

UK materials screening for LUX-ZEPLIN and future rare-event searches

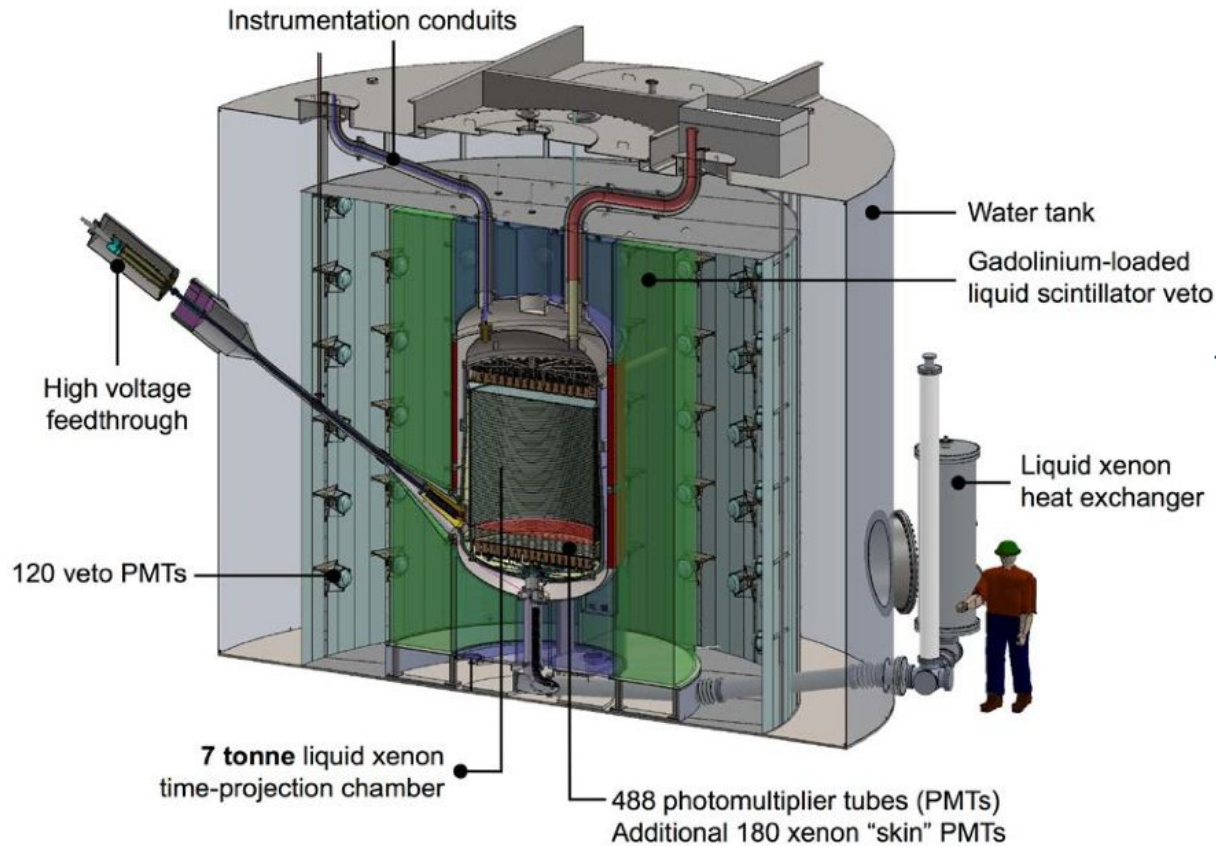
Jim Dobson, University College London

@ IOP HEPP and APP

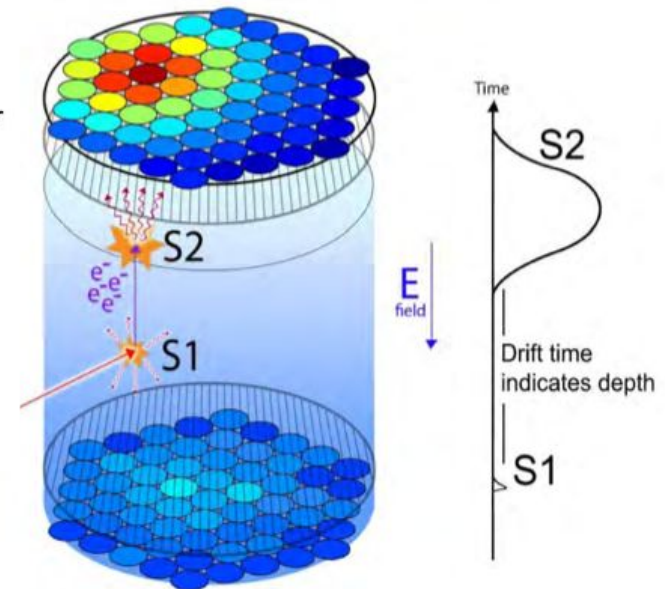
22nd March 2016



- **Background from material radioactivity $\ll$ signal:**
 - Comprehensive material screening campaign
- **Material selection well before construction and installation:**
 - High throughput, low activity assays, particularly U/Th
- **Accurate map of contaminants for high precision background model:**
 - Multiple techniques for complete U/Th chains
