2023/04/28
2nd International Summit on the Future of Neutrinoless Double-Beta Decay
Sudbury, Ontario, Canada

Material and Environmental Backgrounds at SNOLAB

Steffon Luoma, on behalf of the LBC Team
SNOLAB

Collaborators

- LBC Team
  SNOLAB, Sudbury
  L. Anselmo, D. Chauhan, B. Cleveland, J. Farine, N. Fatemighomi, J. Hall, I. Lawson, S. Luoma, T. Sonley and Students

- CTBT radionuclide laboratory CAL05 – Dual CTBT Detector
  Health Canada
  Adrian Botti, Pawel Mekarski, Marc Bean, Colin Vant and Kurt Ungar

- UNAM group – Background Gamma and Neutron Measurements
  Institute of Physics, UNAM, Mexico
  Lead: Eric Vázquez-Jáuregui

- University of Michigan – Vibration Studies
  Bjoern Penning and Sam Venetianer

Introduction

- Motivation
- Laboratory Environmental Backgrounds
  - Neutron Backgrounds
  - Gamma Backgrounds
- Material Screening
  - Gamma Spectrometry
  - Radon Emanation
  - More…
- Vibrations and Seismic Noise Studies
- EM Spectra Cataloguing
- Summary

SNOLAB
Why Go Underground

Many experiments searching for neutrino or dark matter interactions aim to detect very weak signals. They are all fighting against backgrounds from many origins.

Deep underground facilities provide significant rock overburden and commensurate reduction in cosmic ray flux, and cosmic ray-spallation induced products (neutrons).

Muons can be veto'd in anti-coincidence shield; secondary products may be an issue.

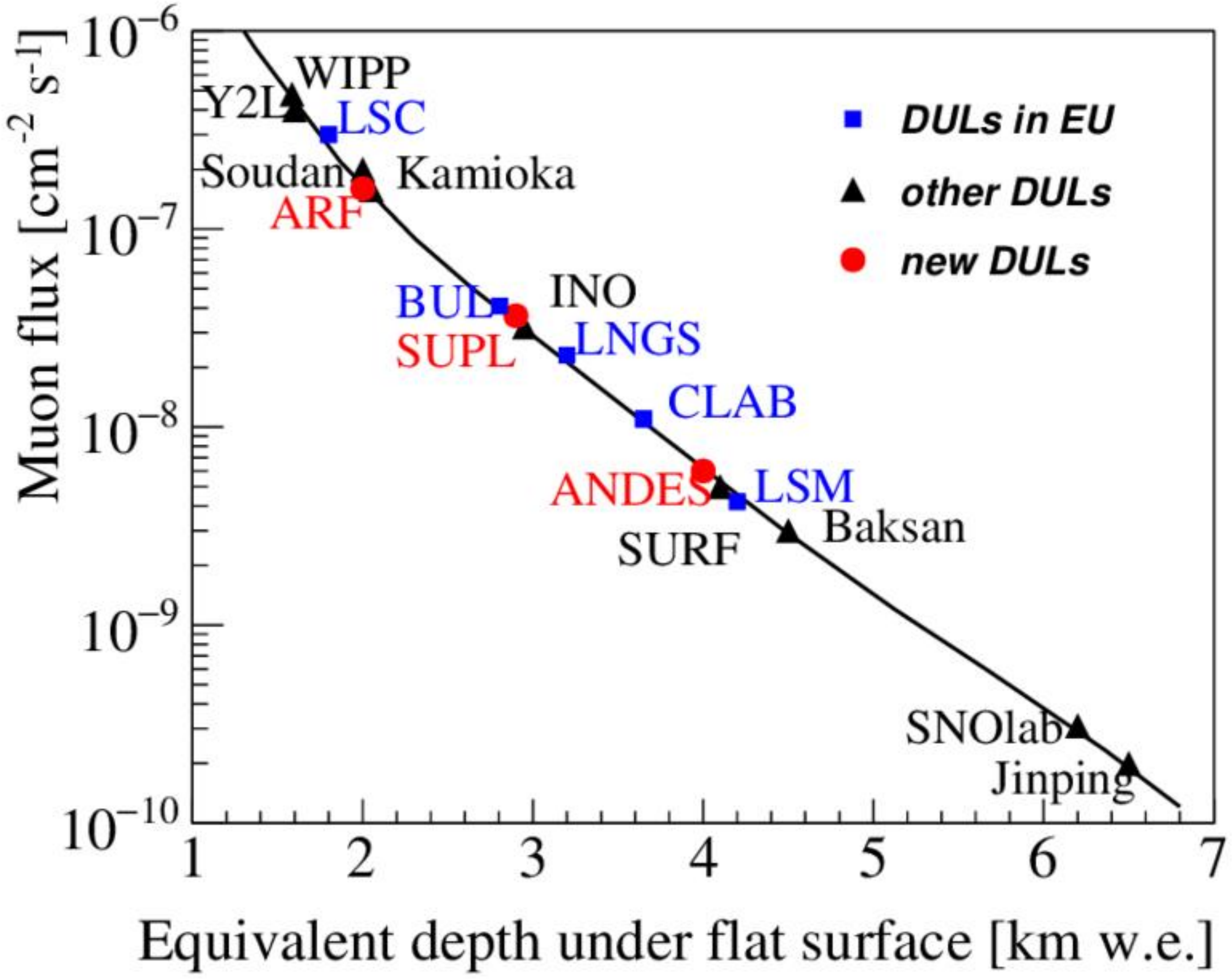
Cosmogenics may require underground material storage, production or purification
- May also contribute to backgrounds (e.g. ^{11}C, ^{7}Be)

Muon flux depends on
- overburden
- overburden profile
- seasonal effects

With all of these backgrounds present, there are several methods to measure them.

Muon Suppression

- 2 km overburden
- 6000 mwe
- Muon Flux: 0.27 muons/ m^2/ day



Aldo Ianni 2020 J. Phys.: Conf. Ser. 1342 012003Aldo Ianni 2020 J. Phys.: Conf. Ser. 1342 012003

Rock Properties

- Analysed using ICP-MS, ICP-AES and XRF
- Gamma Counted with HPGe
- Norite: The same as new lab areas
- Shotcrete: New areas slightly higher for Uranium and more than 2x for Thorium

Norite Density: 2.88 g/cm^3

	Norite Rock	Shotcrete/Concrete
O	47 %	48 %
Si	27 %	28 %
Fe	6.5 %	2.5 %
Al	6 %	6 %
Mg	6 %	1 %
Ca	3.5 %	10 %
Na	1.7 %	2 %
K	1 %	1.7 %
Ti	0.3 %	0.2 %

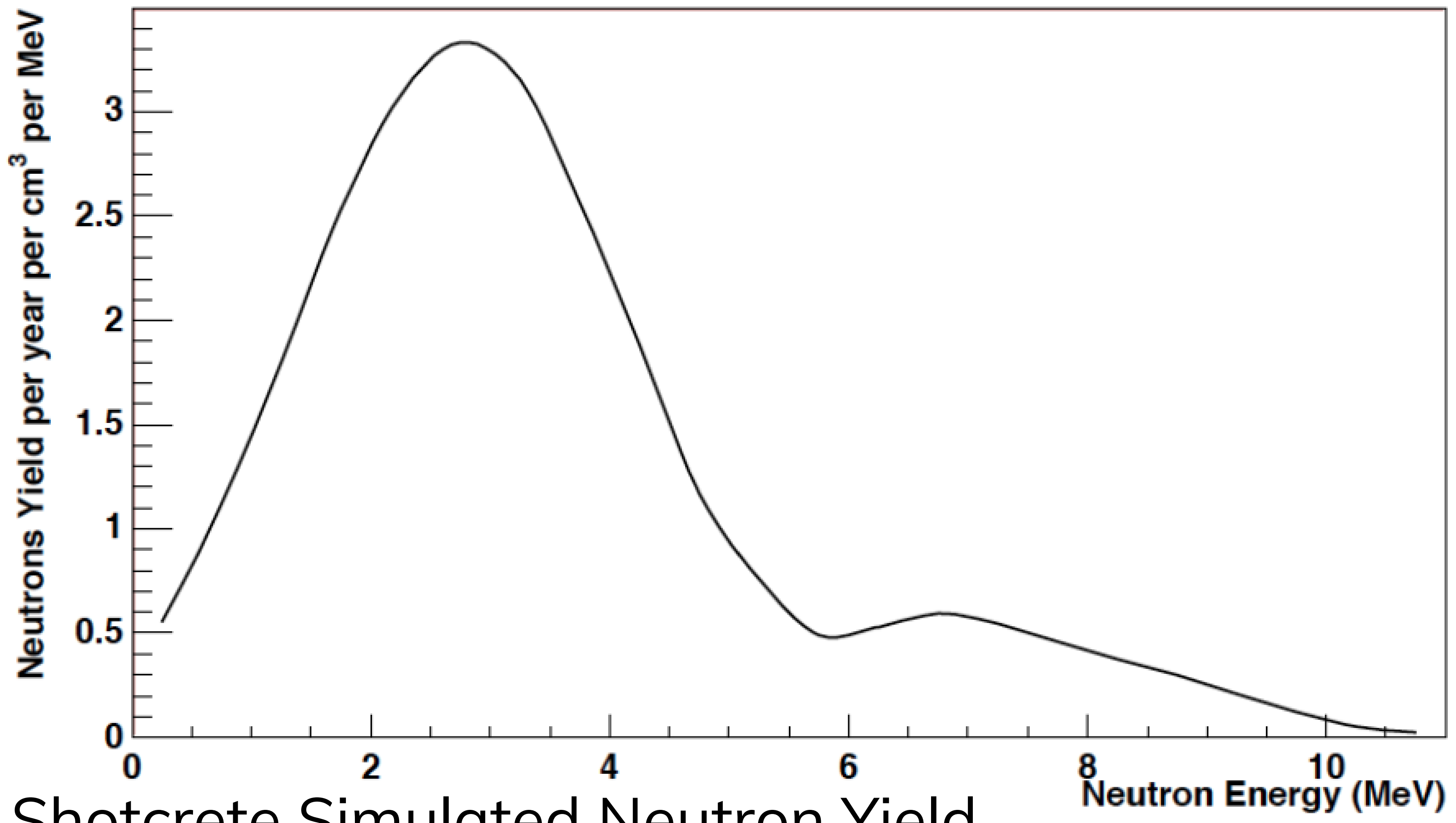
Rock Properties

Isotope	Norite Rock		Shotcrete	
	Concentration	Neutron Production ($n/yr/cm^3$)	Concentration	Neutron Production ($n/yr/cm^3$)
^{232}Th	5.10 ppm	8.13	2.4 ppm	0.99
^{238}U	1.10 ppm	3.51	1.2 ppm	1.05
Spontaneous Fission ^{238}U		1.19		1.03
Total		12.83		3.07

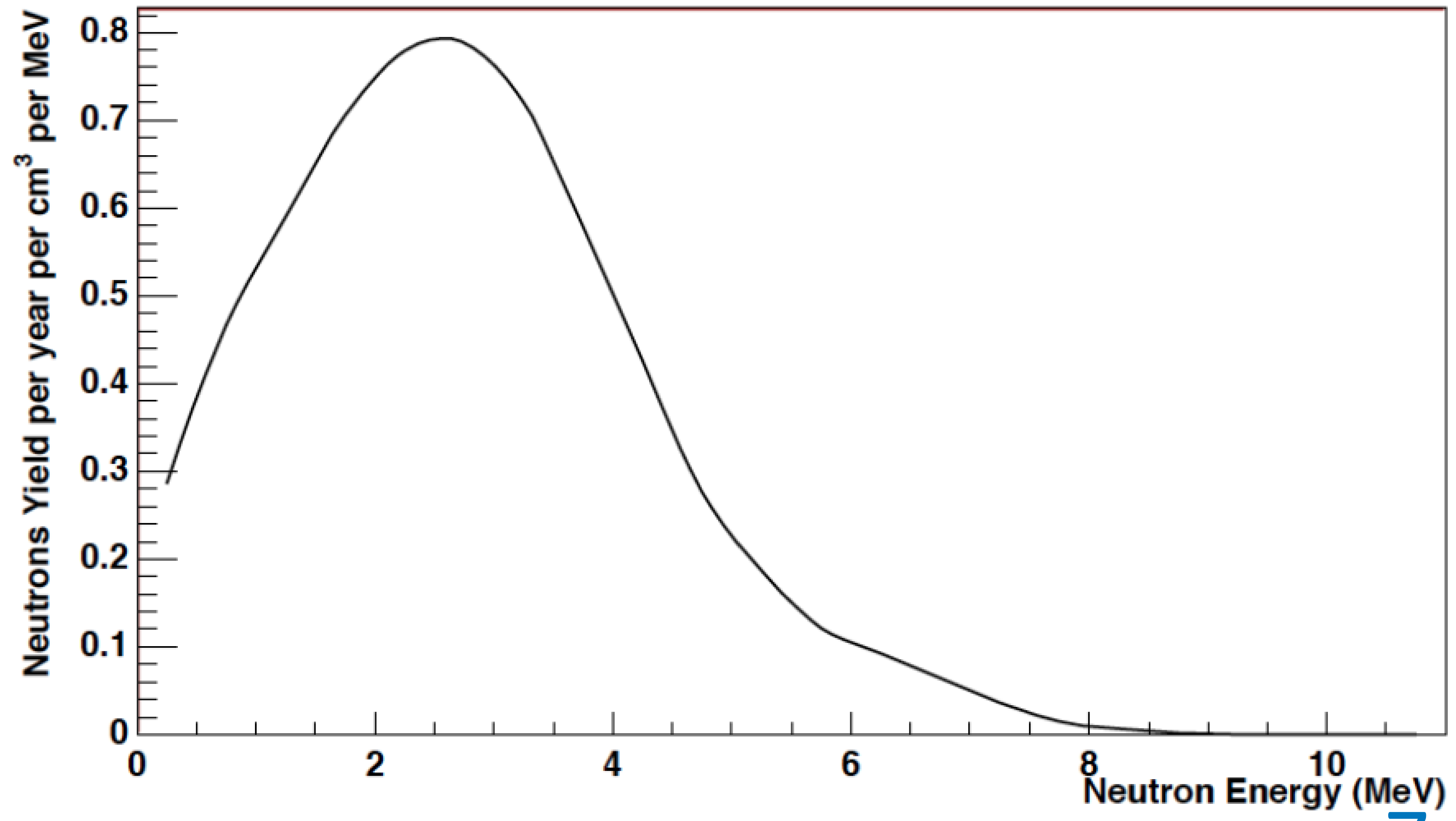
Neutron production estimates were obtained from SOURCES-4C and used as input in GEANT4

- 90%: (α,n) on light elements
- 10%: ^{238}U spontaneous fission
- Measurements from SNO area (1999):
- Thermal Flux: 4144 +- 50 +- 105 neutrons / m^2 / day
- Estimated Fast Neutron Flux: 4000 neutrons / m^2 / day

