UF4 & UF5: Supporting Infrastructure and Synergistic Research

UF4 conveners: Alvine Kamaha (UCLA), Brianna Mount (BHSU), Richard Schnee (SD Mines)

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
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 ($0
\nu\beta\beta$).
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.

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)

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Note: Additional input from experiments which did not respond to initial survey have been received recently. Will be included in the final report</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSINE-100</td>
<td>Argo</td>
</tr>
<tr>
<td>COSINE-200</td>
<td>CANDLES</td>
</tr>
<tr>
<td>DarkSide-20k</td>
<td>CDEX</td>
</tr>
<tr>
<td>DarkSide-LowMass</td>
<td>CUPID</td>
</tr>
<tr>
<td>Hyper-Kamiokande</td>
<td>DARWIN</td>
</tr>
<tr>
<td>KamLAND-Zen</td>
<td>DM-Ice</td>
</tr>
<tr>
<td>Kton Xe TPC for 0vbb</td>
<td>LEGEND</td>
</tr>
<tr>
<td>Majorana Demonstrator</td>
<td>nEXO</td>
</tr>
<tr>
<td>NEXT-CRAB</td>
<td>NEXT-100</td>
</tr>
<tr>
<td>NEXT w/ Ba-Tagging</td>
<td>NEXT-HD</td>
</tr>
<tr>
<td>PIRE-GEMADARC</td>
<td>NuDot</td>
</tr>
<tr>
<td>Snowball</td>
<td>PandaX</td>
</tr>
<tr>
<td>Super-Kamiokande</td>
<td>SBC</td>
</tr>
<tr>
<td>A possible neutrinoless-double beta-decay extension to DUNE</td>
<td>A good range of current and future dark matter and 0νββ experiments around the world</td>
</tr>
</tbody>
</table>
Survey Respondents (facility side)

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)
- LARAF, 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

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: $^{238}\text{U}$, $^{232}\text{Th}$ & $^{40}\text{K}$
**Purpose of Radon reduced cleanrooms**

**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 $0\nu\beta\beta$ experiments for construction phase.

These experiments also need multiple cleanrooms with varying ISO class for storage, assembly and cleaning.
Larger size cleanroom request from noble liquid G3 dark matter detector (e.g. kiloton TPC detector)

- Need 100-300 m² 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

Cleanroom spaces in worldwide facilities

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Depth (mwe)</th>
<th>CR Areas (m^2)</th>
<th>CR ISO Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulby, UK.</td>
<td>2850</td>
<td>800</td>
<td>ISO 7</td>
</tr>
<tr>
<td>Canfranc, Spain [10]</td>
<td>2400</td>
<td>70, 30</td>
<td>ISO 5-6</td>
</tr>
<tr>
<td>Gran Sasso, Italy</td>
<td>3100</td>
<td>13</td>
<td>ISO 7</td>
</tr>
<tr>
<td>Gran Sasso, Italy</td>
<td>3100</td>
<td>86, 32</td>
<td>ISO 6</td>
</tr>
<tr>
<td>Gran Sasso, Italy</td>
<td>0</td>
<td>325</td>
<td>ISO 6</td>
</tr>
<tr>
<td>Gran Sasso, Italy</td>
<td>0</td>
<td>62</td>
<td>(in progress)</td>
</tr>
<tr>
<td>SNOLAB, Canada</td>
<td>6000</td>
<td>4924</td>
<td>Not relayed</td>
</tr>
<tr>
<td>SNOLAB, Canada</td>
<td>6000</td>
<td>3159</td>
<td>Not relayed</td>
</tr>
<tr>
<td>SURF, SD, U.S.</td>
<td>0</td>
<td>37</td>
<td>ISO 6</td>
</tr>
<tr>
<td>SURF, SD, U.S.</td>
<td>0</td>
<td>55</td>
<td>ISO 5-6</td>
</tr>
<tr>
<td>SURF, SD, U.S.</td>
<td>4300</td>
<td>120, 56, 55, 41</td>
<td>ISO 5-6</td>
</tr>
<tr>
<td>SURF, SD, U.S.</td>
<td>4300</td>
<td>52, 18.3</td>
<td>ISO 6-7</td>
</tr>
<tr>
<td>SURF, SD, U.S.</td>
<td>4300</td>
<td>266, 125, 38, 34</td>
<td>ISO 7</td>
</tr>
<tr>
<td>SURF, SD, U.S.</td>
<td>4300</td>
<td>90</td>
<td>ISO 8</td>
</tr>
<tr>
<td>Y2L, Korea</td>
<td>1750</td>
<td>46, 46</td>
<td>ISO 7</td>
</tr>
<tr>
<td>Yemilab (under construction), Korea</td>
<td>2500</td>
<td>23</td>
<td>ISO 5</td>
</tr>
<tr>
<td>Yemilab (under construction), Korea</td>
<td>2500</td>
<td>80, 20</td>
<td>ISO 7</td>
</tr>
<tr>
<td>Kamioka Observatory ICRR, Japan</td>
<td>2700</td>
<td>66</td>
<td>Not relayed</td>
</tr>
<tr>
<td>PNNL, U.S.</td>
<td>38</td>
<td>5×19-60</td>
<td>ISO 6-7</td>
</tr>
</tbody>
</table>

