UF4 & UF5: Supporting Infrastructure and Synergistic Research

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SNOWMASS Summer Meeting in Seattle

July 17-26, 2022

Outline

1. UF4 Report (draft available on the snowmass website, link)
    a. Cleanroom & Radon-reduced room needs and availability
    b. Assay need and availability
    c. Other UF needs and availability (e.g. on-site detector fabrication & machining)

2. UF5 Report (draft available on the snowmass website, link)

3. Summary

Introduction (UF4)

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- A topical group of the underground facility (UF) is the **UF-supporting capability group (UF4)**
  - This topical group have had the task of **evaluating the assets of currently existing underground facilities** as well as that of planned facilities **along with the needs of** current and future **experiments** which will be utilizing those facilities for their science programs.

- Why? **Underground experiments require significant supporting capabilities**, including above-ground and underground **cleanrooms, radon-reduction systems, and low-background assays**... These capabilities are required to create and maintain a low-radioactive environment for the operation of radiation sensitive experiments such as those used in rare event searches, dark matter and neutrino physics ($0\nu\beta\beta$).

Introduction (UF4)

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  - This topical group have had the task of **evaluating the assets of currently existing underground facilities** as well as that of planned facilities **along with the needs of** current and future **experiments** which will be utilizing those facilities for their science programs.

- To this effect, two surveys were sent out to the community to bridge the gap between the supply-side and the demand-side,
  1) One to all current and future underground experiments (survey link)
  2) One to all current and planned underground facilities (survey link)

Survey Respondents (experiment side)

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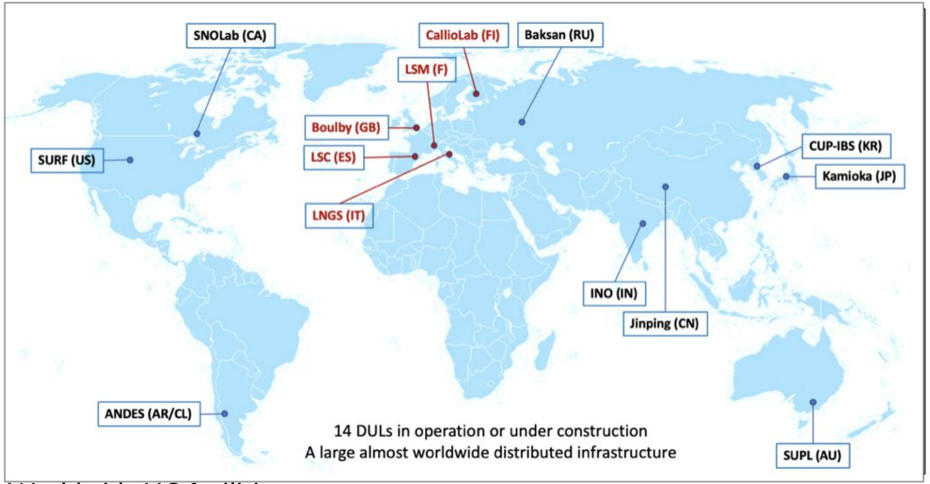
Experiments	
COSINE-100	Argo
COSINE-200	CANDLES
DarkSide-20k	CDEX
DarkSide-LowMass	CUPID
Hyper-Kamiokande	DARWIN
KamLAND-Zen	DM-Ice
Kton Xe TPC for 0vbb	LEGEND
Majorana Demonstrator	nEXO
NEXT-CRAB	NEXT-100
NEXT w/ Ba-Tagging	NEXT-HD
PIRE-GEMADARC	NuDot
Snowball	PandaX
Super-Kamiokande	SBC
A possible neutrinoless-double beta-decay extension to DUNE	

A good range of current and future dark matter and $0\nu\beta\beta$ experiments around the world

Note: Additional input from experiments which did not respond to initial survey have been received recently. Will be included in the final report

Survey Respondents (facility side)