 - Sub-component activities for neutron yields



2-phase Xe TPC:



See earlier talks by S. Shaw and P. Beltrame

An example: LUX-ZEPLIN

See earlier talks by P. Beltrame and S. Shaw

For 1000-live-days and 5600 kg FV:

SI 40 GeV WIMP sensitivity: $\sim \text{few } 10^{-48} \text{ cm}^2$

Need to control BG levels to:

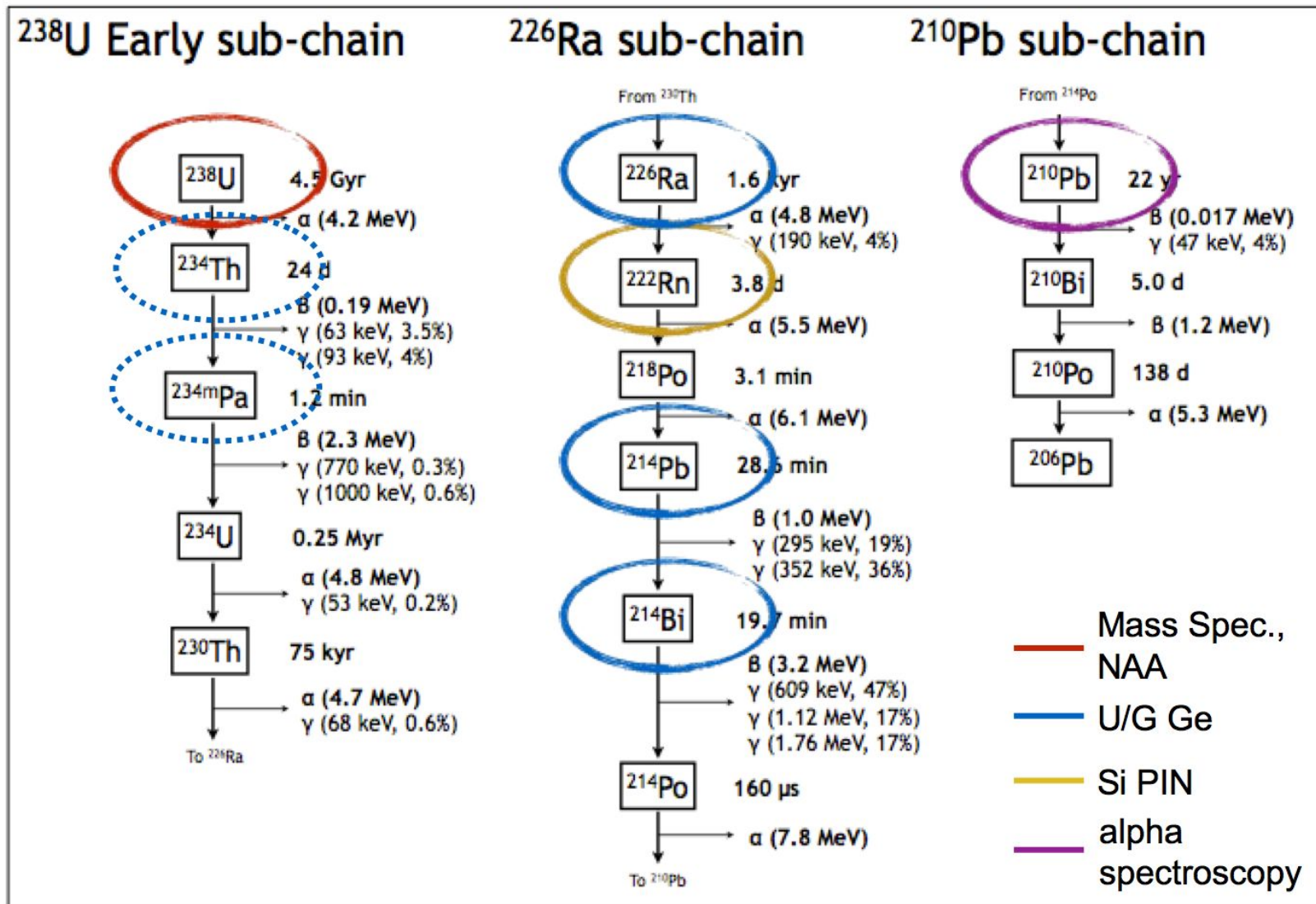
- ER 1.5 - 6.5 keV: $< 1000 \text{ evts} \sim \mathbf{40 \mu\text{DRU}^*}$ (before 99.5% discrimination)
- NR 6.0 - 30 keV: $< 1 \text{ evt} \sim \mathbf{10 \text{ nDRU}}$

