Underground Facilities

In this section, we consider the various aspects of the dark matter community's needs for underground space and related infrastructure. These needs will evolve with time as the size scale of experiments grows and as R&D leads to new avenues of experimental exploration. Space and infrastructure will be needed not just for the expected major experimental G2/G3 program, but also for required auxiliary efforts, such as low-background screening and storage, as well as for R&D on new or alternative techniques. The advantages of a major U.S. or U.S.-Canada underground site and associated facility could be substantial in terms of maintaining U.S. primacy in this ever more important field, developing the synergies between dark matter and other underground science, and ensuring substantial broader impacts of these efforts.

As has been described elsewhere, the U.S. and international DM program is expected to evolve from generation 1 (G1) experiments currently running to generation 2 (G2) experiments beginning construction now or starting in the near future to a generation 3 of experiments (G3) that will aim to reach fundamental background limits from neutrinos of various types. Down-selection and consolidation will occur at each stage given the growing financial cost and manpower needs of these ever more ambitious experiments. The DOE has a formal down-selection process planned in late 2013 leading to expected construction starts in late 2014 for one or more major G2 experiments with a total DOE G2 budget of ≈$30M. Substantial NSF contributions are also expected. XENON1T (U.S.-led but sited in Europe with substantial international contributions) can be considered to be a joint NSF/international G2 experiment. It may be possible for additional G2 experiments to move to construction in the coming year by either having relatively low overall cost or relatively low cost to DOE/NSF. It is unclear when and how the U.S. funding agencies will select G3 experiments, but such a stage is on their planning horizon. It is expected that only one or two U.S.-led G3 experiments at the $100M range will be financially tenable.

These G3 experiments will a major driver of underground space and related infrastructure needs by U.S. scientists. These experiments will be physically large due to the substantial shield/veto systems required to mitigate radiogenic and cosmogenic backgrounds. The DUSEL S4 engineering studies provide a rough envelope for the size of these experiments, which we can take to be 25m x 15m x 15m for this discussion. *Currently, there are no U.S. sites capable of hosting experiments of this size.* The available caverns at the Homestake/SURF site are too small, and no other site of comparable depth exists in the U.S. However, there are a number of internationally available options. The Laboratori Nazionali del Gran Sasso (LNGS) has extensive underground space capable of hosting G3 experiments, but it remains to be shown that its 3000 mwe depth, when combined with a sophisticated cosmogenic shield/veto, yields acceptably low cosmogenic backgrounds for G3 experiments. The SNOLAB Cryopit and Cube Hall caverns are sufficiently deep for G3, but they may not be large enough for the most ambitious

Noble liquid experiments. The Cryopit has no specified occupant yet (though there are groups interested in siting both dark matter and double beta decay experiments there), and the Cube Hall should become available in a few years as Mini-CLEAN and DEAP3600 complete. But they may no longer be available by the time the G3 experiments are considering sites. The Laboratoire Souterrain de Modane (LSM) has a depth of 4800 mwe (comparable to Homestake/SURF) and a major expansion to 17500m^3 is expected to become available in roughly 2017. It could house one Generation 3 experiment. Jin Ping II in China will be a site of substantial depth (7000 mwe). The India Neutrino Observatory (INO) may have an available volume for non-neutrino experiments of about 26000 m^3, but there is some uncertainty about the 2018 timescale.

It is expected that there will be between two and four G3 experiments worldwide, depending on the U.S. , European and Japanese level of support (one or two experiments each) and whether new international participants (e.g., China, India) can provide enough funding to enable an additional experiment. As advocated by IUPAP, open-access policies at major international laboratories are essential for an optimal scientific program world-wide. In the field of dark matter in particular, open-access has made it possible for U.S.-led G1 and G2 experiments to use many sites outside the US. Moreover, these international underground laboratories recognize the high scientific priority of dark matter experiments and are interested in housing international G3 dark matter experiments. However, open-access is fragile and relies on the willingness of each nation or region to contribute its share in terms of advanced facilities. While imbalance could be tolerated in the short term, *it is not clear whether it would be possible in the long run to sustain open-access to underground laboratories for instance if one major country or region chose to take a major role in the research (as U.S. scientists are certain to do) without supporting a facility in that field (a commitment which the US may not accept to make). This risk is compounded by the divestment of the US from many major investments in related fields.* We believe that it is important for the health of worldwide underground science, and our own long term access to international facilities that the US contribute their share and support a frontier US or US-Canada underground facility, capable, for instance, of hosting G3 dark matter experiments.