Worldwide UG facilities

Good representation of various deep UG lab + surface labs

Facilities
Berkeley Low Background Counting Facility, U.S.
Boulby, UK
Gran Sasso, Italy
JinPing, China
Kamioka Observatory SPRF, Japan
KURF, VA, U.S. (not available due to COVID)
LARAFA, French Pyrénées
LLNL Nuclear Counting Facility, U.S.
Modane, France
Pacific Northwest National Laboratory, U.S.
SNOLAB, Canada
SURF, SD, U.S.
Y2L / Yemilab, Korea
U. Alberta, Canada
SD Mines, SD, U.S.
Canfranc, Spain

1) Cleanroom & Rn Reduced Cleanroom Needs and Availability

Photo courtesy: LUX-ZEPLIN Experiment

Purpose of UG & AG cleanrooms

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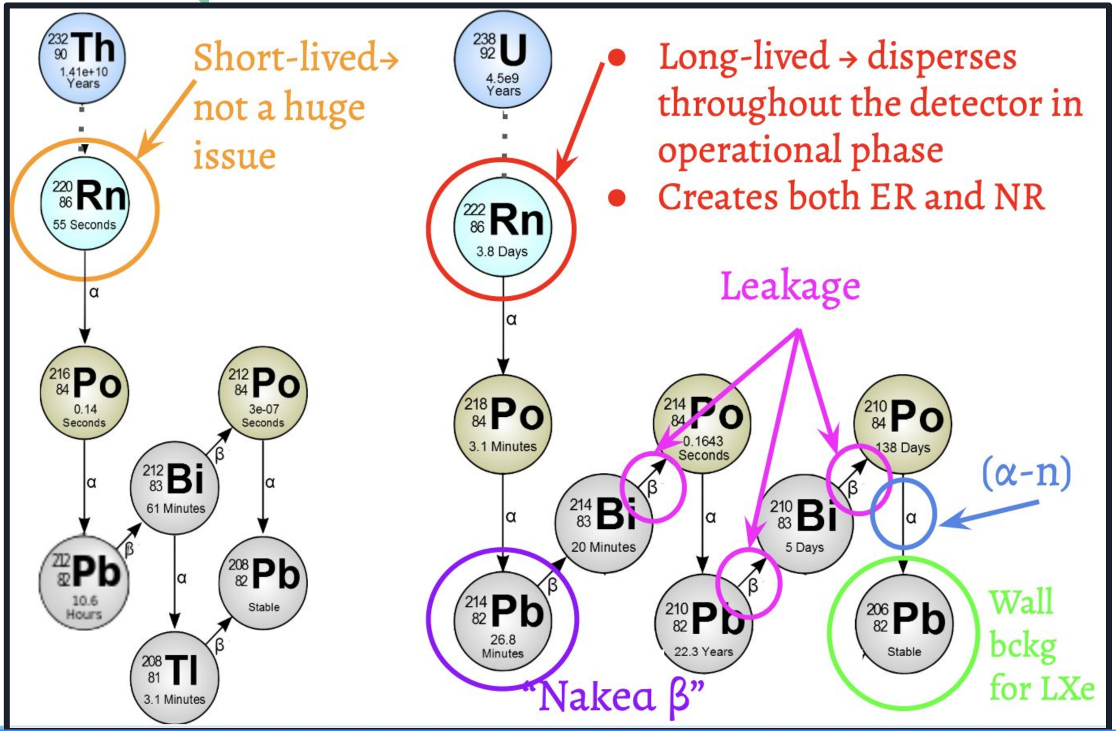


