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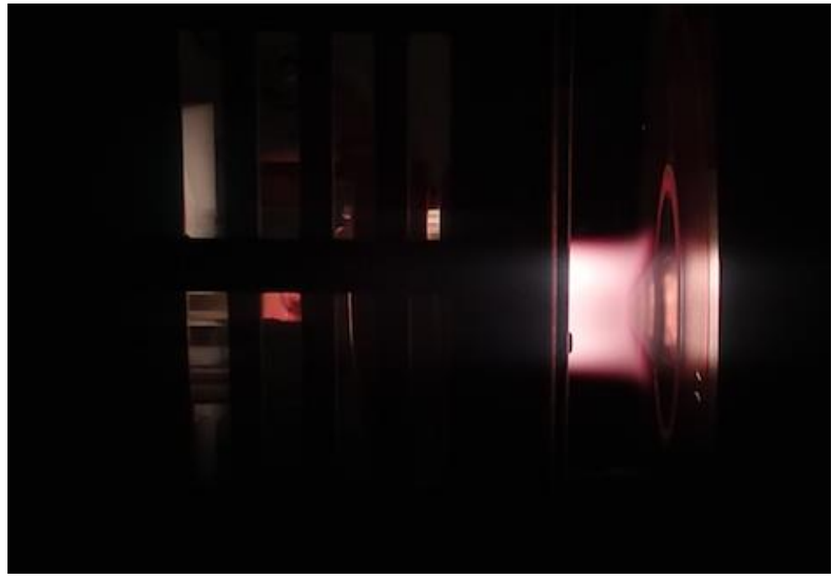
Study of surface contamination on ultralow background (ULB) materials

July 22, 2019

Maria Laura di Vacri

Low Background Lab Workshop

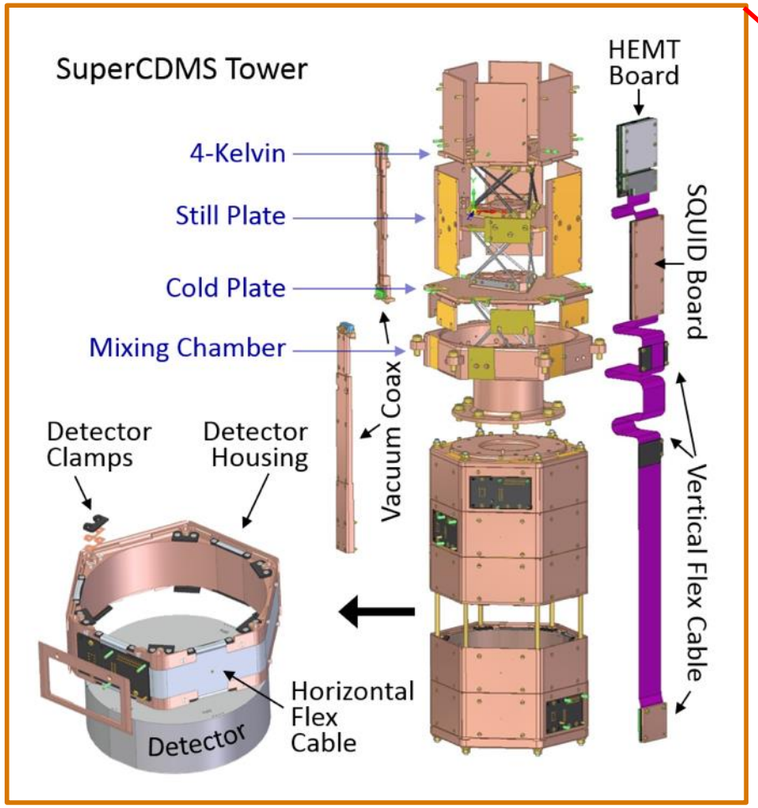


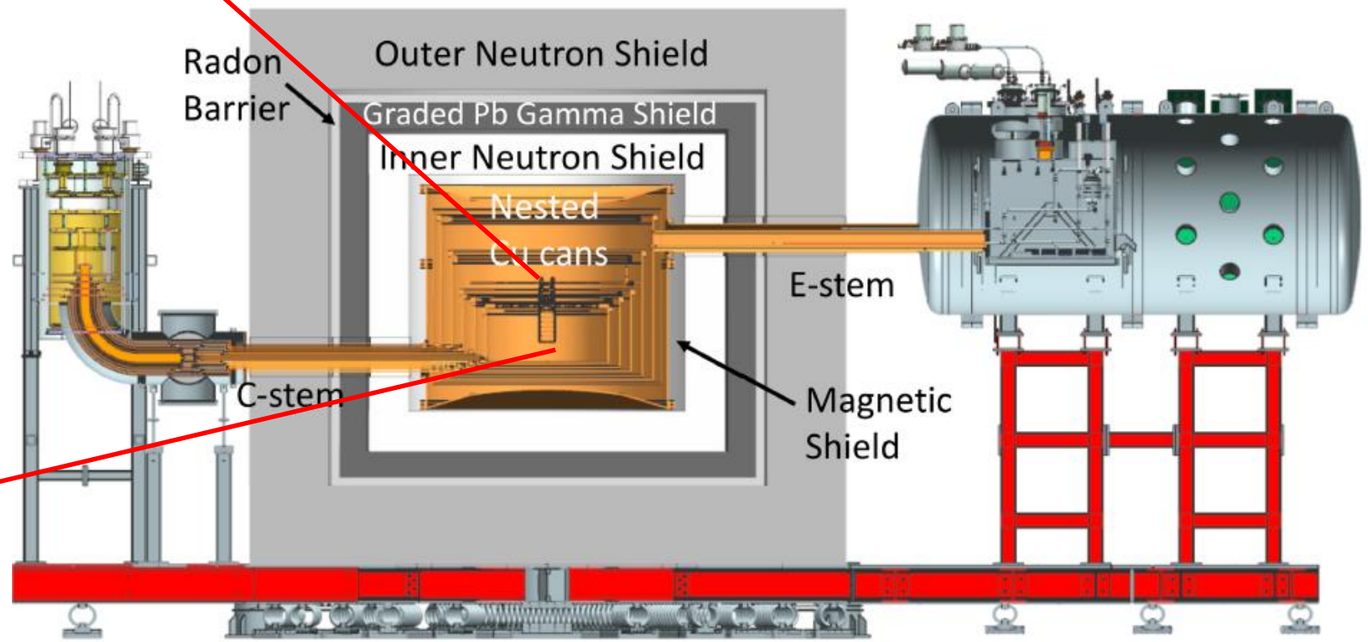
BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Detector components and surrounding materials: a significant background source

SuperCDMS SNOLAB detector





The usual suspects

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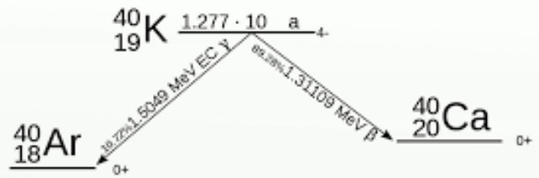
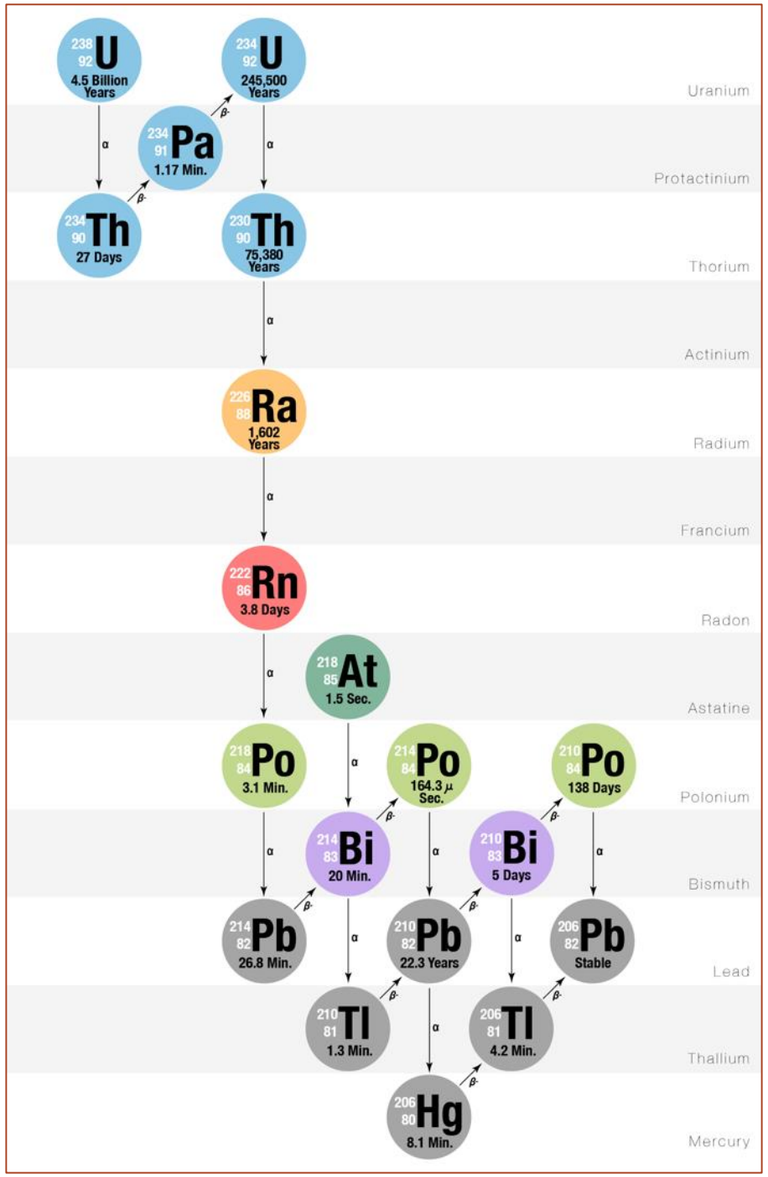
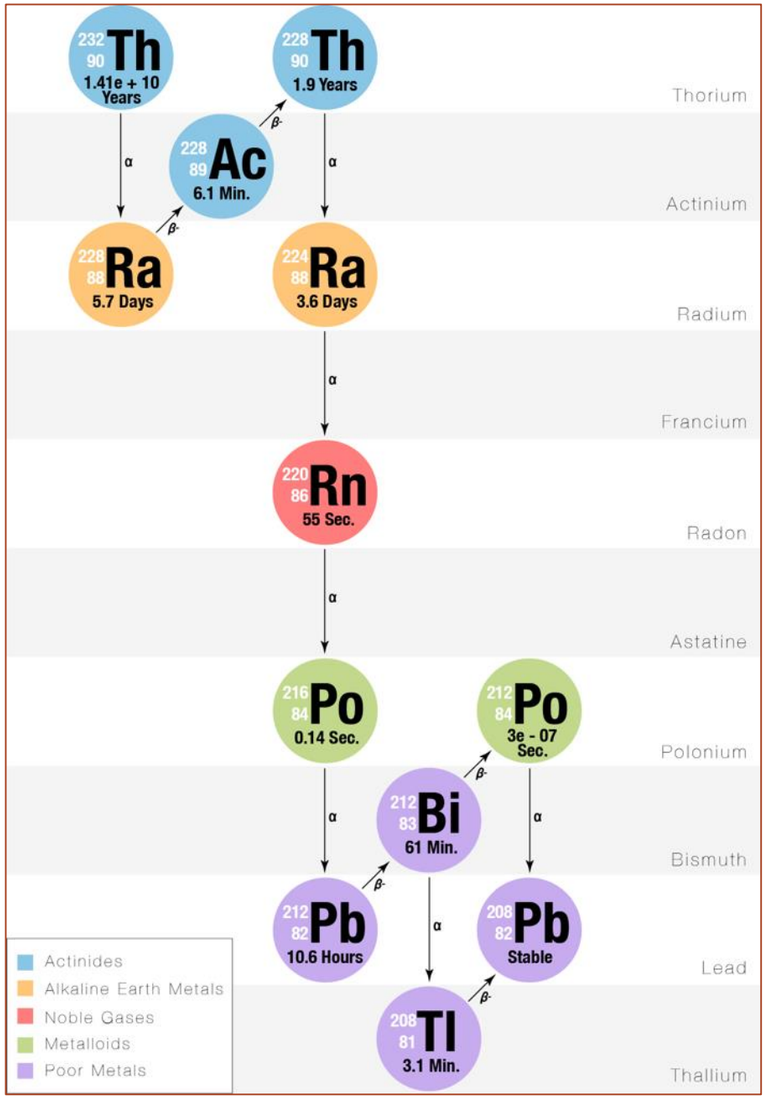
Potassium-40



