SNOWMASS 2021 Underground Facility (UF)- Supporting Capability Topical Group Report

Alvine Kamaha (UCLA)

SNOWMASS21 UF04 co-convener

LRT Conference

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Snowmass 2021

Outline

1) Introduction

2) UFO4 Survey Results
   - Cleanroom needs and availability
   - Radon reduced room needs and availability
   - Assay need and availability
   - Other UF needs and availability (e.g. on-site detector fabrication & machining)

3) Summary & Recommendations ⇒ **Discussion/Input from LRT2022 attendees**

Introduction

- The 2021 particle physics community study, known as "**Snowmass 2021**", has brought together numerous particle physicists around the world to create a unified vision for the field over the next decade.

- One of the areas of focus is the **underground facilities frontier** which addresses the **underground infrastructures and the scientific programs and goals of underground based experiments.**

- A topical group of the underground facility (UF) is the **UF-supporting capability group**
  - 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.

Motivation

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- It is well known that **underground experiments require significant supporting capabilities**, including above-ground and under-ground **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 (0vbb).

Motivation

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- It is well known that **underground experiments require significant supporting capabilities**, including above-ground and under-ground **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 (0vbb).

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

Survey Respondents

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Experiments

Snowball (planned)
Majorana Demonstrator / LEGEND
PandaX
Super-Kamiokande / Hyper-Kamiokande
CANDLES
PIRE-GEMADARC
DARWIN
NuDot
Kiloton Xe TPC for 0vbb
CDEX
KamLAND-Zen
nEXO
NEXT-100 / NEXT-CRAB / NEXT-HD
NEXT with Barium Tagging
DM-Ice/COSINE-100 / COSINE-200
DarkSide-20k / DarkSide-LowMass / ARGO
SBC
A possible neutrinoless-double beta-decay extension to DUNE

Facilities

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

Good representation of experiments & facilities around the world ⇒ *survey results not biased*

1) Cleanroom & Rn reduced cleanroom Needs and Availability


Photo courtesy: LUX-ZEPLIN Experiment

Purpose of UG & AG cleanrooms

Picture of a cleanroom: @ CLIN

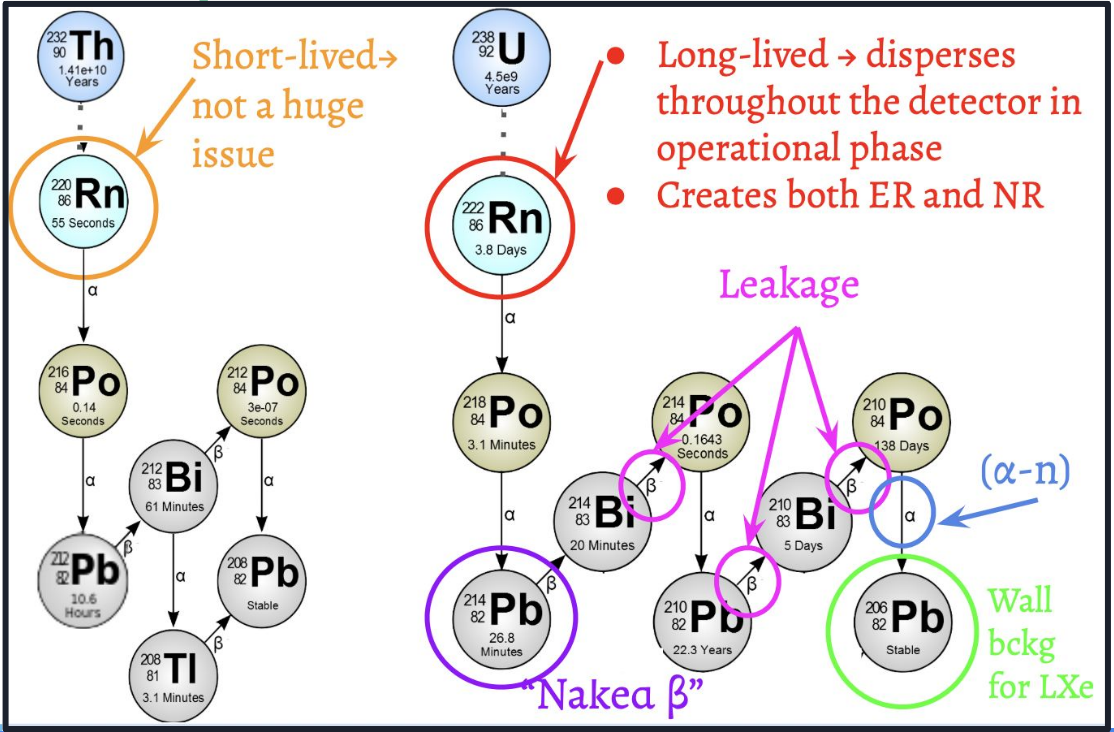
Goal: Reduce exposure to **dust** during different stages:

- 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 UG & AG cleanrooms



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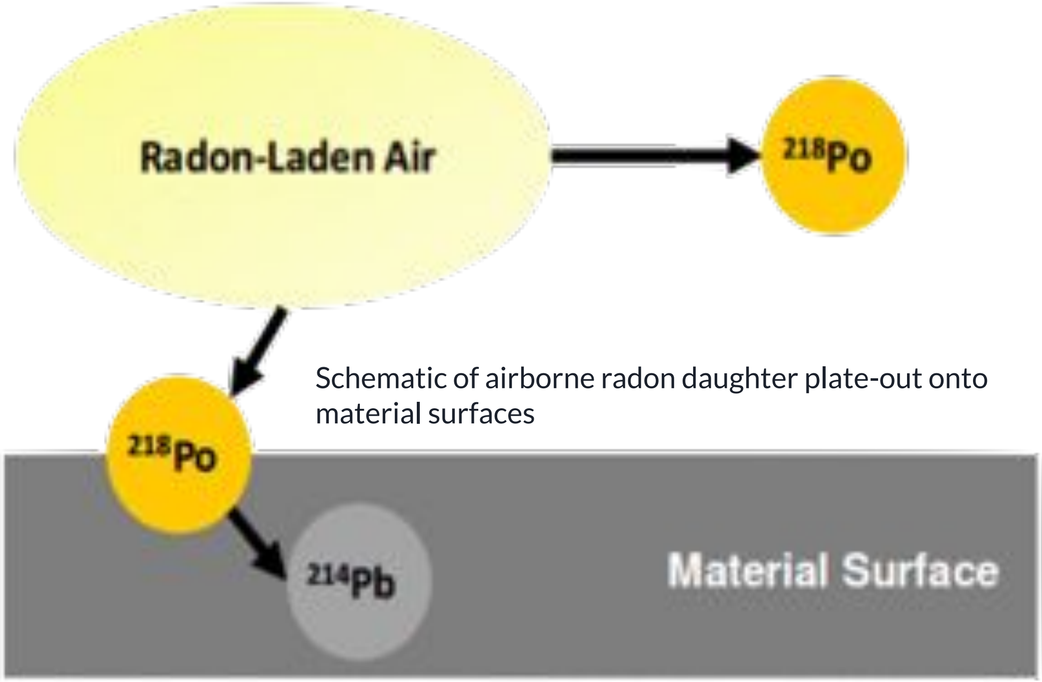
Purpose of Radon reduced cleanrooms