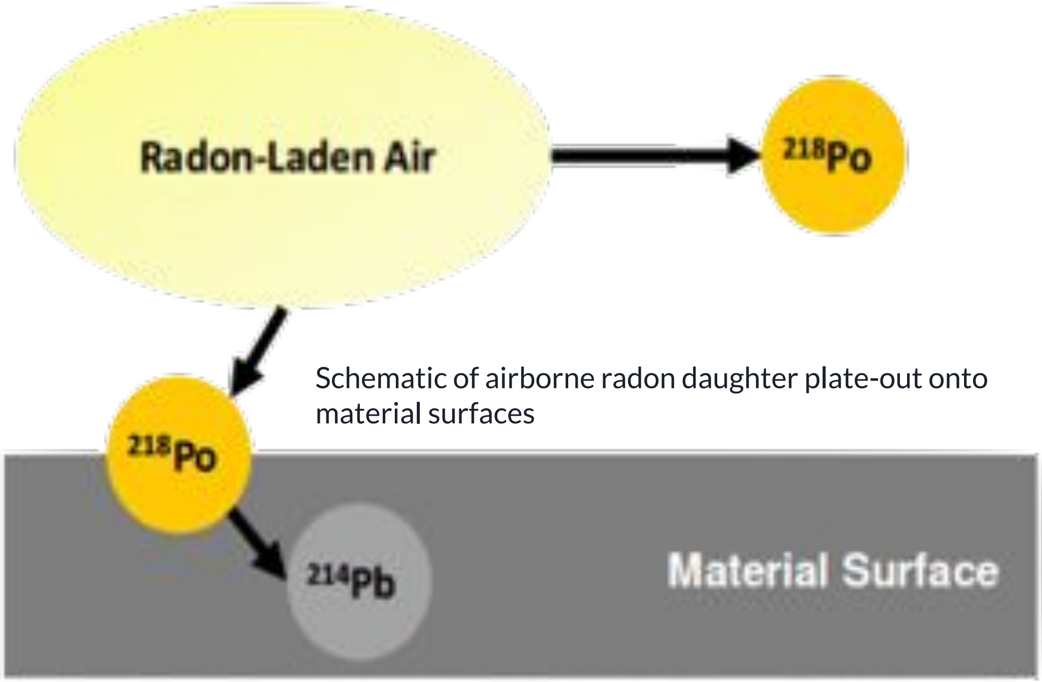
Goal: Reduce exposure to **dust** during different stages:

- Detector material storage
- Detector material handling and assembly
- Detector development & fabrication

Due to many reasons: *e.g.* for LXe experiments, Rn emanation from dust can produce NR & ER background during detector operation phase

Dust radioactivity: ^{238}U, ^{232}Th & ^{40}K

Purpose of Radon reduced cleanrooms



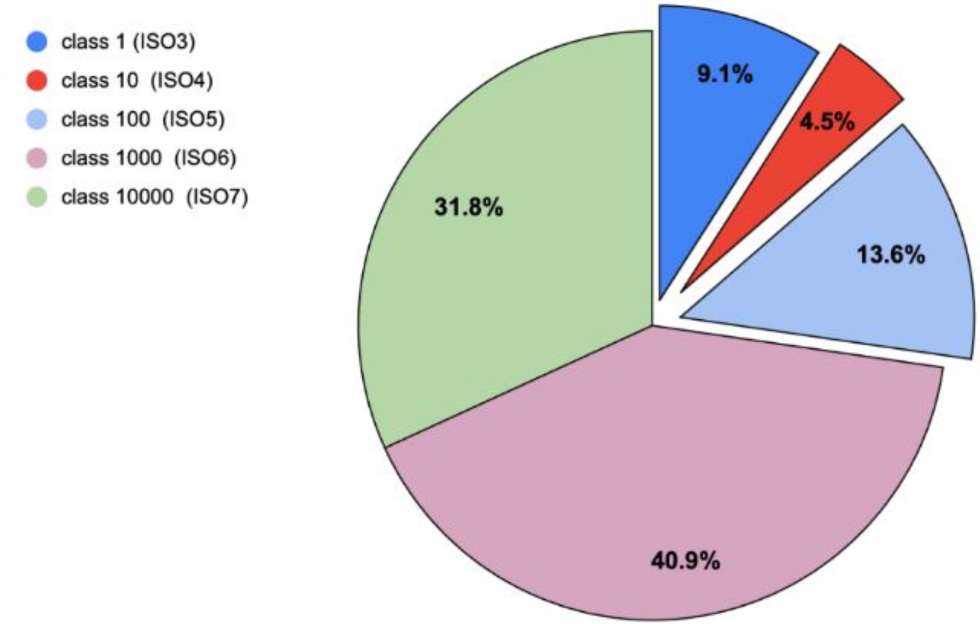
Schematic of airborne radon daughter plate-out onto material surfaces