For comparison to past and future experiments:

- | | <u>ER</u> | <u>NR</u> |
|------------|---------------------------|-------------------------|
| ● LUX: | $\sim 3600 \mu\text{DRU}$ | $\sim 200 \text{ nDRU}$ |
| ● XENON1T: | $\sim 200 \mu\text{DRU}$ | $\sim 40 \text{ nDRU}$ |
| ● Darwin: | $< 10 \mu\text{DRU}$ | $< 0.1 \text{ nDRU}$ |

* DRU = evt/kg/keV/day

U-238 chain



Suite of ultra-low background screening facilities:

- Gamma Spectroscopy @ Boulby underground laboratory
- Mass Spectrometry @ dedicated ICP-MS facility at UCL
- Radon Detection @ trace emanation facility at MSSL (UCL)

Technique	Isotopes	Typical Sensitivity Limits	Sample Mass	Destructive/ Non-destructive	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

BUGs: Boulby Underground Ge Suite

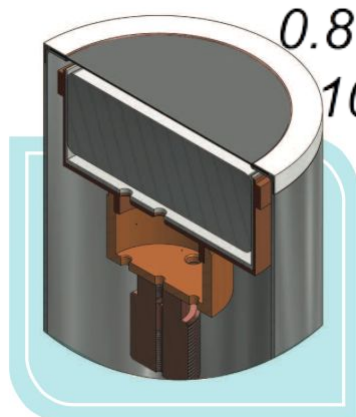


4 Ge detectors in new class 1000 cleanroom

- Remote control, env. monitoring
- Pb+Cu castles which can be purged N₂

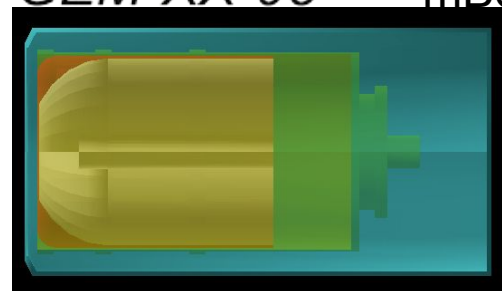


BUGs: Boulby Underground Ge Suite

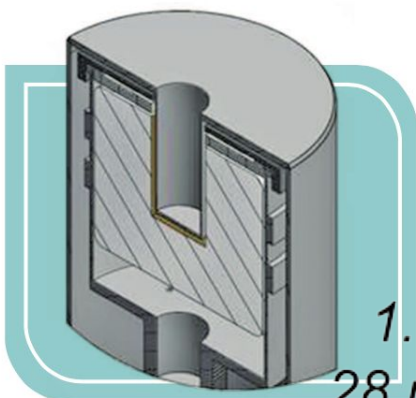


0.8 kg ULB BE5030
10 keV threshold
(U 0.6, Th 0.2 mBq/kg)

2 kg ULB Ortec GEM-XX-95 (U 0.7, Th 0.2 mBq/kg)



