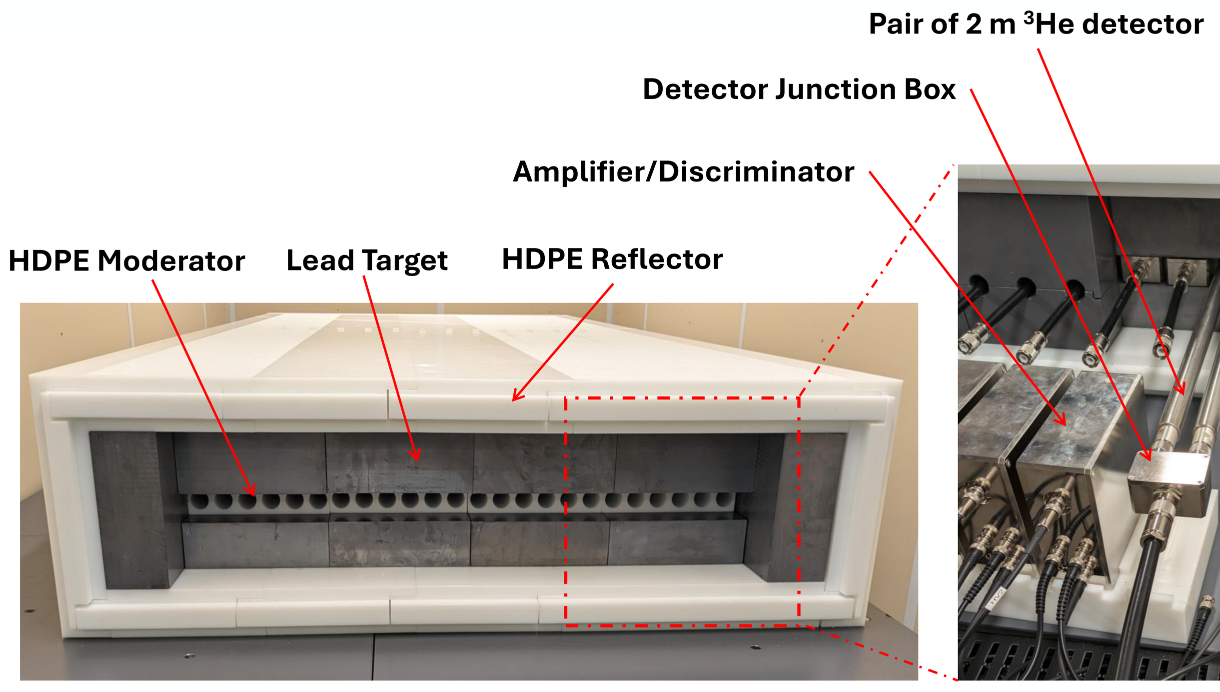

Figure 2: Internal configuration of 4-NM-2023 monitor including arrangement of the ^{3}He detectors