Goal: Reduce exposure to higher level of airborne **Rn & progeny** during different stages:

- Detector material storage
- Detector material handling and assembly
- Detector development & fabrication

Why: Rn progeny plate-out onto detector materials during assembly leads to ER & NR backgrounds during detector operation phase

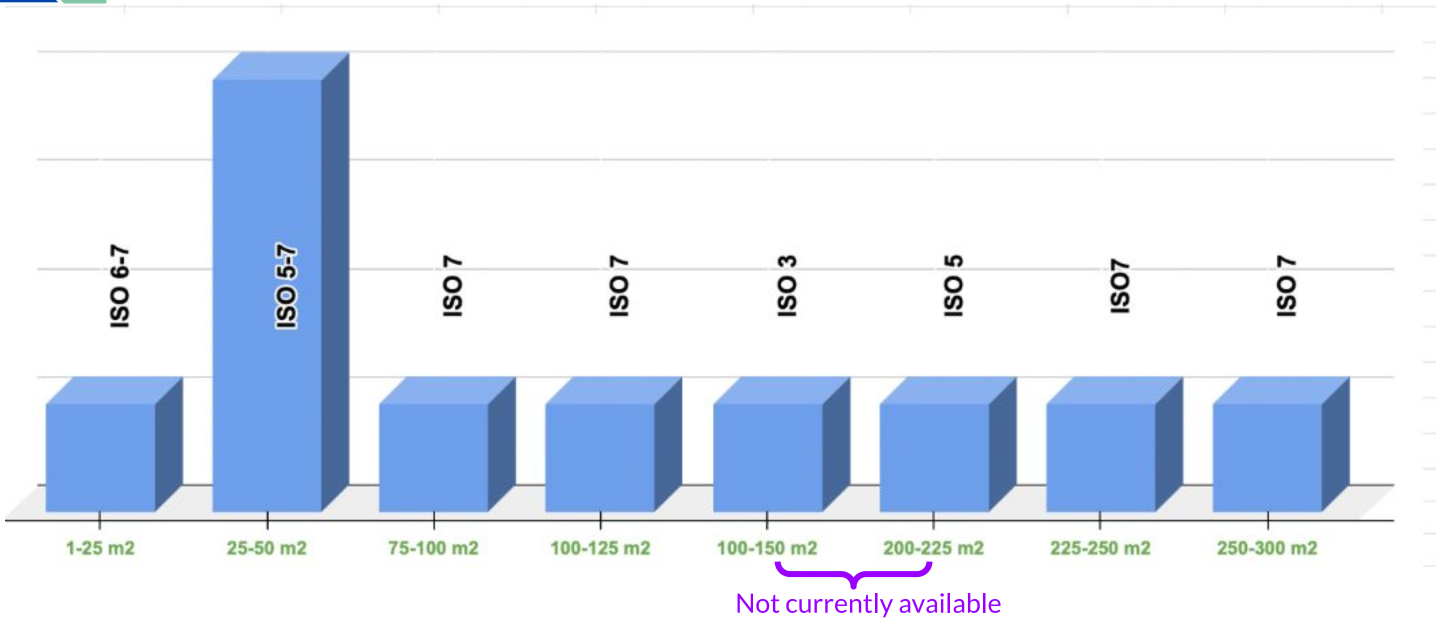
Cleanroom needs for future experiments



Survey result: Cleanroom ISO class

- Most demands are for ISO 6-7 Cleanrooms.
- However stringent constraints on CR class, ISO 5 (and better) from:
  - **Solid state** experiments for crystal preparation, growth & detector fabrication
  - G3 **dark matter and 0νββ** experiments for construction phase.
    - These experiments also need multiple cleanrooms with varying ISO class for storage, assembly and cleaning