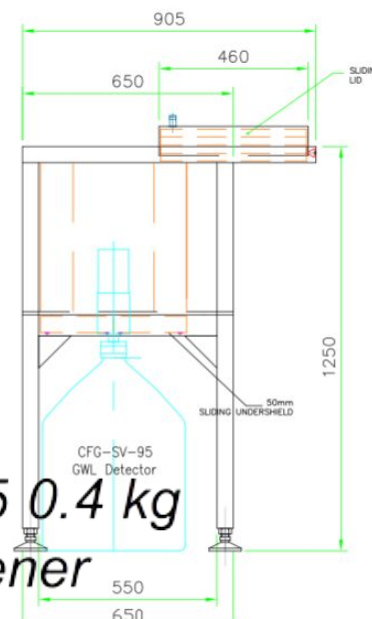
Detector	Crystal	[U] mBq/kg	[Th] mBq/kg	Status
Chaloner	BEGe	0.6	0.3	Online
Lumpsey	Well	1.2	0.4	Online
Lunehead	P-type	1.0	0.4	Online
Wilton	BEGe	7	4	Online



1.5 kg ULB SAGe
28 mm X 40 mm well

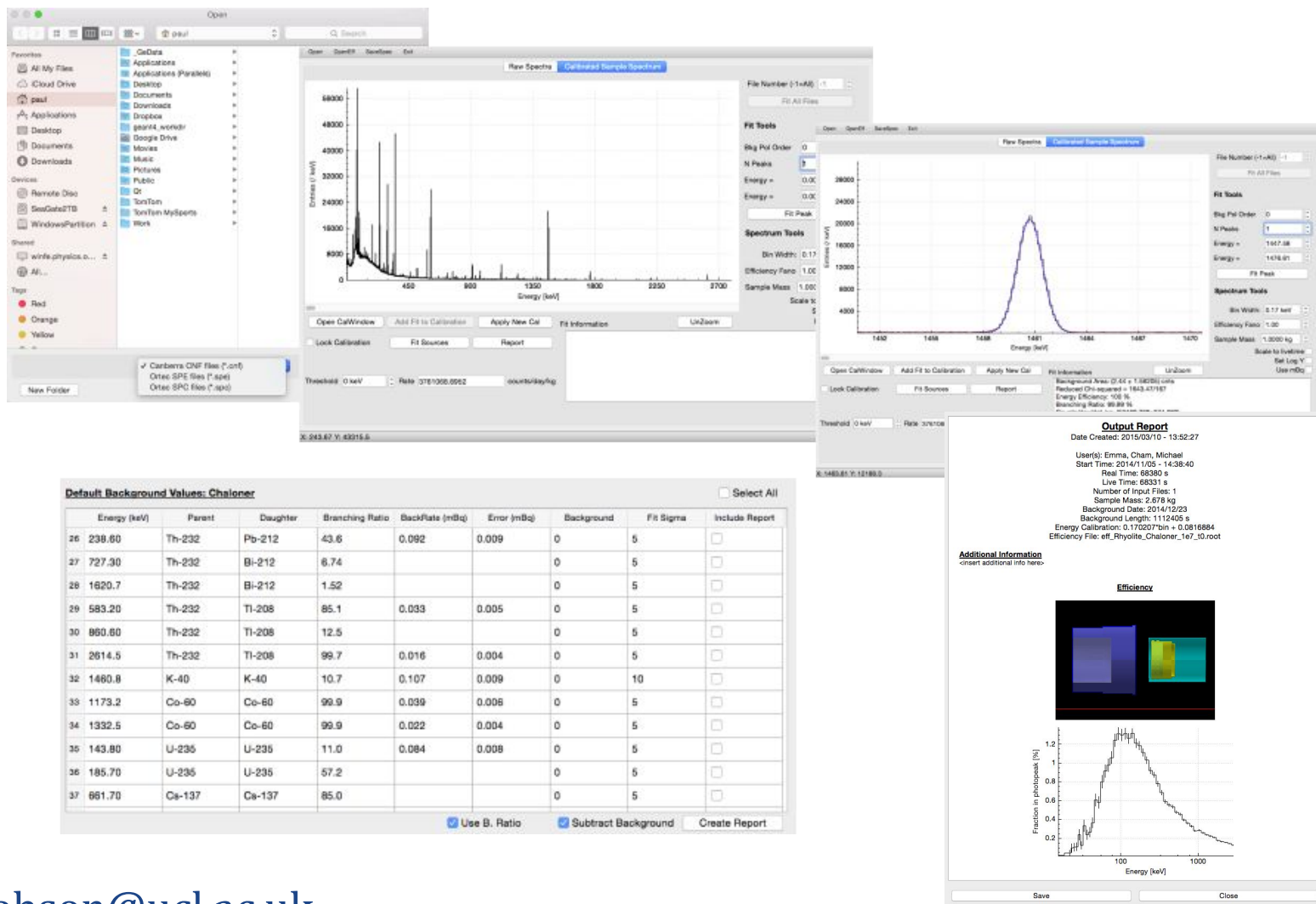
j.dobson@ucl.ac.uk (U 0.4, Th 0.3 mBq/kg)