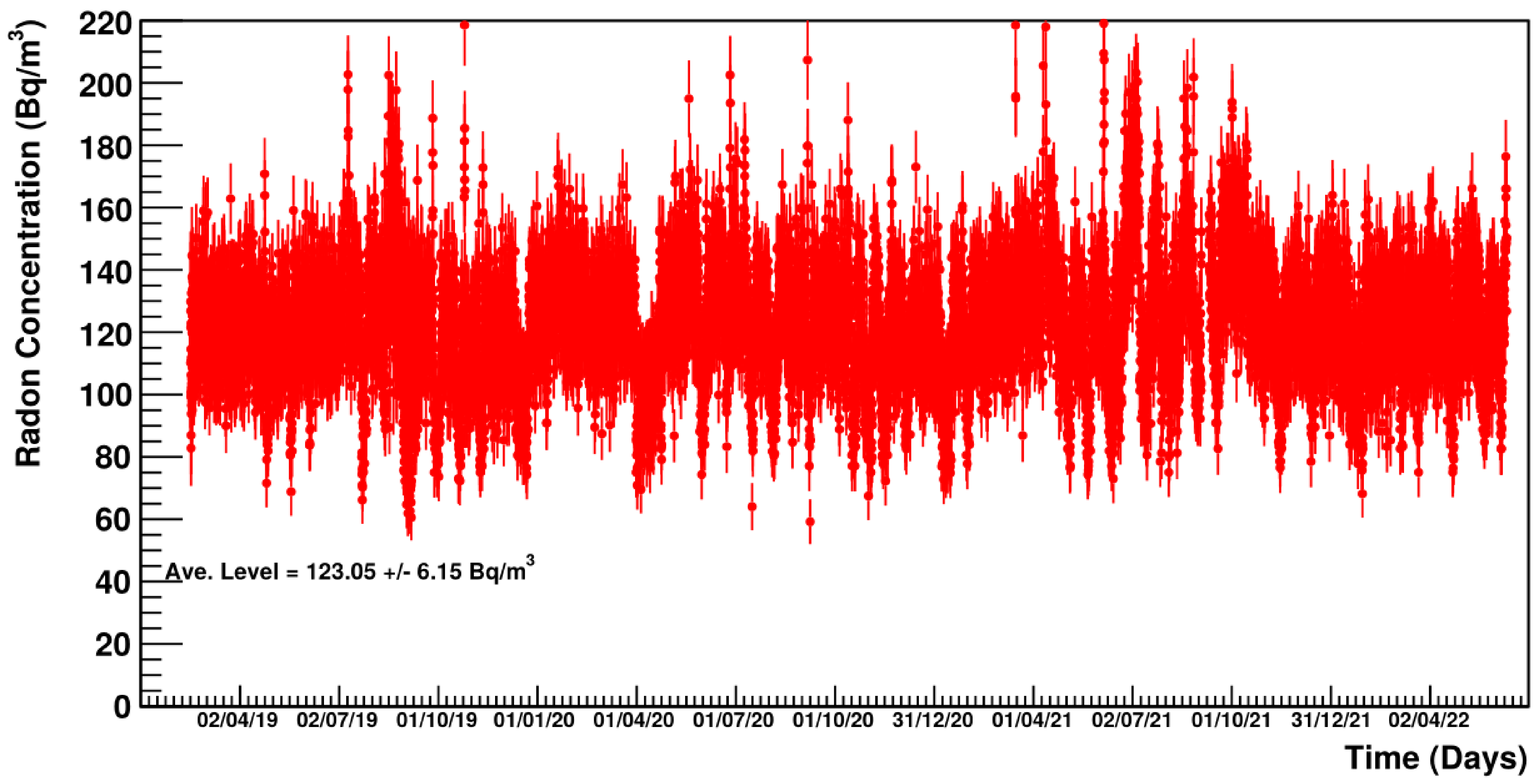
Norite Rock Simulated Neutron Yield



Shotcrete Simulated Neutron Yield



Radon Levels



radoninstrument.com

Average Radon Levels: 123.1 +- 6.2 Bq/m^3

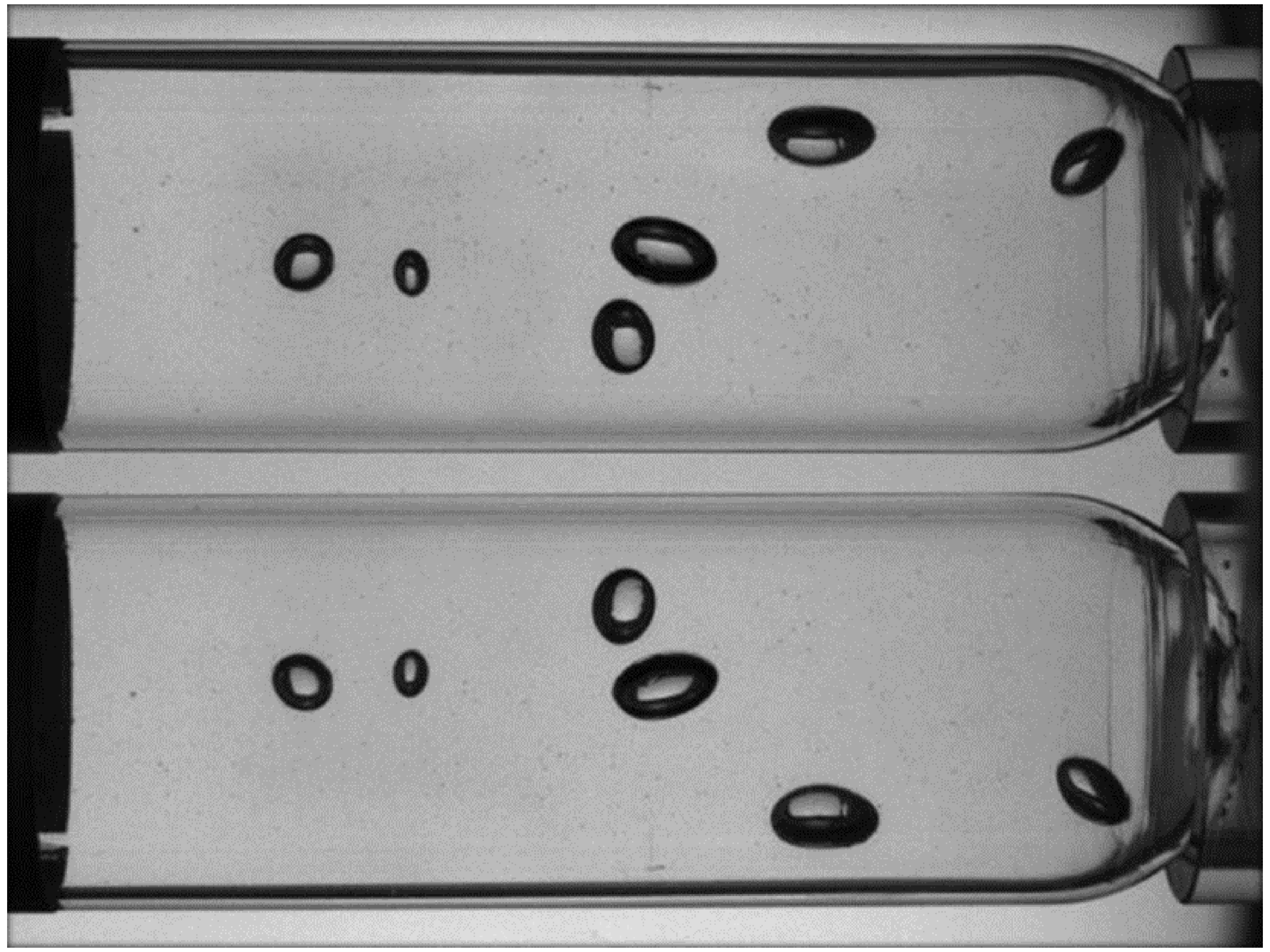
Neutron Measurements

Direct measurement of the neutron spectrum will be useful

- Simulations
- Shield design
- Data Analysis

Low expected rate means long counting times

Bubble Detector Spectrometers (BDS)



- The BDS is generally used nuclear research institutions, nuclear utilities and medical accelerator installations
- Previous use by space agencies
- Manufactured by Bubble Technology Industries for neutron spectrometry
- *Superheated liquid in an elastic polymer gel
- When droplets are struck by neutrons, small gas bubbles are formed that remain fixed and can be counted
- Not sensitive to gammas
- Isotropic angular response
- Six thresholds: 10, 100, 600, 1000, 2500 and 10000 keV

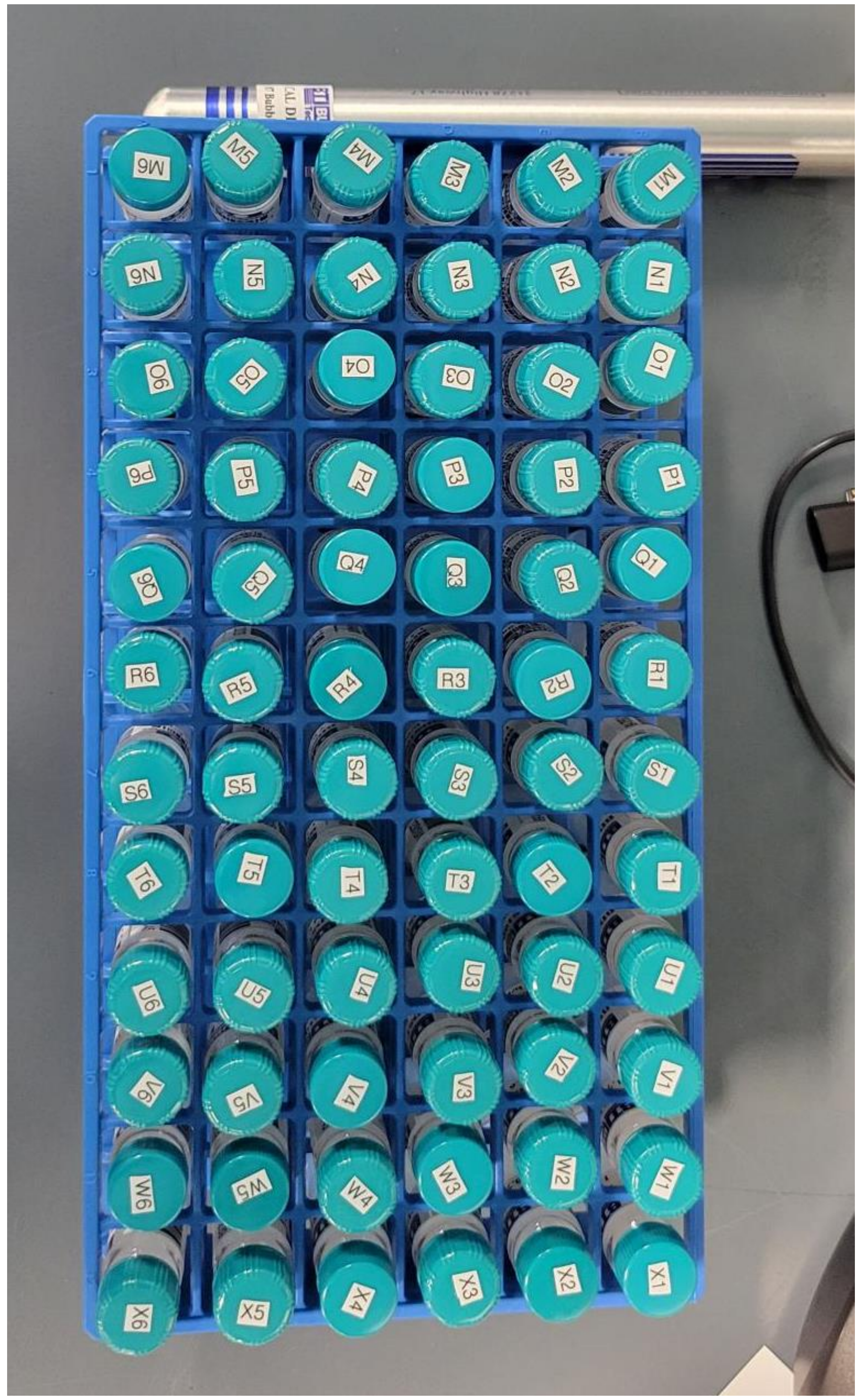
*Ing, H., Noulty R., McLean T.D. (1997). Bubble Detectors- A Maturing Technology. Radiation Measurements 1(27). 1-11. doi:10.1016/S1350-4487(96)00156-4

Bubble Detector Reader III (BDR3)

https://bubbletech.ca/product/bds/

- BDR3 has a vision system to capture images of tubes with bubbles and count them
- Tunable parameters
- Calibrated with a calibration tube with a known number of bubbles
- Efficient for reading tubes with 0-300 bubbles

Neutron Measurements

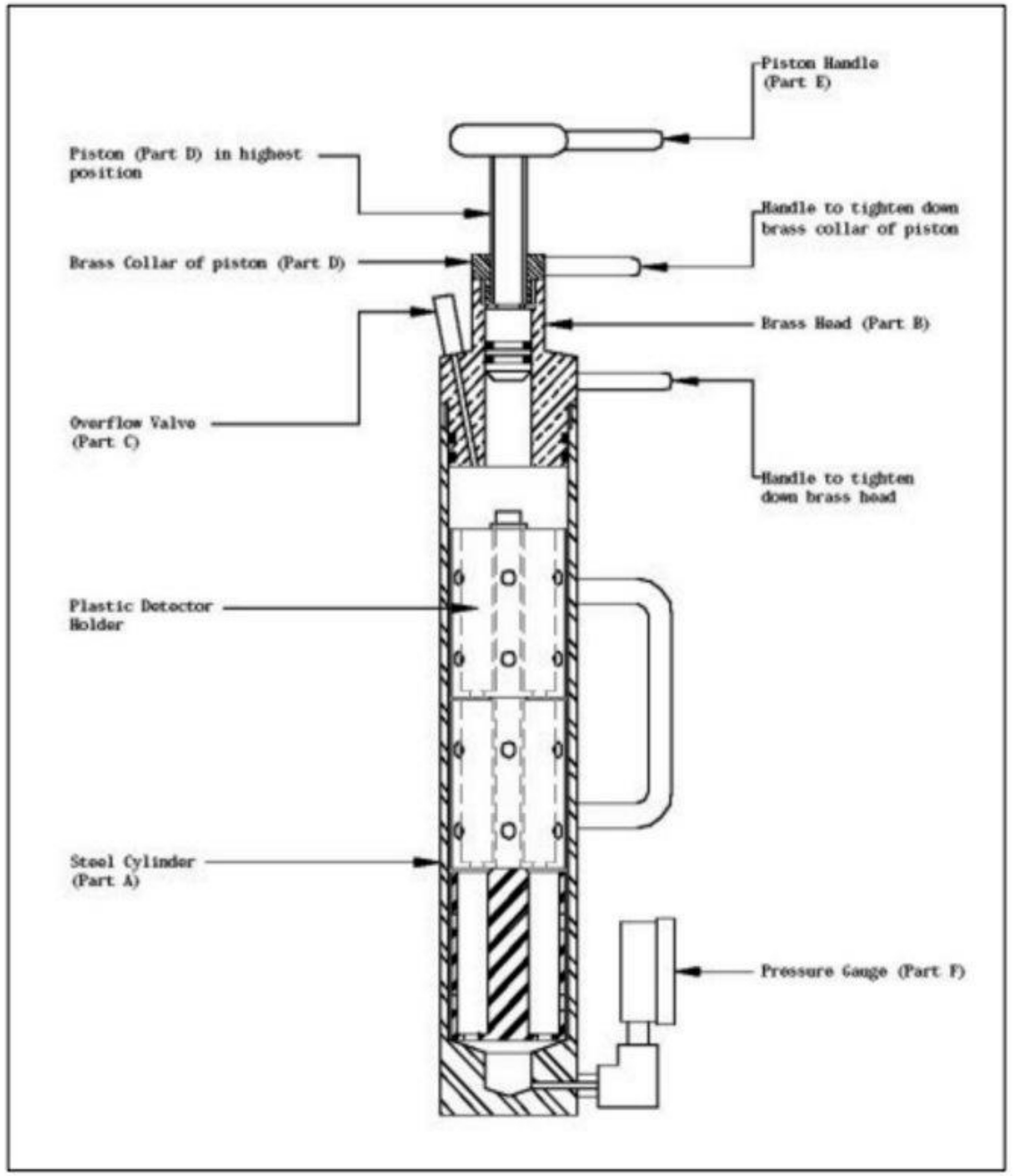


	0.01–0.1 (MeV)	0.1–0.6 (MeV)	0.6–1.0 (MeV)	1.0–2.5 (MeV)	2.5–10.0 (MeV)	10.0–20.0 (MeV)
BDS 10	5.00x10-6	2.50x10-5	2.92x10-5	2.97x10-5	4.15x10-5	4.78x10-5
BDS 100	-	2.27x10-5	3.14x10-5	3.23x10-5	4.47x10-5	5.09x10-5
BDS 600	-	-	1.60x10-5	3.27x10-5	4.75x10-5	5.45x10-5
BDS 1000	-	-	-	1.32x10-5	3.50x10-5	5.90x10-5
BDS 2500	-	-	-	-	2.99x10-5	8.70x10-5
BDS10000	-	-	-	-	-	4.35x10-5

- Each BDS type has different neutron energy cross sections
- Once an average corrected count is found for each detector type, we can calculate the highest energy bin use that results to calculate lower energies

Recompression Chamber-18 (RC-18)

- Bubbles must be regularly removed from the gel through recompression
- Recompresses up to 18 BDS at once
- This is done when bubbles are observed

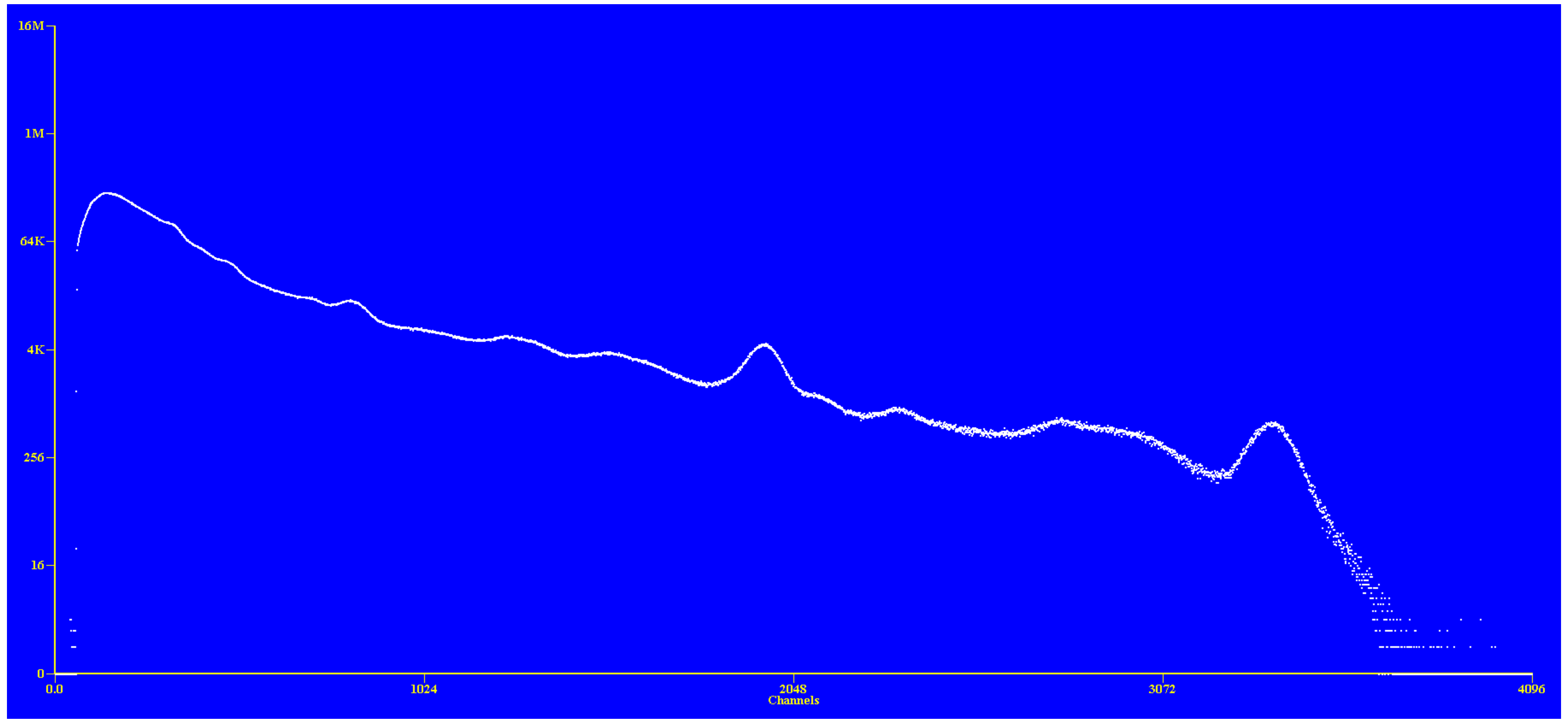


https://bubbletech.ca/product/rc18/

Backgrounds - Neutron Measurements

- 24 sets of 6 BDS detectors (One at each threshold), for a total of 144 detectors
- We have completed system commissioning
- Currently counting underground in the older part of the lab since March
- Every 1-2 weeks the BDS are counted
- Anticipate counting for ~1 year
- Will also be used to generate a spectra of the newer part of the lab
- Generate updated MC

