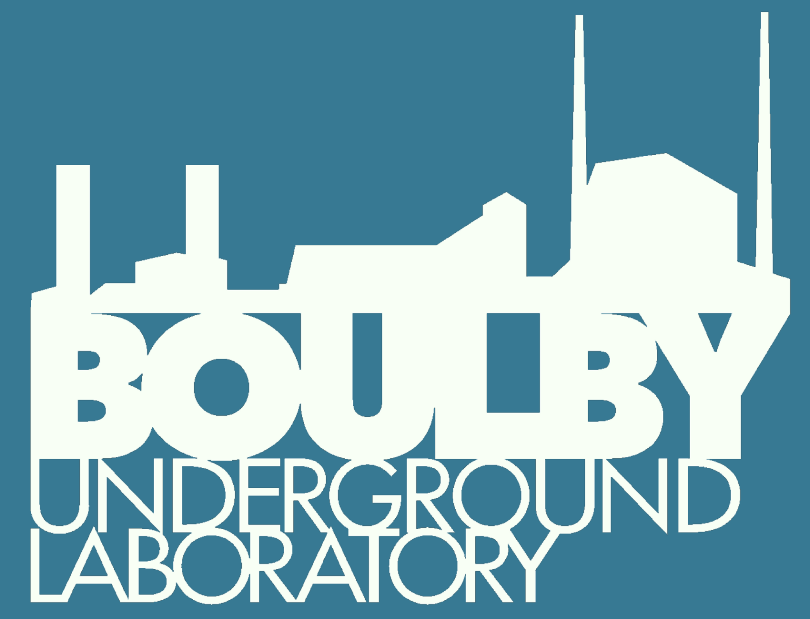


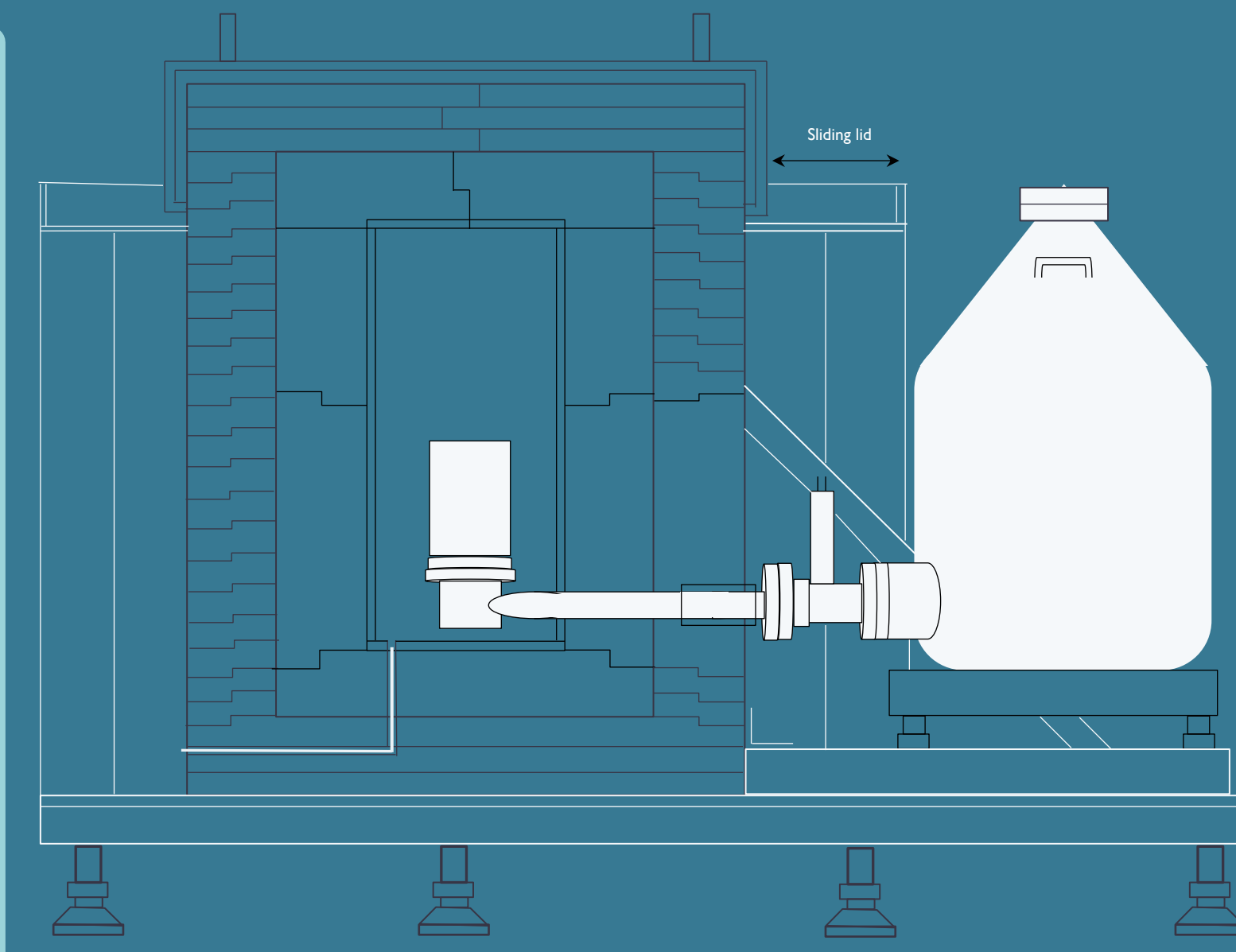