Uranium-238

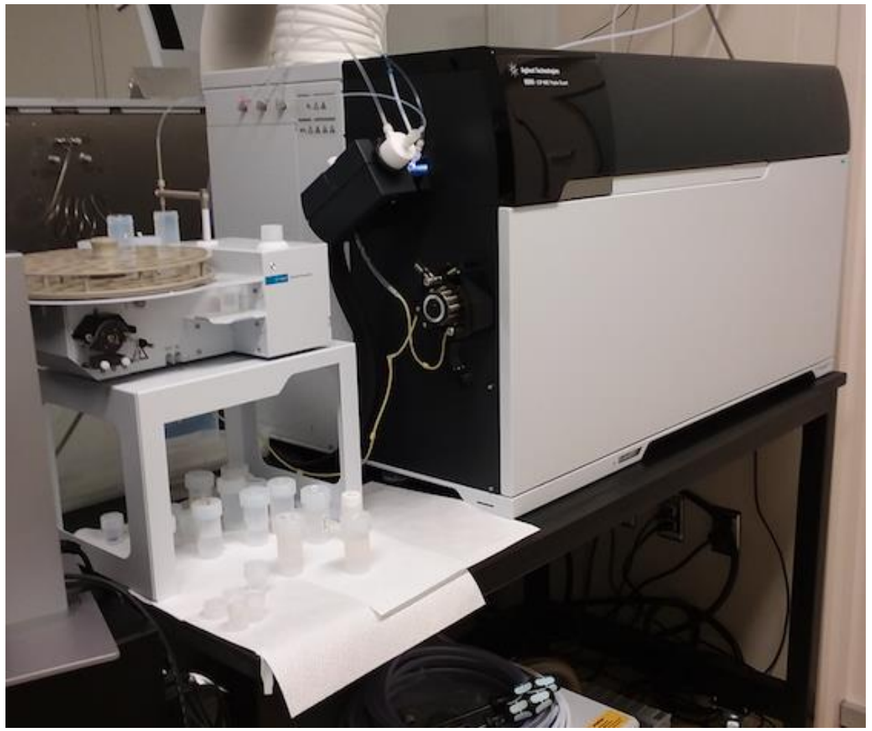


Thorium-232

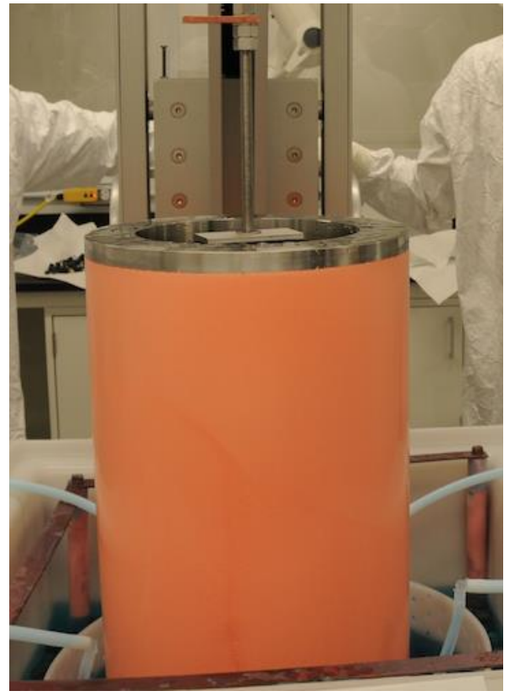


Validation of all materials: a challenging task

→ Extremely stringent radiopurity requirements



μBq/kg
range or lower



- Ultra sensitive analytical techniques
- Dedicated facilities
- Meticulously clean analytical procedure specifically developed
- R&D to develop ultrapure materials (*i.e.*, electroformed copper)

After validation, will materials remain “ultraclean” forever?

→ Surface contamination!

- Manufacturing and processing
- Handling for assembly
- Machining
- Moving and storage

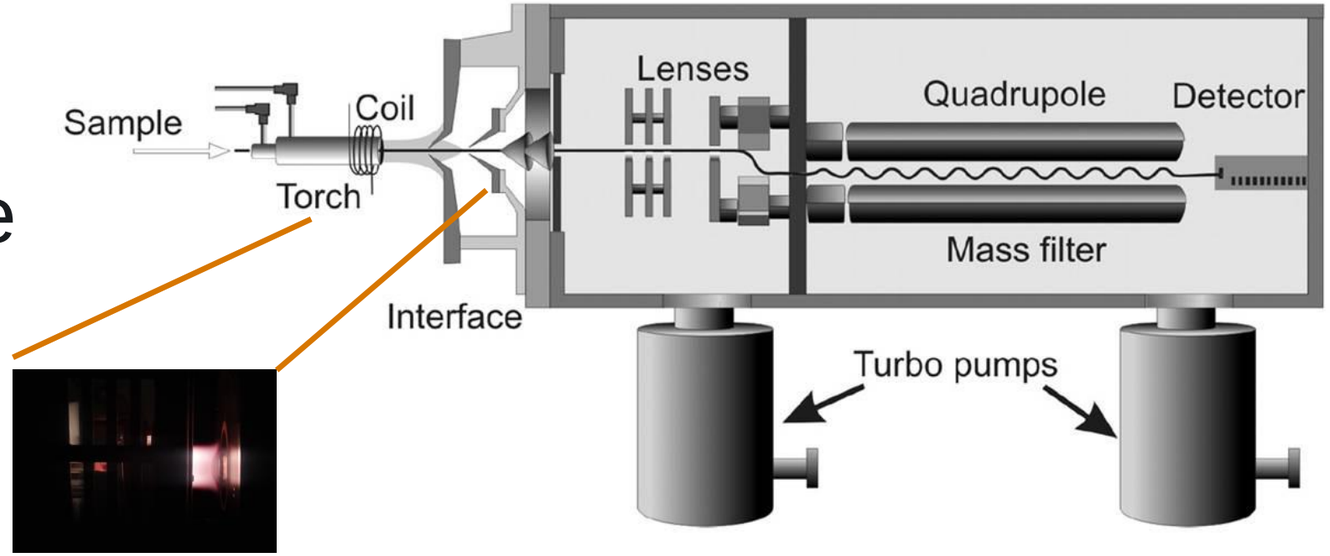
SCDMS detector components

MAJORANA DEMONSTRATOR detector components

- **Exposure to dust, even in clean rooms!**

ICP-MS: a powerful tool

- Direct, fast, quantitative
- Surface and bulk



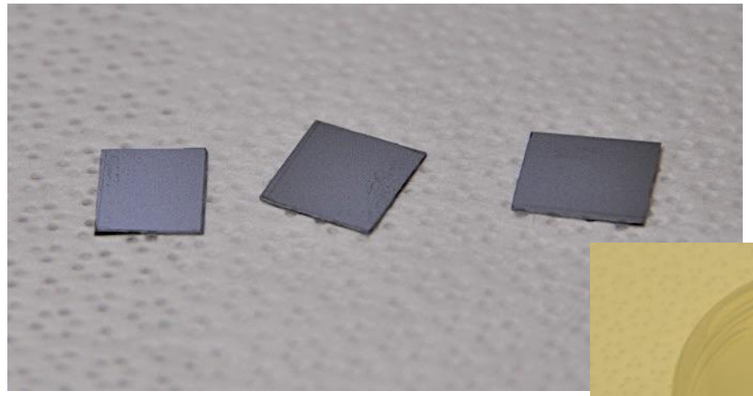
- **Understanding**
- **Identifying** rather than observing (too late!)
- **Quantifying** and **controlling**

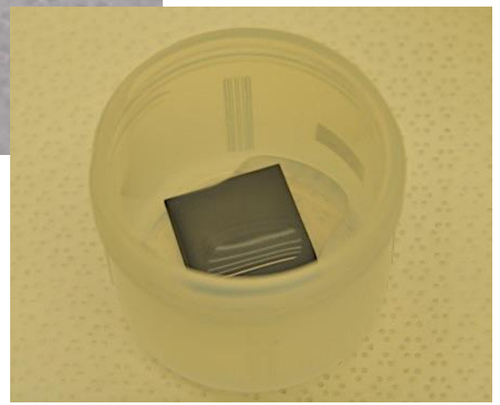
Exposure to dust: direct measurement of dust activity

