Low Background Screening Capability in the UK

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University College London

Low Radioactivity Techniques 2015
18-20 March, 2015

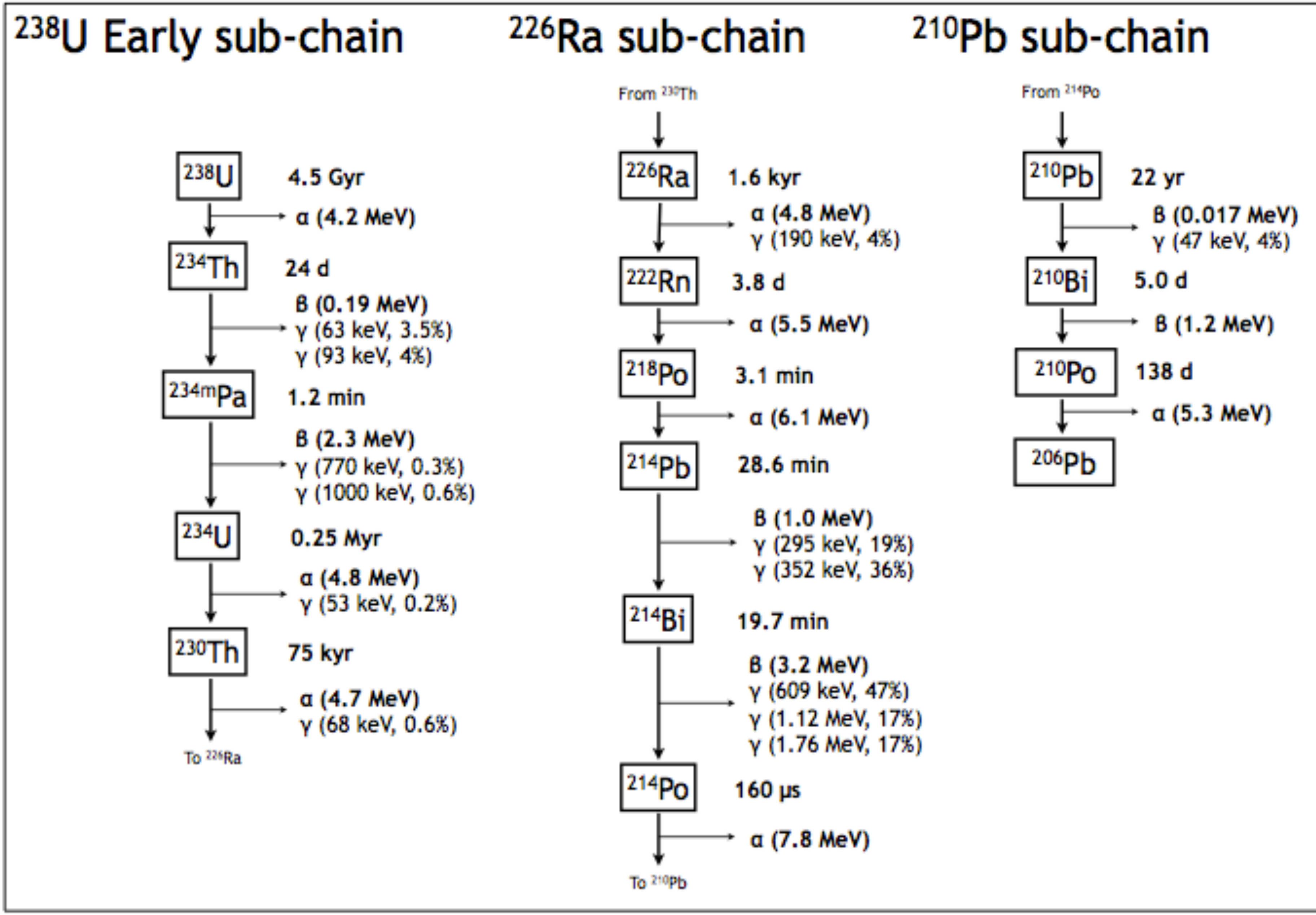
Rare Event Search Experiment Requirements

1) Background from material radioactivity << signal
   - *Comprehensive material screening campaign*