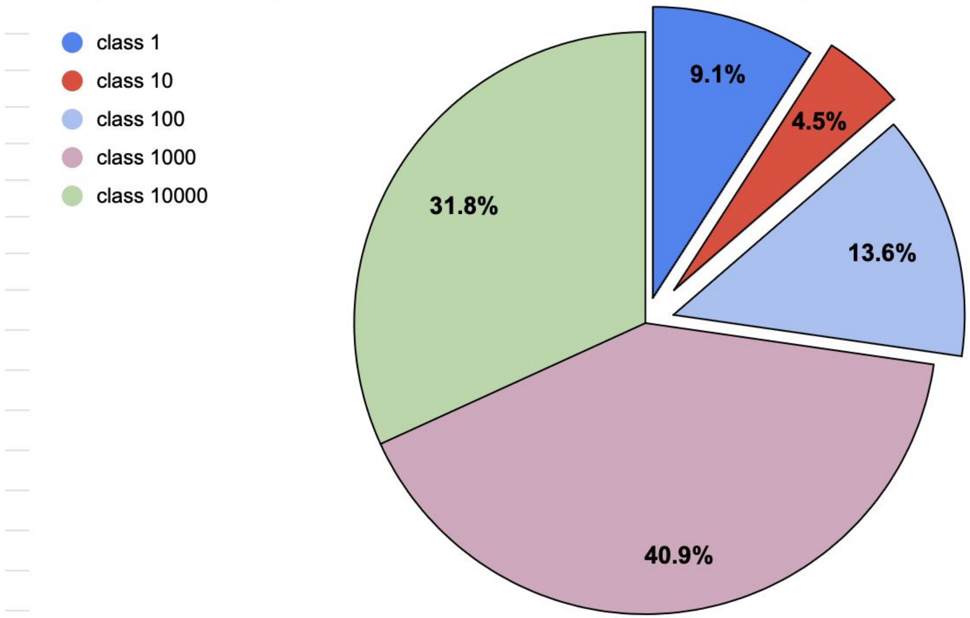
Schematic of airborne radon daughter plate-out onto material surfaces

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

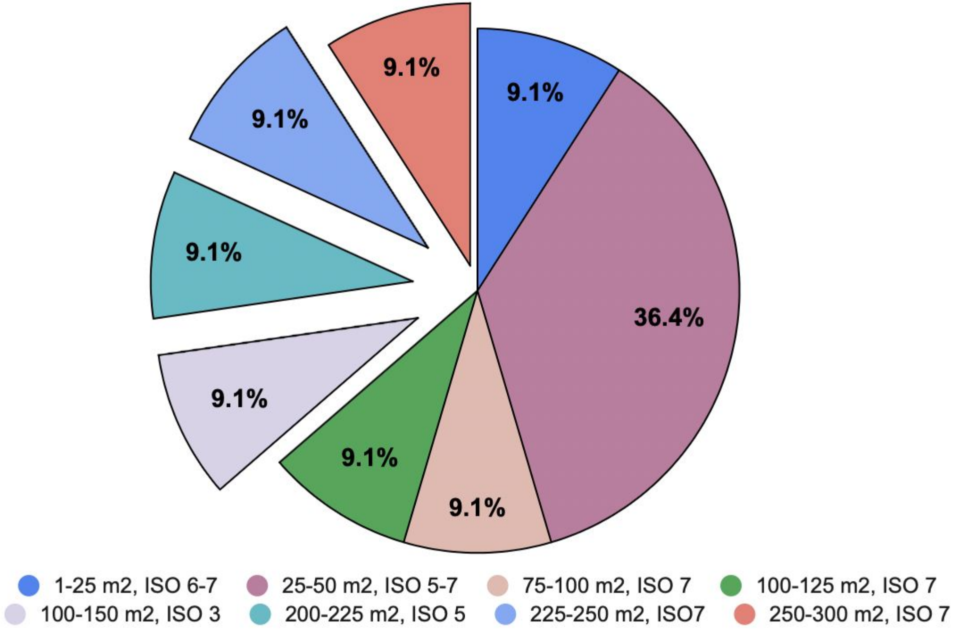


Survey result:
Cleanroom ISO class

Stringent constraints on ISO class comes from
1) **Solid state** experiments during crystal preparation, growth & detector fabrication: Need ISO 3-5 (class 1-100)
2) G3 **dark matter and 0vbb** experiments during construction phase: Need ISO3- 7 (class 100-10000), mostly ISO6

- 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 comes from noble liquid G3 dark matter detector (e.g. kiloton TPC detector)

- Need 100-300 m^2 size during detector construction phase
- Most stringent demand for these larger cleanrooms: ISO-5 but could be loosen to ISO 6
  - ★ Solid state detector requested a smaller size cleanroom but with higher ISO class.