- Surface exposure
- Surface leaching
- Quantitative analysis

PFA (Perfluoroalkoxy alkane)
Exposed surface ~ 7cm^2

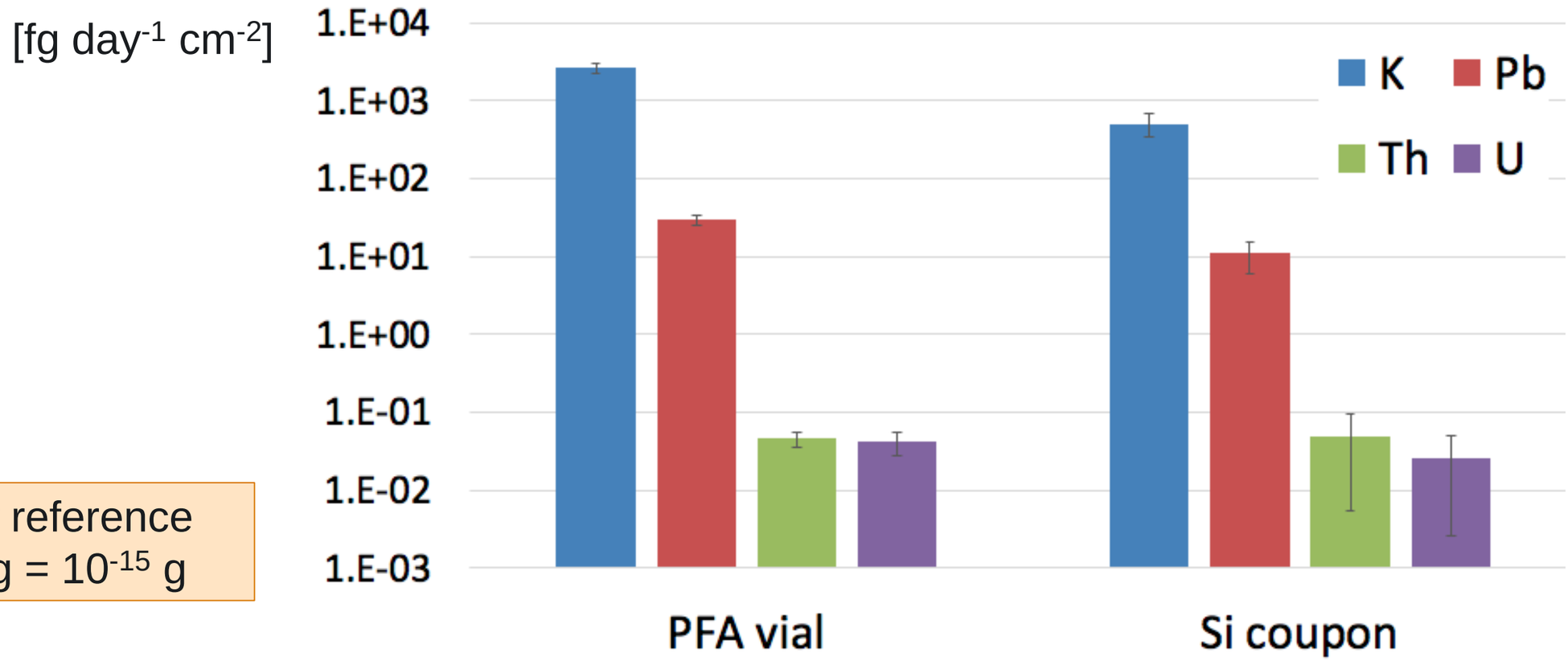
Silicon
Exposed surface ~5cm^2





Method validation

Accumulation rate on PFA and Si surfaces



For reference
1 fg = 10^{-15} g

Class 10000 clean room at PNNL, 29 day exposure

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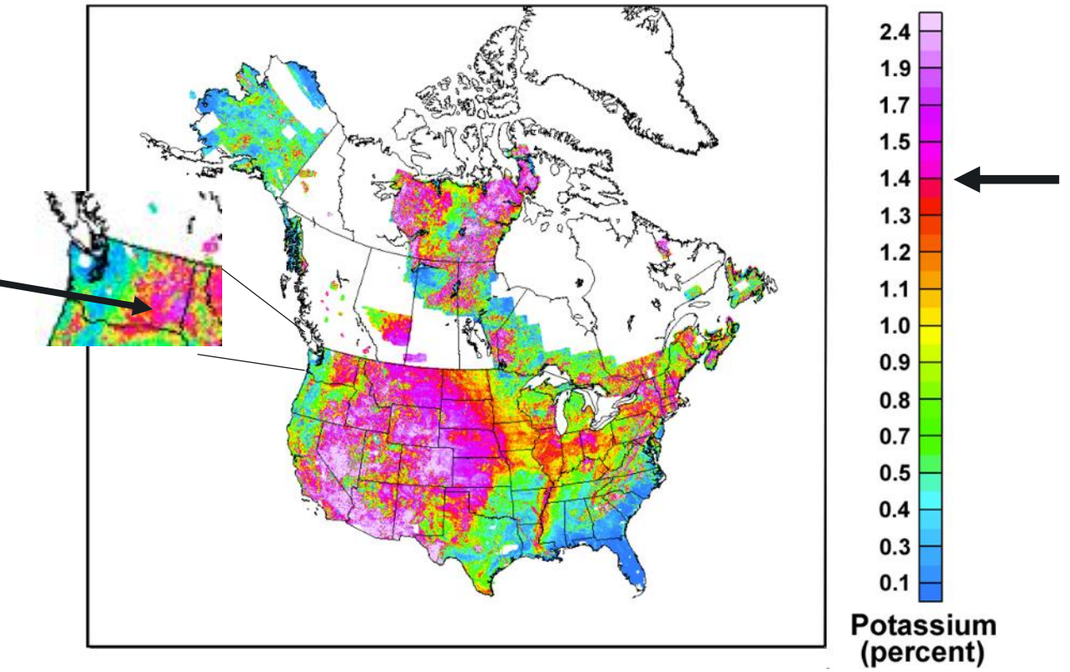
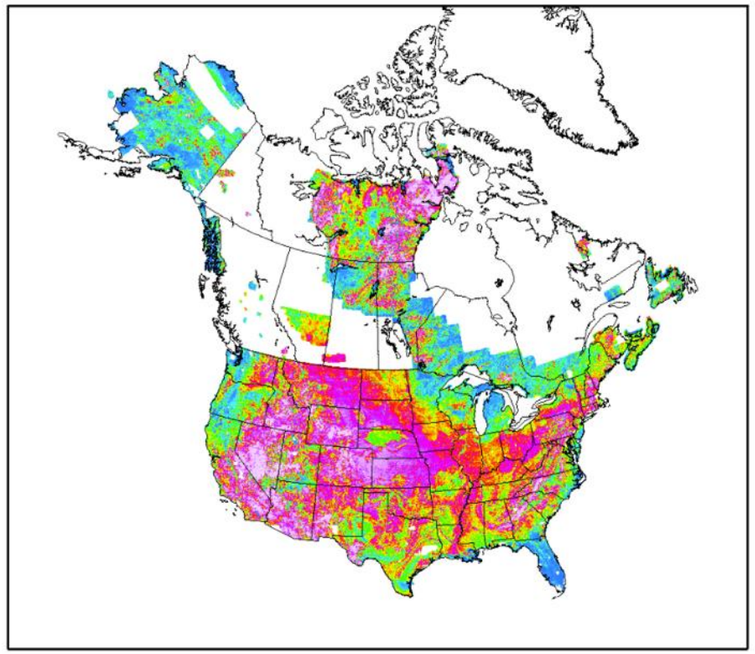
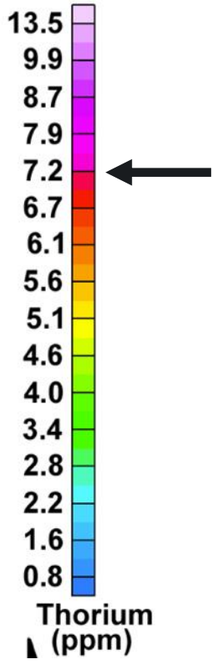
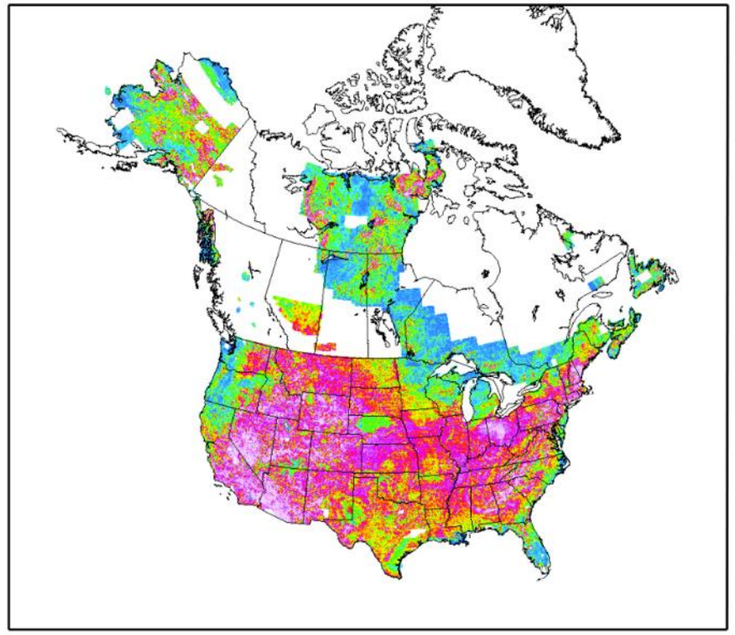
PNNL

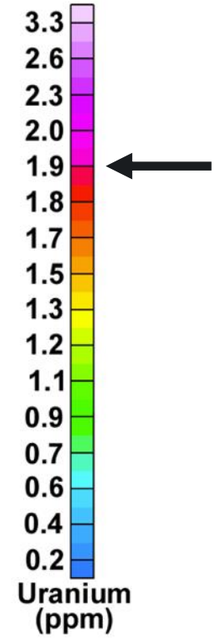


K ~ 1.4 E+4 ppm
Th ~ 7.2 ppm
U ~ 1.2 ppm





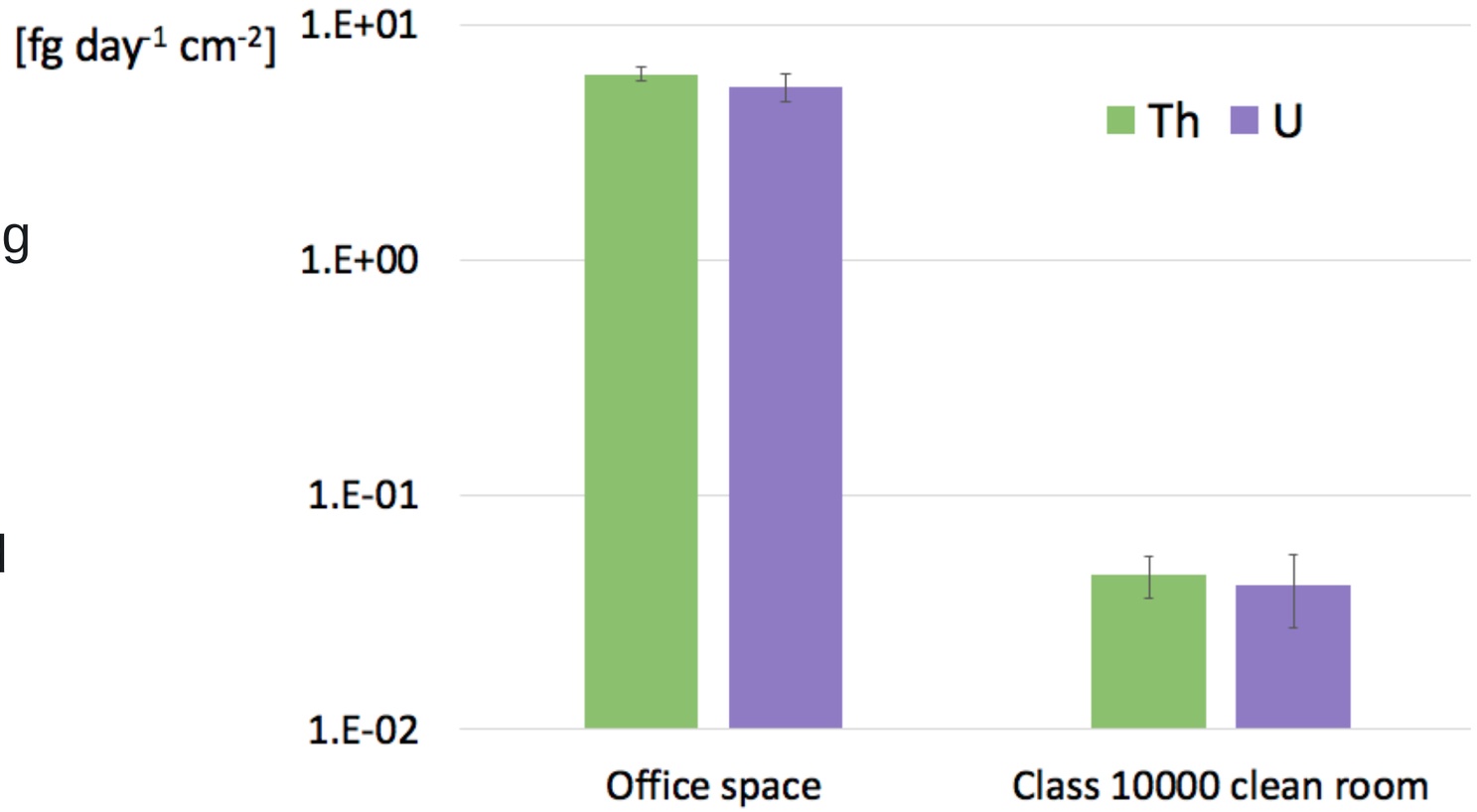




Source: https://pubs.usgs.gov/of/2005/1413/maps.htm

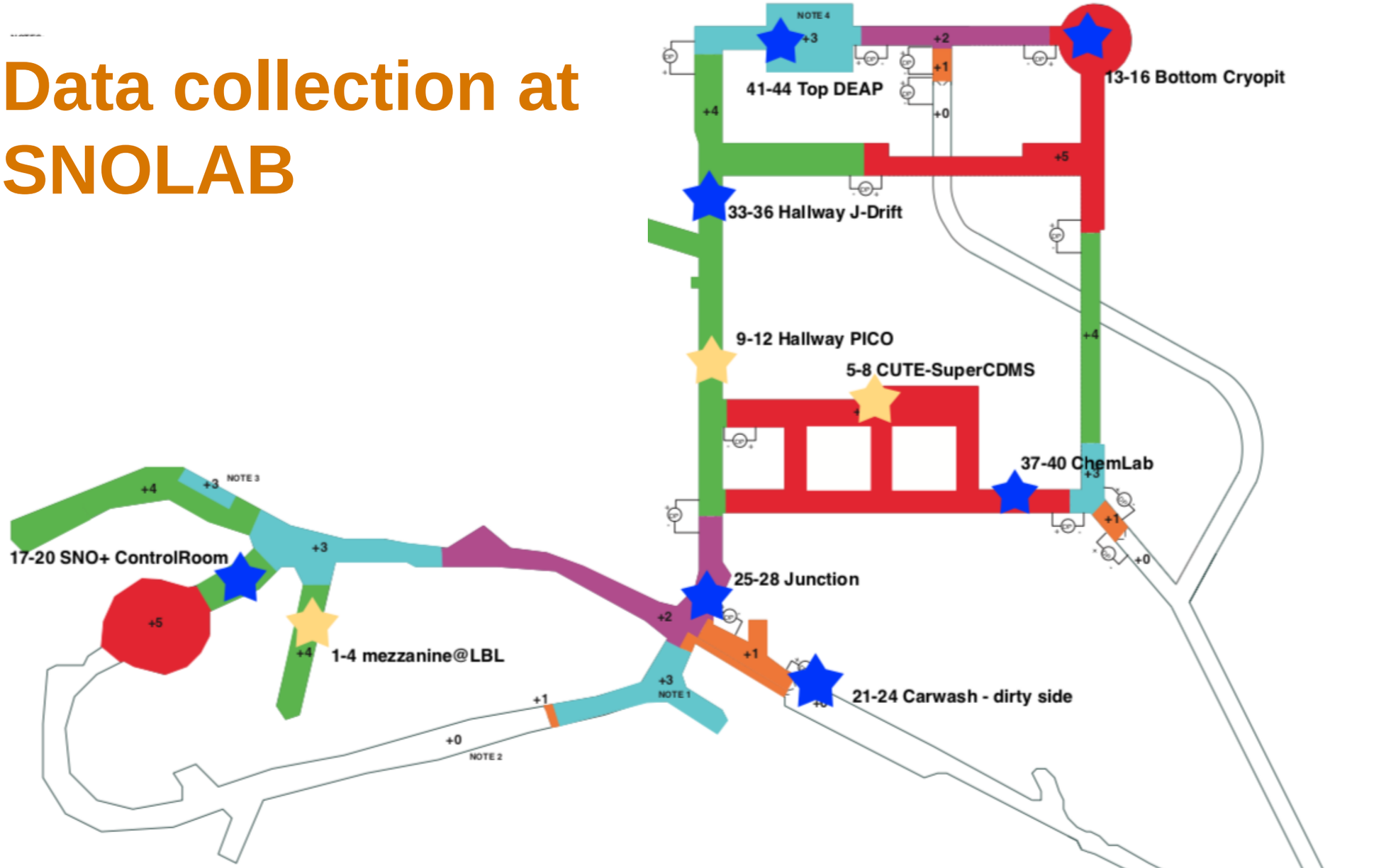
Room air – Class 10000 clean room comparison