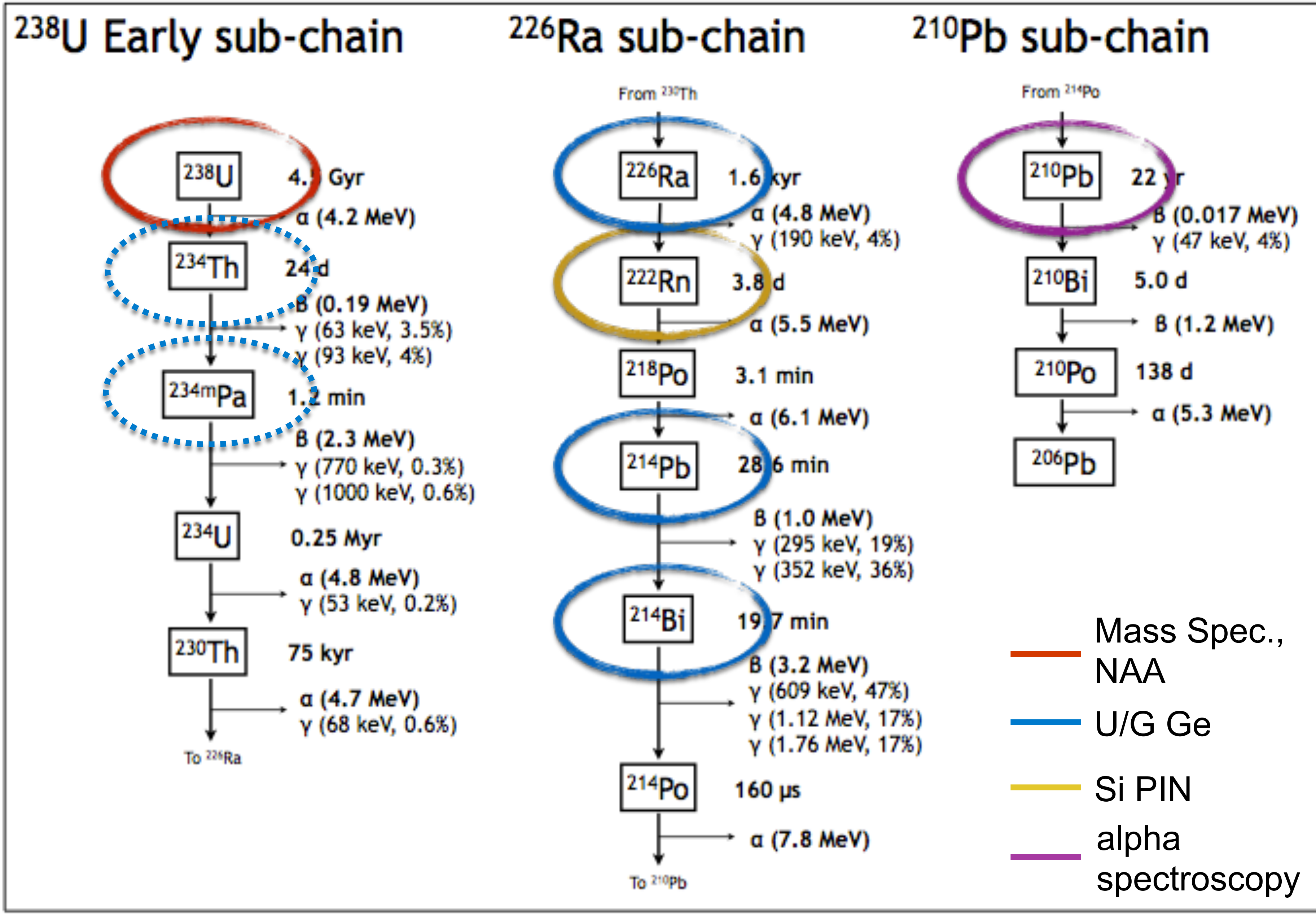
2) Accurate map of contaminants for high precision background model
   - *Multiple techniques for complete U/Th chains*
   - *Sub-component activities for neutron yields*

3) Material selection well before construction and installation
   - *High throughput, low activity assays, particularly U/Th*

^{238}U Chain


238U Early sub-chain
238U 4.5 Gyr
α (4.2 MeV)
234Th 24 d
β (0.19 MeV)
γ (63 keV, 3.5%)
γ (93 keV, 4%)
234mPa 1.2 min
β (2.3 MeV)
γ (770 keV, 0.3%)
γ (1000 keV, 0.6%)
234U 0.25 Myr
α (4.8 MeV)
γ (53 keV, 0.2%)
230Th 75 kyr
α (4.7 MeV)
γ (68 keV, 0.6%)
To 226Ra
226Ra sub-chain
From 230Th
226Ra 1.6 kyr
α (4.8 MeV)
γ (190 keV, 4%)
222Rn 3.8 d
α (5.5 MeV)
218Po 3.1 min
α (6.1 MeV)
214Pb 28.6 min
β (1.0 MeV)
γ (295 keV, 19%)
γ (352 keV, 36%)
214Bi 19.7 min
β (3.2 MeV)
γ (609 keV, 47%)
γ (1.12 MeV, 17%)
γ (1.76 MeV, 17%)
214Po 160 μs
α (7.8 MeV)
To 210Pb
210Pb sub-chain
From 214Po
210Pb 22 yr
β (0.017 MeV)
γ (47 keV, 4%)
210Bi 5.0 d
β (1.2 MeV)
210Po 138 d
α (5.3 MeV)
206Pb

^{238}U Chain



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Mass Spec., NAA
U/G Ge
Si PIN
alpha spectroscopy

Ultra-low Background Screening in the UK

- Gamma Spectroscopy
  - ➢ Boulby underground laboratory
- Mass Spectrometry
  - ➢ Dedicated low-background facility at UCL
- Radon Detection
  - ➢ Trace emanation facility at MSSL (UCL)

Technique	Isotopes	Typical Sensitivity Limits	Sample Mass	Destructive/ Non-desctructive	Assay Duration	Notes
HPGe	^{238}U, ^{235}U, ^{232}Th chains, ^{40}K, ^{60}Co, ^{137}Cs (any γ emitter)	50 ppt U, 100 ppt Th	kg	Non-destructive	Up to 2 weeks	Very versatile, not as sensitive as other techniques, large samples
ICP-MS	^{238}U, ^{235}U and ^{232}Th (top of chain)	10^{-12} g/g	mg to g	Destructive	Days	Requires sample digestion, preparation critical
Rn Emanation	^{222}Rn, ^{220}Rn	0.1 mBq	kg	Non-destructive	Days to weeks	Large samples, limited by size of emanation