ULB BE2825 0.4 kg
pre-screener
(U 7, Th 4 mBq/kg)



BUGs: Boulby Underground Ge Suite

Fully automated analysis software -> automatic report generation



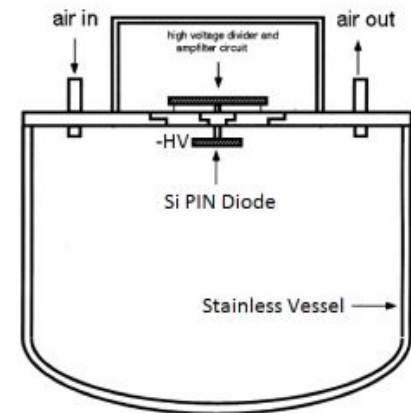
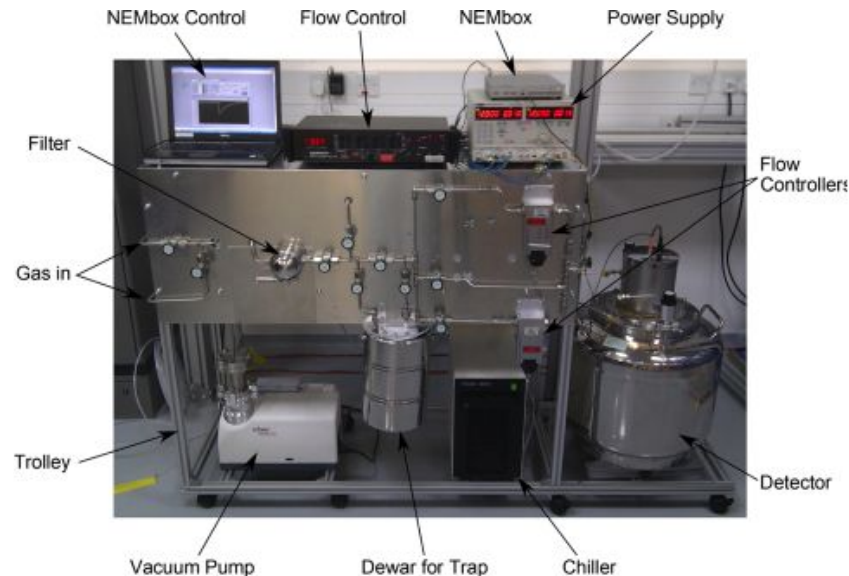
Comparison to known sources