- Accumulation rate scaling of 100X, as expected
- Exposure in a Class 10 area (30 days) : instrumental background level



PFA surface, 30 day exposure

Data collection at SNOLAB



42 days exposure in all locations, except *Bottom cryopit* and *top DEAP* locations → 50 day exposure

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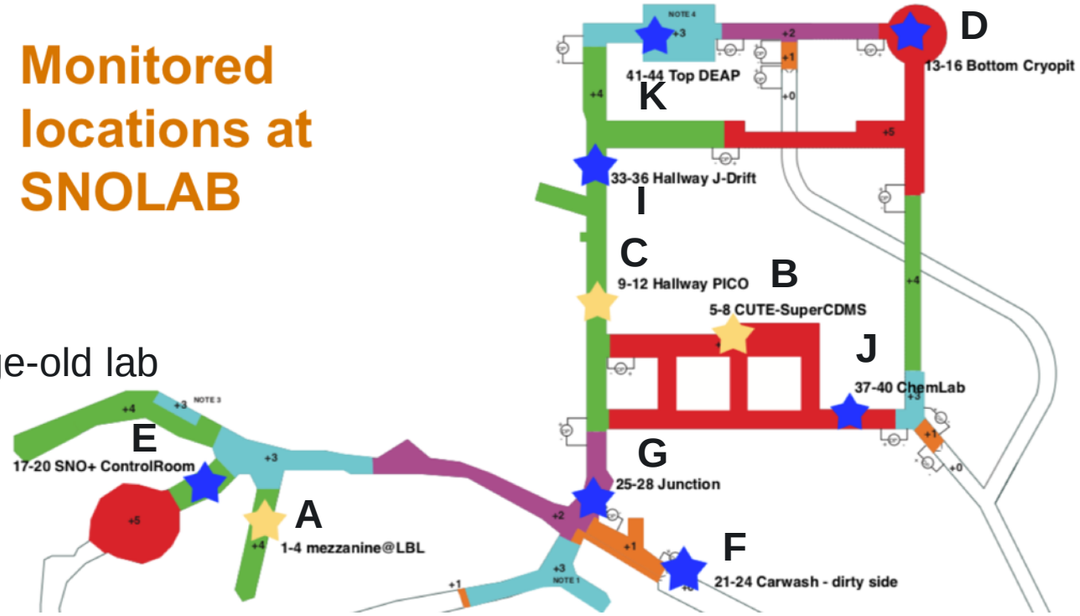
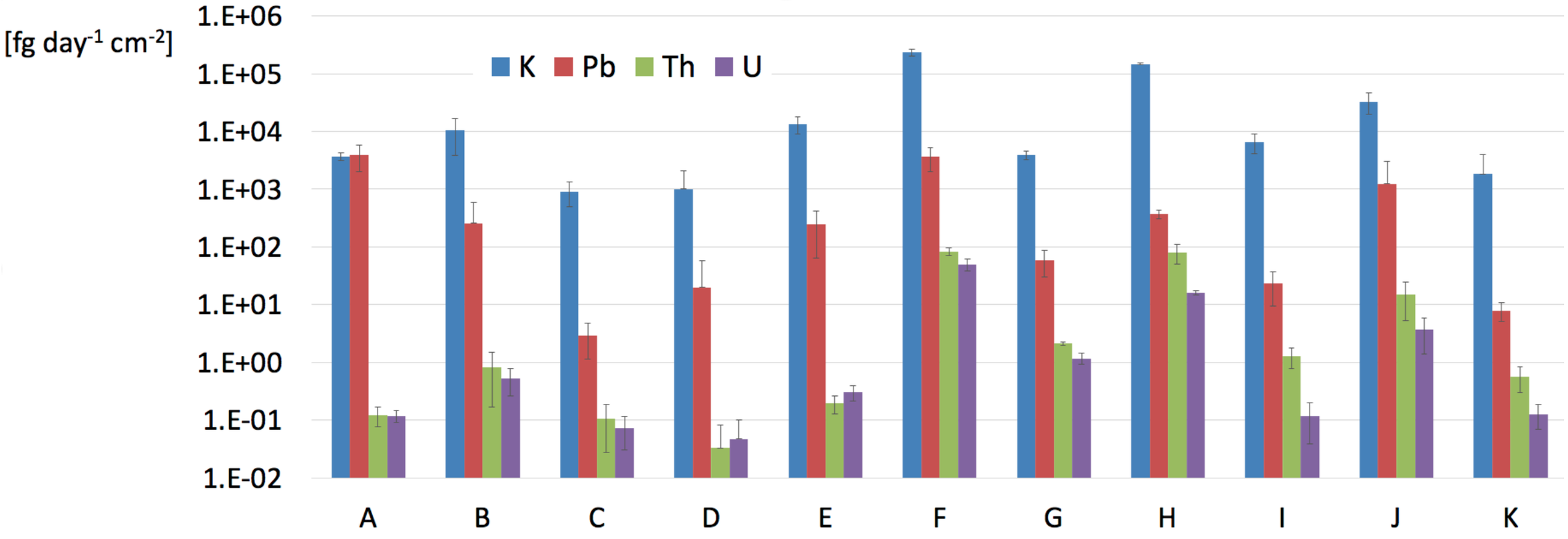
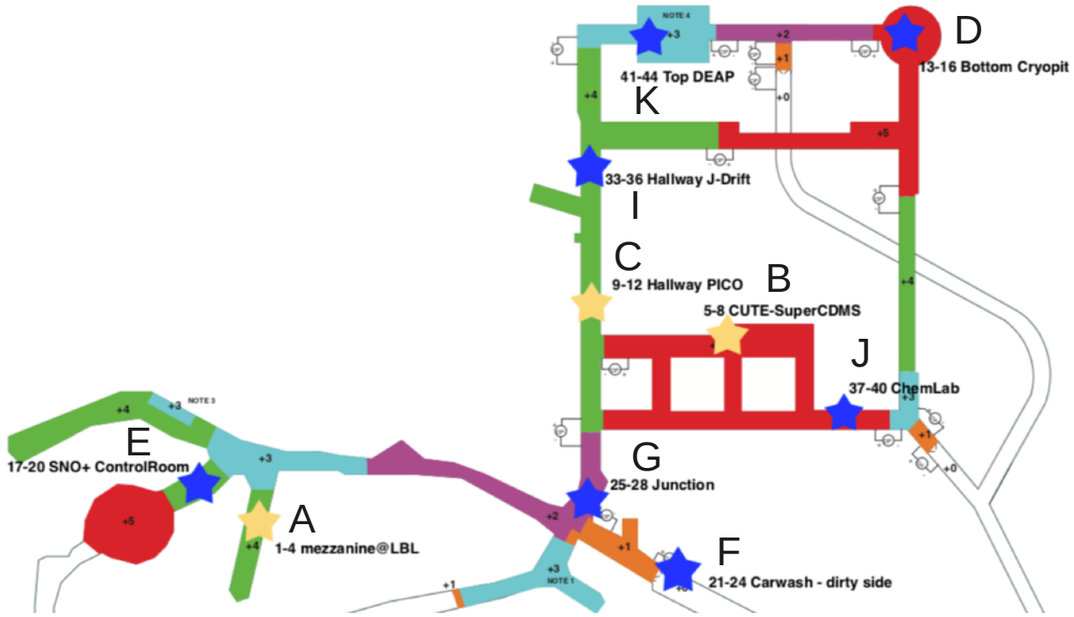
A: Mezzanine at LBL on desk
B: Close to dust monitor in SCDMS area
C: Hallway close to PICO @ 2.5m
D: Bottom of cryopit (quiet area) on desk
E: SNO+ control room
F: Dirty side of the carwash
G: Close to dust monitor in junction carwash-refuge-old lab
H: Surface building at 3rd floor
I: Hallway drift at 2.5m
J: Chem lab on top of cabinet
K: Top of the stairs entering the DEAP area