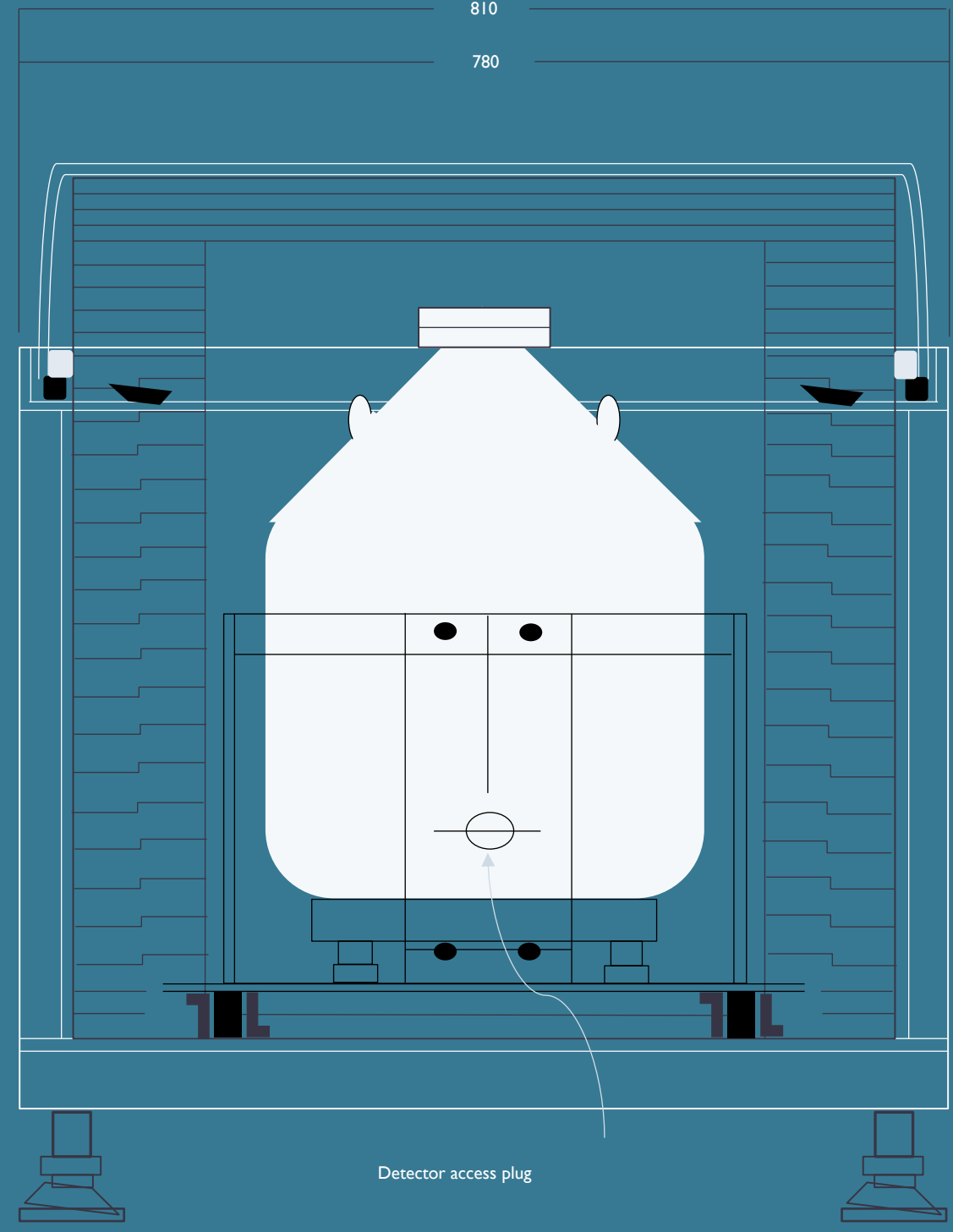
Material Assay using Germanium Detectors in Boulby Underground Screening Facility