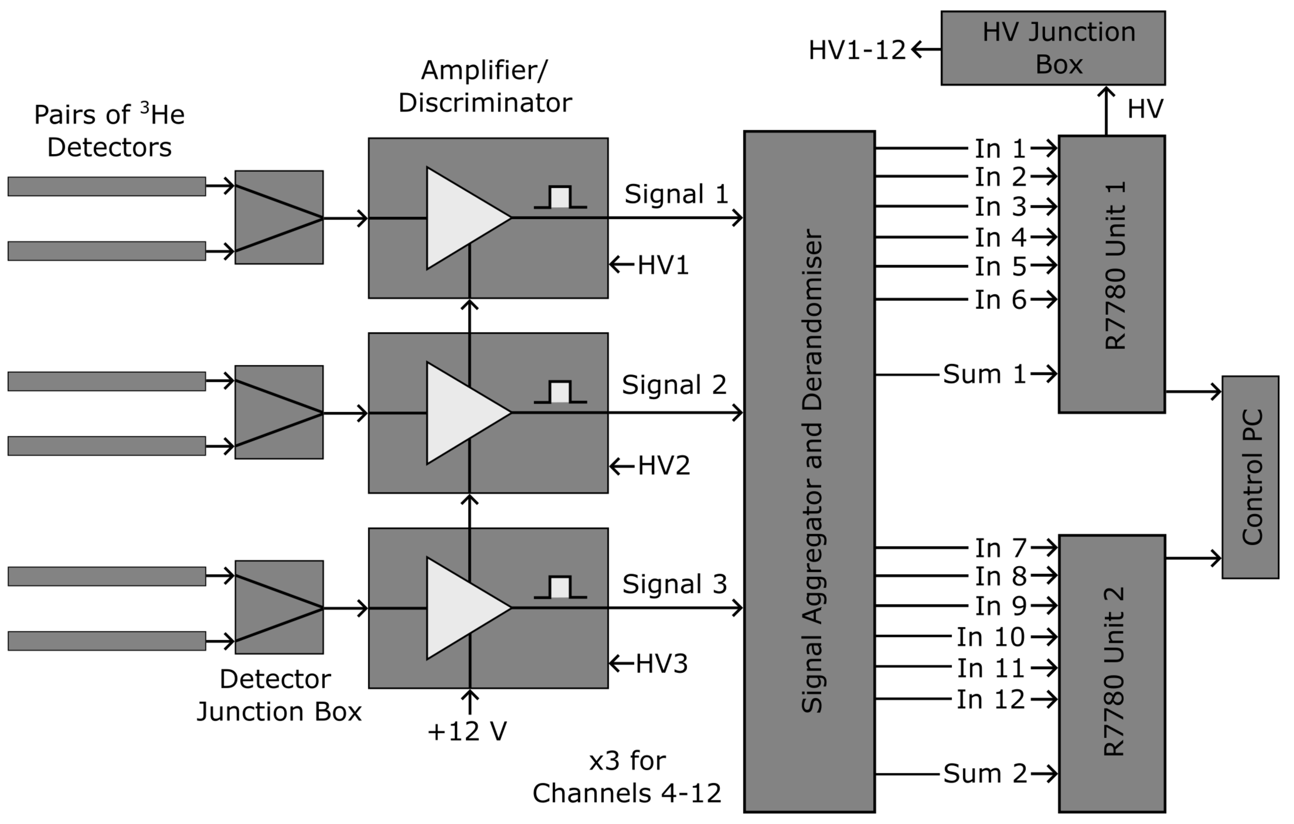

Figure 3: Schematic diagram of the 4-NM-2023 counting chain

Nucleonics Design

Cosmic rays generate spallation neutrons within the monitor that are thermalised and are then:

- Detected by **24 ^{3}He tubes** (1", 2 m, 4 atm) separated into four banks of six detectors (Hence the "4" in 4-NM-2023)
- Signals from pairs of detectors are combined and processed using amplifier/discriminators
- Signals are then **aggregated** and **derandomised**
- Summed signal is processed by two separate **CAEN R7780** shift register modules for redundancy
  - Unattended transfer of summed rate **every 60 s**
  - Individual channels are also monitored for **state-of-health checks**