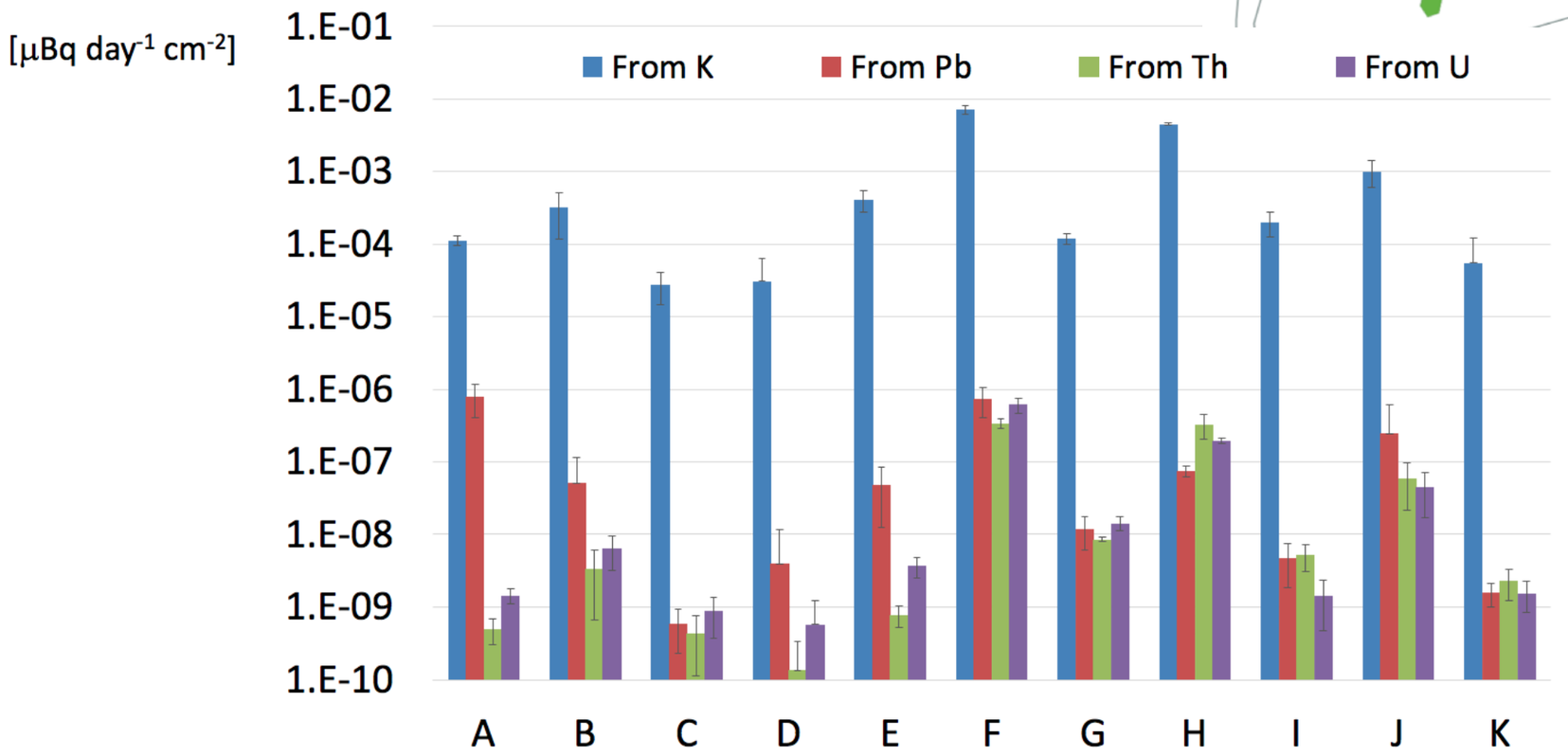
Monitored locations at SNOLAB





In terms of radioactivity

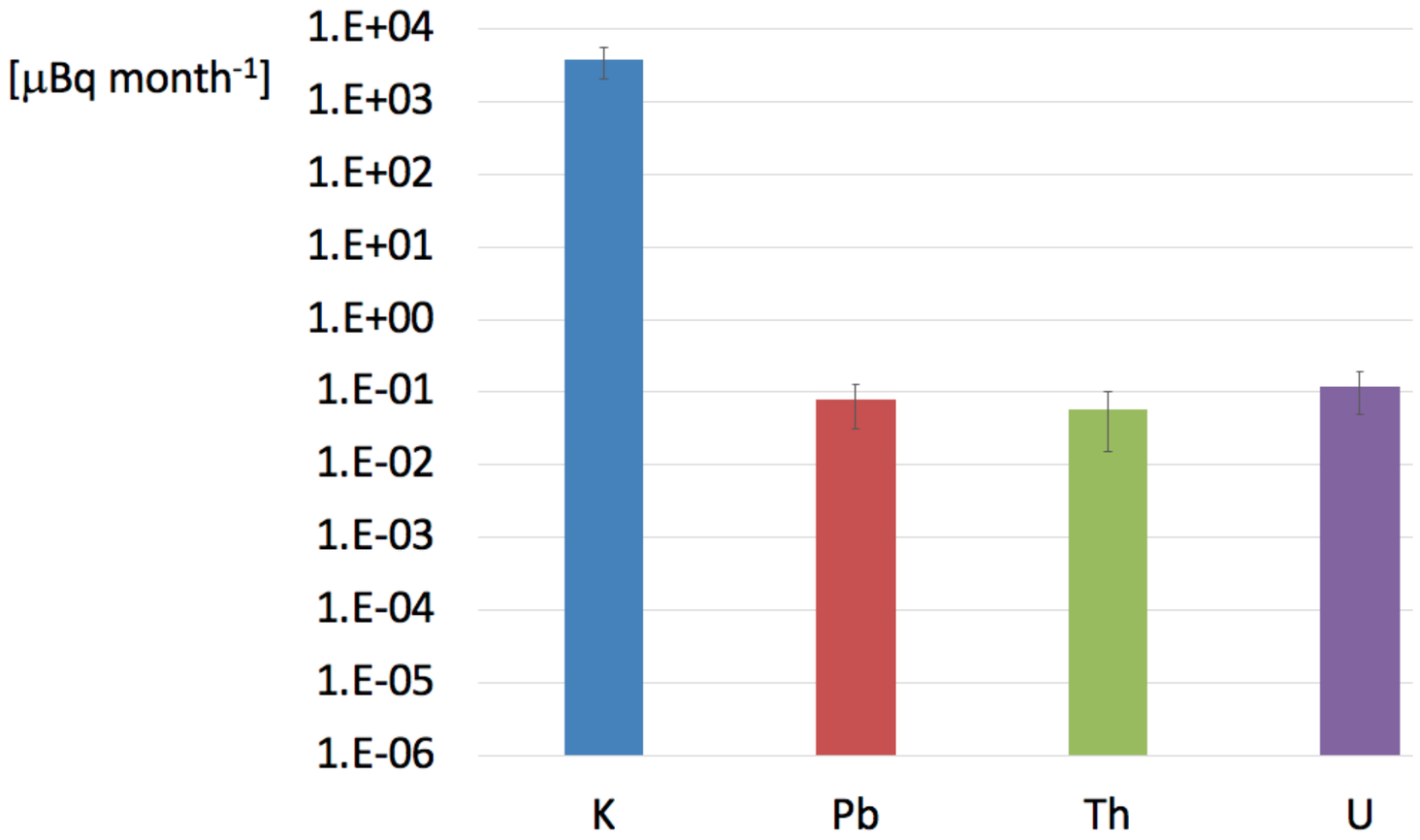


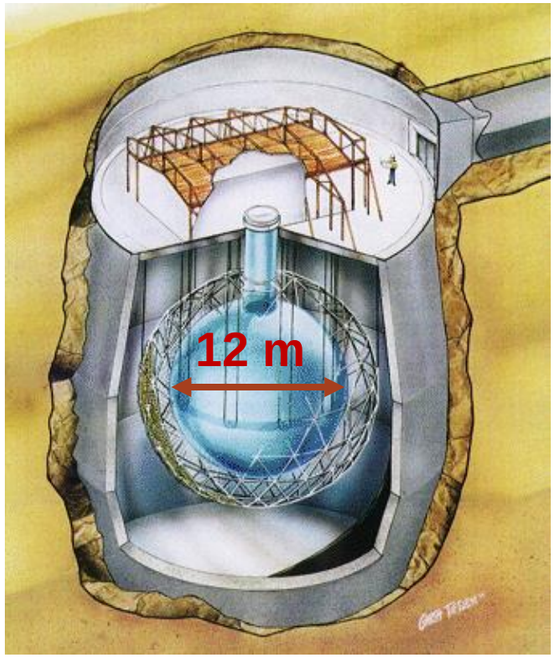


Nat Pb activity 200Bq/kg from A.Alessandrello et al./Nucl. Instr. And Meth. In Phys. Res. B 142 (1998) 163-172

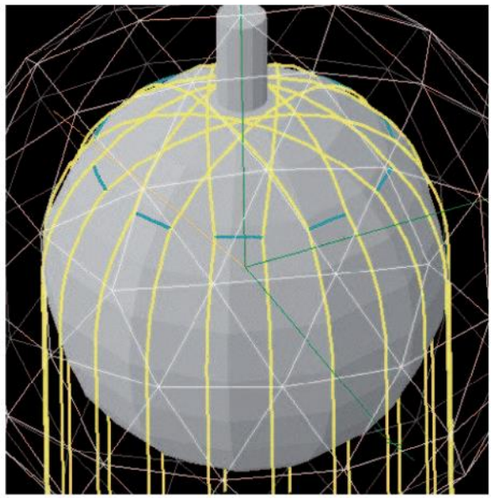
A large component: the acrylic vessel from the SNO+ detector

- 30 days, SNOLAB location C (Hallway close to PICO)





SNO+ detector

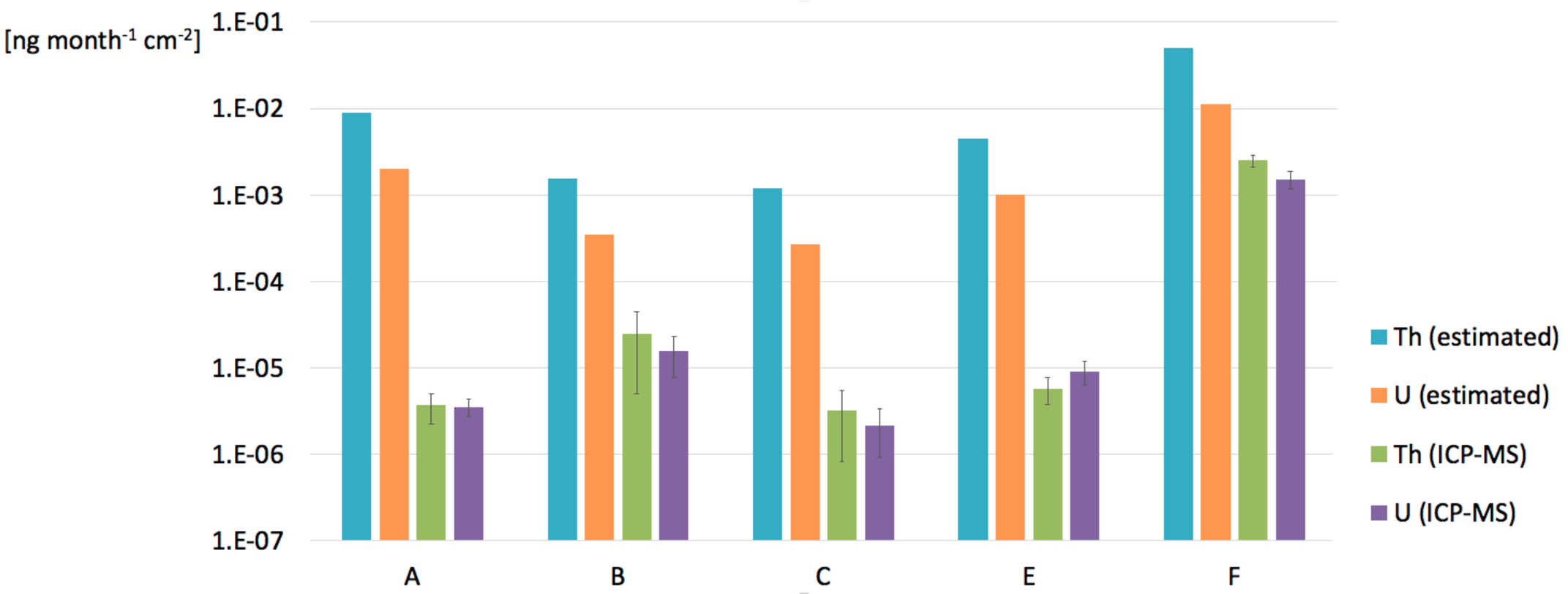


The acrylic vessel

Th & U accumulation from mine dust: Estimated* (Fe, XRF) vs measured (ICP-MS)

***SNOLAB-STR-2007-003**
Fe/Th = 1.1E+4
Fe/U = 4.9E+4

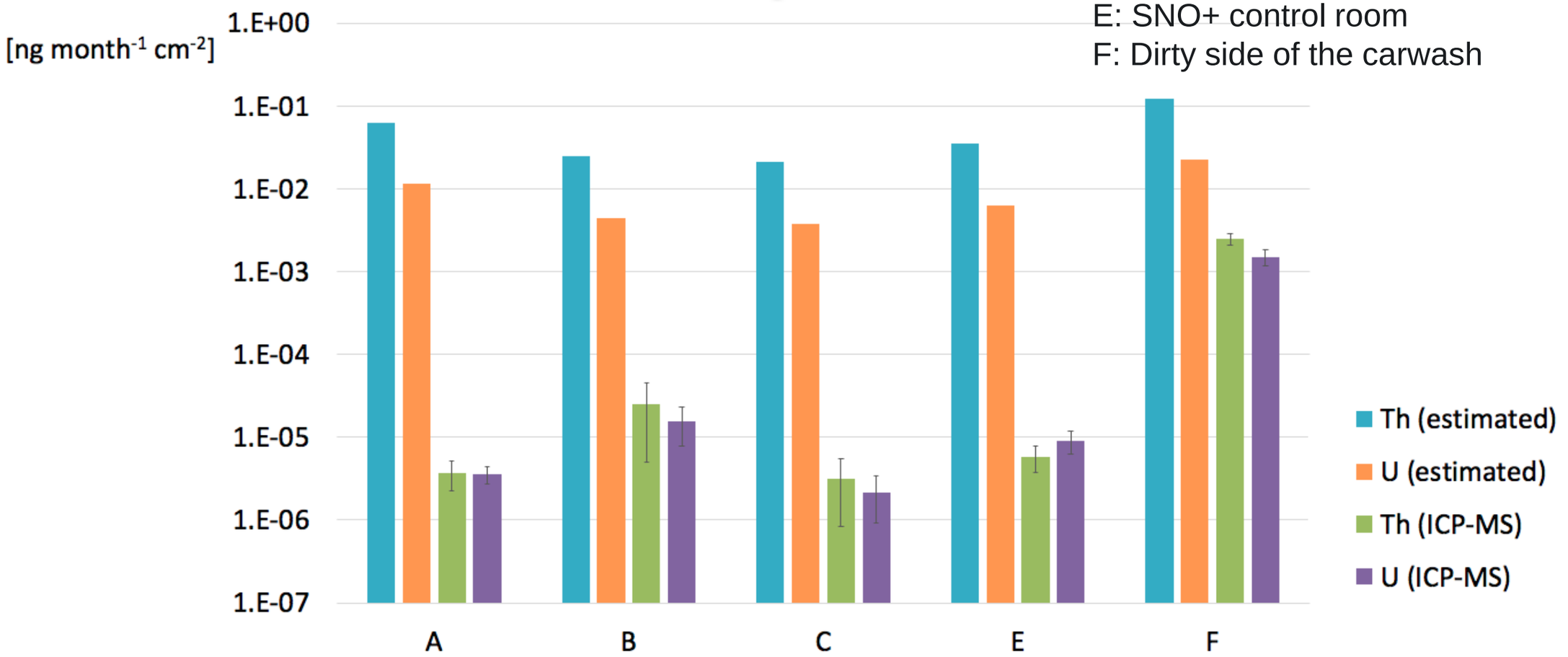
A: Mezzanine at LBL on desk
B: Close to dust monitor in SCDMS area
C: Hallway close to PICO @ 2.5m
E: SNO+ control room
F: Dirty side of the carwash