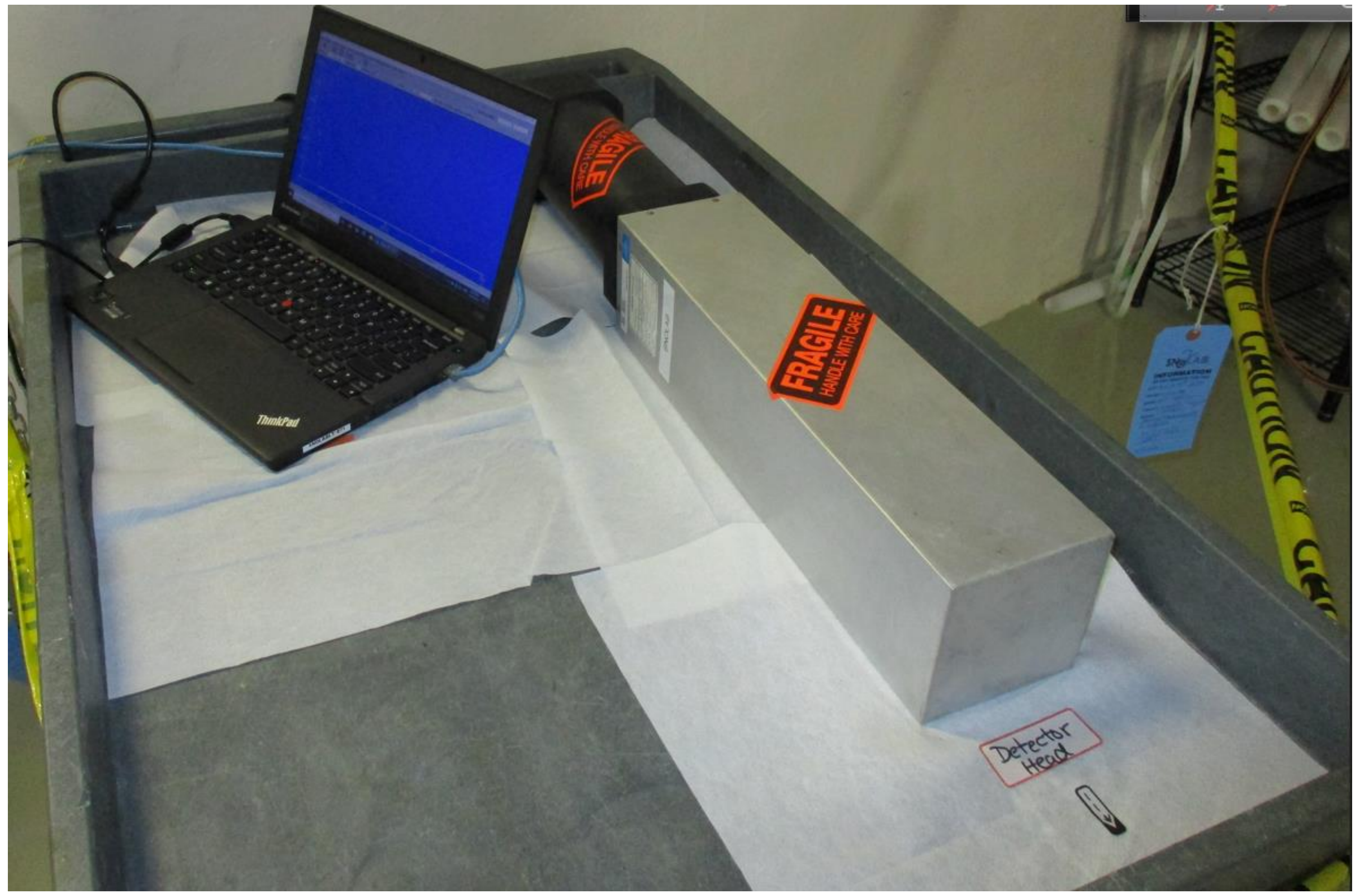
Backgrounds – Gammas

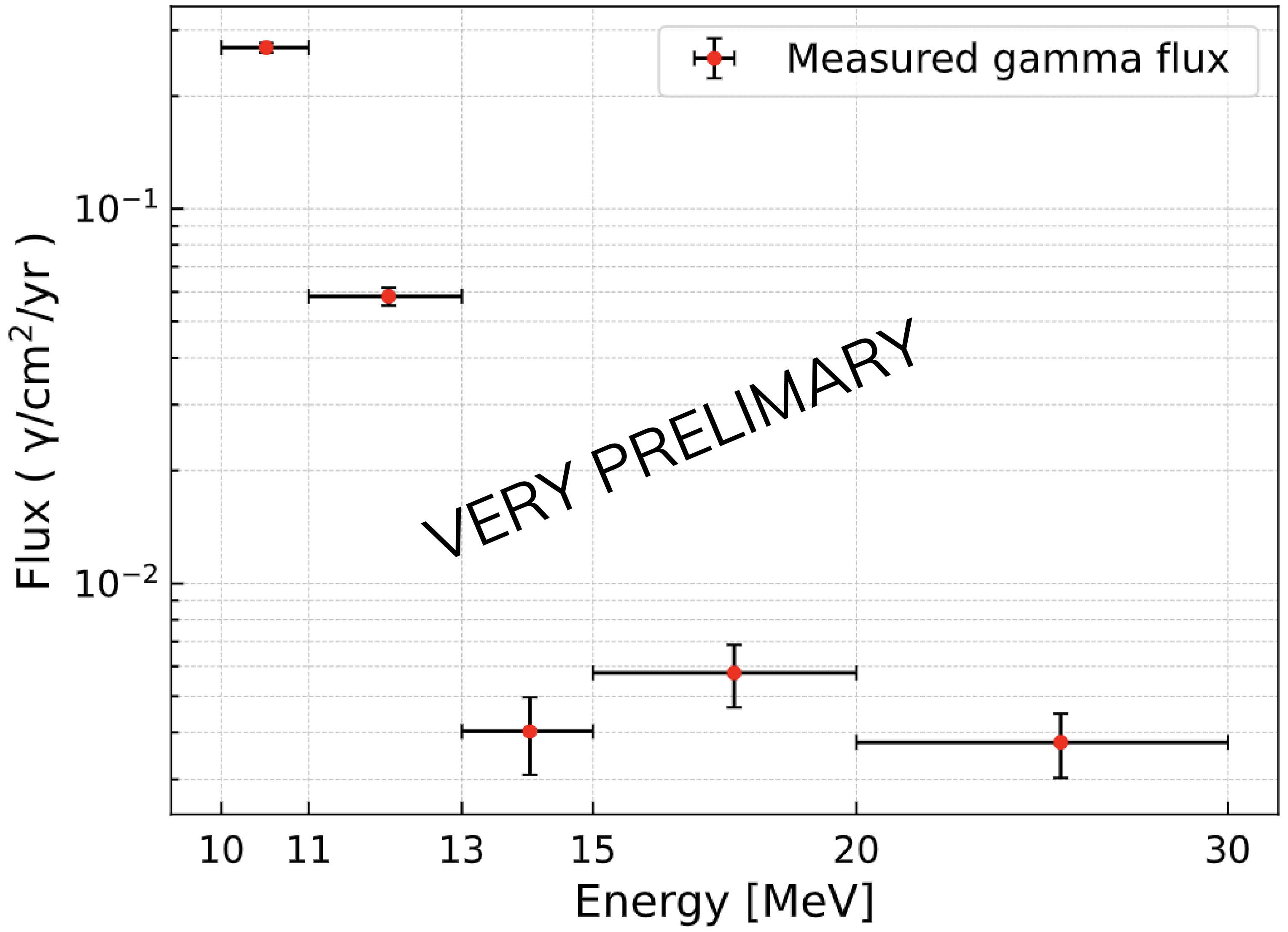


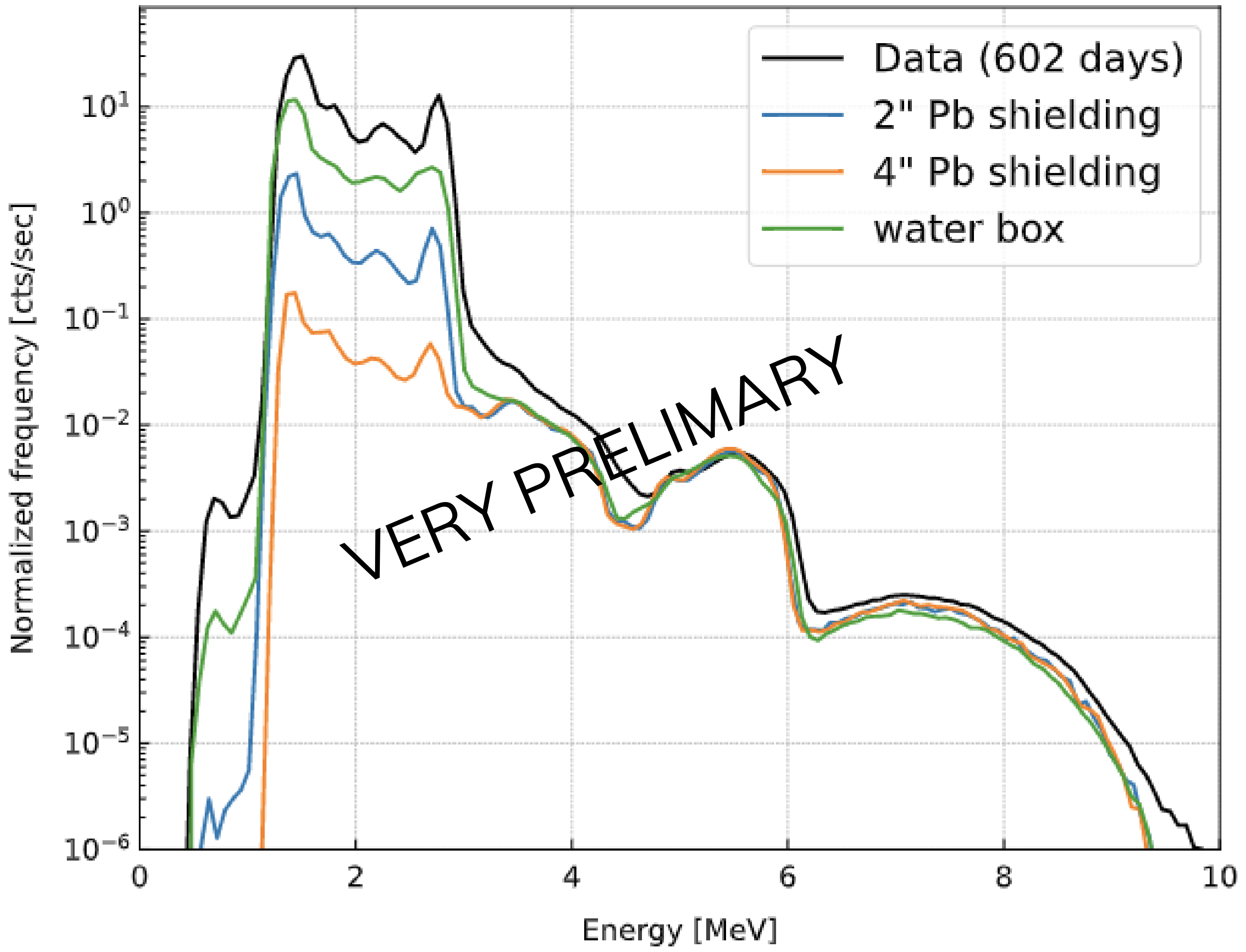
Sample of raw data from one of the small NaI crystal after 7.4 days

- Detailed gamma spectra below 3 MeV in different areas of the laboratory is of interest
- This spectra depends on the rock composition and materials, so it varies within the lab
- We have two 1.5 x 1.5 inch NaI(Tl) crystal and MCAs
- Currently measuring internal backgrounds
- A lab survey will be completed to generate spectra for areas of interest in the lab

Backgrounds - Gammas





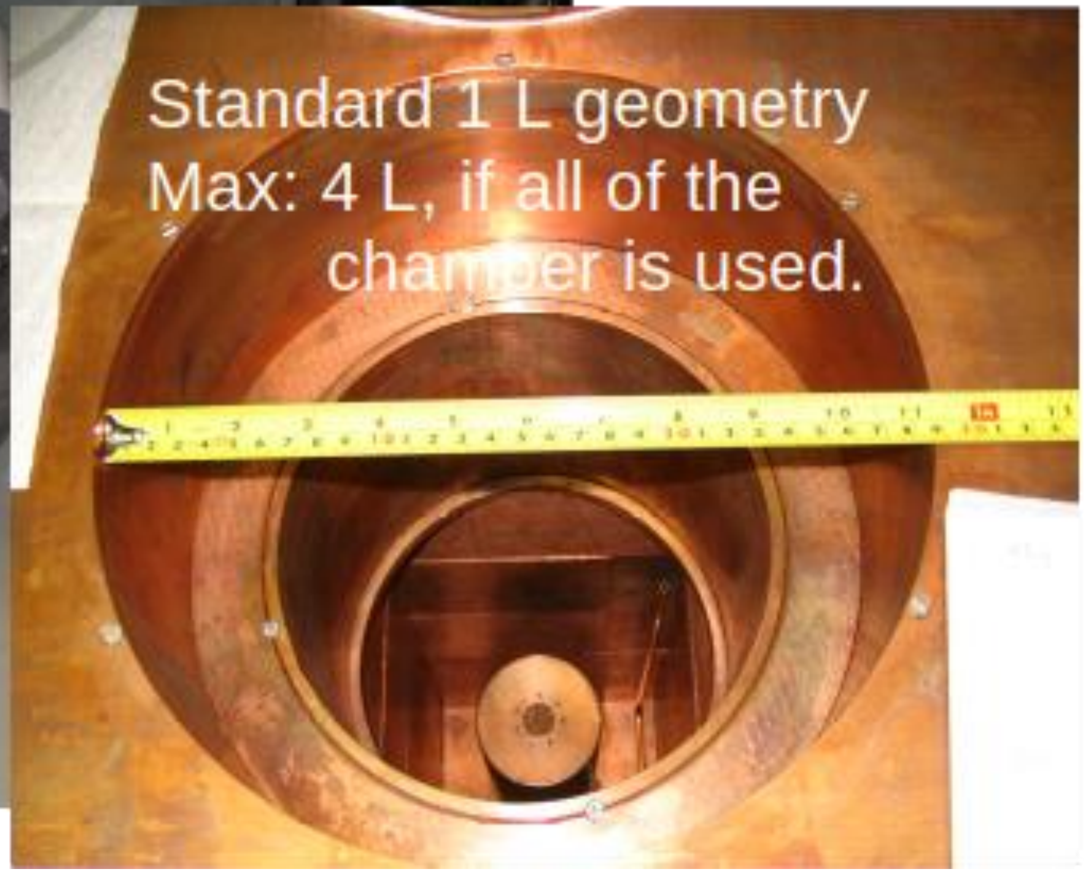


- The high energy gamma spectra, above ~10 MeV, is from cosmogenics
- A single measurement is being done with a large NaI crystal, 15.6 kg, and has been running for more than 4 years
- These high energy gammas will be very relevant for future multi-tone scale experiments
- A detailed spectra is needed. running for more than 4 years.
- We are showing less than 2 years and there is no background subtraction

Low Background Lab

Gamma Spectrometry
Typical Coaxial Germanium Detector Setup

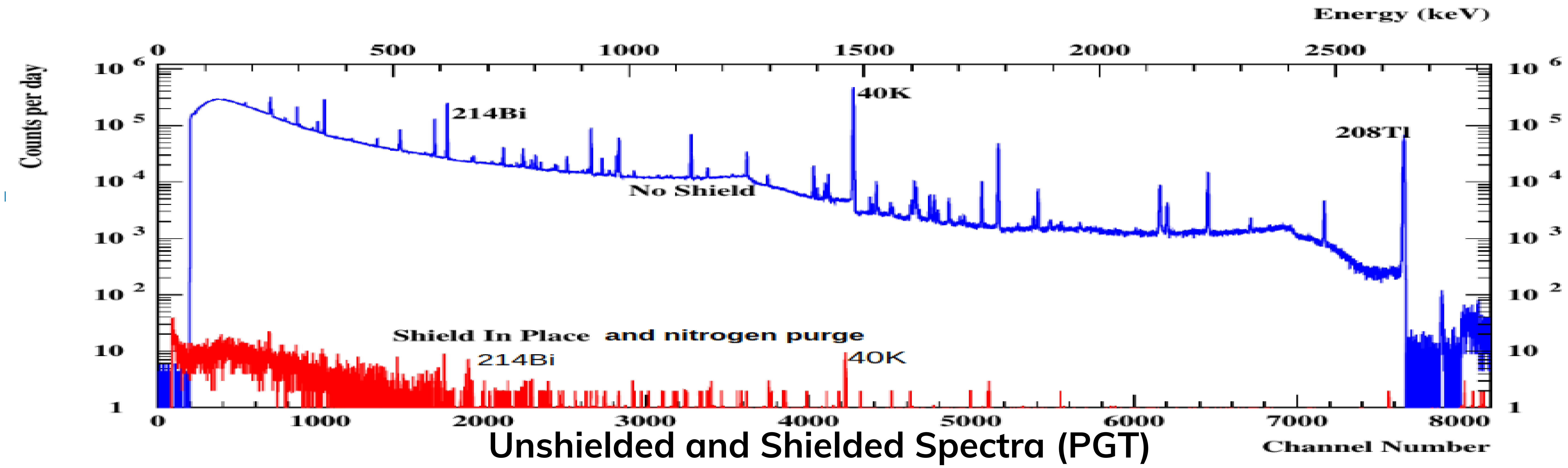
- Five different operating HPGe detectors
- different energy range and isotope sensitivities
- different chamber (and sample) size