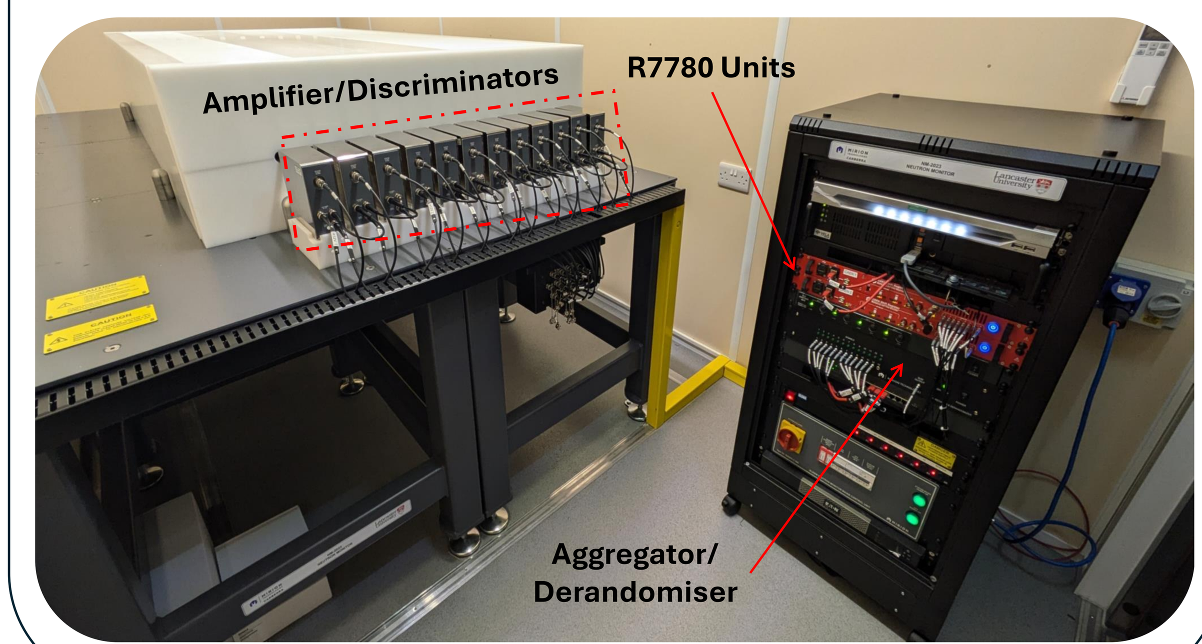

Figure 4: 4-NM-2023 monitor and control cubicle within the ISO container

System Characterisation

4-NM-2023 was tested and commissioned at Mirion's Warrington facility.

- The ^{3}He detectors were assessed for consistency and **optimal operating voltage** - determined to be 900 V
- **Channel efficiencies** were assessed using a reference ^{252}Cf source in recesses on top of the monitor:
  - Uniform efficiency of **~2.6 %** across the middle channels
  - Efficiency higher at edges due to larger volume of HDPE
- **CR background count rate** of ~72 cps (~6 cps/ch) at (Lat: 53.42°, Long: -2.52°, Alt: 22 m) in Oct-Nov 2024
- Parameters required for **multiplicity analysis** of induced spallation events were also assessed:
  - Neutron **die-away time** ≈ 132 μs.
  - Summed signal **deadtime** ≈ 0.43 μs