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

Most CR currently are ISO-7

CR size mostly <100 m^2
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

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Depth (mwe)</th>
<th>CR Area (m²)</th>
<th>CR ISO Class</th>
<th>Rn Concentration (mBq/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canfranc, Spain</td>
<td>2400</td>
<td>70</td>
<td>ISO 5-6</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Gran Sasso, Italy</td>
<td>3100</td>
<td>13</td>
<td>ISO 7</td>
<td>10</td>
</tr>
<tr>
<td>Gran Sasso, Italy</td>
<td>3100</td>
<td>86</td>
<td>ISO 6</td>
<td>50</td>
</tr>
<tr>
<td>Gran Sasso, Italy</td>
<td>3100</td>
<td>32</td>
<td>ISO 6</td>
<td>50</td>
</tr>
<tr>
<td>Modane, France</td>
<td>4800</td>
<td>16</td>
<td>(planned)</td>
<td></td>
</tr>
<tr>
<td>SNOLAB, Canada</td>
<td>6000</td>
<td></td>
<td>ISO 6</td>
<td>(in progress)</td>
</tr>
<tr>
<td>SURF, SD, U.S.</td>
<td>4300</td>
<td>45</td>
<td>ISO 7</td>
<td>100</td>
</tr>
<tr>
<td>Y2L</td>
<td>1750</td>
<td>46</td>
<td>ISO 7</td>
<td>1000</td>
</tr>
<tr>
<td>Yemilab (planned)</td>
<td>2500</td>
<td>23</td>
<td>ISO 5</td>
<td>planned</td>
</tr>
<tr>
<td>Yemilab (planned)</td>
<td>2500</td>
<td>80</td>
<td>ISO 7</td>
<td>planned</td>
</tr>
</tbody>
</table>

Existing radon-reduced CR Rn concentration varies from <5-1000 mBq/m²

Large underground CR (footprint >100 m²) with lower Rn level (~1mBq/m³) does not currently exist.

All existing underground reduced-radon cleanrooms have size <100 m²
Radon reduced room needs and availability

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
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

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.

<table>
<thead>
<tr>
<th>1 Bq U-238/kg</th>
<th>= 81 ppb U</th>
<th>(81 x 10^{-9} gU/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Bq Th-232/kg</td>
<td>= 246 ppb Th</td>
<td>(246 x 10^{-9} gTh/g)</td>
</tr>
<tr>
<td>1 Bq K-40/kg</td>
<td>= 32300 ppb K</td>
<td>(32300 x 10^{-6} gK/g)</td>
</tr>
<tr>
<td>1 Bq U-235/kg</td>
<td>= 1.76 ppm U</td>
<td>(1.76 x 10^{-6} gU/g)</td>
</tr>
</tbody>
</table>
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

- 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.

- Current best limit for ICP-MS for underground science is ~100 nBq/kg
Alpha Screening and Radon Emanation

- 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 $\sim 1 \text{ mBq/m}^2$. Future experiments require down to $0.001 \text{ mBq/m}^2$.

- 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

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; 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
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.
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 …
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:

**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!