LRT 2026 – Beth Green, Boulby Underground Laboratory



Boulby UnderGround Screening facility (BUGS)

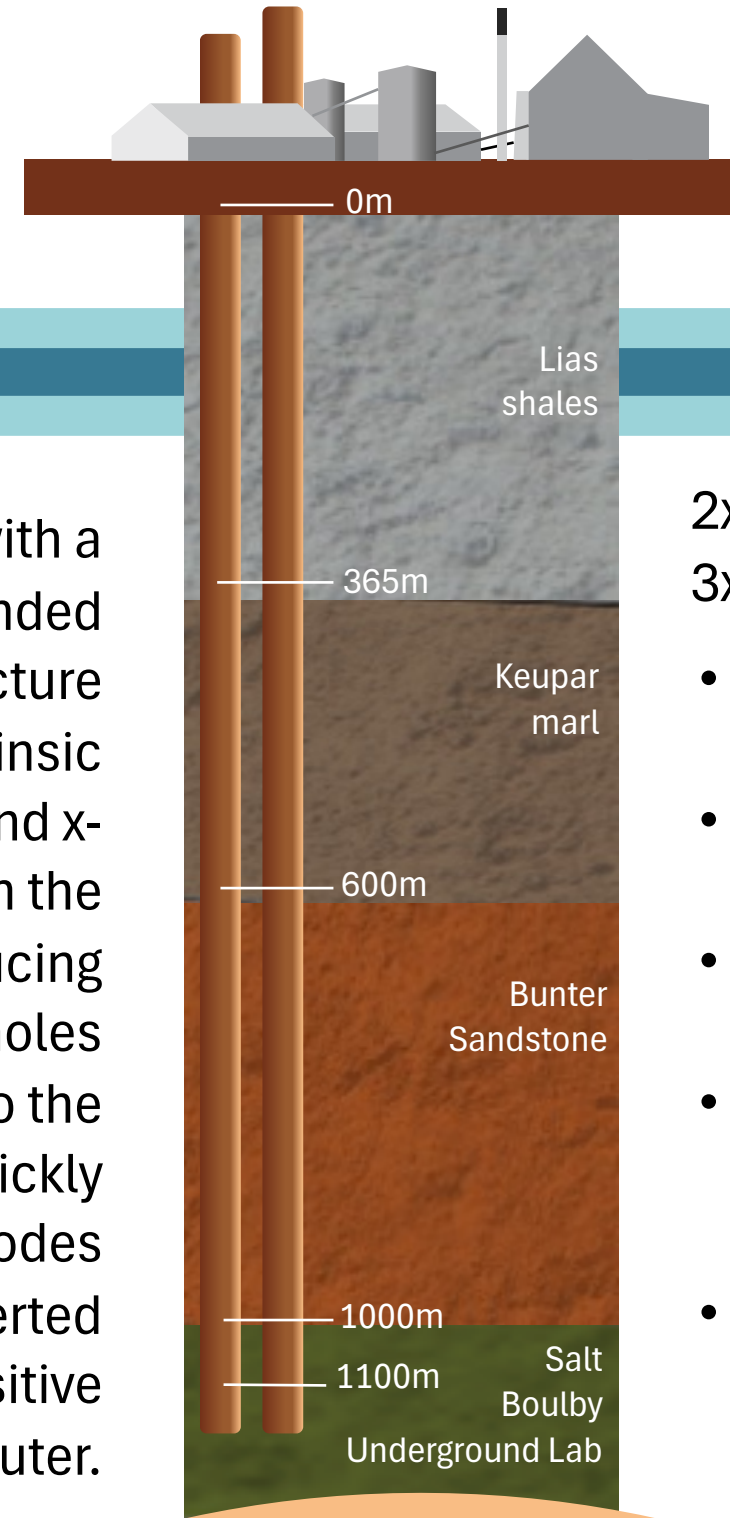
- BUGS is Boulby Underground Laboratory's world class material assay facility located **1.1km** underground in Boulby mine - the largest and deepest mine in the UK, beneath the Northeast coast.
- Housing 8 germanium detectors, 2 XIA UltraLo-1800s, our radon emanation facility and our surface ICP-MS
- Provides screening for worldwide experiments
- Operating in a class **1000 cleanroom**, these detectors are running samples 365 days a year!
- Boulby's natural rock overburden grants us the ability to work in an environment with **1 million** times less interference from cosmic rays than experienced on the surface
- Currently, our germanium detectors detect gamma ray energies in the range from **3keV** to approximately **3MeV**
 - The natural radon levels in this area amount to **<3 Bq/m³** making Boulby an ideal location for low background particle physics.