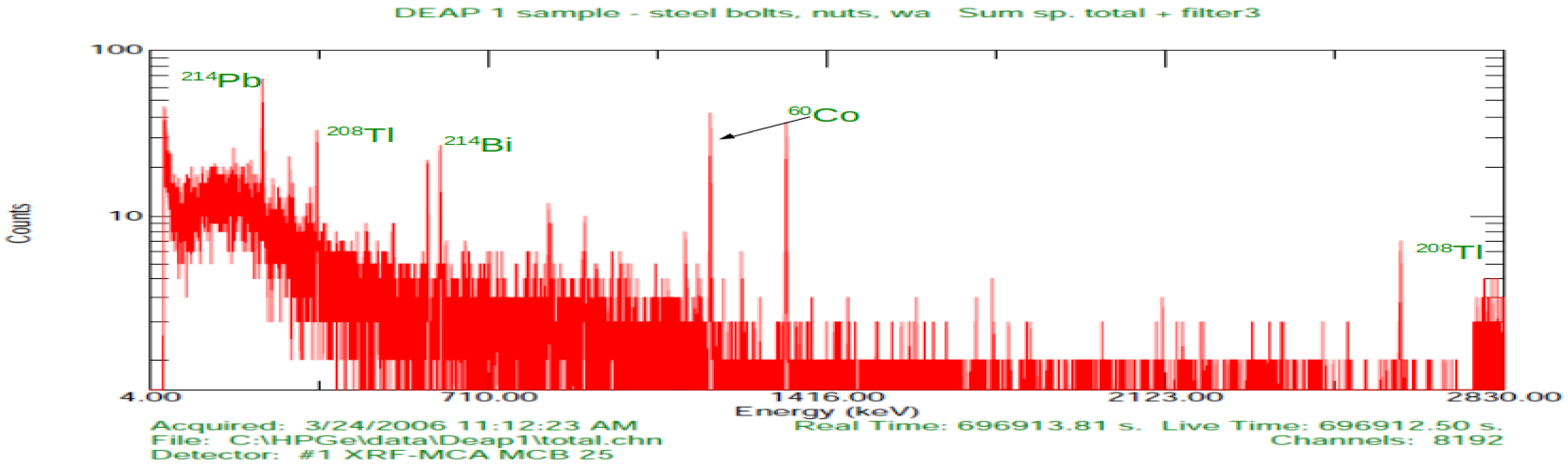
Ge Spectrometry
Detector Sensitivities

Isotope	SNOLAB Gamma Counter 1 (mBq) PGT	SNOLAB Gamma Counter 2 (mBq) Well	SNOLAB Gamma Counter 3 (mBq) Lively	SNOLAB Gamma Counter 4 (mBq) VdA	SNOLAB Gamma Counter 5 (mBq) Gopher
^{238}U	0.11 mBq	0.02 mBq	0.05 mBq	0.09 mBq	0.17 mBq
^{235}U	0.16 mBq	0.01 mBq	0.02 mBq	0.06 mBq	0.08 mBq
^{232}Th	0.10 mBq	0.02 mBq	0.06 mBq	0.08 mBq	0.21 mBq
^{40}K	1.42 mBq	0.92 mBq	0.45 mBq	1.22 mBq	1.01 mBq
^{60}Co	0.04 mBq	0.03 mBq	0.02 mBq	0.02 mBq	0.04 mBq
^{137}Cs	0.13 mBq	0.02 mBq	0.02 mBq	0.05 mBq	0.08 mBq
^{54}Mn	0.043 mBq	0.033 mBq	0.021 mBq	0.034 mBq	0.044 mBq
^{210}Pb	N/A	0.55 mBq	31.53 mBq	7.71 mBq	16.49 mBq

Ge Spectrometry



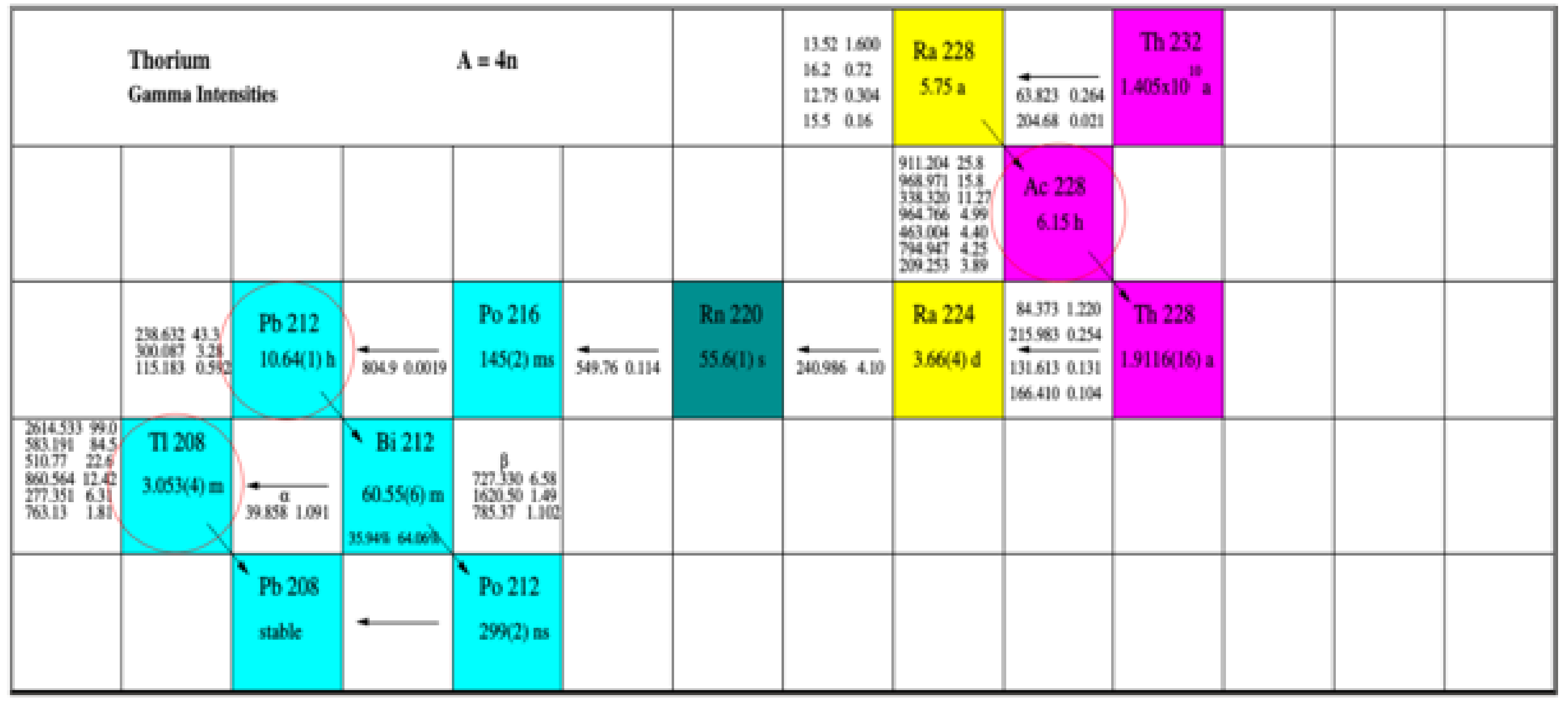
Unshielded and Shielded Spectra (PGT)



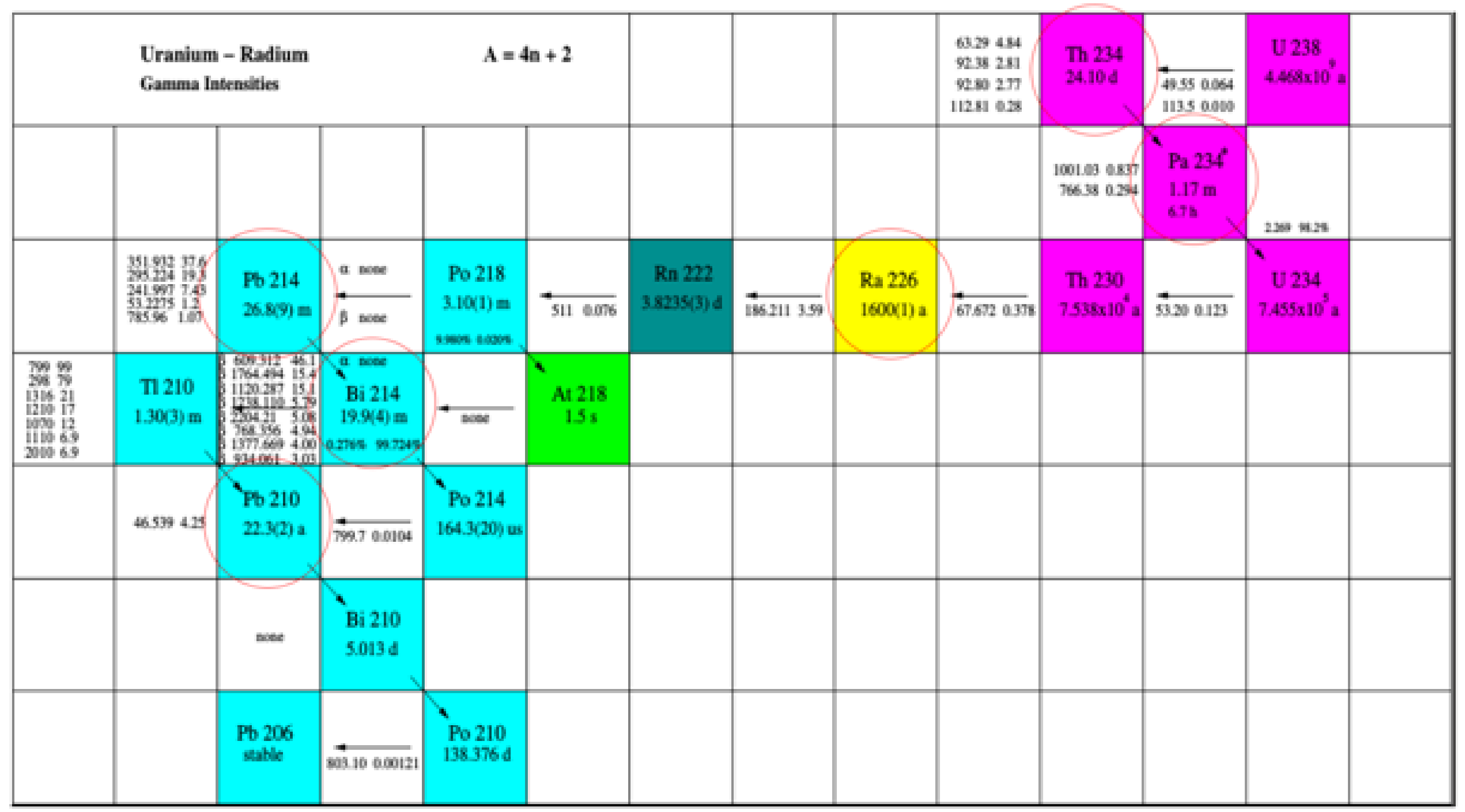
Typical Stainless-Steel Spectrum

Ge Spectrometry

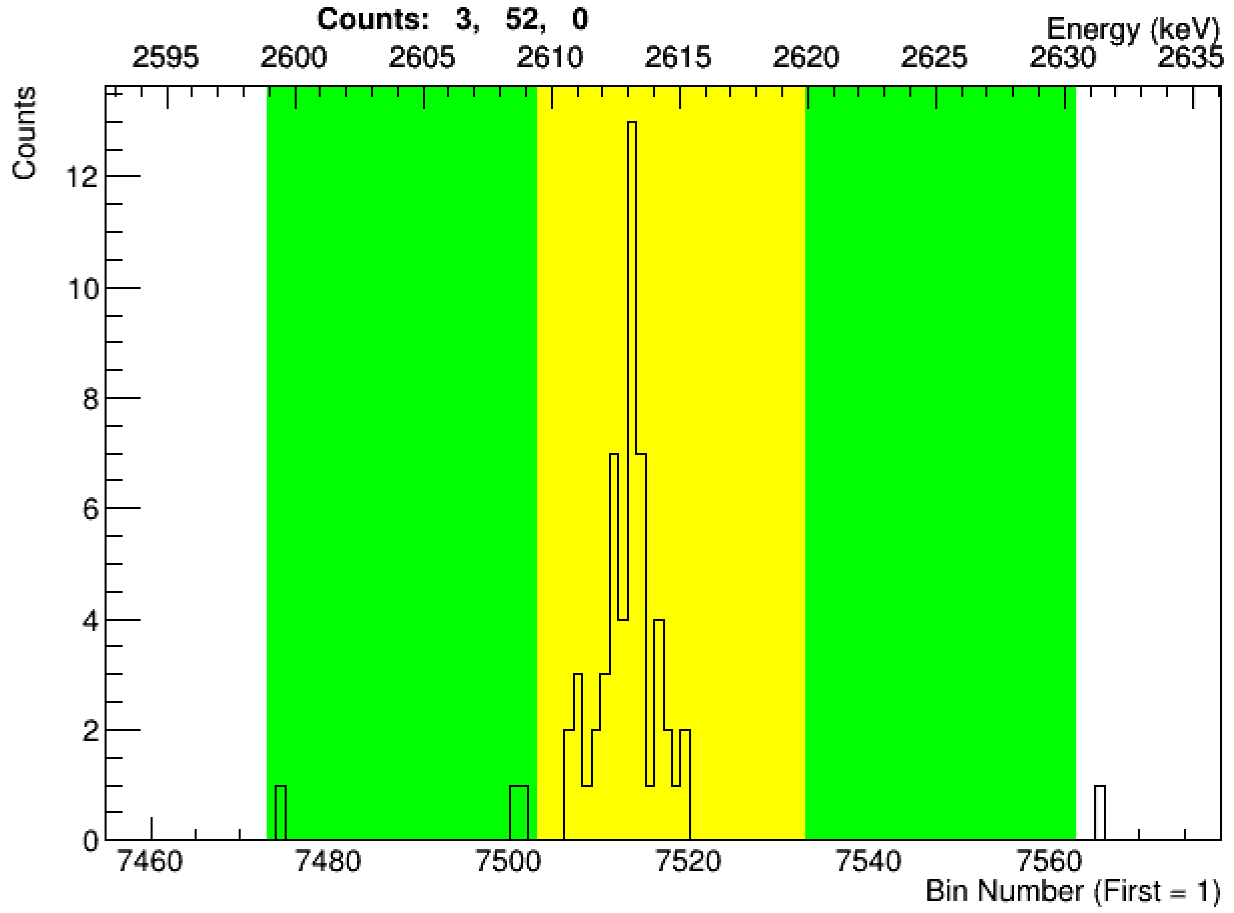
Thorium Decay Chain



Uranium Decay Chain



Natural radioactivity (238U, 232Th, 40K)



- Collected spectra are analyzed with a custom C++-based set of scripts. It is a ROOT-based implementation. Peak detection efficiencies are estimated from analyzing the Geant4 MC simulations
- Incomplete Charge Collection + Gamma Cascade

Dual Detector
Comprehensive Nuclear Test Ban Treaty Detector

Comprehensive Nuclear Test Ban Treaty

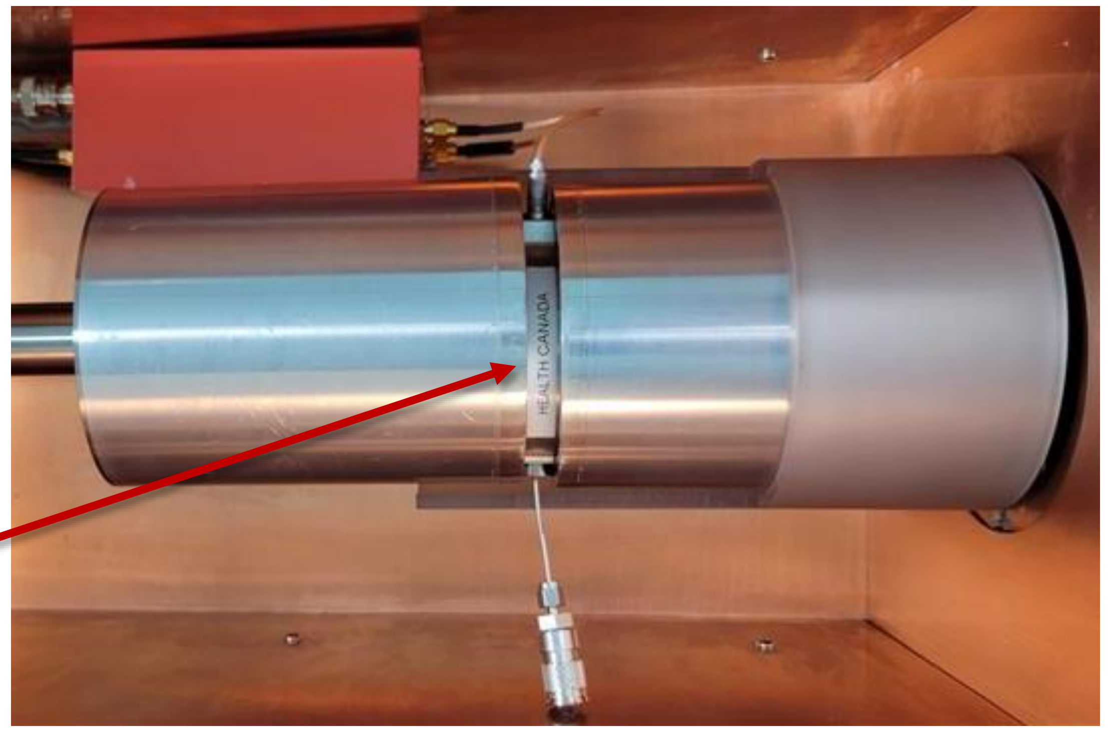
Health Canada's radionuclide laboratory CAL05