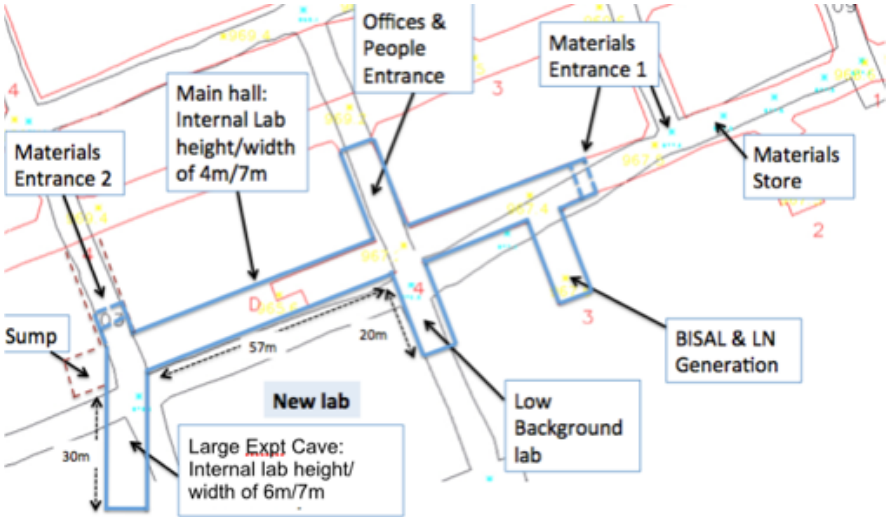
Boulby Underground Laboratory

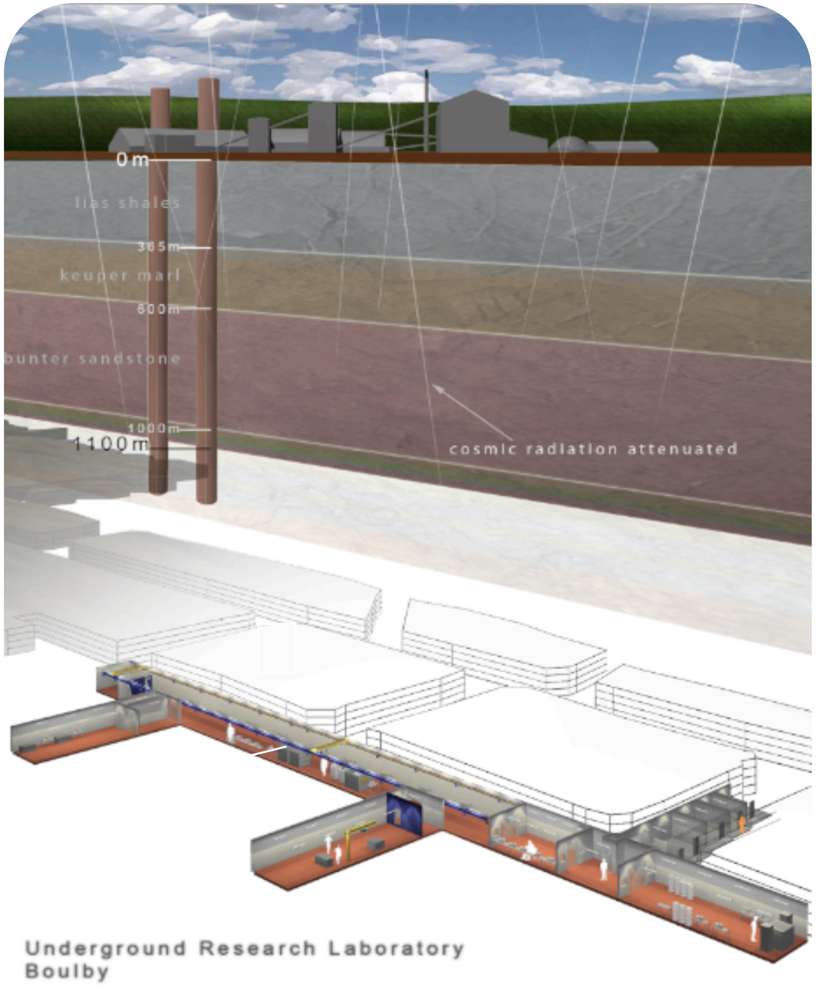
Long Dark Matter history

- *ZEPLIN programme*
- *Directionality (DRIFT)*

Major lab upgrade

- *Dedicated Low Background Counting Facility*

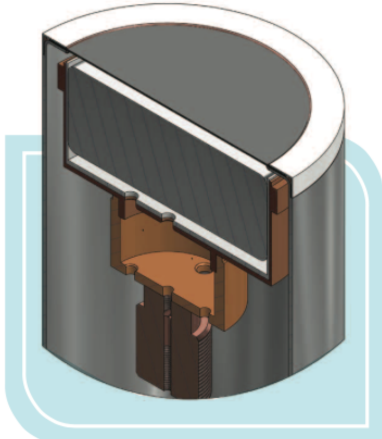




Boulby Underground Germanium Suite (BUGS)

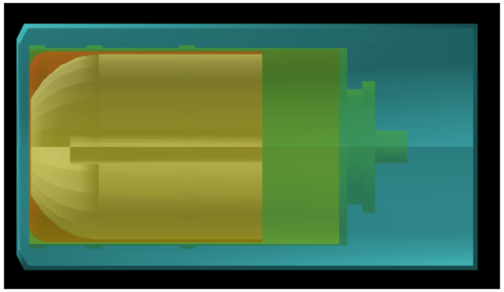
- Four detectors in Class 10,000 clean room

- Operations
  - Automated LN2 fills
  - Remote control, env. monitoring
  - Emergency systems, UPS
- Interchangeable Pb+Cu castles
  - Interlocking retractable roof
  - N2 purge fed through Pb/Cu to cavity

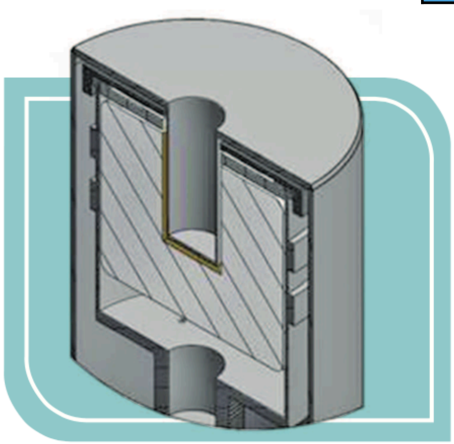


0.8 kg ULB BE5030
10 keV threshold

2 kg ULB Ortec
GEM-XX-95

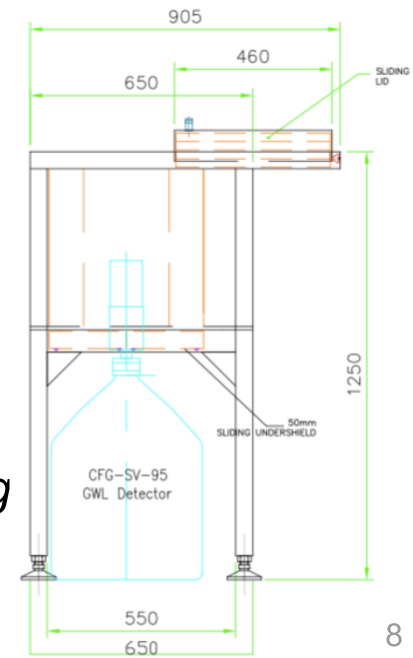


Detector	Crystal	[U] mBq/kg	[Th] mBq/kg	Status
Chaloner	BEGe	0.6	0.3	Online
Lumpsey	Well	1.2	0.4	June '15
Lunehead	P-type	1.0	0.4	Online
Wilton	BEGe	7	4	May '15