Moreover, while the available space may appear ample, especially if one experiment is led by and sited in China or India, substantial concerns exist. The issue of cosmogenic backgrounds may eliminate the very attractive LNGS site; more will be learned on this front as the G2 experiments at LNGS assess their achieved backgrounds. The suitability of existing space at SNOLAB for some of the largest experiments is unclear. There will be substantial competition with comparably sized neutrinoless double-beta-decay experiments planned for a similar timescale (EXO and 1TGe).

Beyond the basic issue of availability of space, there is an additional issue critical to the CSS2013 planning effort: *Lack of a deep U.S. site puts at risk the current U.S. leadership of this field*. Five of the eight proposed G2 experiments listed in [Table 3.1

of Lankford report] are led by the U.S, yet only one of them proposes to be sited in the U.S. (LZS), and only two of the eight's G1 stages are sited in the U.S. Without an expansion of deep underground U.S. space, *all the G3 experiments worldwide, including U.S.-led experiments, will be sited outside the U.S.* Furthermore, it must be recognized that the massive size of G3 experiments will necessitate major contributions from the host-country which will demand to play a central role in the scientific and technical management. Based on their experience with such arrangements, many scientists are concerned that the U.S. cannot truly play the dominant leadership role in such situations. Moreover the credit for major discoveries will tend to go the hosting country. *It will be very difficult for the U.S. to maintain leadership of these experiments, and correspondingly its preeminence in the field, when it must rely so substantially on international contributions and foreign infrastructure.*

A new U.S. deep site sized for G3 dark matter experiments would solve many of these problems: it would add to the international inventory of G3-capable space, would indicate the U.S.'s commitment to an appropriate infrastructure role in international underground science, and would maximize the potential for U.S. leadership in this field. Such a site would carry substantial additional benefits:

- A deep national facility would support the development of ultra-low radioactive background expertise and be the natural focus of powerful radiopurity screening equipment. The cost of infrastructure such as water purification, copper electroforming, underground machining, and materials growth (e.g., germanium crystals) could be shared between several experiments and could evolve with time. The cost savings from such common infrastructure could be substantial.
- A site capable of hosting more than one experiment would result in promulgation of common engineering and safety standards and dissemination of expertise in these areas, possibly also yielding cost savings.
- A national facility would naturally provide a site and infrastructure for long-term R&D at depth.
- The successive investments in a facility over time would yield a cumulative effect increase in capability via the reuse of cavities and other infrastructure over time. (LNGS is an excellent example of this.)
- A facility shared by multiple experiments (of various sizes and covering a range of science goals, such as dark matter and neutrinoless double-beta decay) would naturally stimulate a vibrant intellectual environment, couple strongly to undergraduate and graduate education, and be a cradle for new ideas. The DUSEL effort made the case that a multidisciplinary facility (extending beyond nuclear and particle physics) would enhance these impacts even further.
- Such a common facility can provide a highly effective K-12 enrichment program and public outreach through coherence of the activities, generalization of effective practices, and larger programs with national impact.

- In the long run, a national facility would considerably strengthen the US leadership in underground science and its impact on society.

An alternative that would carry many of the same benefits, perhaps at reduced cost but also with less direct U.S. leadership benefits and control, would be to engage with Canada in an expansion of the SNOLAB deep facility, adding caverns and more convenient access, expanding the scientific campus, and enhancing the local academic and outreach environment. SNOLAB's proximity renders it almost as accessible to U.S. institutions as the Homestake site, with only an international border presenting a modest inconvenience.

Furthermore, even with a major U.S. (or U.S.-Canada) underground site, there will remain good reason to undertake smaller activities at shallower sites nearer to universities such as KURF, WIPP, and Soudan.

With such a geographically widespread community, an organizing entity could yield advantages in the same vein as those argued above for an expanded underground site. Such a *U.S. Dark Matter Forum* would provide continuing exchanges on the science, instrumentation, engineering, safety, and outreach. It would be a natural means for the community to interact in an experiment-non-specific way with DOE and NSF as well as with national planning and advisory panels, and it would provide a natural user voice for the underground facility proposed above.