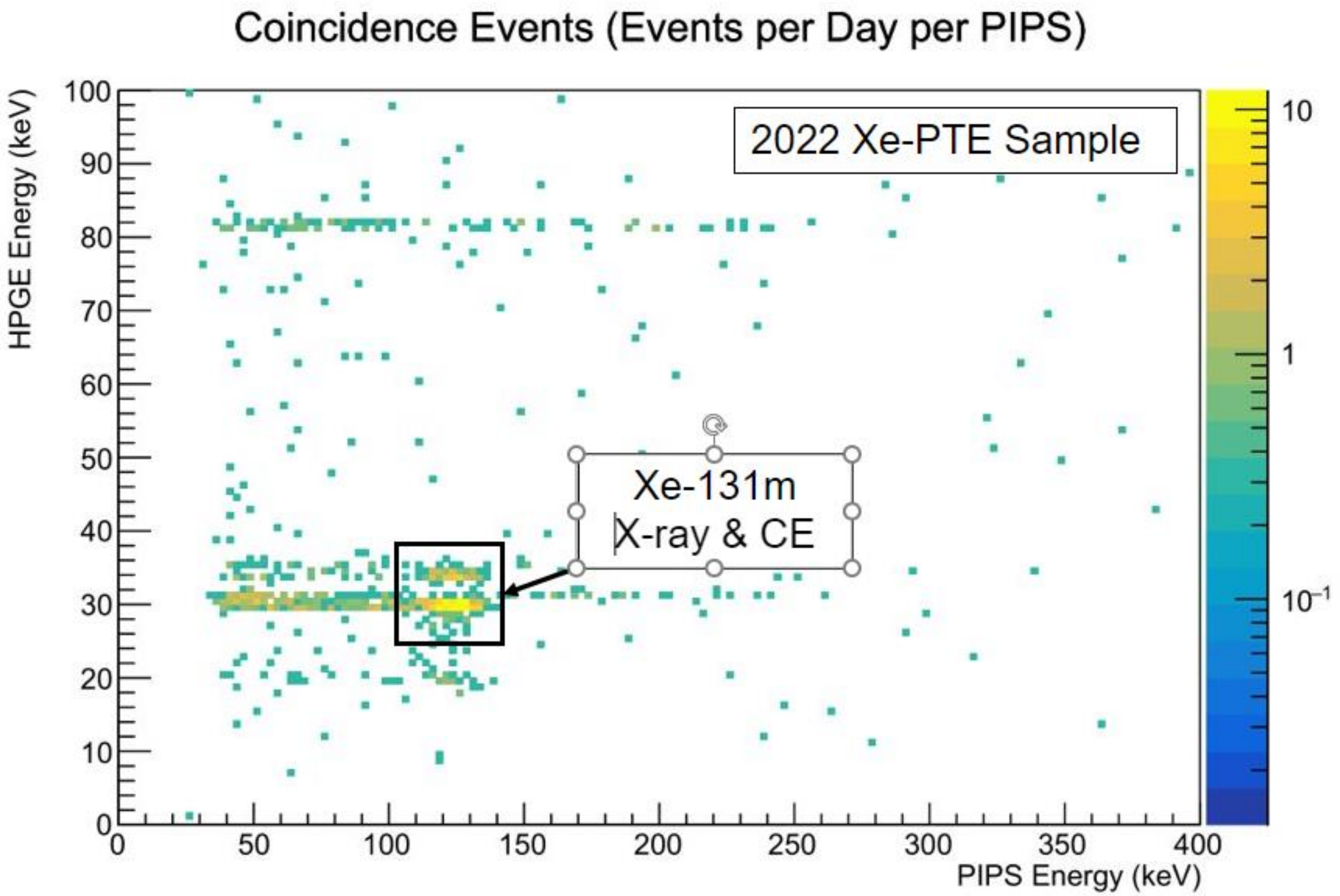
Two Broad Energy Germanium Detectors

Coincidence between both detectors

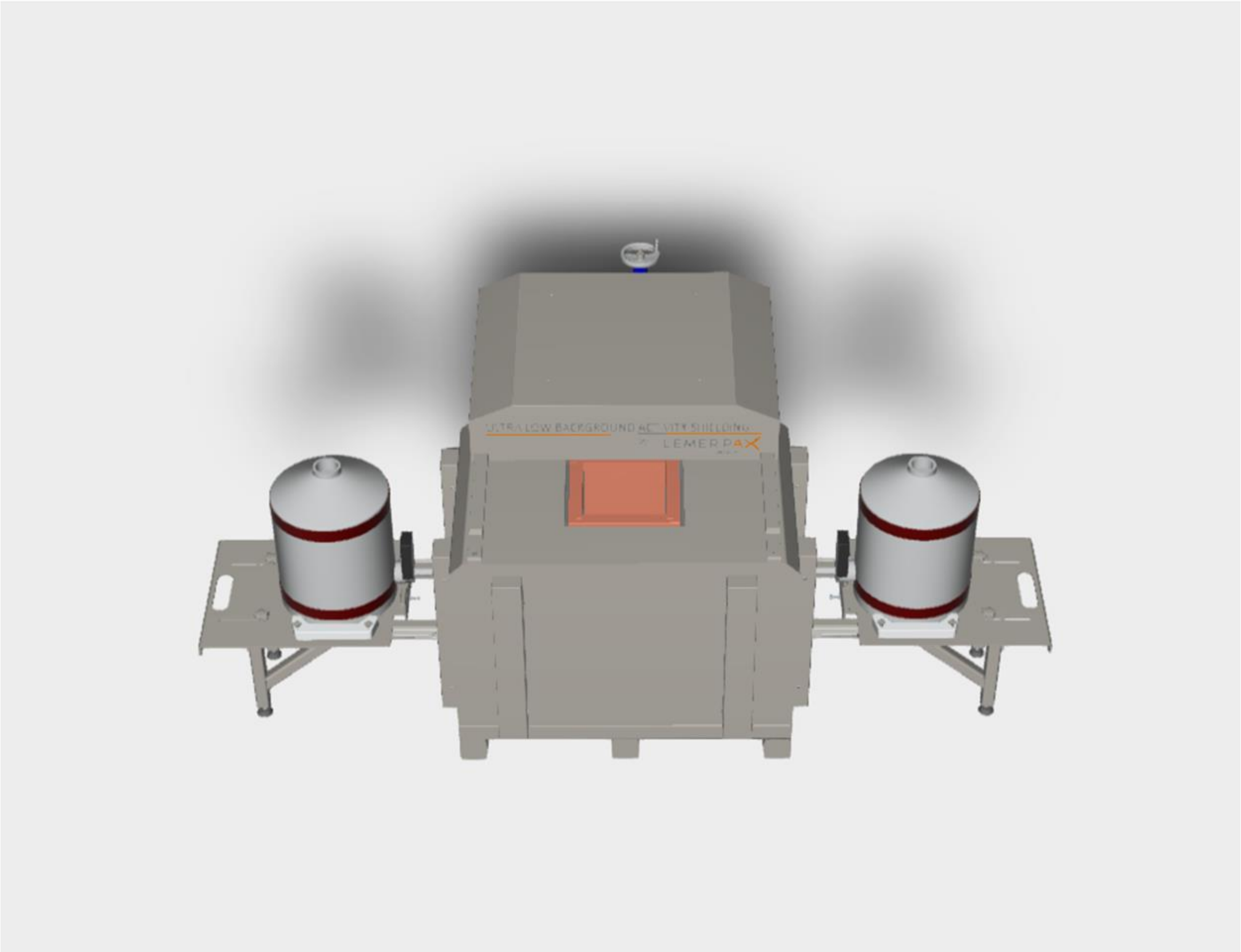
Dual Detector
Addition of PIPS

- Atmospheric radioxenon monitoring
- A PIPSBOX detector was added
  - Two thin passivated implanted planar silicon wafers
  - Beta Detector
- Gas samples are placed in the detector
- Coincidence of Beta-Gamma





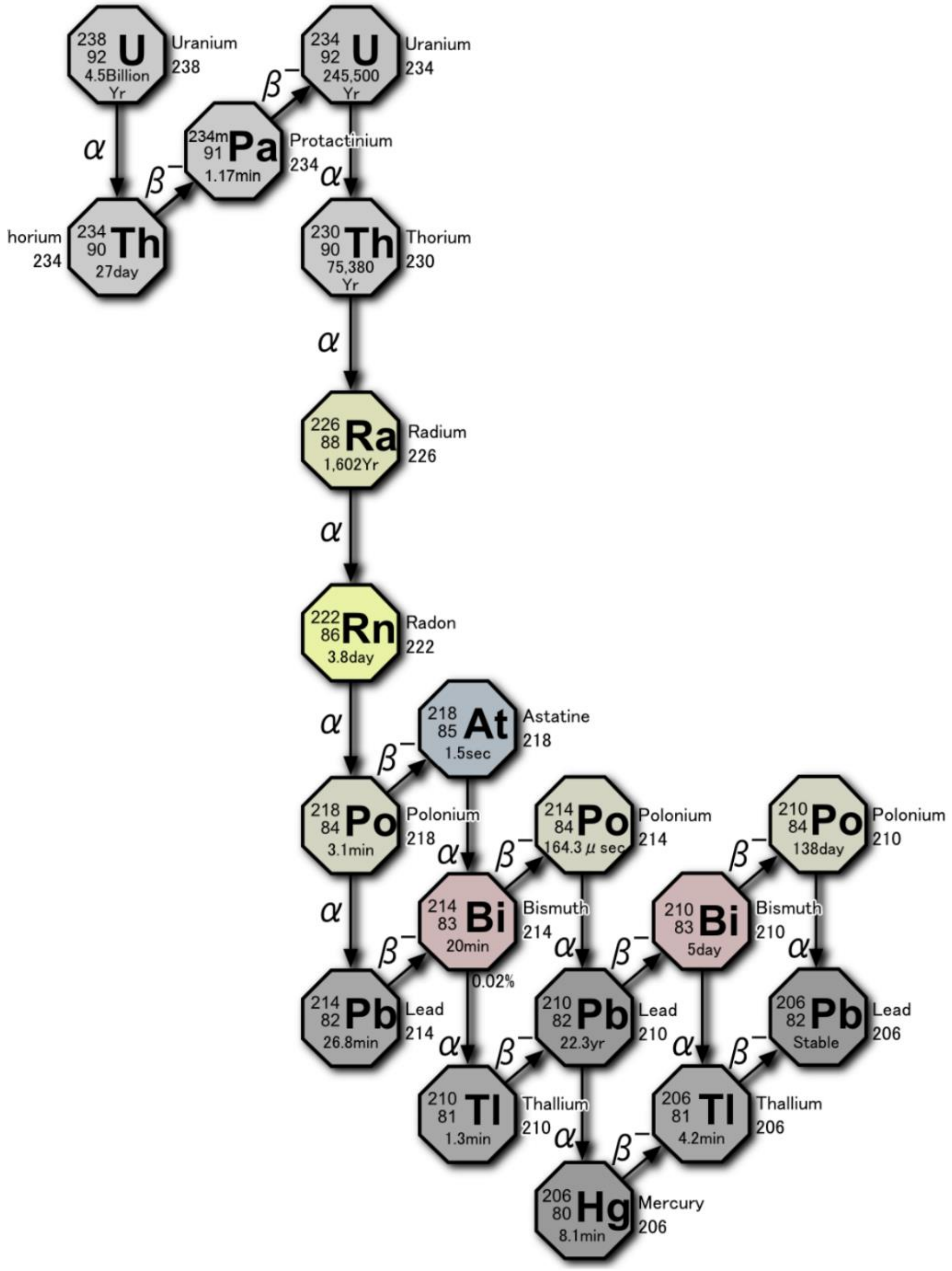
Dual Detector
Future Work



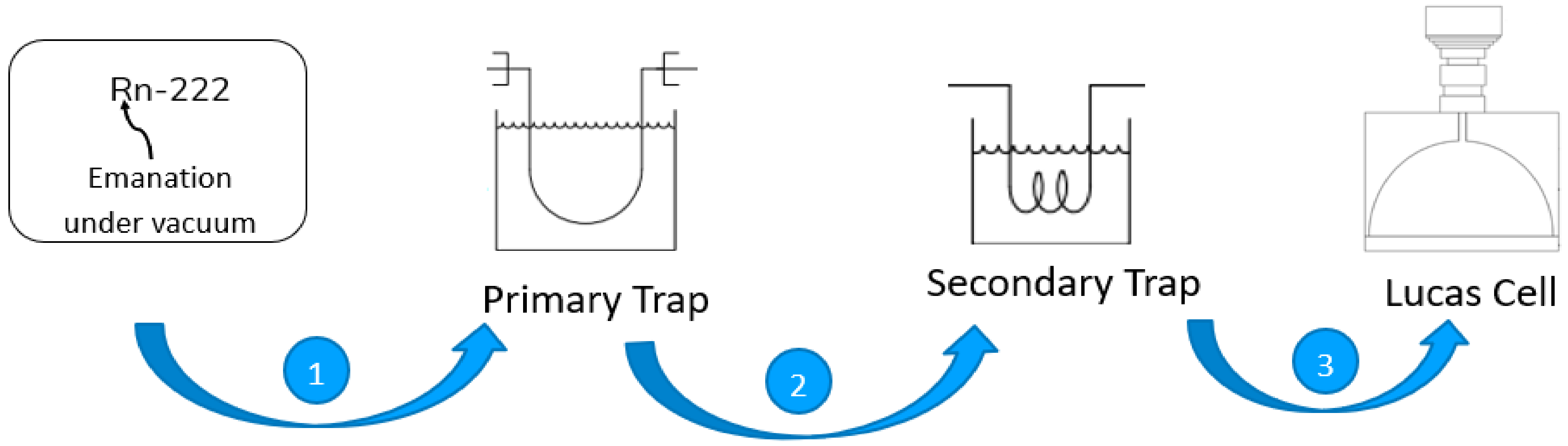
- Permanent Shielding is being manufactured
- Working on measuring backgrounds
- Conduct coincidence studies
- Detection and measurement of radioactive noble gas signals at significantly lower concentrations than currently achievable

Radon Screening

- Radon-222 is generated in the Uranium 238 chain
- Present in lab air ~ 120 Bq/m3
- Relatively Short Lived (3.8 d)
- Need the capability to screen Rn-222 levels at site
- It presents a background to many rare-event detectors
- SNOLAB has three radon boards
  - Water system board
  - Surface board
  - UG mobile board



SNO technique for Radon assay under vacuum

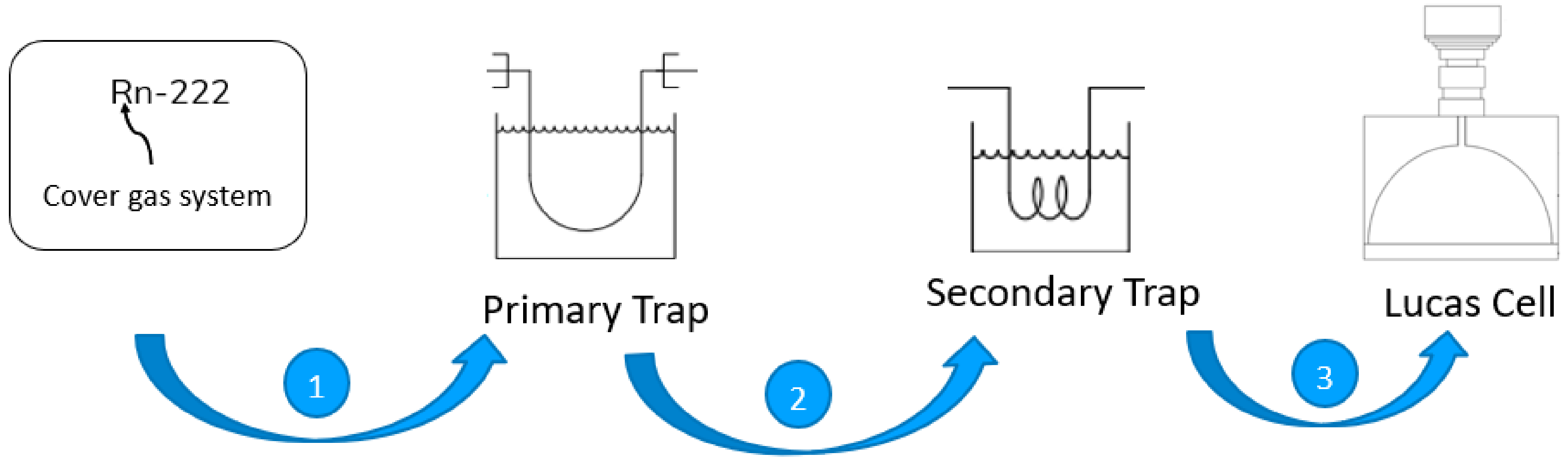


- Vacuum pull transfer
- Primary Trap cooled in Liquid N_2

- Cryopump transfer
- Primary Trap heated to 100 C
- Secondary Trap cooled in Liquid N_2