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

Radon Emanation

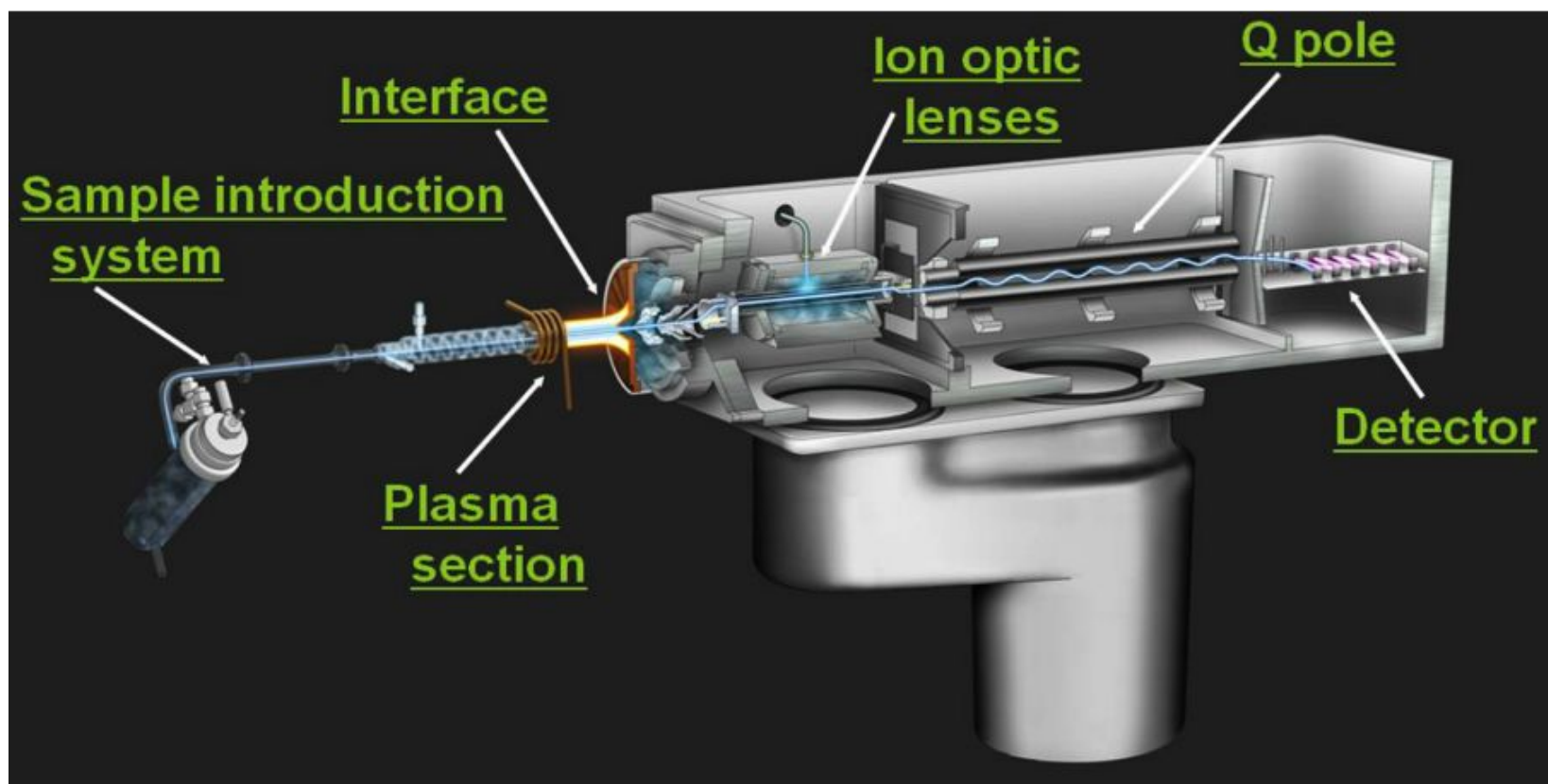
- Radon cannot be “fiducialised” away ...see Xin Ran Liu’s talk
- Sensitivity at ~ 0.1 mBq required
- System developed for SuperNEMO
- Silicon PIN diode in 70 litre electro-polished vessel
- Connected to radon concentration line
- Emanation chamber for screening components



Inductively Coupled Plasma Mass Spectrometry

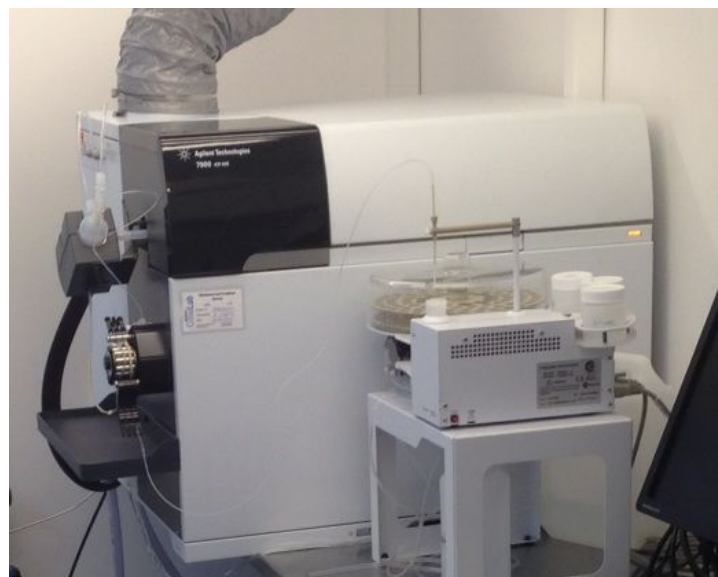
Can analyse almost all stable elements on earth (Li - U): ionises elements, selects them based on ion mass to charge ratio, and counts.