Th & U accumulation from concrete: Estimated* (Ca, XRF) vs measured (ICP-MS)

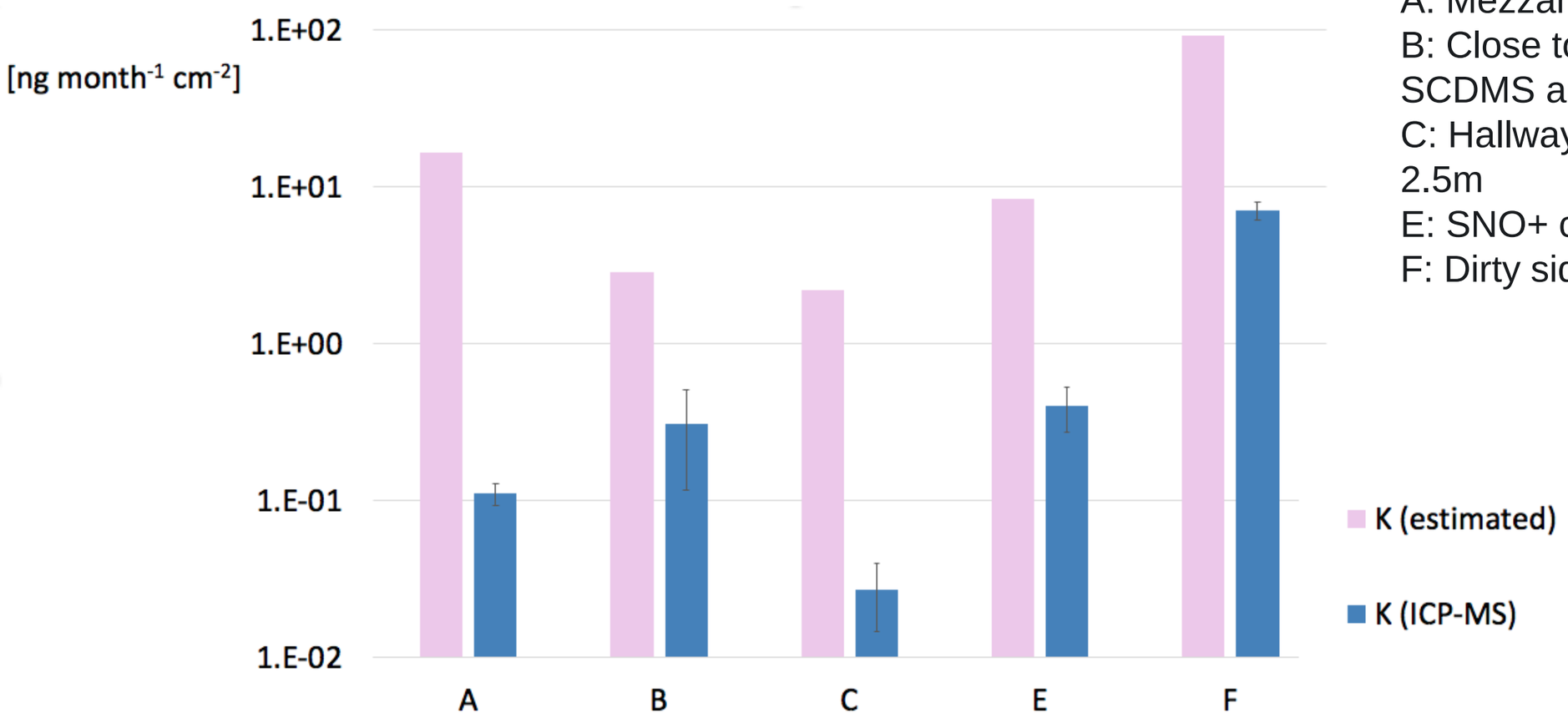
***SNOLAB-STR-2007-003**
Ca/Th = 7.7E+3
Ca/U = 4.2E+4

A: Mezzanine at LBL on desk
B: Close to dust monitor in SCDMS area
C: Hallway close to PICO @ 2.5m
E: SNO+ control room
F: Dirty side of the carwash



K accumulation from mine dust: Estimated* (Fe, XRF) vs measured (ICP-MS)

***SNOLAB-STR-2007-003**
Fe/K = 6.56 (rock)

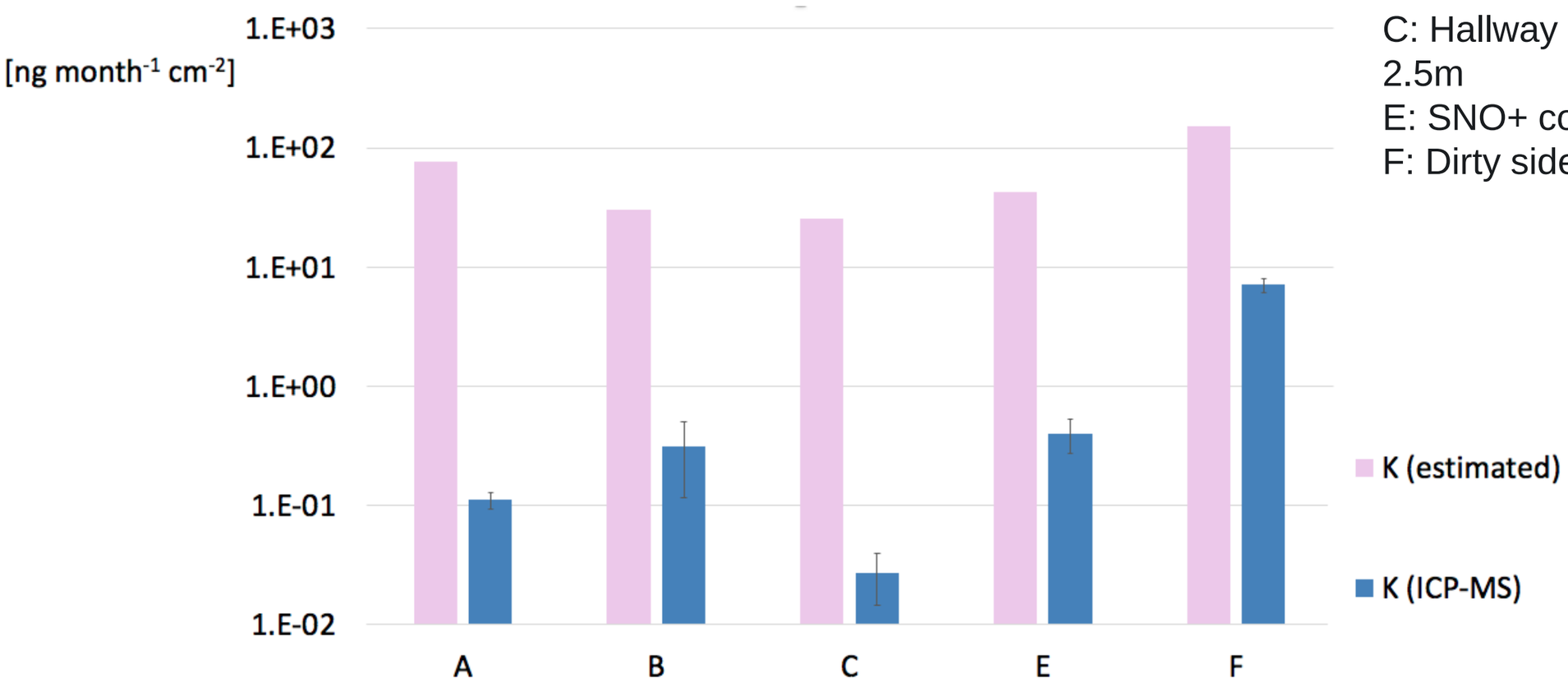


A: Mezzanine at LBL on desk
B: Close to dust monitor in SCDMS area
C: Hallway close to PICO @ 2.5m
E: SNO+ control room
F: Dirty side of the carwash

K accumulation from concrete: Estimated* (Ca, XRF) vs measured (ICP-MS)

***SNOLAB-STR-2007-003**
Ca/K = 6.27 (concrete)

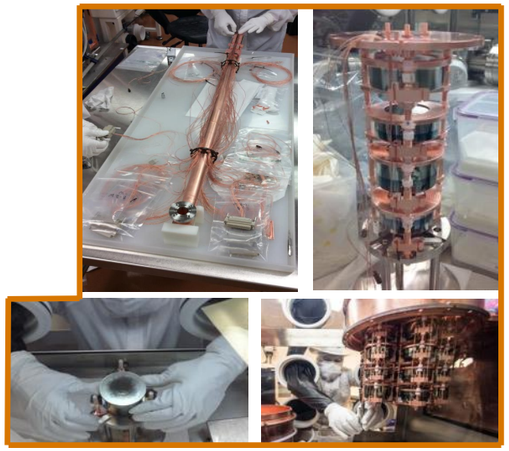
A: Mezzanine at LBL on desk
B: Close to dust monitor in SCDMS area
C: Hallway close to PICO @ 2.5m
E: SNO+ control room
F: Dirty side of the carwash



Summary

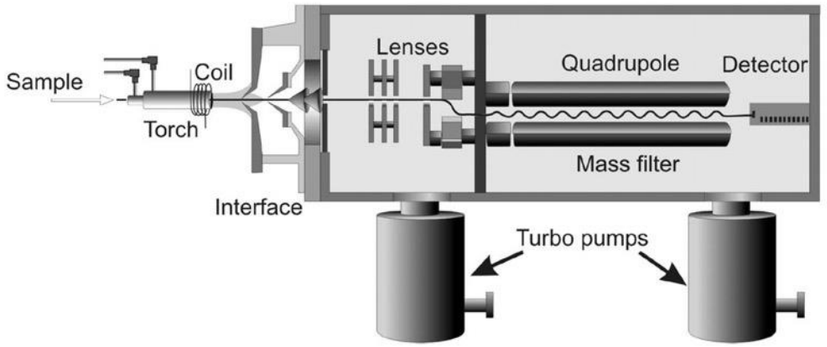
- **Dust contribution to surface contamination**
  - Limiting
  - Inferred, estimated, assumed

SCDMS detector components

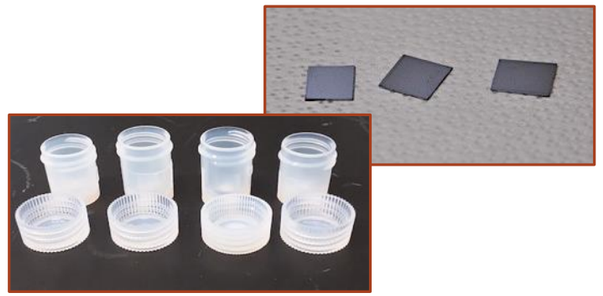


MAJORANA DEMONSTRATOR detector components

- **ICP-MS**
  - Rapid, direct identification and quantitation
  - Ultra sensitive
  - Bulk + **surface analysis**



- **First direct measurement of deposition rate of contamination from dust**
  - Actual direct measurement not matching predictions
  - Informing backgrounds



How can we support ULB detectors?

- **Contribution to contamination from exposure to dust (even in clean rooms!)**
  - First direct measurement
  - Qualitative and quantitative
- **Study of contribution in significant locations**
  - Valuable for planning detector assembly and installation
- **Study of contribution variation with ongoing activities**
- **Measurement not limited to K Pb Th U!**
  - ICP-MS potential analysis of almost all the periodic table
  - Forensic: identification of the contamination source
  - Finger print of unwanted contamination carriers

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Thank you

Sonia Alcantar
Khadouja Harouaka

DOE Detector R&D for High Energy Physics (KA-25)

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BACK UP SLIDES

From SNOLAB-STR-2007-003

Element	Detection Limit (ppm)	Rock Sample 8 (ppm)	Rock Sample 11 (ppm)	Shotcrete Sample 15 (ppm)	Concrete Sample 14 (ppm)
Th	0.02	5.54	5.19	14.9	13.1
U	0.005	1.21	1.14	2.56	2.38

Table 2: The ICP-MS results for each measured element in ppm. Note that N.D. is used if the element was not detected.