Germanium Detectors



Germanium detectors are semi-conductors with a p-i-n structure. An electric field can be extended over the intrinsic/depleted region of the structure when under reverse bias. Due to this intrinsic region being so sensitive to gamma rays and x-rays, incoming photons will interact with the material in this region of the detector, producing charge carriers (electrons and holes). The holes and electrons have a charge corresponding to the energy of the incoming photons and are quickly attracted to the positive and negative electrodes within the detector. Here, they are then converted into voltage pulses by a charge sensitive preamplifier and sent to the computer.



2x P-type BEGe detectors 1x P-Type SAGE Well detectors
3x P-Type COAX detectors 2x BEGe in Twin set up

- Housed in Ultra low background lead castles with an ultrapure copper liner to reduce background
- Cooled using a mix of electronic coolers and liquid nitrogen from our underground nitrogen system
- Purged with radon reduced nitrogen gas at a rate of 3lpm
- Constant environmental monitoring of radon, temperature, humidity, particle count, oxygen, LN2, high voltage, gas flow and UPS.
- User friendly online sample request form for sample senders from numerous projects to input upcoming samples and get automatic updates on their status

Our Detectors in BUGS

	Crystal Weight	Relative Efficiency	Background
COAX			
Merrybent	2.0kg	110%	Ultra-Low
Belmont	3.2kg	160%	Ultra-Low
Lunehead	1.8kg	71%	Very Low
BEGe			
Roseberry	0.9kg	60%	Ultra-Low
Chaloner	0.8kg	48%	Very Low
SAGE			
Lumpsey	1.4kg	67%	Ultra-Low