Fast analysis at ppm - ppt in seconds



ICP-MS facility at UCL

- Agilent 7900 ICP-MS + HF capability
- New ISO Class 6 (1000) cleanroom (ISO class 5 (100) laminar flow unit)
- Microwave digestion and ashing systems for sample prep
- ICP-MS system moved to new lab and sample preparation and auxiliary systems commissioned Oct. 15
- System operating at design sensitivity



ICP-MS facility at UCL

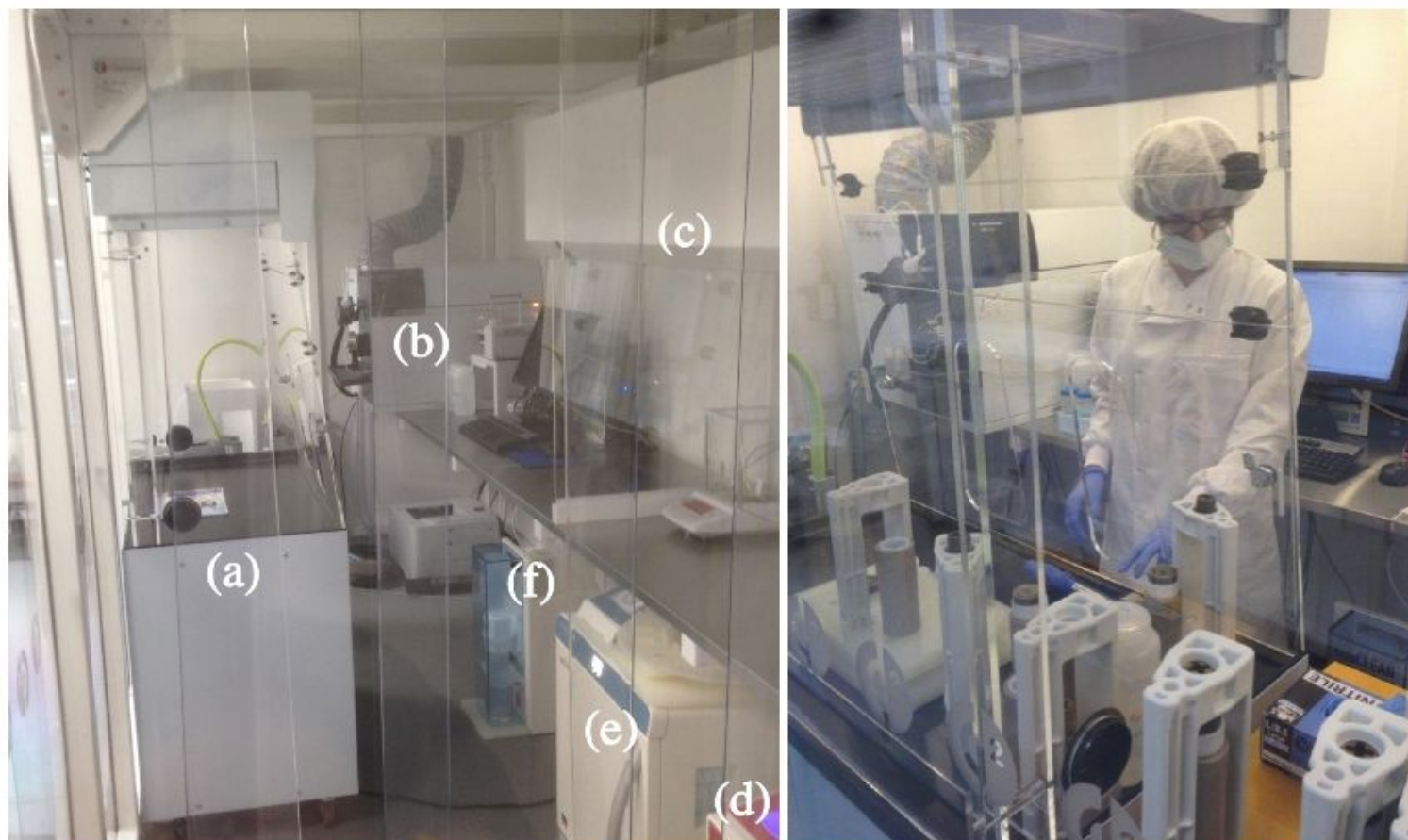
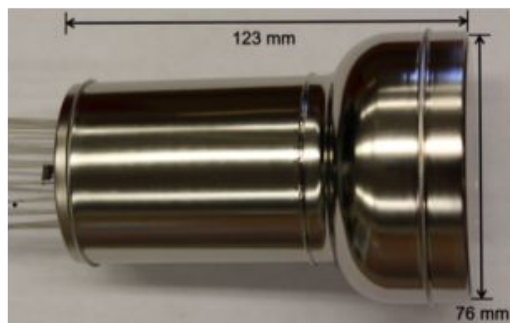