Cleanroom needs and availability

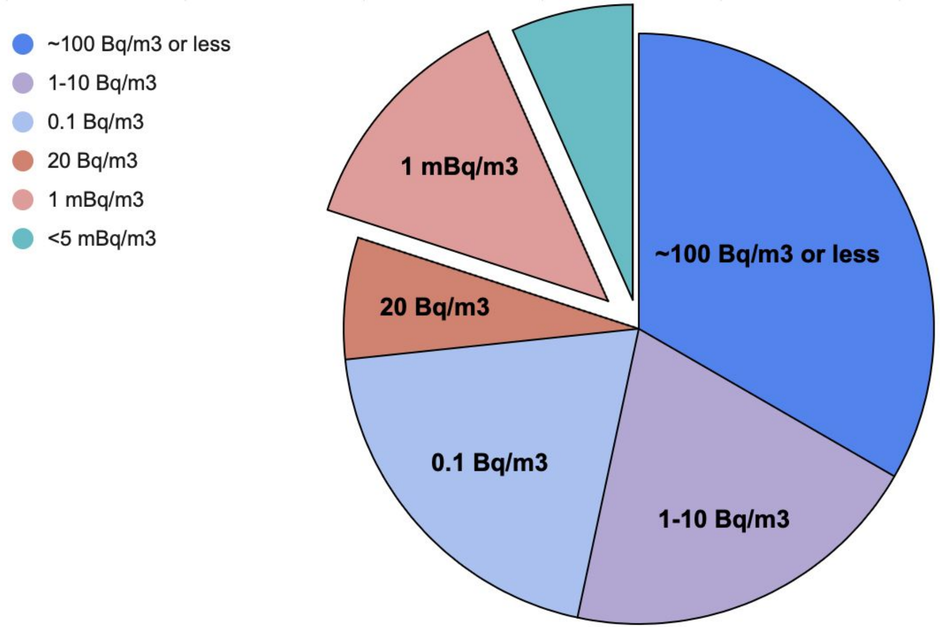
Bridging the gap

- **Existing facilities** have a broad range of cleanroom (CR) size & ISO class
  - However avg **CR size ~100 m^2** in many facilities & **not** many CR with class **above ISO 6**
- **A few future large experiments** request **larger CR [100-300 m^2] with higher ISO class** for minimal dust fallout onto detector surfaces during assembly
  - Some CR ISO class demands can be loosen if increase efforts put into measuring and monitoring CR class. CR size cannot be loosen due to the size of these experiments.

Recommendation

- Although the requested number of larger & higher class CR by future experiments is not appreciably larger than what are currently offered by facilities, these experiments will benefit from a few additional larger cleanrooms with higher ISO class than what currently exist (ISO-5 and up)
- 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.

Radon reduced space needs for future experiments



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

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

Radon reduced room availability from facilities

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Laboratory	Depth (mwe)	CR Area (m^2)	Rn Concentration (mBq/m^2)
Gran Sasso, Italy	3100	13	10
Gran Sasso, Italy	3100	86	50
Gran Sasso, Italy	3100	32	50
Gran Sasso, Italy	0	325	(in progress)
Gran Sasso, Italy	0	62	(in progress)
Modane, France	4800	16	(planned)
SNOLAB, Canada	6000		(in progress)
SURF, SD, U.S.	4300	45	100
SURF, SD, U.S.	0	55	500
Y2L	1750	46	1000
Yemilab (planned)	2500	80	planned
U. Alberta, Canada	0	100	?
SD Mines, U.S.	0		20

Existing radon reduced CR Rn concentration varies from 1-1000 mBq/m^2

Size of existing Rn reduced room worldwide varies. Range [13-325 m^2] & Avg <100 m^2

Radon reduced room needs and availability

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Bridging the gap

- Existing facilities have a broad range of radon reduced cleanroom sizes, **mostly < 100 m^2 with Rn level of [1-1000 mBq/m^3]**
- However, **future** larger size detector also require lower level of Rn progeny plate-out. These **experiments requested larger CR [100-300 m^2] with lower Rn level ~ 1 mBq/m^3**
- There is also a demand to increase efforts put into measuring and monitoring Rn levels in these rooms (use of multiples counters placed in strategic locations)