Detector Sensitivity

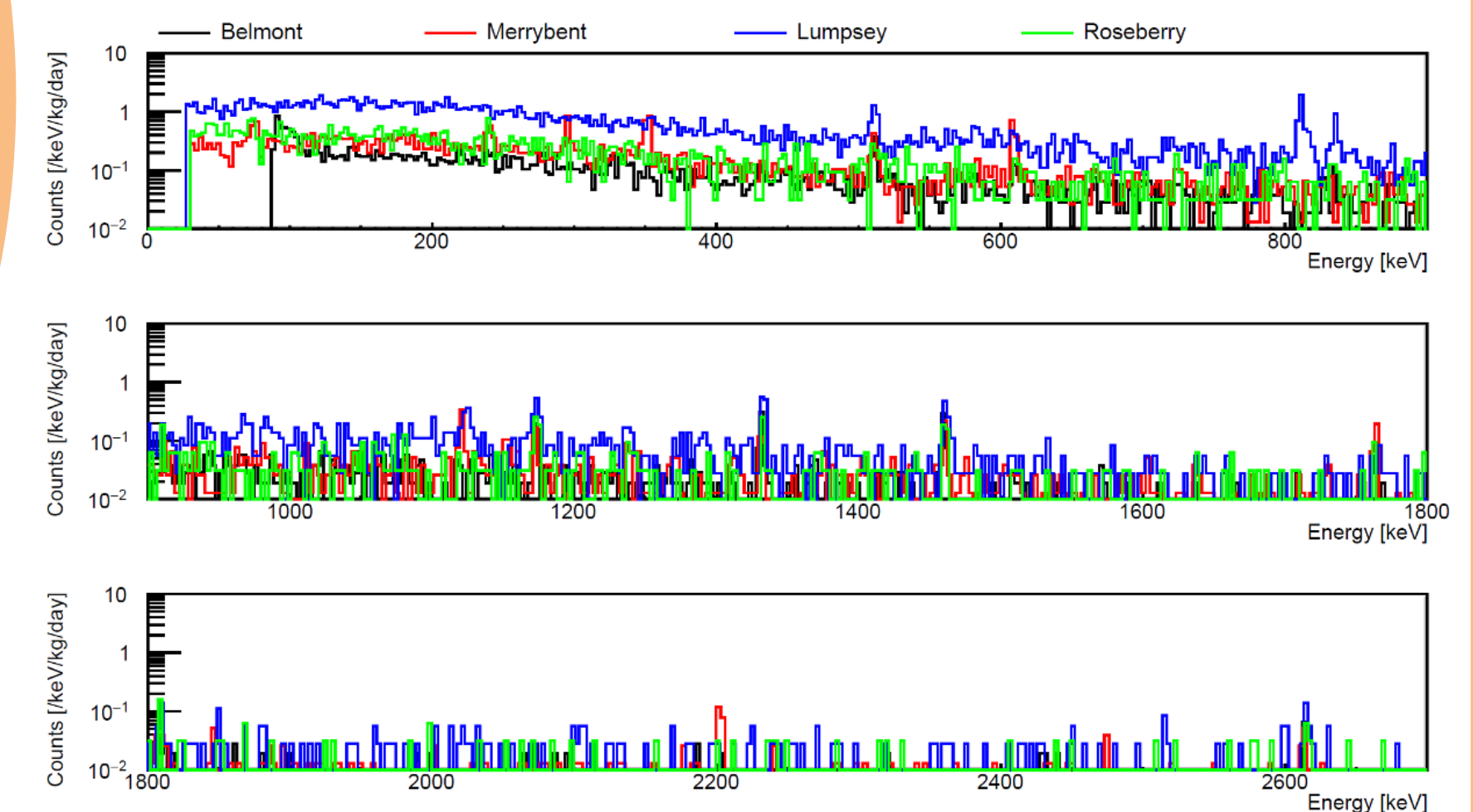
For a germanium detector to be at its most sensitive, there must be minimal interference from unwanted radiation, microphonics, moisture and condensable contaminants. To prevent the thermal generation of charge carriers within the detector, the detectors are cooled electrically, or by using liquid nitrogen which is produced ourselves from the air within the mine. Without this, a leakage current could produce noise capable of destroying the energy resolution of the detector. We also improve sensitivity by keeping the detectors within a low background lead and copper shield, acting as an additional physical barrier.

Detector Name:	Detector Type or relative efficiency:	Background Count Rate (kg/day)				
		351 keV ²¹⁴ Pb	609 keV ²¹⁴ Bi	238 keV ²¹² Bi	1461 keV ⁴⁰ K	2615 keV ²⁰⁸ K
Roseberry	BE6530	0.15(7)	0.15(7)	0.8(3)	0.8(2)	0.2(1)
Chaloner	BE5030	5(1)	4(1)	7(1)	8.4(14)	2.1(5)
Belmont	I60%	0.7(2)	0.4(1)	0.13(6)	1.0(2)	0.3(1)
Merrybent	I00%	2.5(3)	1.8(3)	0.3(1)	1.9(3)	0.8(2)
Lunehead	I00%	5.6(5)	4.7(4)	8.3(5)	9.1(6)	2.0(3)
Lumpsey	SAGE/Well	1.1(7)	1.3(3)	1.1(7)	1.7(7)	0.7(2)



Background Spectra

The image demonstrates the low backgrounds achieved with the germanium detectors, and we can subtract these counts from our sample assays. The backgrounds are achieved by improving the shielding configuration, optimizing the nitrogen purge and improving the calibration protocols. The Germanium detectors are each calibrated monthly using Na22-Eu155 source to ensure continuity in nuclide energy peaks, FWHM (full width half max), CPS (counts per second) and error ranges. Background runs are frequently scheduled for accuracy in sample analysis.