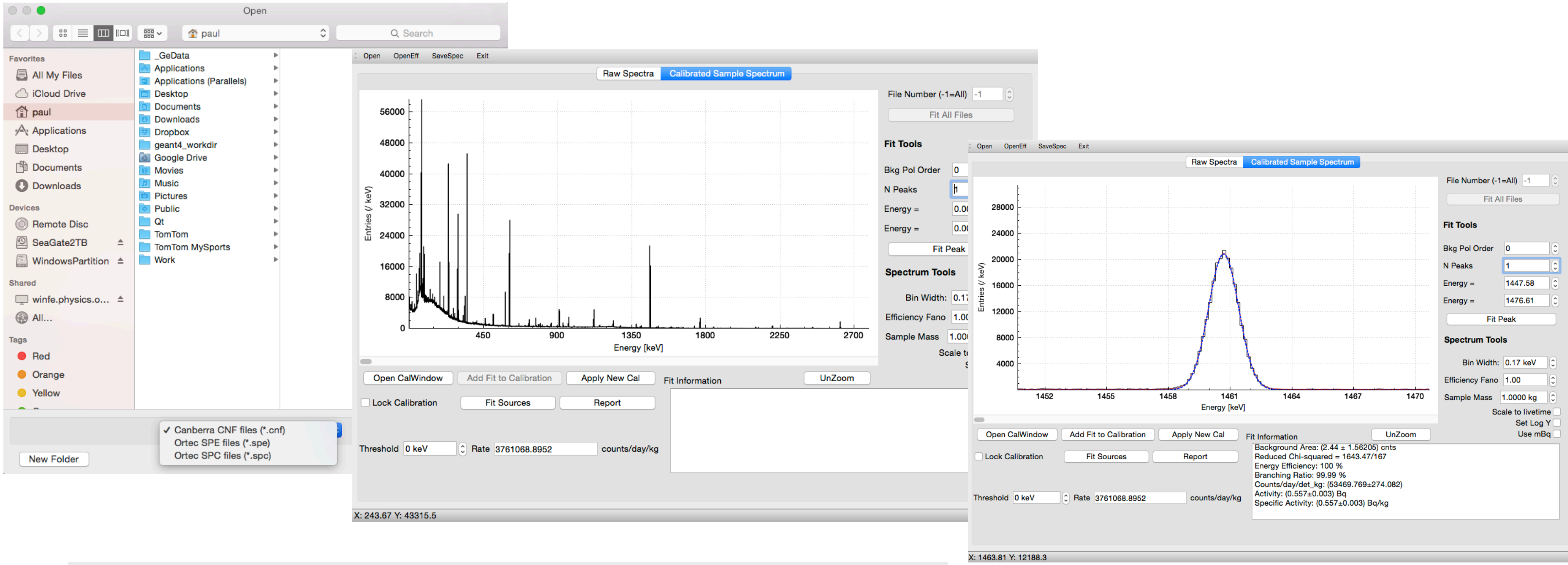


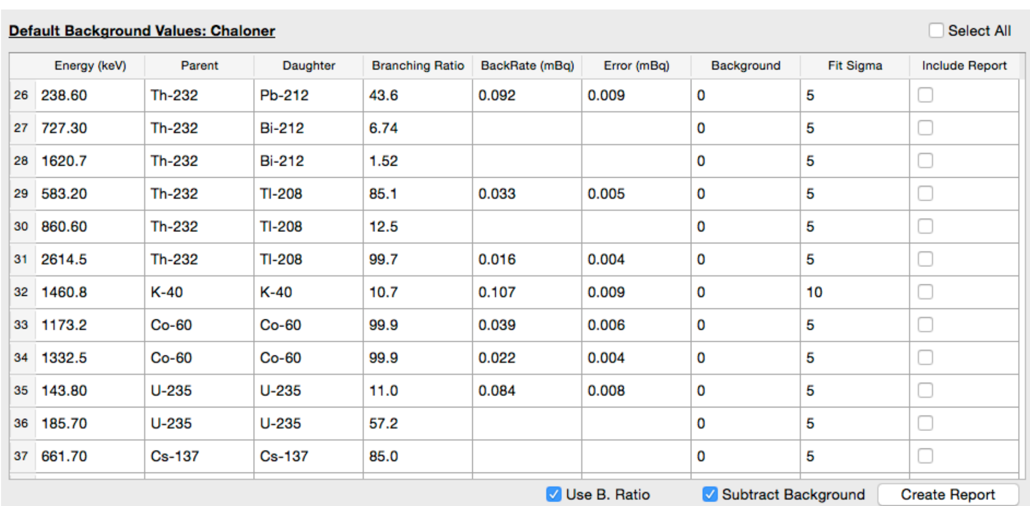
1.5 kg ULB SAGe
28 mm X 40 mm well

ULB BE2825 0.4 kg
pre-screener



Analysis Software



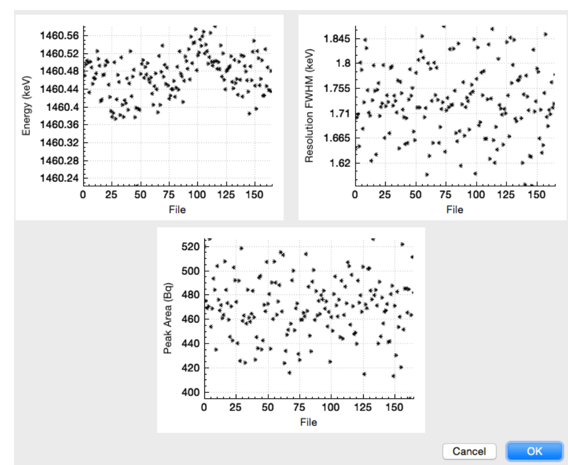


Default Background Values: Chaloner

☐ Select All

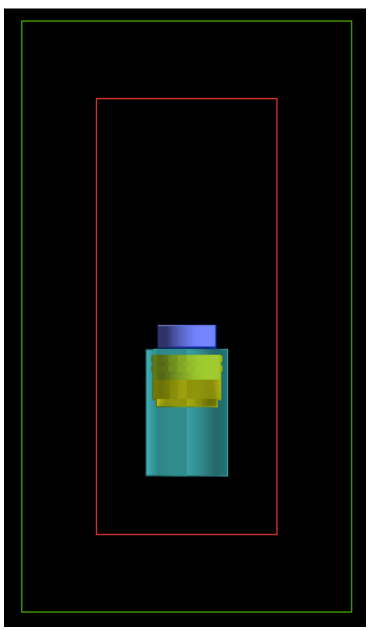
	Energy (keV)	Parent	Daughter	Branching Ratio	BackRate (mBq)	Error (mBq)	Background	Fit Sigma	Include Report
26	238.60	Th-232	Pb-212	43.6	0.092	0.009	0	5	☐
27	727.30	Th-232	Bi-212	6.74			0	5	☐
28	1620.7	Th-232	Bi-212	1.52			0	5	☐
29	583.20	Th-232	Tl-208	85.1	0.033	0.005	0	5	☐
30	860.60	Th-232	Tl-208	12.5			0	5	☐
31	2614.5	Th-232	Tl-208	99.7	0.016	0.004	0	5	☐