Element	Detection Limit (ppm)	Rock Sample 8 (%)	Rock Sample 11 (%)	Shotcrete (%)	Concrete (%)
Al	100	6.01	6.43	6.04	5.86
Ca	90	3.43	3.80	9.54	10.10
Fe	200	6.37	6.68	2.54	2.61
K	30	0.97	1.02	1.76	1.61

Table 3: The ICP-AES results for Al, Ca, Fe, K, Mg, Mn and Na. The WD-XRF results for silicon and the gamma-ray spectroscopy results for H, C and O.

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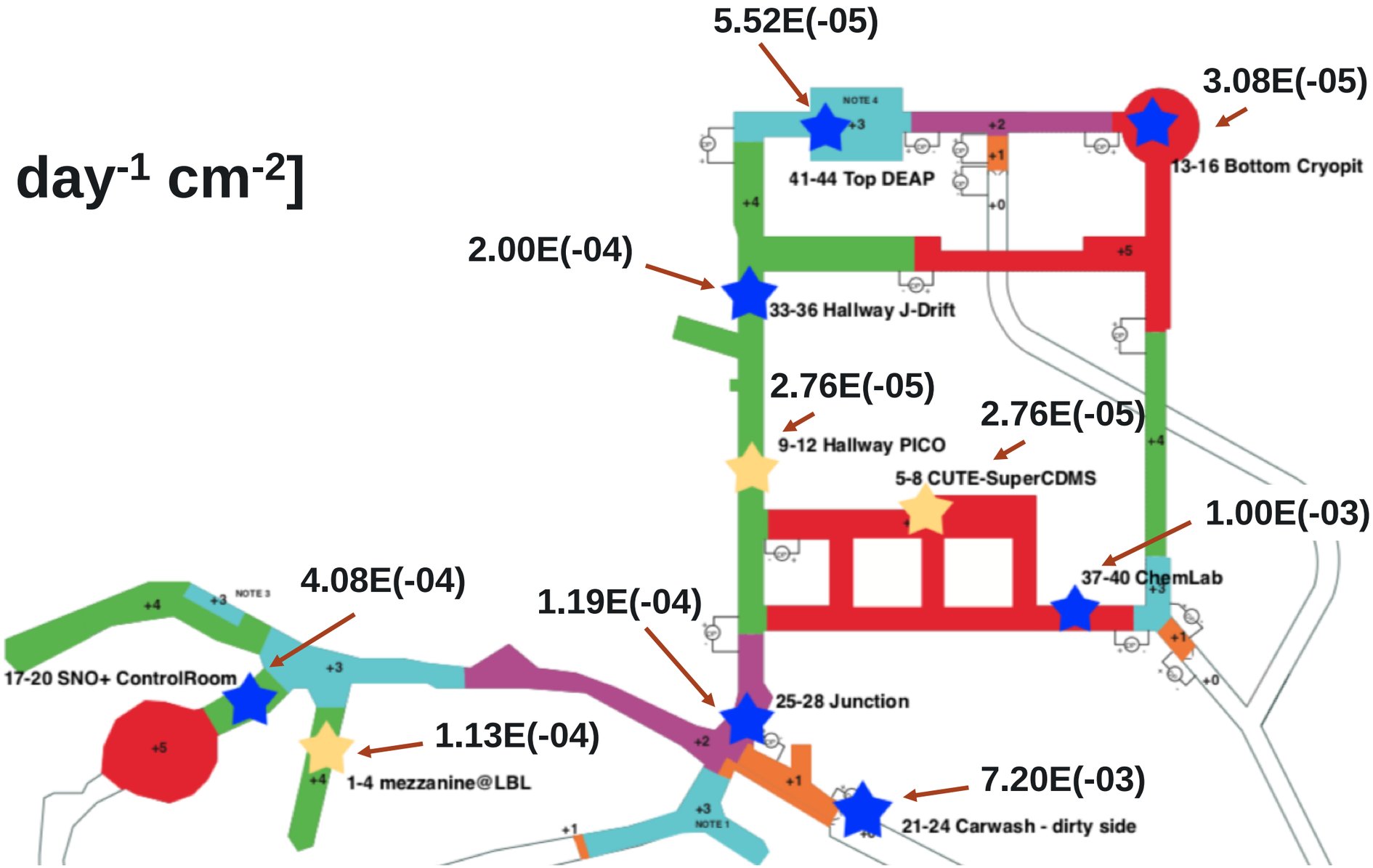
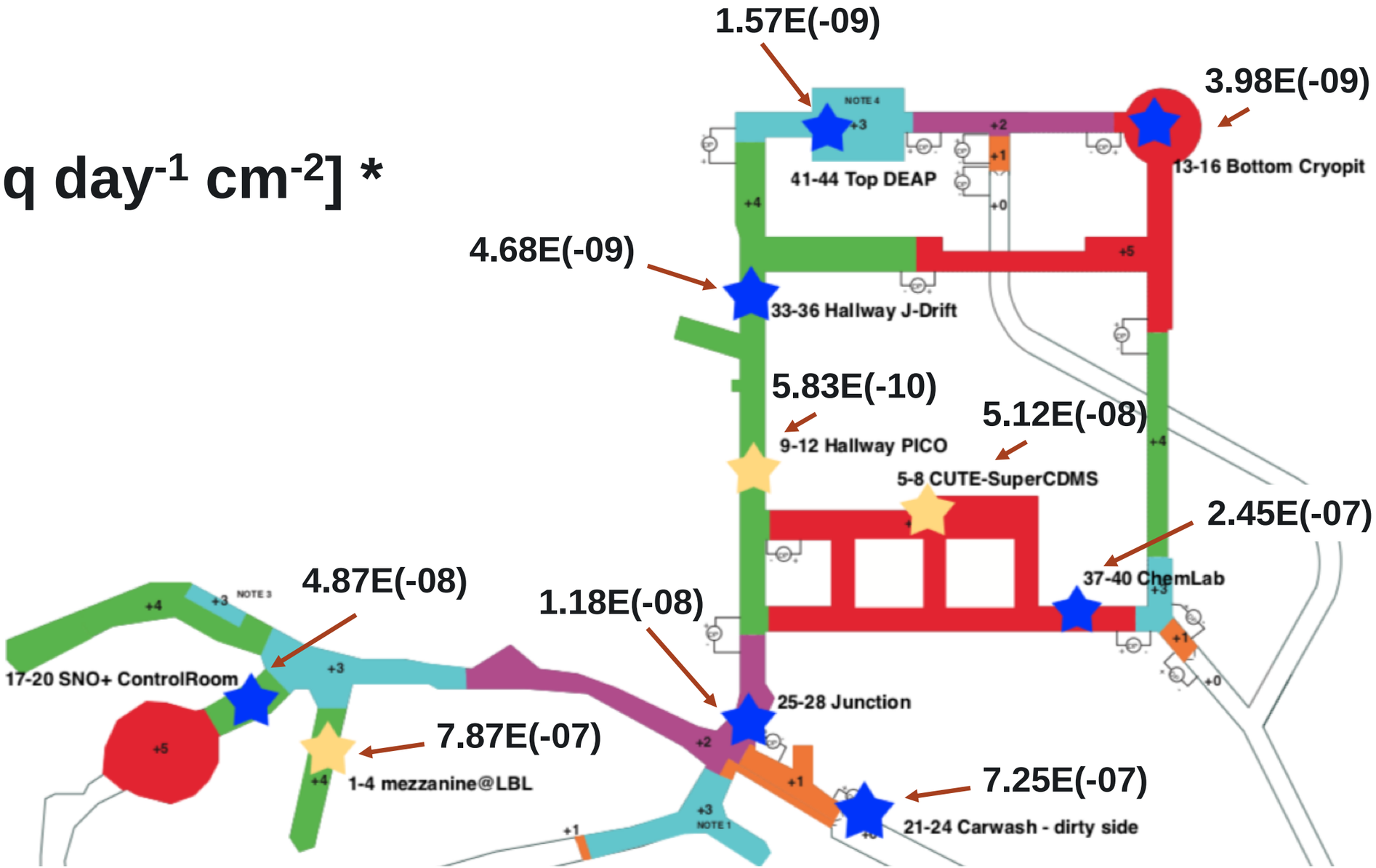
K [μBq day^{-1} cm^{-2}]

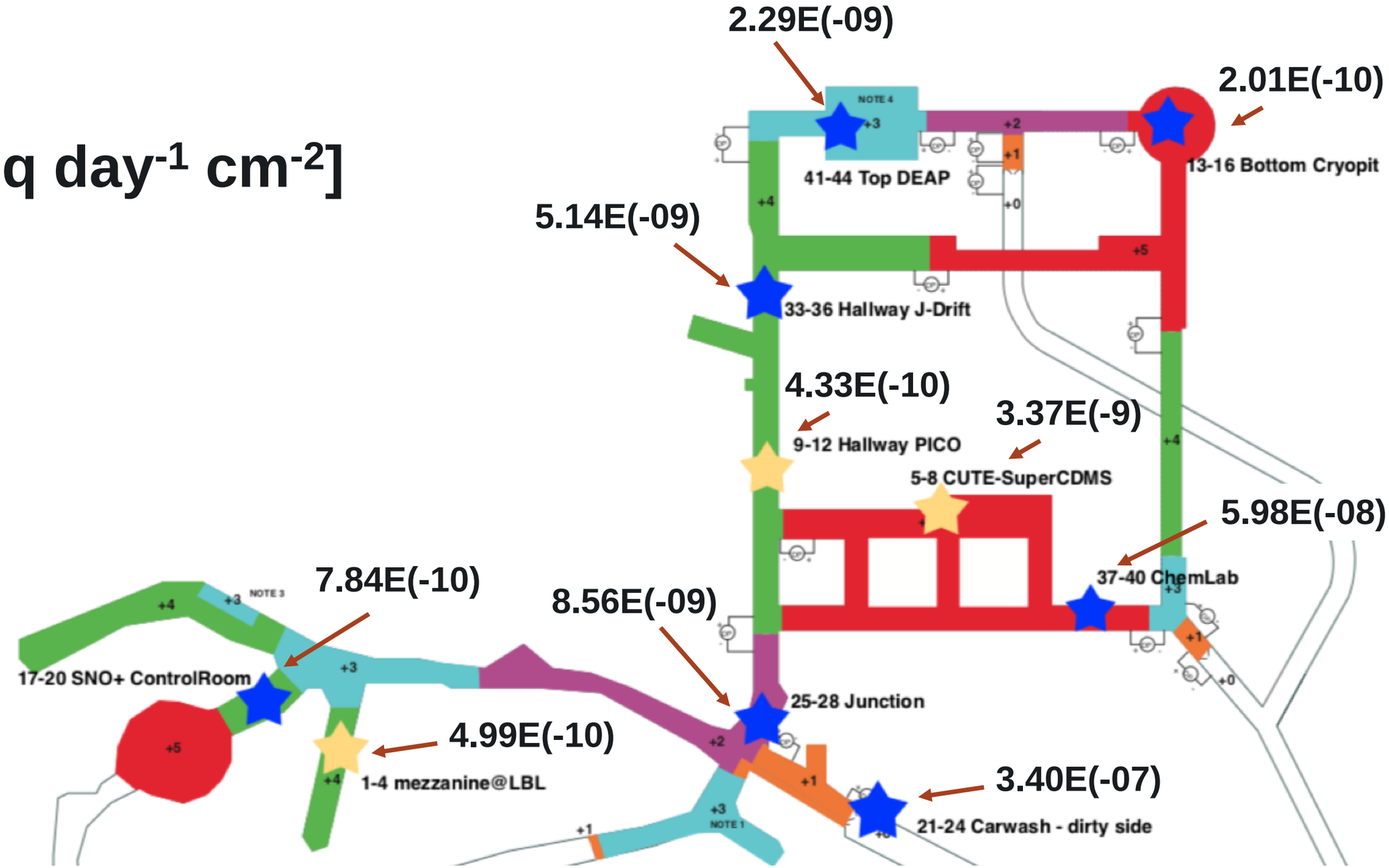


Pb [μBq day^{-1} cm^{-2}] *



* Nat Pb activity from A.Alessandrello et al./Nucl. Instr. And Meth. In Phys. Res. B 142 (1998) 163-172