Samples and Collaborators

- In 2025, **109 samples** were assayed in the Boulby Underground Screening facility. These samples primarily came from low background particle detector collaborations.
- Gamma Spectroscopy is a crucial step in preparation for low background particle detectors to construct it with minimal background from radionuclides within the detector components.
- With our XIA detectors, radon emanation system and ICP-MS, our range of screening detectors allows us to easily transfer samples between Ge and other assay techniques without the need for travel.
- As well as searches for rare event particles such as dark matter, the germanium detectors in our screening facility have applications into nuclear security and environmental studies.
- The BUGS team are working in collaboration with XLZD to build a new castle shielding our coax detector, Belmont. This includes screening lead samples and improving cleanroom protocols to reach the required background levels.
- Material screening facilities like BUGS are imperative for developing new detectors that reach background requirements. The detectors at Boulby have screened samples for LZ[1], Hyper-Kamiokande[2], DAMIC[3], DarkSide[4], QUEST-DMC[5], XLZD, BUTTON, LEGEND, Sabre, AWE and environmental studies.
- Sample assays can easily be requested through our Boulby Underground screening website <https://www.boulby.ac.uk/BUGS/SampleRequest>
- With BEGe, Coax and SAGE detectors, senders can select their desired detector type based on the energy range of radionuclides they are particularly interested in.



1] The LUX-ZEPLIN (LZ) radioactivity and cleanliness control programs. [2] N. Castelló-Mor. DAMIC-M experiment: Thick, silicon CCDs to search for light dark matter. [3] Vicente Pesudo. Material assay campaign of the DarkSide-20k experiment. [4] QUEST-DMC: Background Modelling and Resulting Heat Deposit for a Superfluid Helium-3 Bolometer. [5] Characterization of germanium detectors for the first underground laboratory in Mexico.

Development and Future

- A new nitrogen gas line has been installed in January 2026 to reduce total pipe length to allow for increased gas flow to determine the optimum flow rate.
- Our new environmental monitoring dashboard allows us to view particle count, temperature, humidity, count rate, radon levels, purge, high voltage, flow rate, LN2 levels, UPS battery and gas levels in real time and to export data through measurements to identify anomalies.
- We are currently installing a new and improved radon reduction system to improve the quality of the nitrogen purge and therefore reduce contaminants within the castle.
- We have had a summer student in 2026 creating a calibration model and procedures to collect more data to be used to characterize detectors and improve simulations.
- We are working with UCL to apply a pulse shape analysis method as in LEGEND to the BUGS detectors to improve material screening efficiency by installing new digitizers and software.



Twin Detector Setup:
Our twin detectors, Upleatham and Kirkleatham, sit in a remote-controlled shield which shifts the gap between the detectors to make room for samples depending on their size.

The shield was intentionally designed in layers, with a large cavity to allow for additional lead and copper shielding to be installed within the castle.

Assaying lead samples from our underground archive where lead has been stored for decades – the lead store. We have identified low background lead samples and plan to reuse this bricks to create enhanced shielding for our twin detector setup.

The **XIA UltraLo-1800** are ultra-low background surface and bulk alpha counters situated in our BUGS cleanroom. The XIA employs electronic background suppression to achieve background rates of **0.0001 alphas/cm²/hr**, significantly lower than if they were to be operated on the surface. The chamber is filled with pure argon gas, which is ionized by alpha particles emitted from the sample, leaving an ionization track within the argon gas. The electron then reaches the anode creating a signal pulse. The sample area can be up to 1800cm² in full mode, or 706.68cm² in wafer mode, and the adjustable tray heights allow for samples. The XIA UltraLo plays a vital role in material selection and reviewing cleaning techniques in preparation for next generation dark matter detectors.