32	1460.8	K-40	K-40	10.7	0.107	0.009	0	10	☐
33	1173.2	Co-60	Co-60	99.9	0.039	0.006	0	5	☐
34	1332.5	Co-60	Co-60	99.9	0.022	0.004	0	5	☐
35	143.80	U-235	U-235	11.0	0.084	0.008	0	5	☐
36	185.70	U-235	U-235	57.2			0	5	☐
37	661.70	Cs-137	Cs-137	85.0			0	5	☐

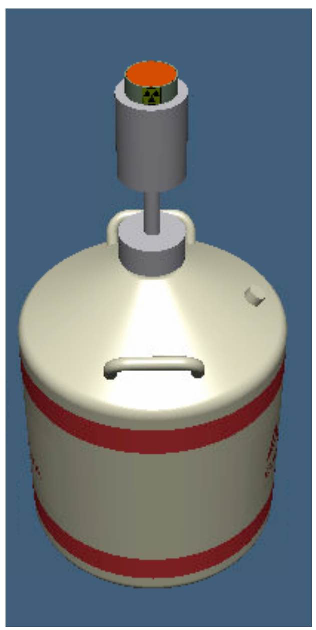
☑ Use B. Ratio ☑ Subtract Background Create Report

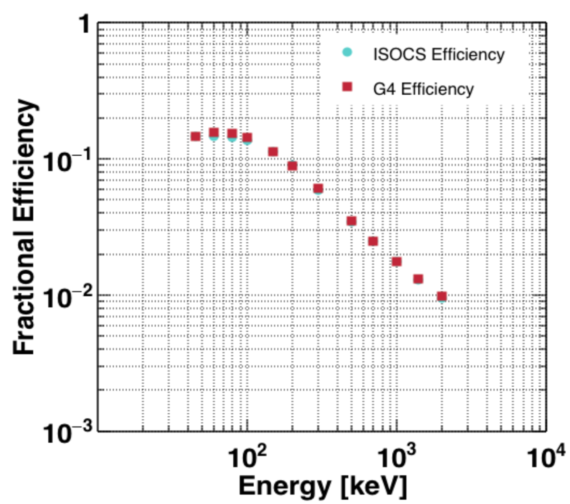


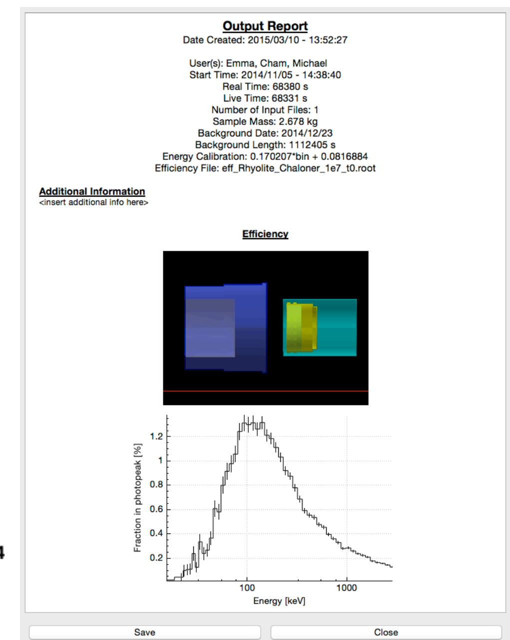
Simulations

- Modeled detectors ‘bottom-up’ with engineering drawings
- Calibrated with detector scans, validated with sources
- GEANT4 based simulation integrated into analysis software