Cleanroom needs for future experiments



Survey result:
Cleanroom ISO class and sizes

Larger size cleanroom request from noble liquid G3 dark matter detector (e.g. kiloton TPC detector)

- Need 100-300 m^2 size during detector construction phase **(available at LNGS, SURF & SNOLAB)**
- But stringent constraint of **ISO 3-5** for these larger cleanrooms **not currently met**.

Cleanroom availability and conclusion

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Cleanroom spaces in worldwide facilities

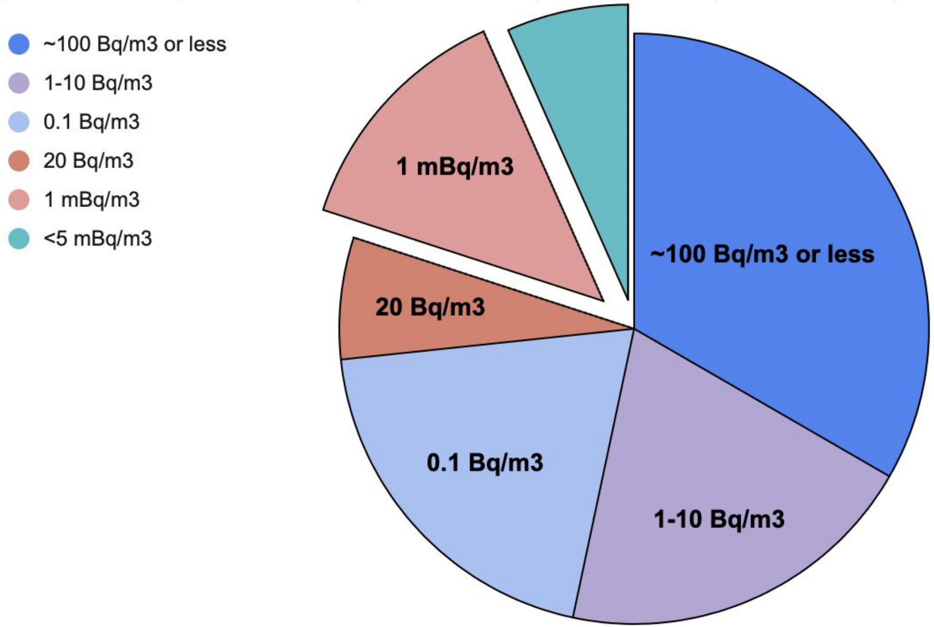
Laboratory	Depth (mwe)	CR Areas (m^2)	CR ISO Class
Boulby, UK.	2850	800	ISO 7
Canfranc, Spain [10]	2400	70, 30	ISO 5-6
Gran Sasso, Italy	3100	13	ISO 7
Gran Sasso, Italy	3100	86, 32	ISO 6
Gran Sasso, Italy	0	325	ISO 6
Gran Sasso, Italy	0	62	(in progress)
SNOLAB, Canada	6000	4924	Not relayed
SNOLAB, Canada	6000	3159	Not relayed
SURF, SD, U.S.	0	37	ISO 6
SURF, SD, U.S.	0	55	ISO 5-6
SURF, SD, U.S.	4300	120, 56, 55, 41	ISO 5-6
SURF, SD, U.S.	4300	52, 18.3	ISO 6-7
SURF, SD, U.S.	4300	286, 125, 38, 34	ISO 7
SURF, SD, U.S.	4300	90	ISO 8
Y2L, Korea	1750	46, 46	ISO 7
Yemilab (under construction), Korea	2500	23	ISO 5
Yemilab (under construction), Korea	2500	80, 20	ISO 7
Kamioka Observatory ICRR, Japan	2700	66	Not relayed
PNNL, U.S.	38	5×19-60	ISO 6-7