Th [μBq day^{-1} cm^{-2}]



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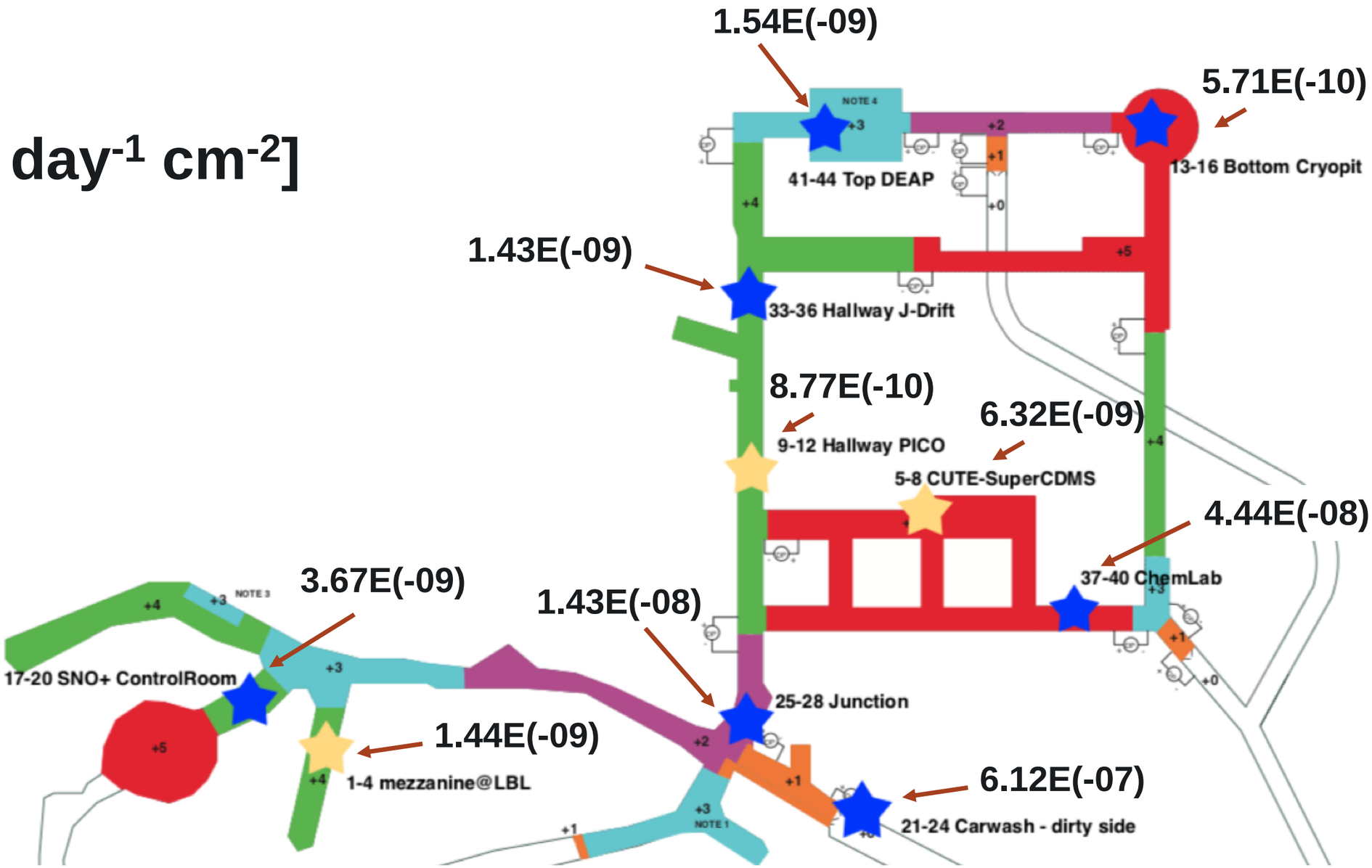
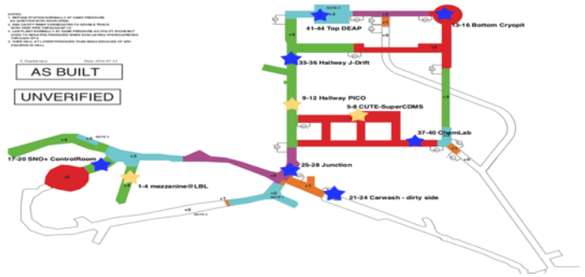
U [μBq day^{-1} cm^{-2}]



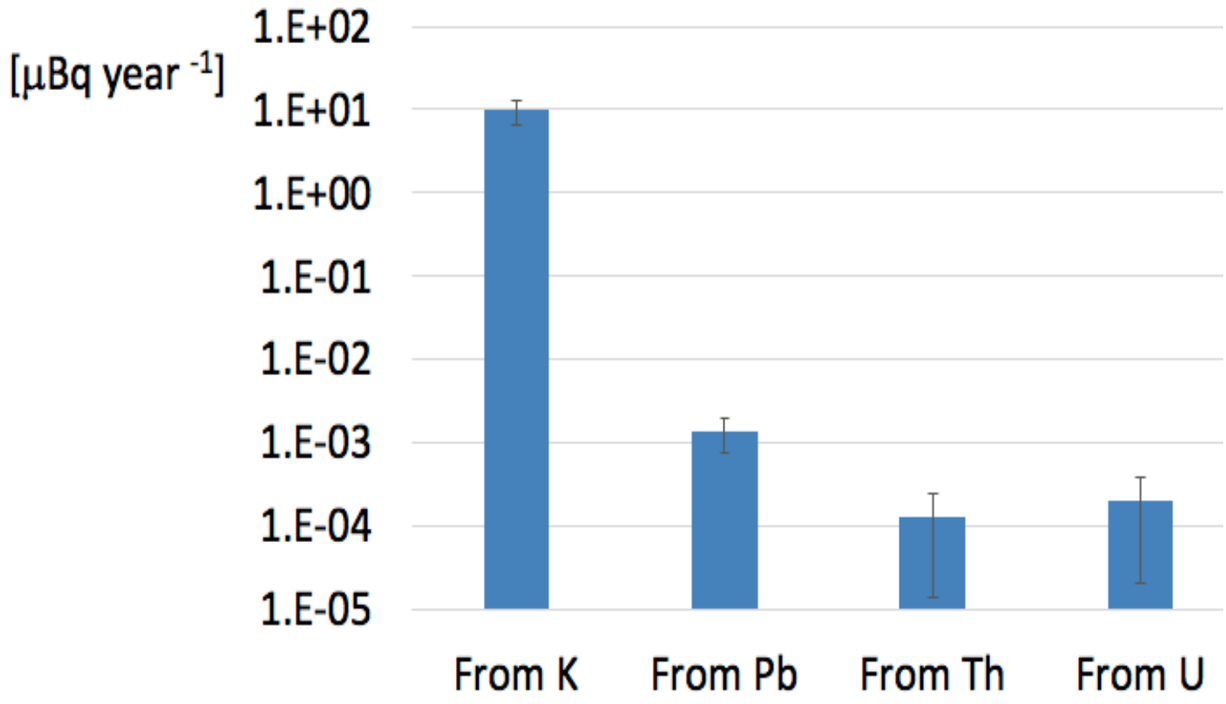
Exposure of a Si wafer

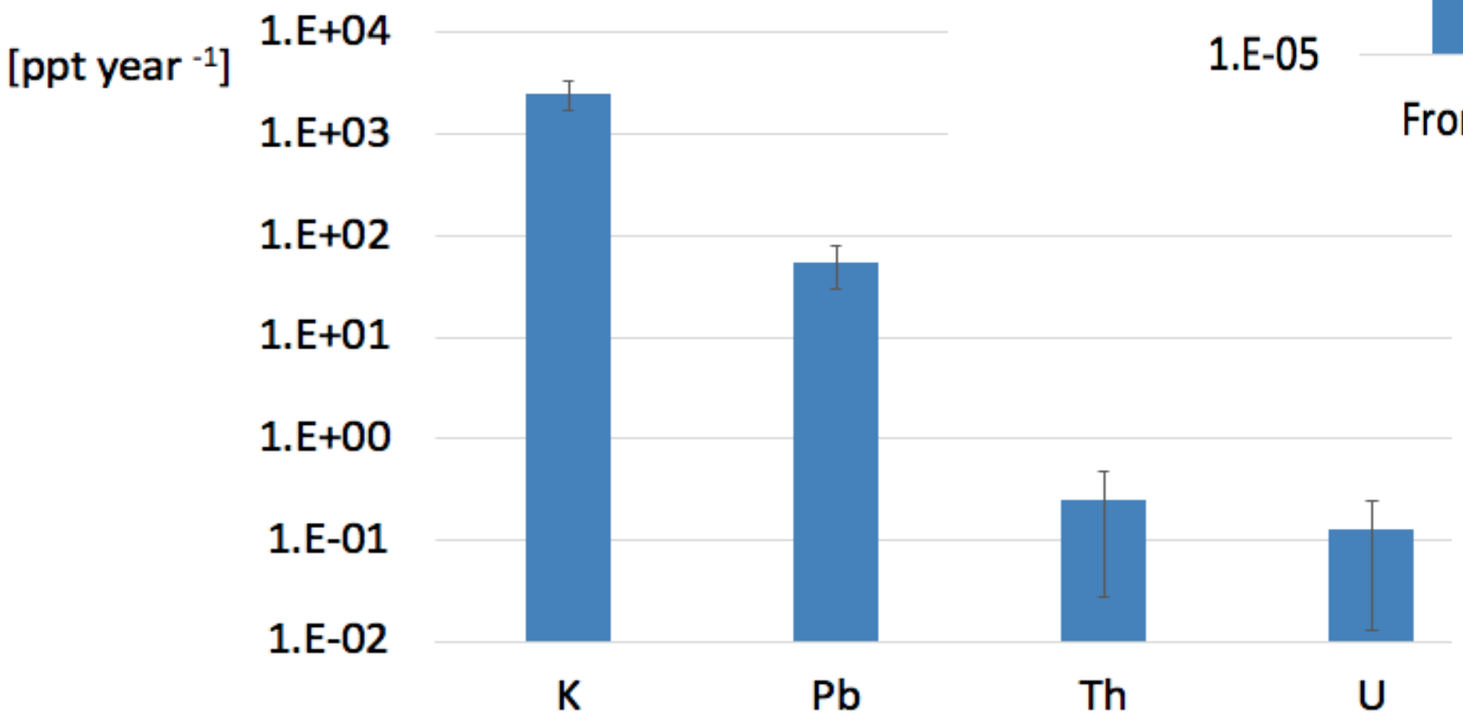


Si wafer
Surface ~ 700 cm^2
Thickness 0.77 mm
Density 2.33 g cm^{-3}

https://www.svmi.com/silicon-wafers/300mm-wafers/

1 year exposure in a Class 10000 clean room





Contamination after a month exposure of the Si wafer in SNOLAB locations normalized to the total wafer mass

		Th [ppt/month/wafer]	sd	U [ppt/month/wafer]	sd
A	Mezzanine at LBL on desk	2.04E-02	7.78E-03	1.97E-02	4.58E-03
B	Close to the dust monitor in SCDMS area	1.37E-01	1.10E-01	8.60E-02	4.29E-02
C	Hallway close to PICO @ 2.5m	1.77E-02	1.31E-02	1.19E-02	6.88E-03
D	Bottom of cryopit (quiet area) on desk	5.46E-03	8.21E-03	7.77E-03	8.99E-03
E	SNO+ control room	3.20E-02	1.09E-02	4.99E-02	1.51E-02
F	Dirty side of the carwash	1.39E+01	2.16E+00	8.33E+00	1.90E+00
G	Close to dust monitor in Juntion carwash-Refuge-OldLab	3.49E-01	2.10E-02	1.94E-01	4.31E-02
H	Surface building @ 3rd floor	1.32E+01	4.92E+00	2.67E+00	1.89E-01
I	Hallway J Drift @ 2.5m	2.10E-01	8.21E-02	1.95E-02	1.30E-02
J	Chem Lab on top of cabinet	2.44E+00	1.57E+00	6.04E-01	3.72E-01
K	Top of the stairs entering the DEAP area	9.36E-02	4.35E-02	2.10E-02	9.53E-03