- Volume sharing
- Secondary Trap heated to room temperature

Under vacuum



Gas assay technique

- Transfer with carrier gas (1 L/min)
- Primary Trap cooled in Liquid N_2

- Cryopump transfer
- Primary Trap heated to 100 C
- Secondary Trap cooled in Liquid N_2

- Volume sharing
- Secondary Trap heated to room temperature

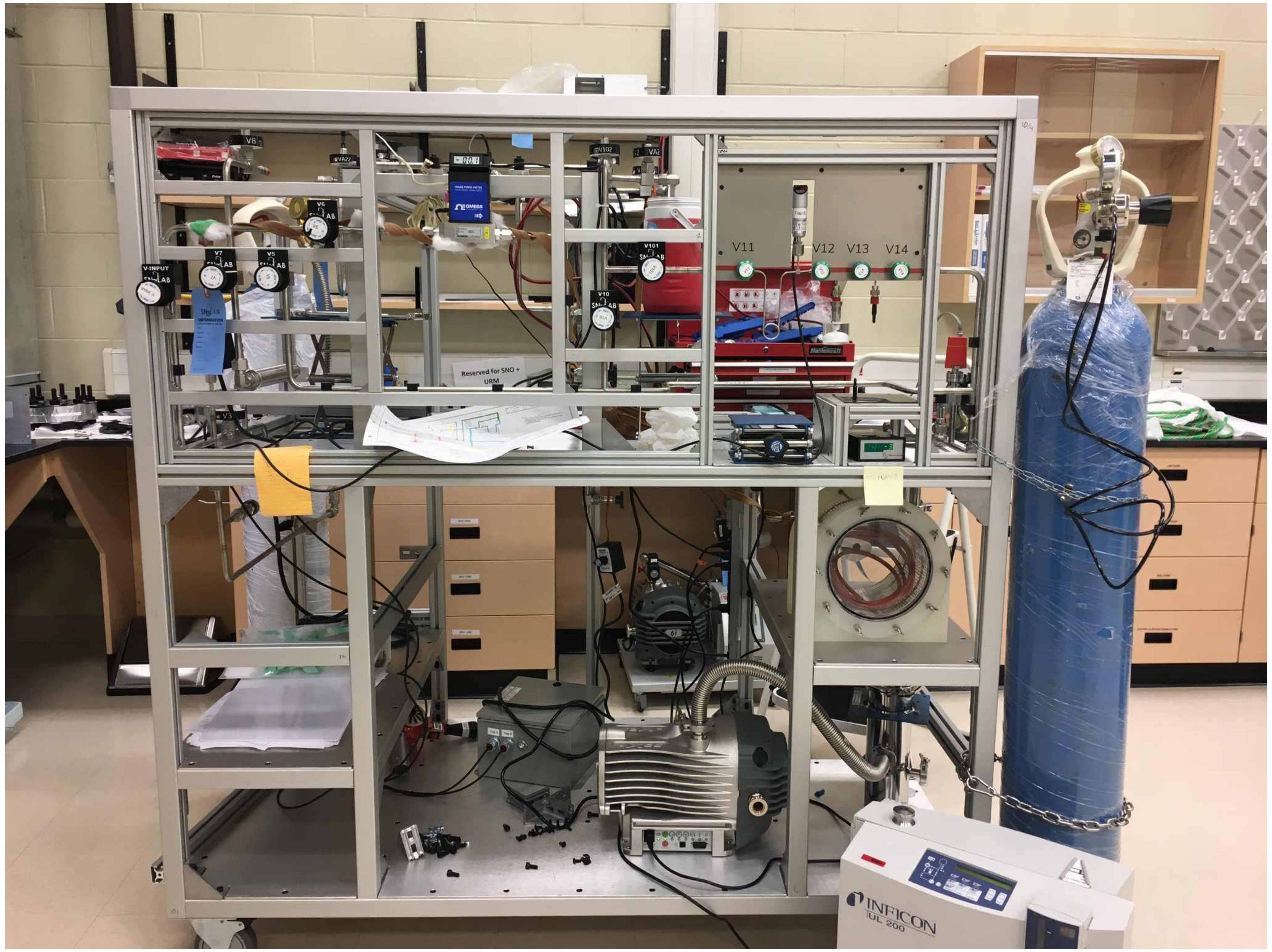
Radon Screening

- Name after Henry Lucas (1957)
- Current design developed at Queen's University
- ZnS(Ag) scintillates when an alpha particle hits it, ideal for radon detection.
- Typical efficiency of a cell is ~70%

Underground Mobile Board

- Can be easily moved around the lab and has an emanation chamber
- Refurbished in late 2020
- Recently used for gas assays of experimental components:
- Examples: SNO+ covergas system, SNOLAB boil-off N2

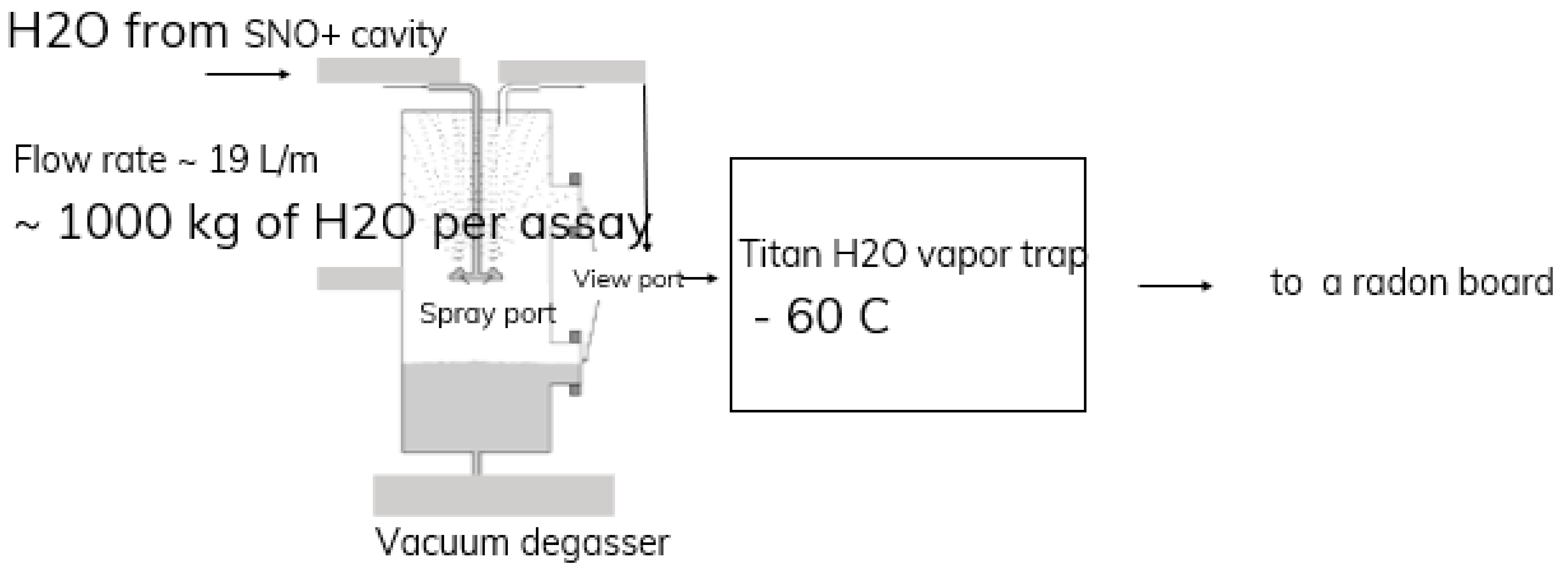
Surface Radon Board



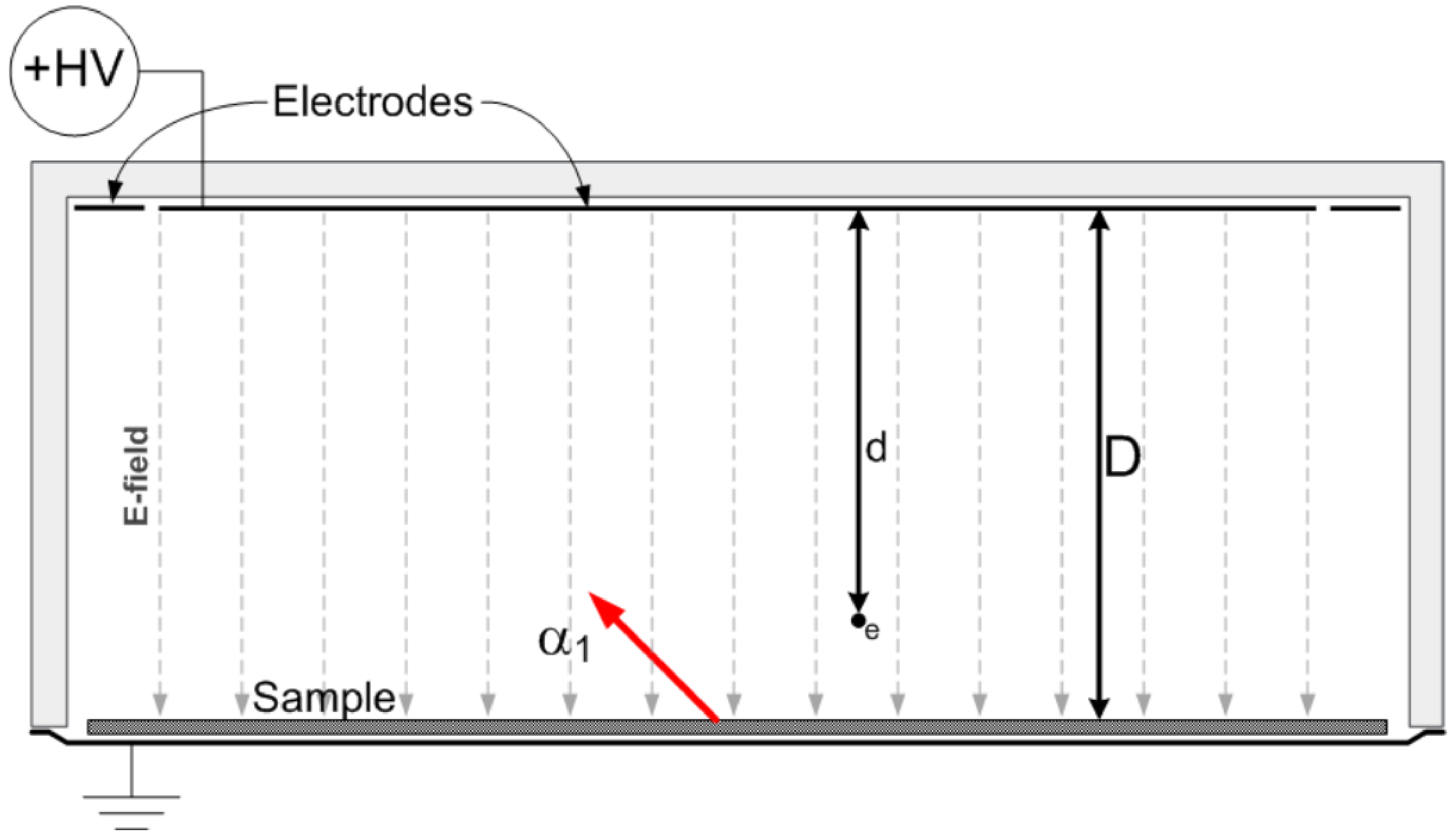
- A new board with one emanation chamber is fully built and currently in use for material screening
- Plan to add additional emanation chambers

Underground Ultra Pure Water Assay System

- Measures the Rn-222 concentration in UPW
- Used for Rn-222 measurement of the SNO+ cavity in regular basis
- Can measure SNOLAB UPW radon level at the UPW plant



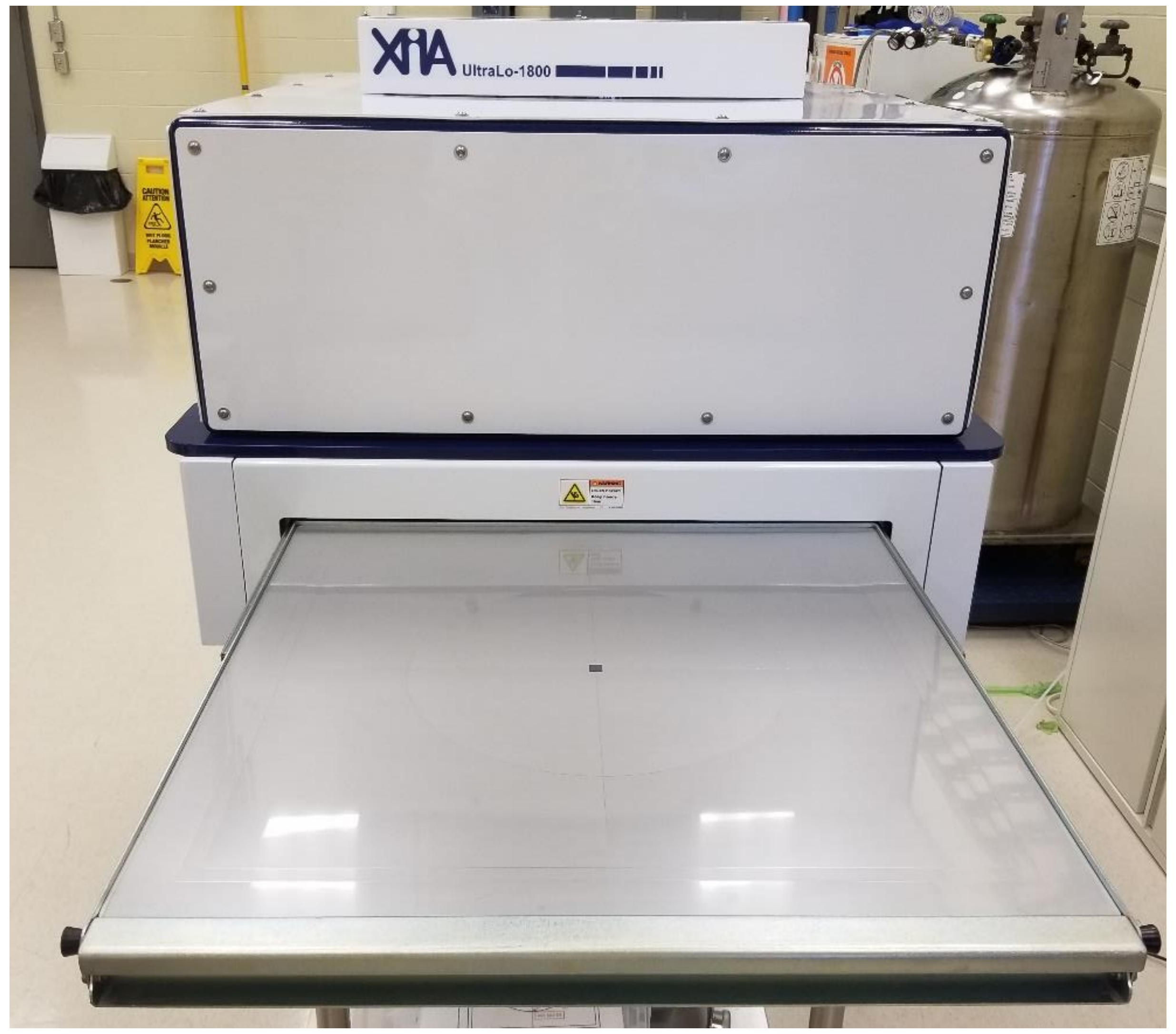
XIA Ultra-Lo 1800



Argon gas drift chamber for Alpha rate measurement

Uses electronic amplification rather than gas amplification

“Background Free” measurements



XIA Ultra-Lo 1800

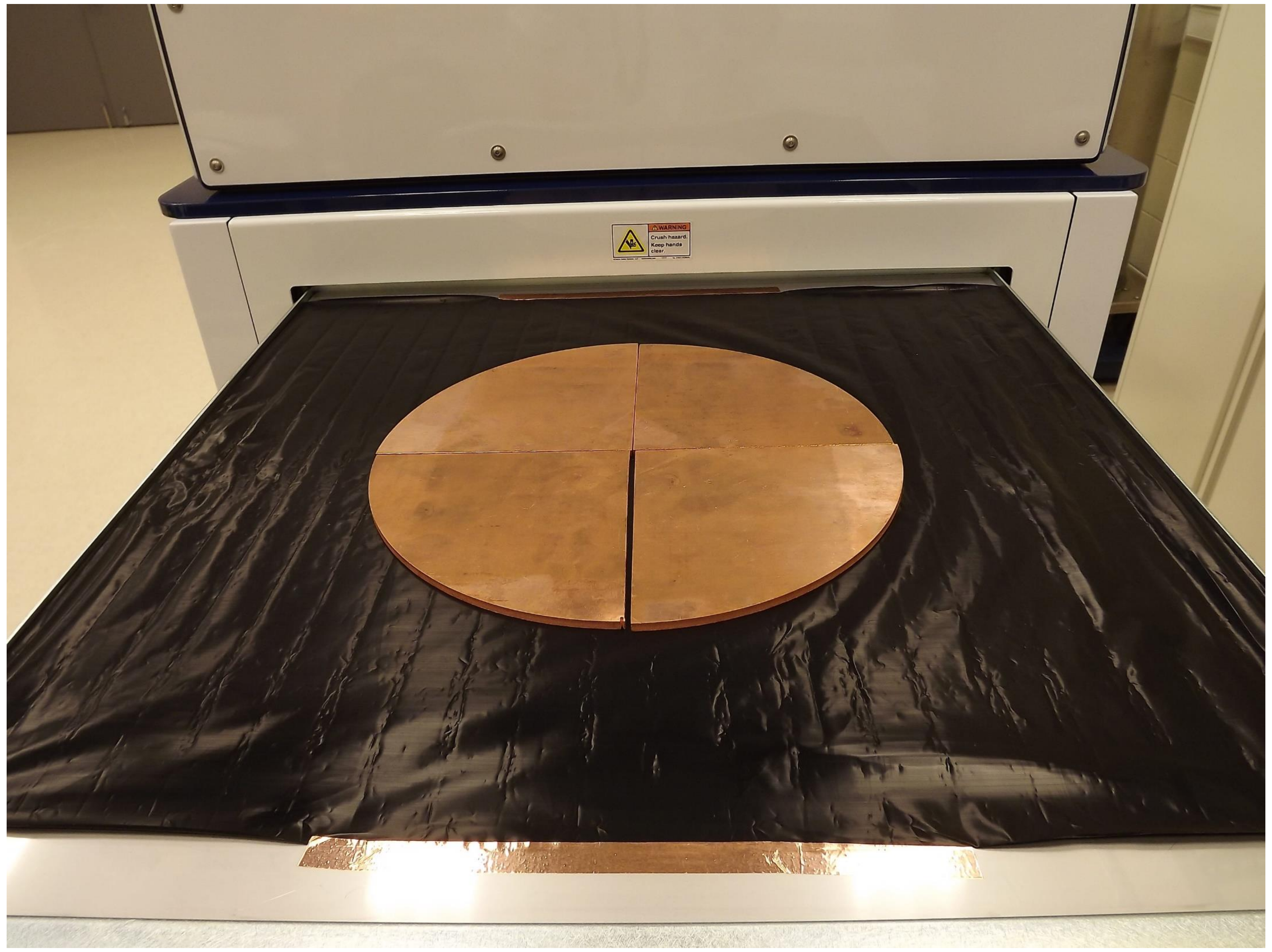
Activities as low as 6 +/- 1 x 10^{-4} alphas/cm^2/hour
= 180 +/- 30 nBq/cm^2 have been measured.