- Most CR currently are ISO-7
- **CR size mostly <100 m^2**

Bridging the gap → Conclusion

- Future experiments will benefit from a few additional larger (100-300 m^2) cleanrooms with better ISO class than what currently exist (ISO-5 and better)
- Improvement in CR class monitoring
  - Annual QA of cleanroom ISO class by external companies
  - Increase efforts put into measuring and monitoring dust concentration and fallout.
    - This could enable to loosen requirements for better CR ISO class

Radon reduced space needs for future experiments



Stringent constraints on radon level mainly come from next generation noble TPC experiments (such as DarkSide_Low Mass and future phases of NEXT experiment)

- 1-5 mBq/m^3 during construction phase

Underground radon-reduced cleanrooms

Laboratory	Depth (mwe)	CR Area (m^2)	CR ISO Class	Rn Concentration (mBq/m^3)
Canfranc, Spain [11]	2400	70	ISO 5-6	<5
Gran Sasso, Italy	3100	13	ISO 7	10
Gran Sasso, Italy	3100	86	ISO 6	50
Gran Sasso, Italy	3100	32	ISO 6	50
Modane, France	4800	16		(planned)
SNOLAB, Canada	6000		ISO 6	(in progress)
SURF, SD, U.S.	4300	45	ISO 7	100
Y2L	1750	46	ISO 7	1000
Yemilab (planned)	2500	23	ISO 5	planned
Yemilab (planned)	2500	80	ISO 7	planned

Existing radon-reduced CR Rn concentration varies from <5-1000 mBq/m^2

All existing underground reduced-radon cleanrooms have size <100 m^2

Large underground CR (footprint >100 m^2) with lower Rn level (~1mBq/m^3) does not currently exist.

Radon reduced room needs and availability

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Bridging the gap

- Existing underground radon-reduced cleanrooms are relatively small, **all < 100 m^2 with Rn level of [1-1000 mBq/m^3]**
- However, **future** larger-size **experiments need larger CR [100-300 m^2] with lower Rn level ~ 1 mBq/m^3**
- There is also a need to increase measuring and monitoring Rn level and plate-out rates in these rooms

Conclusion

- Several future experiments need **larger CRs with lower Rn levels** than currently exist.
- Increase existing **monitoring** efforts on Rn concentration & Rn progeny plate-out

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2) Assay needs and availability

Good introduction to radioassay detectors in Section 5 of the Cosmic Frontier White Paper (“*Calibrations and backgrounds for dark matter direct detection*”, link)

5 assay detector-types to screen materials for bulk and surface contaminations

- HPGe
- NAA
- ICP-MS
- Alpha screening
- Radon Emanation

Bulk material assay sensitivity

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The surveyed current and planned experiments relayed a variety of needed sensitivities for sample assays, with most next-generation experiments aiming for **100 nBq/kg assay** capability for inner detector materials. However, KamLAND-Zen related their requirement of achieving on the order of **1 nBq/kg**.

1 Bq U-238/kg	=	81 ppb U	(81×10^{-9} gU/g)
1 Bq Th-232/kg	=	246 ppb Th	(246×10^{-9} gTh/g)
1 Bq K-40/kg	=	32300 ppb K	(32300×10^{-6} gK/g)
1 Bq U-235/kg	=	1.76 ppm U	(1.76×10^{-6} gU/g)

HPGe detectors worldwide (from survey)