Recommendation

- Although the requested number of lower reduced-radon cleanrooms is not appreciably larger than the number existing/planned, future experiments will benefit from additional **larger CR with lower Rn level** than what currently exist.
- Increase existing **monitoring** efforts on Rn concentration & Rn progeny plate-out

Cleanroom airborne Contaminant Concentration and Deposition Monitoring

Surface contamination requirement varies per experiments

- Dust fallout: most stringent one is <10^{-17} g (U,Th) /cm^2
- Rn progeny (mainly long-lived ^{210}Pb) plate-out: most stringent constraint is < 0.1 mBq/m^2

Current monitoring detector sensitivities are ~ okay.

Request is about increasing various monitoring tools

- Witness coupons
- dust particle and radon counters installed in various locations from prompt feedback
- Annual QA of cleanroom ISO class by external companies
- Assay of washdown water used in detector remedial cleaning

witness coupons assay technique

2) Assay detector needs and availability

Assay types

- Many folks at this conference have come together to put this nice whitepaper (https://arxiv.org/pdf/2203.07623.pdf) together, which describes radioassays for underground experiments very well
    - HPGe
    - NAA
    - ICP-MS
    - GD-MS
    - Alpha screening
    - Radon Emanation, etc.

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-.035
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
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

- *Please let us know if any numbers here should be corrected, etc!*
- There are currently more than **61** HPGe detectors in total serving underground experiments worldwide
- Current detector limits **~10 uBq/kg**

Assay take-aways

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- ➢ If each of these HPGe detectors counts **a sample for two weeks** on average, the **world-wide capability** for ultra-low background **counting is approximately 1,500 samples per year** (not including calibrations and background checks).

- ➢ Many **experiments** responding to the survey indicated they would **need on average 100 samples counter per year.**

- ➢ Therefore, we seem to have **an adequate number of HPGe within the community world-wide**

Assay take-aways

- **However**
  - **Limits of sensitivity** for **currently available HPGe** may not reach the levels required by the next generation of dark matter and 0vbb experiments. **An increased number of "next generation" assays (HPGe or other)** will be needed to provide assays to "next generation" experiments.

  - We cannot realize the full efficiency of having all world-wide detectors subscribed with the current model of each experiment "owning" detectors. **World-wide collaboration among low background counting labs is needed** to fully realize the potential.

Assay take-aways

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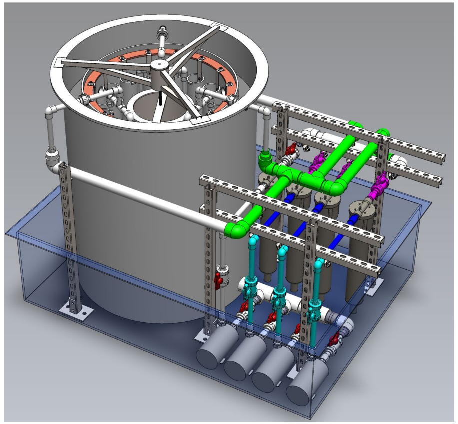
- Most of the underground facilities surveyed either have 1-2 ICP-MS systems on site at their surface facilities, or have relationships with nearby labs for use of their ICP-MS systems.
  - It was reported that most of these ICP-MS systems are located in cleanroom facilities with dedicated sample preparation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

- While the survey to the underground facilities did not include questions regarding **GDMS, alpha screening or radon emanation** (so we are not able assess their availability) many of the **experiment respondents listed** these capabilities **as necessities** in their current and planned assay campaigns.

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 environment 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**

UG liquid material purification facility

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

➢ **Such facility is present in all UG labs, mainly @ SNOLAB**

UG detector fabrication facility

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

➢ ***Recommendation:*** improve upon UG capability for detector fabrication

~~Conclusion~~ ⇒ Discussion:

Input from LRT2022 participants

Your thoughts

Comments

& Questions …

What do you feel is important moving forward? What do you feel should be included in the Snowmass report?