Small residual background due to radon and cosmic rays slipping through cuts.

Available for assays.

Large (30 x 30 cm or more), thin (<1cm), conductive materials are best.

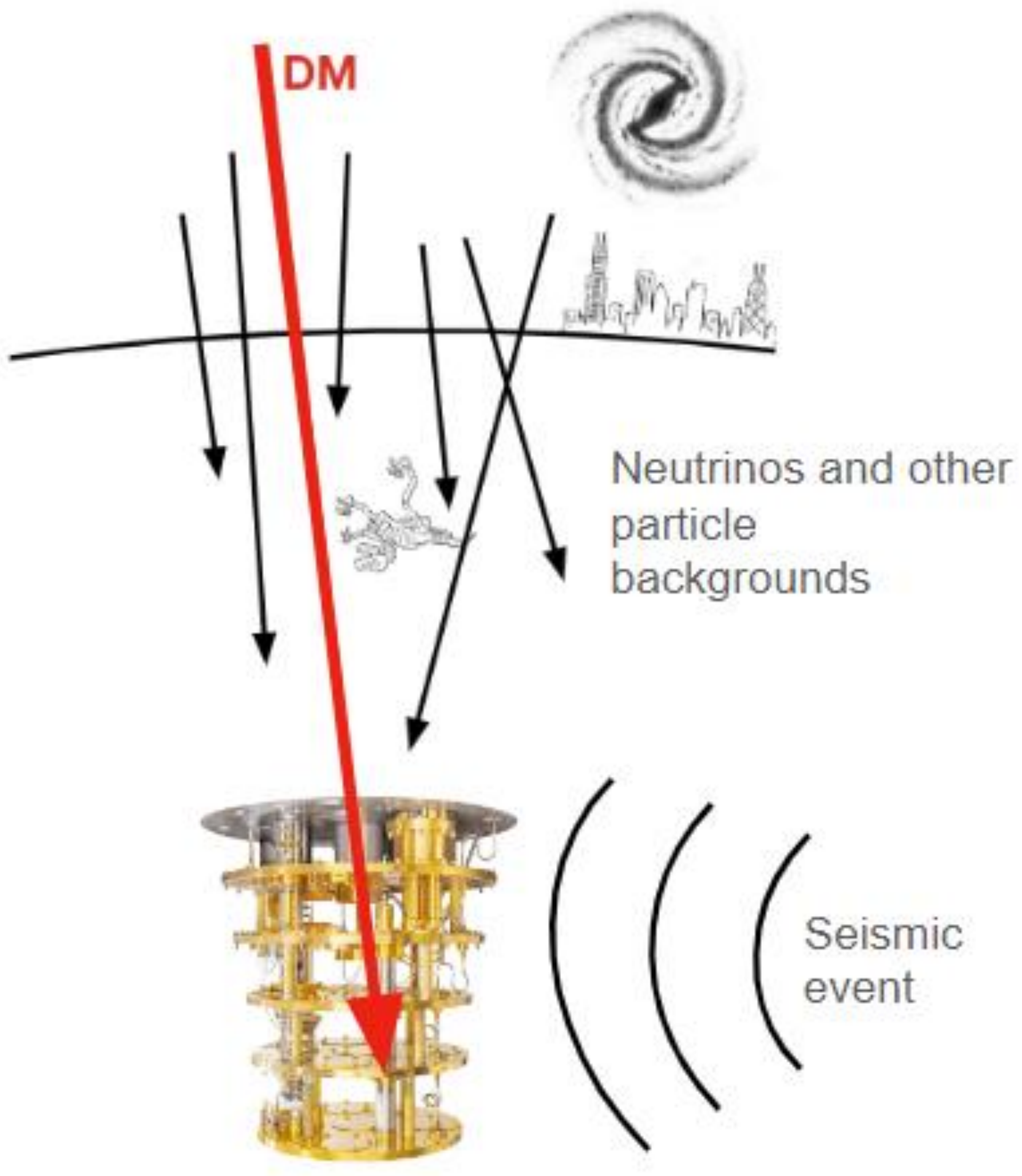
Count region: 1800cm2 and 707cm2 circular
Maximum sample weight: 9kg, Maximum sample thickness: 6.3mm



Inductively coupled plasma - mass spectrometry

- Agilent 8900 ICP-QQQ advanced application model (triple quadrupole ICP-MS)
- System will be run in our surface facility clean labs
- Used for elemental analysis at trace detection levels.
- Our aim is to achieve sub-ppt detection of a variety of elemental analytes in samples
- Our first effort will be an ultra-low detection method for UPW monitoring
- Current key analytes of interest for ICP-MS at SNOLAB are currently: U, Th, K, Pb
- We will also be using the instrument to perform isotopic ratio analysis

Seismic and Vibration Monitoring

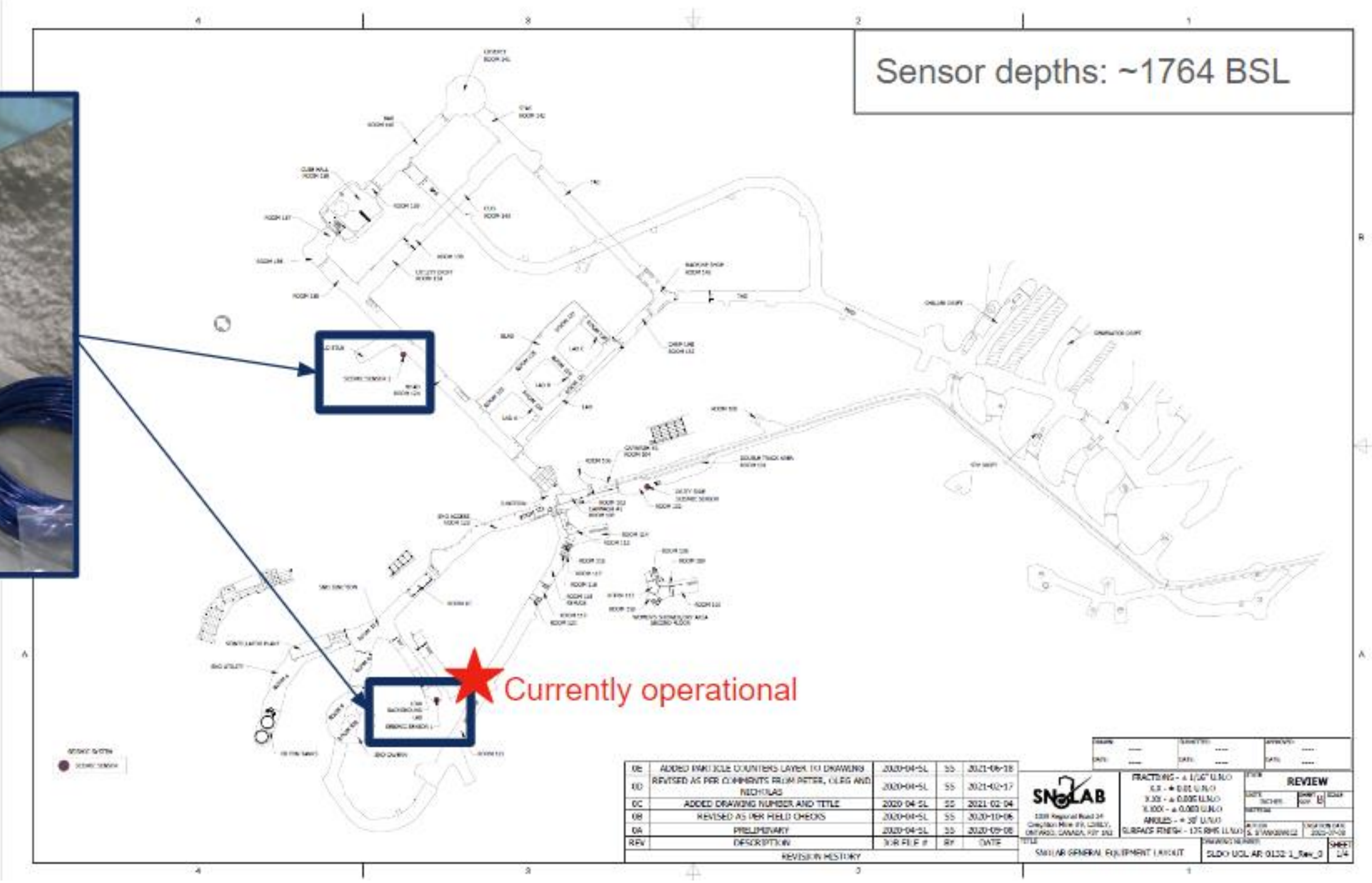


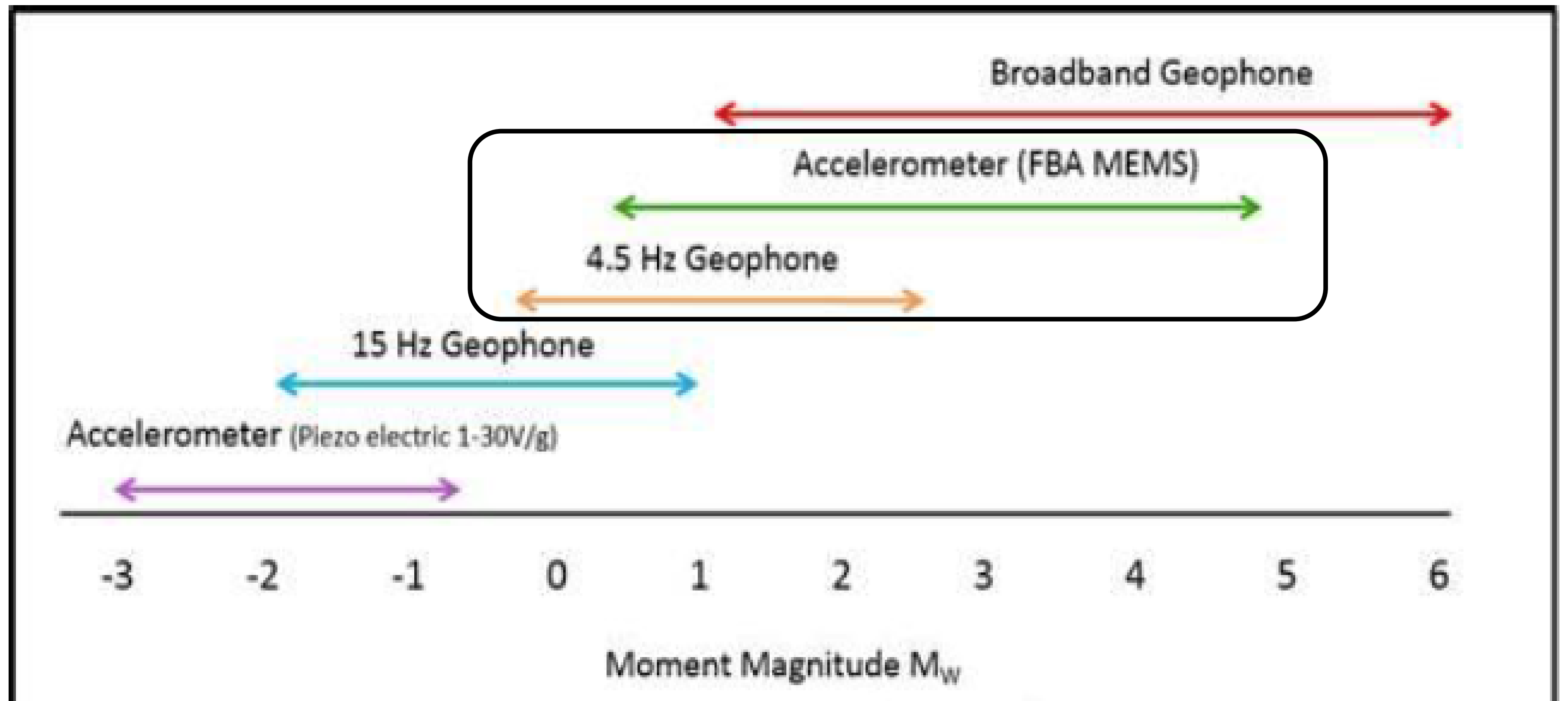
- SNOLAB is located in an active mine
- Mining activates including routine drilling, blasting and large equipment operation may cause an environment vibrations and microphonics
- Vibration sensitive systems should be designed to mitigate microphonics when required

Seismic and Vibration Monitoring

- Two seismic monitoring stations UG
- Each station has a triaxial Force Balance Accelerometer and triaxial Geophone
- Working on having the stations sync with PTP
- Not intended for triangulations

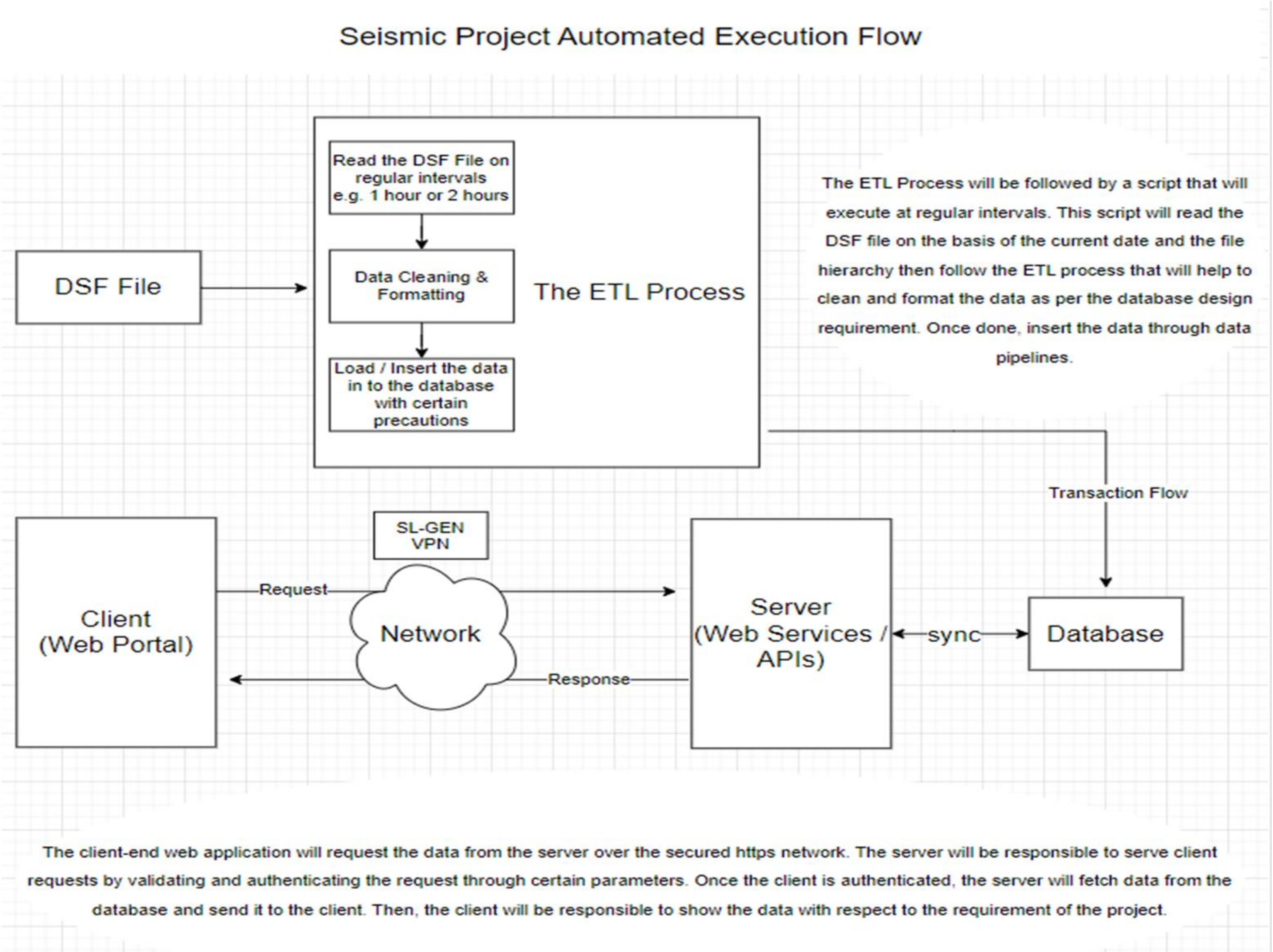
Force Balance Accelerometer and Geophone