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Facility	Apx. Facility Overburden (mwe)	# Low Background HPGe	Apx. Sensitivity [U], [Th] (mBq/kg)
China Jinping Underground Laboratory	6720	3	1
SNOLAB	6000	5	.04 - .35
Sanford Underground Research Facility (SURF)	4850	6	.05 - .7
LPSC/LSM Laboratoire Souterrain de Modane	4800	2	.4 - 4
Gran Sasso National Laboratory (LNGS)	3100	8	.016 - 15
Boulby Underground Laboratory UK	2850	6	< .1 - 1
Kamioka Observatory, ICRR, Univ. of Tokyo	2700	3	Not relayed
Y2L/Yemilab	1750/2500	3	Not relayed
Canfranc Underground Laboratory	2400	7	0.1 - 1
LAFARA underground laboratory, French Pyrénées	220	5	Not relayed
Pacific Northwest National Laboratory	38	14	Not relayed
Berkeley Low Background Counting Facility	15	1	6 - 24
LLNL Nuclear Counting Facility	10	3	Not relayed
South Dakota School of Mines and Technology	0	2	200 - 2000

- There are currently more than 68 HPGe detectors in total serving underground experiments worldwide. With an estimate of ~1400 samples/yr and experiments need of ~100 samples/yr, we have an adequate number of HPGe within the community *if worldwide collaboration is implemented*.
- Current detector limits ~10 uBq/kg. Need to improve on sensitivity (e.g. multiple crystal HPGe detector) for next-gen experiments

Another bulk assay technique: ICP-MS

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- Most of the underground facilities surveyed either have 1-2 ICP-MS systems on site at their surface facilities, or have relationships with nearby labs for use of their ICP-MS systems.
  - It was reported that most of these ICP-MS systems are located in cleanroom facilities with dedicated sample preparation areas.

ICP-MS facility @ PNNL

- Current best limit for ICP-MS for underground science is ~100 nBq/kg
  - B.D. LaFerriere, T.C. Maiti, I.J. Arnquist, E.W. Hoppe. NIM A (2015)
  - I.J. Arnquist, J.W. Grate, M. Bliss, E.W. Hoppe. Analytical Chemistry (2017)

Alpha Screening and Radon Emanation

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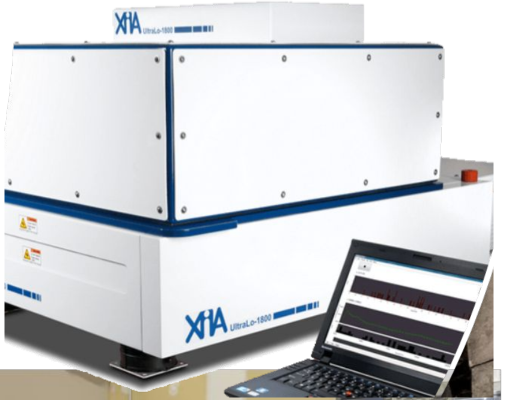
- ❖ Alpha screening most important for providing feedback on radon-daughter plate-out during detector assembly.
  - ➢ Improved sensitivity (beyond XIA Ultra-Lo 1800) would be beneficial. Current best underground sensitivity for XIA Ultra-low 1800 is **~1 mBq/m^2**. Future experiments require down to **.001 mBq/m^2**.

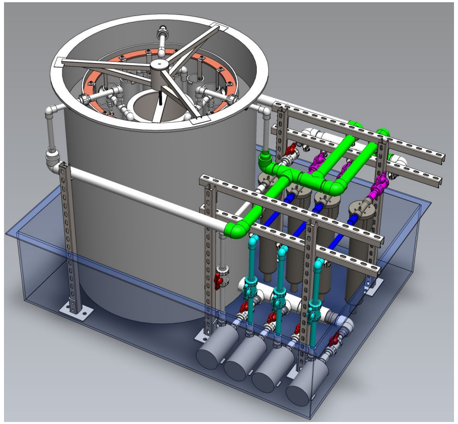


- ❖ Existing facilities for radon emanation appear sufficient in number for future experiments.
  - ➢ Provided there is sufficient sharing of resources
- ❖ Improvements in sensitivity (beyond the standard 0.2 mBq) and/or ability to emanate large volumes of materials would be beneficial to future experiments.