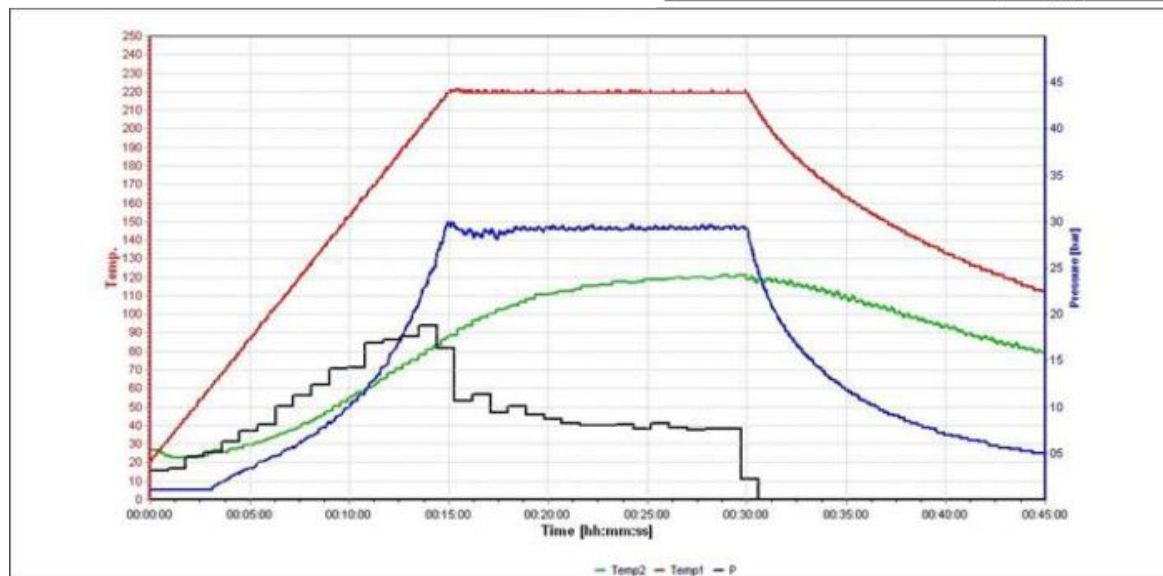
FIG. 1: *Left*: view of the ISO Class 6 cleanroom through changing room curtain showing the fume cupboard (a), Agilent 7900 ICP-MS (including integrated auto-sampler and control PC) (b), the class 5 laminar flow hood (c), the Milestone Pyro 260 microwave ashing (d) and ETHOS UP microwave digestion (e) systems, and the SubCLEAN subboiling distillation unit (f). *Right*: sample preparation in the fume cupboard, an unassembled TFMTM PTFE sample preparation vessel can be seen in the workstation jig.

- Microwave digestion (with D. Rowe, Milestones UK Product Manager at Analytix Ltd's facility)
 - High pressure reactors constructed from materials transparent to microwave
 - 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 material
- 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
$$(\text{CH}_2)\text{X} + \text{HNO}_3 \rightarrow \text{CO}_2(\text{g}) + \text{NOX}(\text{g}) + \text{H}_2\text{O}$$
 - HCl for Fe-based alloys due to ability to hold high chloro-complex in solution
 - HF acid used for decomposing silicates

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

- **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 H₂ line reaction capability
 - Microwave digestion and ashing closed, clean systems for sample prep
 - LZ construction material screening started
- **Radon** Required for ²²²Rn and ²²⁰Rn; backgrounds impervious to self-shielding
 - Radon emanation measurement capability to <90 μBq