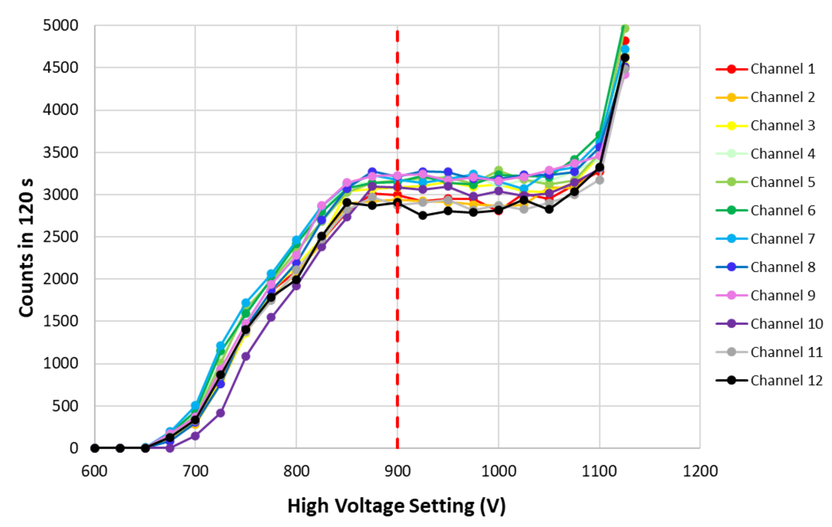

Figure 5: High voltage plateau for each measurement channel

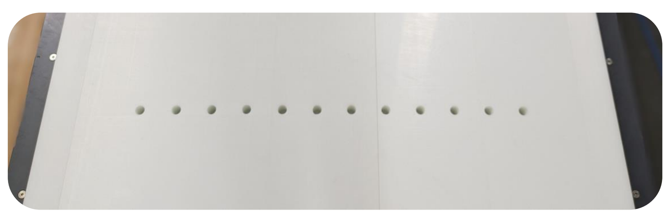

Figure 6: Measurement recesses in the top surface of the monitor

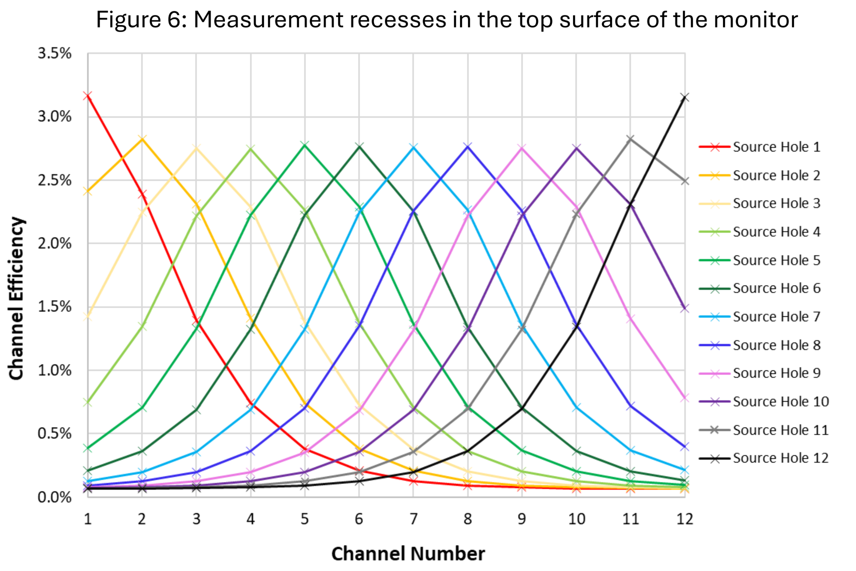

Figure 7: Channel efficiencies for each source recess position

Installation

4-NM-2023 has now been **installed at the Camborne MET Office site** in Cornwall.

- Performing as expected compared to nearest monitor[3]
  - ~33% lower vs 9-NM-64
- Awaiting full integration into the MOSWOC and NMDB networks
- **1-NM-2023 also installed** at Lancaster University and University of Rome Tor Vergata.

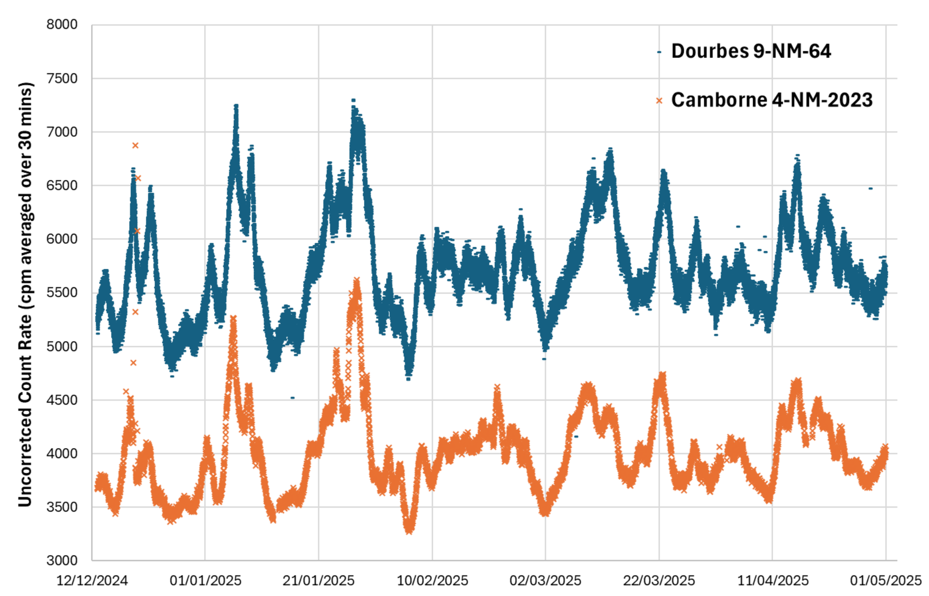

Figure 8: Comparison of the uncorrected count rates from the Dourbes 9-NM-64 and Camborne 4-NM-2023

Figure 9: Left/Middle: 4-NM-2023 installed at Met office Camborne site. Right: 1-NM-2023 installed at Lancaster University

References: [1]Space Weather Innovation, Modelling, Measurement and Risk (SWIMMR) S5: Networkable instruments for Ground-Level Neutron Monitoring Proposal. [2]Aspinall, D M., et al. "A new ground level neutron monitor for space weather assessment." *Scientific Reports* 14.1 (2024): 7174. [3]NMDB Data Retrieval: https://www.nmdb.eu/nest/

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