Efficiency

Isotope	Chaloner Bq/kg	Lunehead Bq/kg	IAEA Recommended
Tl-208	9.87 ± 0.13	10.24 ± 0.16	11.6 ± 2.1
Pb-210	39.39 ± 0.44	-	35.5 ± 3.9
Bi-212	33.87 ± 0.77	34.57 ± 0.92	34.2 ± 4.0
Bi-214	17.80 ± 0.40	18.49 ± 0.48	19.6 ± 1.6
Pb-214	20.84 ± 0.13	21.05 ± 0.19	21.6 ± 1.2
Ac-228	29.45 ±0.37	31.23 ± 0.53	31.5 ± 1.4
Th-234	30.73 ± 0.31	-	28.7 ± 5.9
K-40	563.07 ± 2.18	557.69 ± 2.45	611.0 ± 11.0
Cs-137	20.85 ± 0.11	20.66 ± 0.13	21.74 ± 1.78

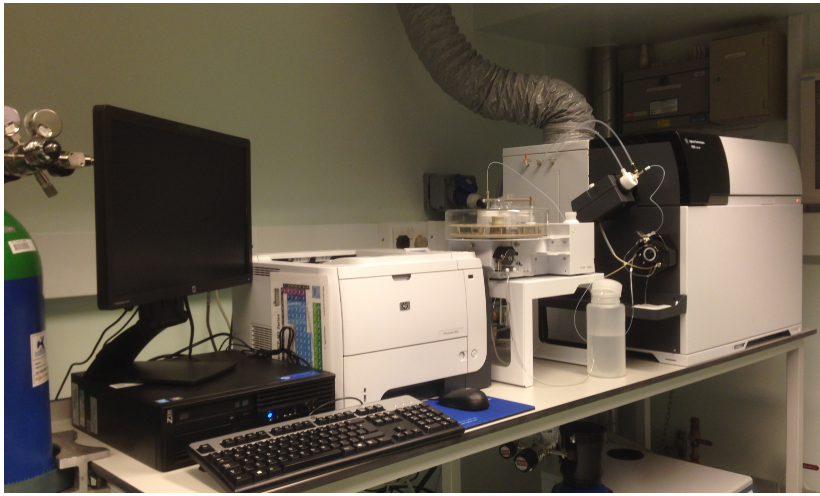
Isotope	Chaloner Bq/kg	Lunehead Bq/kg	Rhyolite Recommended
Th232	45.00 ± 0.25	43.07 ± 0.08	48.47 ± 1.88
U238 (e)	98.01 ± 2.72	116.37 ± 0.96	117.22 ± 15.21
U238 (l)	97.00 ± 0.61	94.47 ± 0.10	103.68 ± 12.55
K40	870.16 ± 4.47	881.61 ± 0.79	904.94 ± 73.50

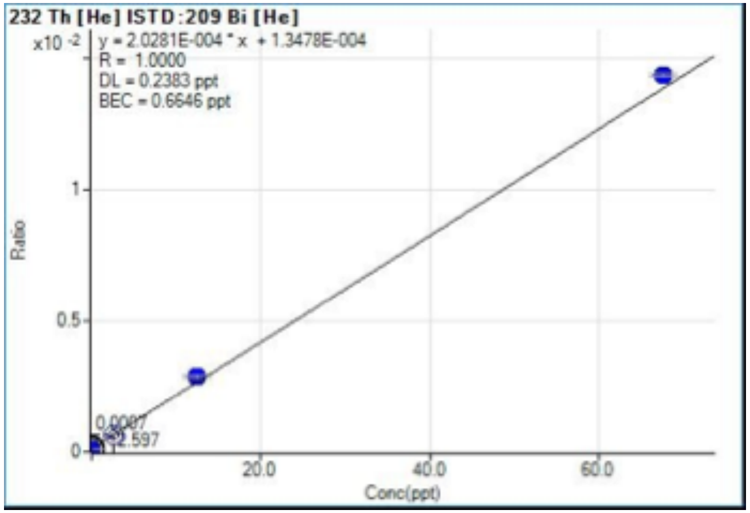
Status of BUGS

- Chaloner and Lunehead installed Sept 2014
- Approximately 50 ppt U/Th sensitivity achieved
- QR code sample tracking system in-place, results fed to LZ database
- LZ material screening initiated
  - *Screening schedule integrated into project*
  - *Live-time requirements informed by Monte Carlo*
- Lumpsey and Wilton on-line May/June 2015
- Neutron moderator, enclosures, scintillator installation mid-2015

Mass Spectrometry at UCL

- New Agilent 7900 ICP-MS mainframe procured exclusively for ultra-low background assays
- Installed and commissioned at UCL Aug 2014
- Standard detection sensitivity at ~ppt for U/Th
- Upgraded Feb 2015
  - HF capability (30%), microflow nebulizer, Pt skimmer/sampling cones
  - Reaction cell (H2) discrimination capability in addition to no gas, and He mode KED
- Presently in HEP lab at UCL, to be moved with sample preparation equipment to dedicated LZ ICP-MS lab (class 10K clean room)





ICP-MS Sample Preparation

- Milestone EthosUP digestion system
  - *No hot plate; high T/P; reduces digestion to mins.*
  - *ensures full recoveries*
  - *no cross-contamination*

- Pyro-260 microwave ashing system (PTFE, acrylics, …)
- Acid distillation and reflux cleaning systems
- Reproducible, high throughput closed system screening
- Installation in UCL cleanroom April 2015
- Digestions routines under development with Analytix
  - IAEA385 standard (soil)
  - Ti
  - PTFE
  - R11410 PMT components

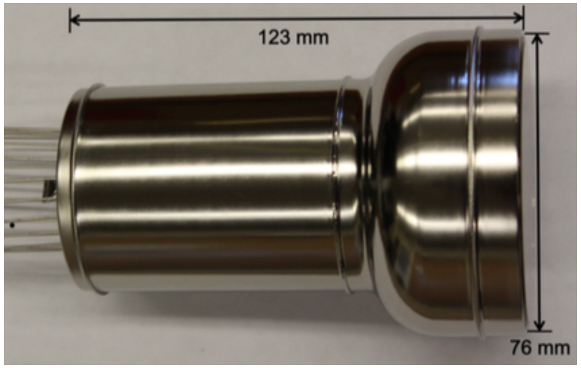
ICP-MS Sample Preparation

Microwave digestion *(with D. Rowe, Milestons UK Product Manager at Analytix Ltd's facility)*