3) Other UG support needs and availability

Purpose

- UG material storage
- Glovebox installation for cleaner detector assembly
- Plant for liquid material purification
- UG Detector Machining & Fabrication
  - UG Ge detector fabrication
  - Electroplating & Electroforming



CAD drawing of an electroforming system @ PNNL
Talk by E. Hoppe, LRT2022

3) Other UG support needs and availability

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Facility for UG material storage

1) Mainly used are non-CR space; mainly for cosmogenic activation decay. If needed, low-Rn reduced CR environmen can be achieved by bagging materials in Rn impermeable bags (or gloveboxes purged with low-Rn gas)

2) Minimally used are CR space

➢ Such facility is present in all UG labs; for most, the non-CR space is sufficiently large

UG material purification facility

1) Water purification and Rn removal from water
2) Scintillator purification and degassing
3) Isotopic purification

➢ Such facility is present in some UG labs

UG detector fabrication & Machining facility

1) UG electroplating & electroforming: exist @SURF & PNNL, planned @Boulby & SNOLAB
2) UG Ge detector fabrication: **non-existing!**
3) UG Machining shops: exist @ SURF, SNOLAB, Gran Sasso

➢ **Such facility is present in some UG labs but more UG machining will be needed by future experiments**

Conclusion (UF4: Supporting Capabilities)

- The larger, lower-background experiments planned for the future will require larger support facilities that also enable lower backgrounds than are currently available.

- Gaps between existing facilities and future needs include the following:
    - Some experiments require larger and/or lower reduced-radon cleanrooms than currently exist.
    - Dust assay sensitivity needs to be improved modestly beyond current techniques, which are currently limited primarily by systematic, procedural contamination issues.
    - Existing surface-screening methods for radon-daughter plate-out are not sufficient to inform experiments during assembly as to whether their needs are met.
    - Most assay needs may be met by existing worldwide capabilities with organized cooperation between facilities and experiments.
    - Improved assay sensitivity is needed for assays of bulk and surface radioactivity for some materials for some experiments, and would be highly beneficial for radon emanation.
    - Improved infrastructures for UG detector fabrication and machining as needed by future exp.

Introduction (UF5: Synergistic Research)

❖ Another topical group of the underground facility (UF) is the **UF-synergistic Research (UF5)**

- ➢ This topical group have had the task of **evaluating the other scientific and engineering research activities ongoing in underground laboratories (beside dark matter searches or neutrino physics) such as:**

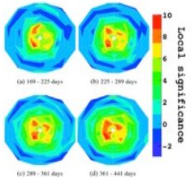
- Quantum Information science
- Accelerator-based nuclear Astroparticle physics
- Experiments in Fundamental symmetries
- Underground Gravitational wave detection
- Geology and Geophysics
- etc …

KAGRA, Mount Ikenoyama, Japan

Underground GW detection

QIS (e.g. superconducting qubits)

Geology & geophysics



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  - This topical group have had the task of **evaluating the other scientific and engineering research activities ongoing in underground laboratories (beside dark matter searches or neutrino physics) such as:**
  - **Main goals**
    - Identify the breadth and nature of scientific and engineering research conducted in underground research facilities
    - Place in context needs and requirements for these research efforts
    - Identify synergies and/or conflicts as they present themselves
    - Integrate awareness of the breadth of underground science into the strategic plan for underground facilities and infrastructure

Conclusion (UF5: Synergistic Research)

- A broad range of scientific and engineering research is possible in underground laboratories, beyond the physics-focus (dark matter and neutrino) activities described in the other underground facility and infrastructure topical group reports. These share UG facilities to escape noisy environments (i.e., seismic, atmospheric, and electromagnetic phenomena) and benefit from reduced cosmic radiation background.

- No out-right conflicts in research programs have been identified (or appropriately tailored facilities are available and in use)

- In several cases, smaller research programs benefit from economy-of-scale associated large particle physics programs
  - Recommends holistic assessment of total science impact from UF investments


That's all Folks!