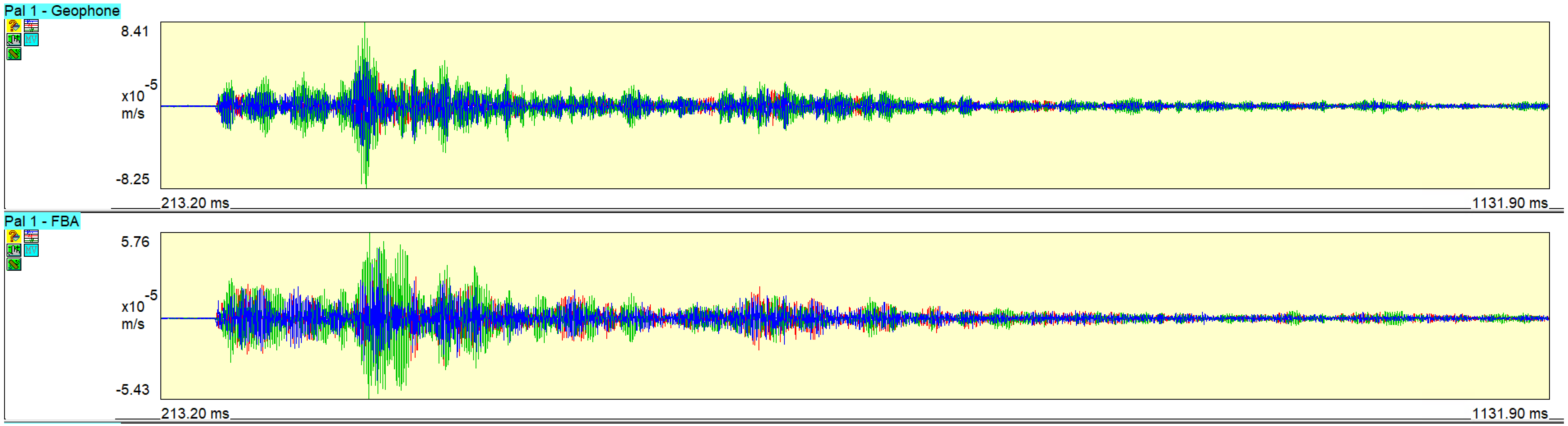


ESG's Microseismic Monitoring System User Guide

Seismic and Vibration Monitoring



Seismic Vibration Data



- Triggered waveform are all recorded and saved as csv files for easy manipulation
- Work has started on developing a classifier for different types of vibrations (machinery, environment for example)
- Goal is to characterize the vibration backgrounds in the lab

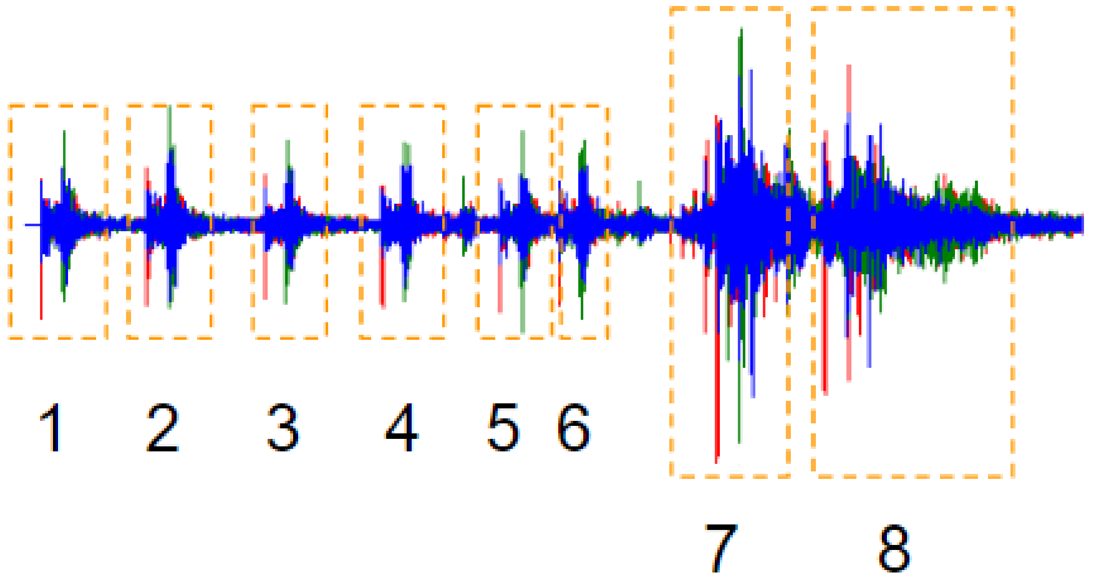
Seismic and Vibration Studies

1 Find individual pulses and extract properties

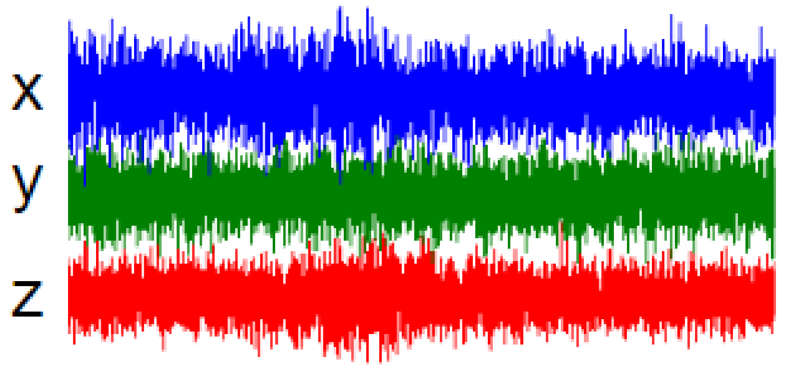
2 Determine appropriate trigger threshold

3 Identify pulse sources based on properties

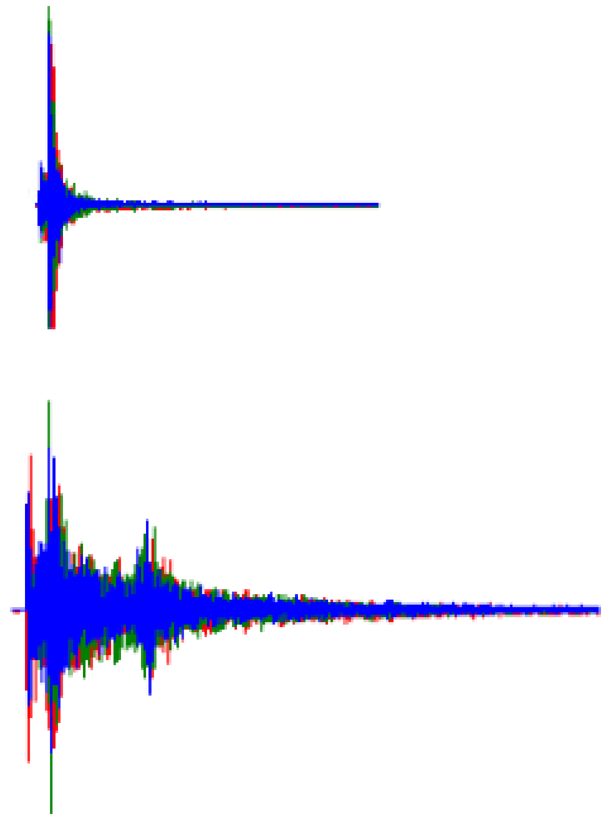
Mon, Jan 09, 23, 3:02am

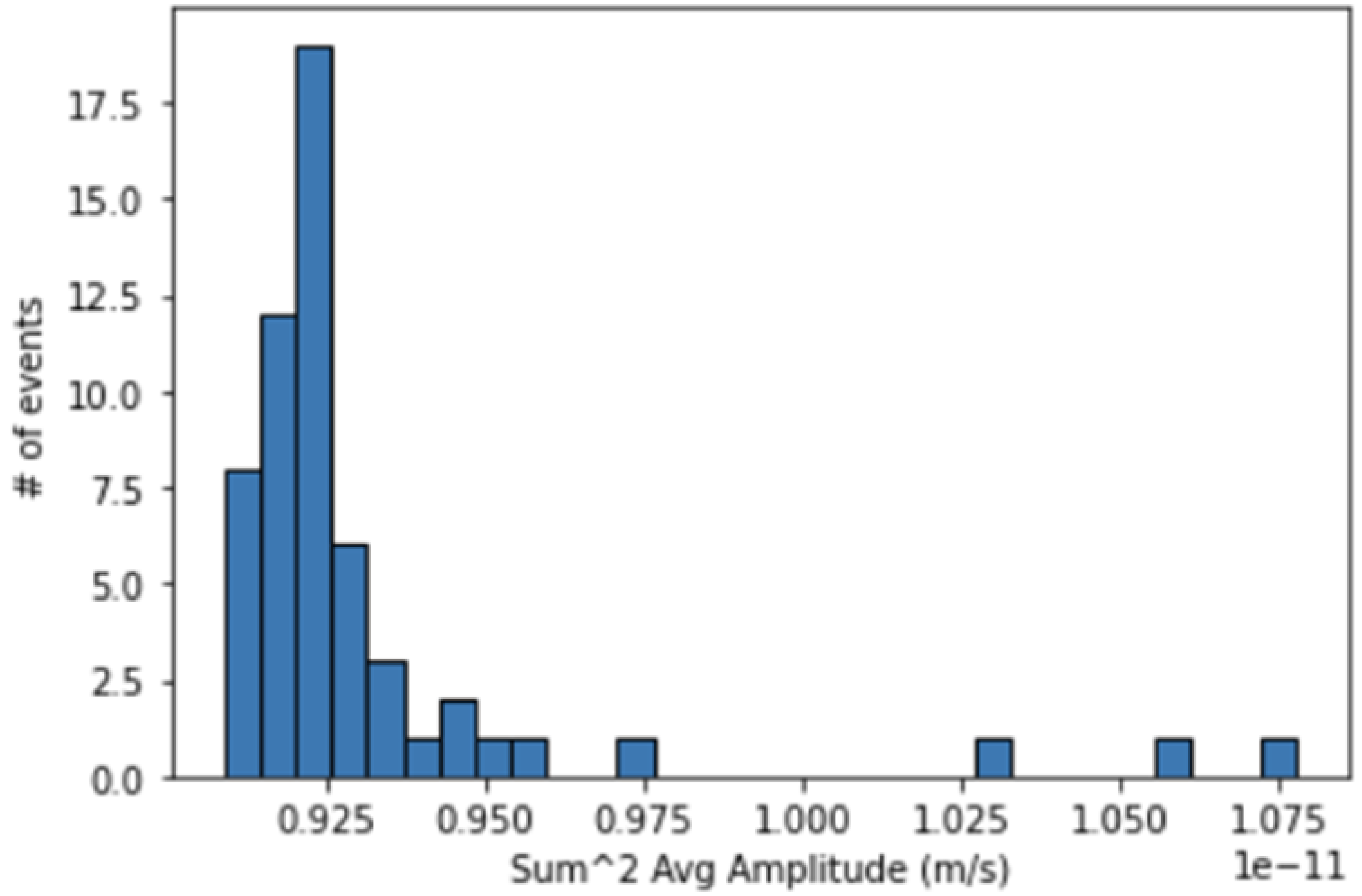


Sun, Jan 08, 23, 5:00pm
Background Measurement



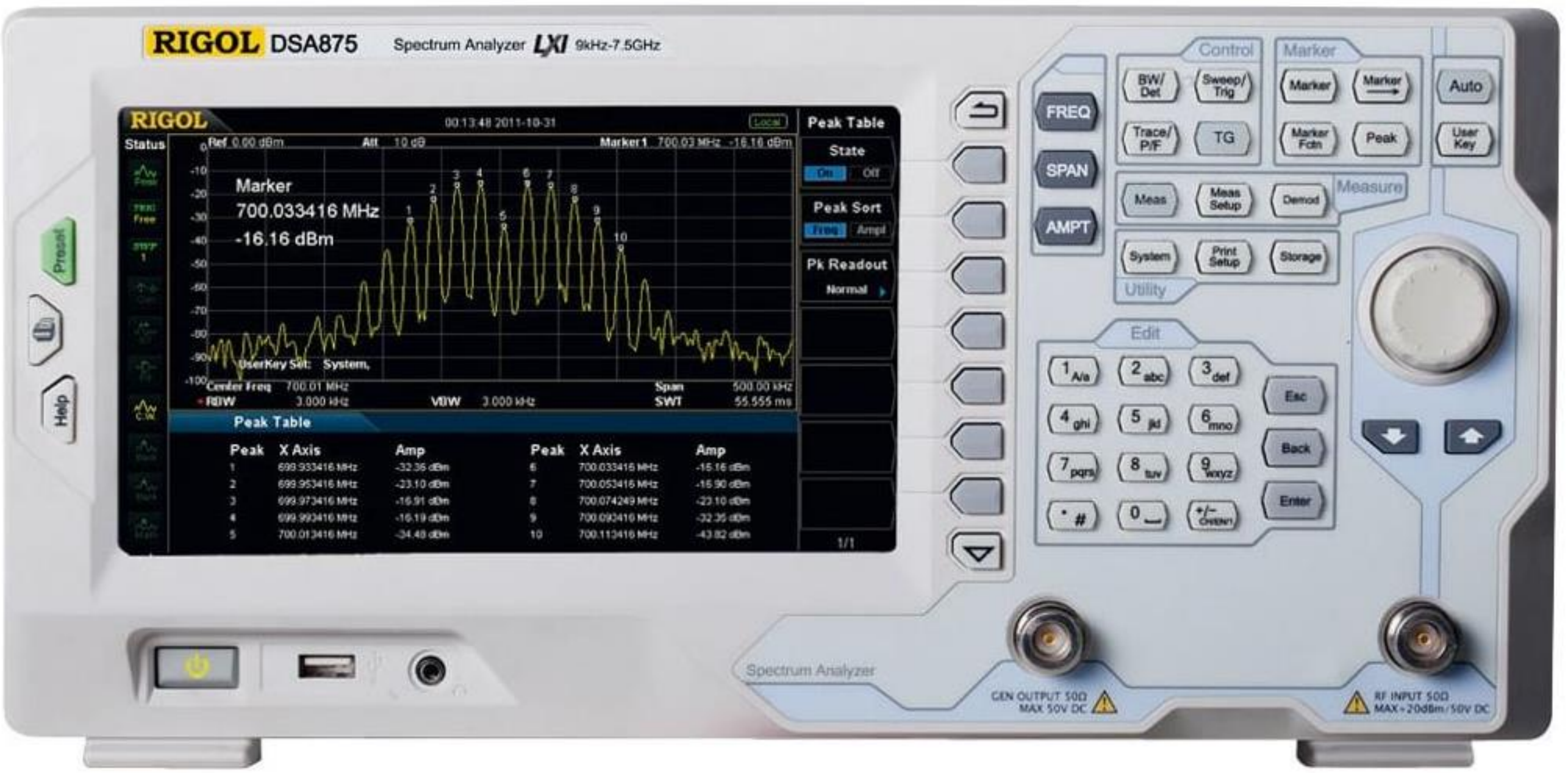
Why? The threshold determines what types of events the system captures (i.e. localized versus widespread, low amplitude versus high amplitude). This threshold can be set for each channel separately.





We are trying to understand the properties and effect of the vibration, not triangulate the source.

EM Signature Catalogue



- Spectrum Analyzer with a 9 kHz - 7.5 GHz frequency range
- Survey and catalogue sources of electrical noise in the lab

Summary

- Neutron measurements are currently underway in the old section of the lab and will continue for ~1 year
- Gamma measurements (in different energy ranges) continue and analysis is underway
- Input from these measurements can be used for simulations and design of rare event experiments
- Several different techniques available to measure low radioactive backgrounds to help the underground and low-background community with material selection
- Seismic system is operational and vibration studies are underway
- Continue to develop and improve the low radioactivity techniques

Thank You

- LBC Team
  SNOLAB, Sudbury
  L. Anselmo, D. Chauhan, B. Cleveland, J. Farine, N. Fatemighomi, J. Hall, I. Lawson, S. Luoma, T. Sonley and Students

- CTBT radionuclide laboratory CAL05 - Dual CTBT Detector
  Health Canada
  Adrian Botti, Pawel Mekarski, Marc Bean, Colin Vant and Kurt Ungar

- UNAM group
  Institute of Physics, UNAM, Mexico - Background Gamma and Neutron Measurements
  Lead: Eric Vázquez-Jáuregui

- University of Michigan – Vibration Studies
  Bjoern Penning and Sam Venetianer