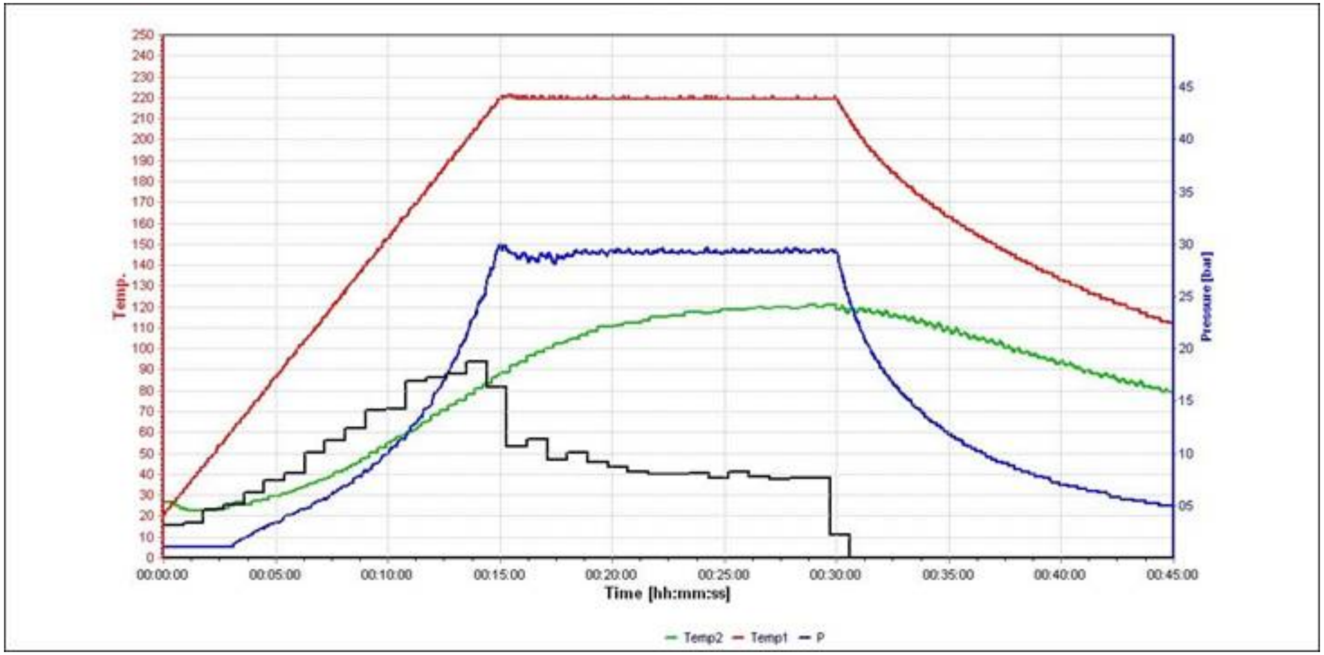
- High pressure reactors constructed from materials transparent to microwaves
- Microwave energy couples directly to ions, rotates around the dipole to cause friction and release heat (hence TFM, etc; low or no dipole moment)
- Acids have higher dipole moments, absorb microwaves readily, for fast and even heating of reactant solutions
- Reaction sped up with HP closed vessel; acids to be heated beyond boiling points

- For PMT components used 220C with mixture of Nitric, Hydrochloric and Hydrofluoric acids to fully dissolve materials
- Optimised ratio and quantity of acid required for complete dissolution of samples
- Each acid has specific purpose during digestion, optimisation required:
  - Nitric acid commonly used to digest any organic material present
    $(CH_2)_X + HNO_3 \rightarrow CO_2(g) + NO_X(g) + H_2O$
  - HCl for Fe-based alloys due to ability to hold high chloro-complex in solution
  - HF acid used for decomposing silicates

ICP-MS Sample Preparation



Sample	Weight	Acids
1 Quartz Plate	0.200g	4ml HF
3 Kovar Sheet	0.492g	3ml HCl 3ml HF 3ml HNO3
3 Kovar Sheet	0.469g	3ml HCl 3ml HF 3ml HNO3
4 Cobalt free metal sheet	0.491g	3ml HCl 3ml HF 3ml HNO3
4 Cobalt free metal sheet	0.490g	3ml HCl 3ml HF 3ml HNO3
6 Stainless steel sheet (mat surface)	0.475g	3ml HCl 3ml HF 3ml HNO3
6 Stainless steel sheet (mat surface)	0.488g	3ml HCl 3ml HF 3ml HNO3
7 Stainless steel sheet (mat surface)	0.477g	3ml HCl 3ml HF 3ml HNO3
7 Stainless steel sheet (mat surface)	0.461g	3ml HCl 3ml HF 3ml HNO3
8 Quartz insulator	0.1966g	4ml HF
10 Kovar sheet	0.482g	3ml HCl 3ml HF 3ml HNO3
10 Kovar sheet	0.498g	3ml HCl 3ml HF 3ml HNO3

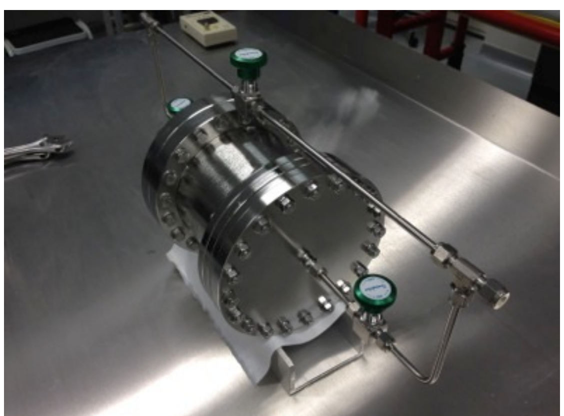


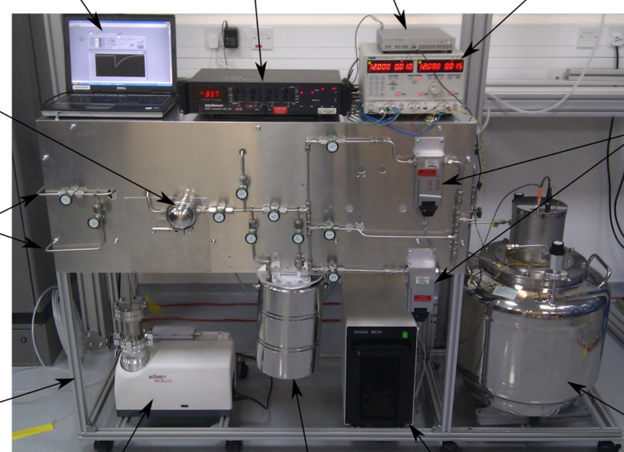
Int T (thermocouple)
Int P (transducer)
Ext T (infra-red)
Microwave power

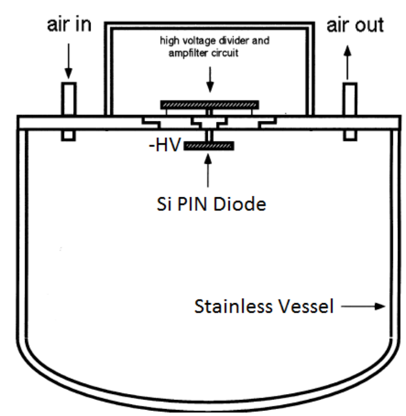
Radon Emanation Detector at UCL (MSSL)

…see Xin Ran Liu's talk

- Radon cannot be "fiducialised" away
- Sensitivity at ~0.1 mBq required
- System developed for SuperNEMO
- Silicon PIN diode in 70 litre electro-polished vessel
- Connected to radon concentration line
- Emanation chamber for screening components

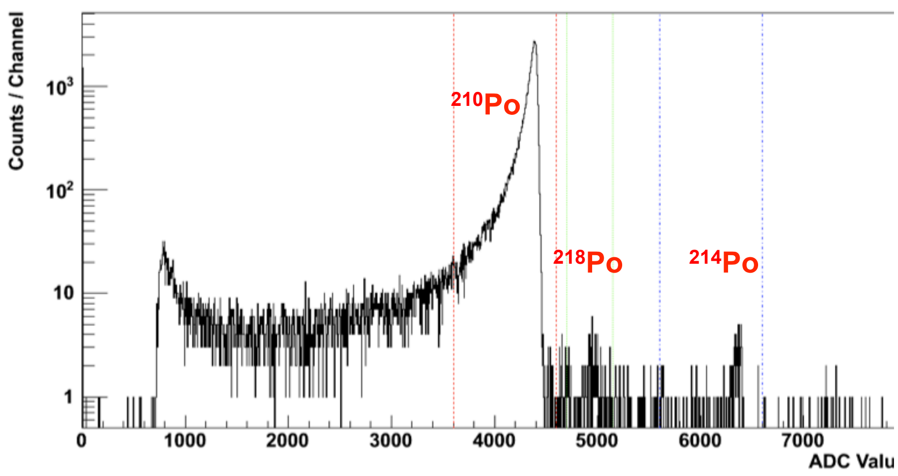


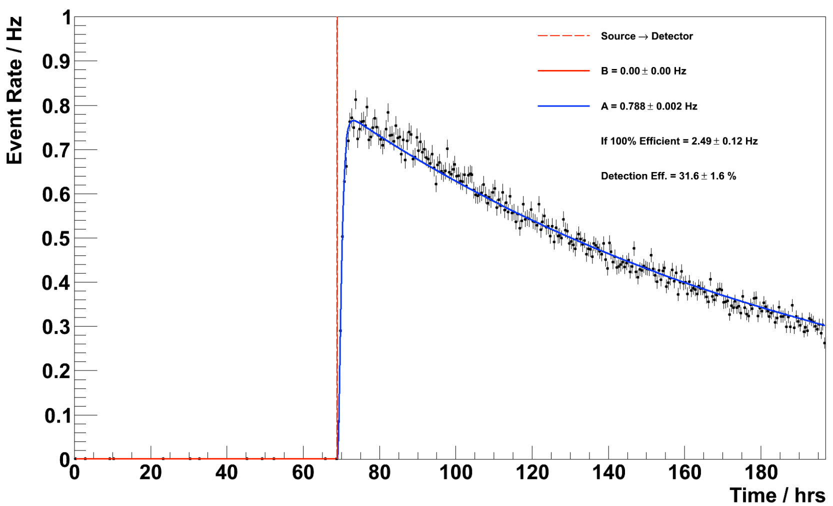




Radon Emanation Sensitivity

- Regular calibration with ^{226}Ra 'flow-through' source
- High efficiency, ^{214}Po = 31.6 ± 1.6%
- Samples prepared in clean room, UV inspection
- Emanation sensitivity (90% C.L.)
    - ***^{214}Po < 90 µBq***
    - ***^{218}Po < 120 µBq***





Summary

Direct Gamma Counting

- *Required for U/Th mid-late chain measurements*
  - Boulby Underground Laboratory facility with 4 ULB counters
  - Varied detector types provide range for sample types and sub-chain sensitivity
  - Detectors integrated into LZ screening program

Mass Spectrometry

- *Required for progenitor U/Th measurements and high throughput*
  - Dedicated ultra-low background ICP-MS facility
  - Agilent 7900 ICP-MS with HF and H_2 line reaction capability
  - Microwave digestion and ashing closed, clean systems for sample prep
  - LZ construction material screening initiated

Radon

- *Required for ^{222}Rn and ^{220}Rn; backgrounds impervious to self-shielding*
  - Radon emanation measurement capability to <90 µBq
  - SuperNEMO demonstrator on-line screening