Exploring New Frontiers in Deep Underground Science

by Samantha Kuula and Blaire Flynn

Establishing a clean lab two kilometers underground in an active mine may seem unusual, but it is essential to the experiments underway at SNOLAB, Canada's underground research laboratory specializing in particle astrophysics. Particle physics has a rich history underground and it has been long-known that overcoming the dirty, hot environment present in a mine is well worth the extremely quiet conditions that can be achieved by going deep underground [1]. By the mid 1960s, neutrino experiments were underway in Kolar Gold Mine in India, East Rand Property Gold Mine in South Africa and in Homesake Gold Mine in South Dakota, USA. As the field of astroparticle physics developed, experiments required more sensitive detection systems and by the late 1960s full fledged laboratories were coming on board in locations across the globe [2].

DEEP UNDERGROUND LABORATORIES

There are a number of underground physics labs in the world (Table 1). These facilities are generally established in mines or in cavities excavated for transportation or power generation initiatives. SNOLAB is situated on the 6800 level of Vale Creighton Mine, an active nickel mine in Sudbury, ON and consists of a network of caverns and hallways with a total volume of over 37,000 m^3 [3]. Each underground laboratory has its own advantages and SNOLAB is the deepest clean lab with the entire space maintained as a Class 2000 clean room (less than 2000 particulates over 0.5 µm in each cubic foot of air).

Summary

SNOLAB is an underground laboratory that began as the Sudbury Neutrino Observatory and subsequently expanded not only physics experiments such as searches for dark matter and supernovae, but fruit fly genetics and the Presence or Absence of Ionizing Radiation. The laboratory is an ultra clean facility located at the 6800 level of Vale's Creighton mine near Sudbury, Ontario.

The flat overburden of 2070 m of norite rock results in a cosmic-ray muon flux of 0.27 μm^{-2} day^{-1} at SNOLAB (see Fig. 1) resulting in a 50 million times reduction in muons from surface [4]. Since the rock itself is a source of natural radioactive backgrounds, the lab relies on an extensive ventilation system of 13 air handlers and strict cleanliness protocols to minimize the presence of uranium and thorium in the lab air.

SNOLAB was constructed using standard mining techniques with ground support in all areas of the lab. The development of the lab took place in two phases between 2004 and 2011 with the official opening taking place in 2012. The excavation was a meticulous 4.5 year process lead by the J.S. Redpath Group that saw 87 000 t of rock excavated [5] and required 8300 tonnes of shotcrete,

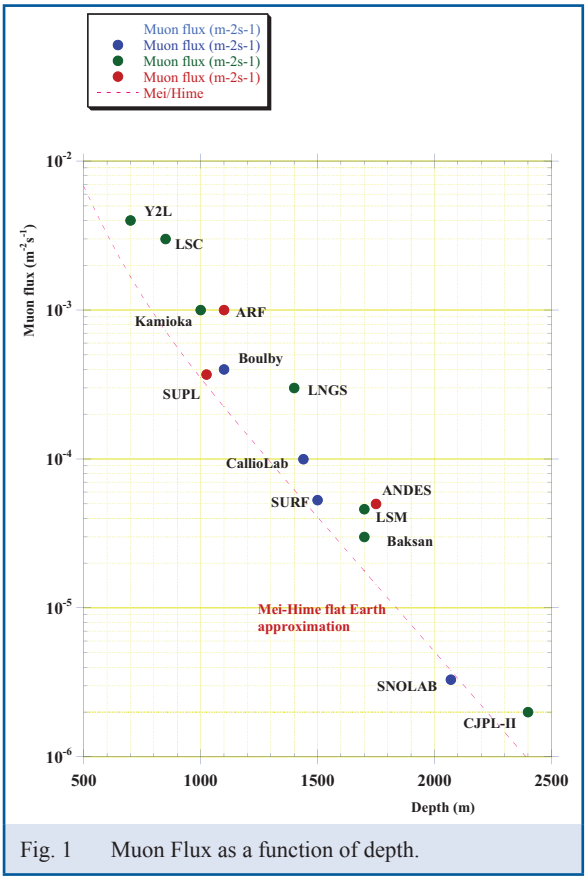

Fig. 1 Muon Flux as a function of depth.

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Table 1
A Global Summary of Deep Underground Science Labs

Site	Depth (m)	Access	Muon Flux ($m/m^2/s$)	Radon (bq/m^3)	Cleanliness Class
Kamioka	1000	Horizontal	10^{-3}	80	Only in sectors
SNOLAB	2070	Vertical	$3.1\ 10^{-6}$	130	2000 or better
LSC	850	Horizontal	$3\ 10^{-3}$	100	Only in sectors
CJPL	2400	Horizontal	$2\ 10^{-6}$	40	Only in sectors
SURF	1480	Vertical	$5.3\ 10^{-5}$	300	3000
Gran Sasso	1400	Horizontal	$3\ 10^{-4}$	80	Only in sectors
CJPL-II	2400	Horizontal	$2\ 10^{-6}$	40	Only in sectors
Boulby	1100	Vertical	In Construction	<3	10000
LSM	1400	Horizontal	Planned	15	ISO9
LSC-CUNA	850	Horizontal	Planned	100	Only in sectors
LBNF/SURF	1480	Vertical	Planned	300	3000
ANDES	1750	Horizontal	Planned	-	-
Baksan	1550	Horizontal	Planned	40	Only in sectors

30 000 rock bolts, 8500 sheets of ground support screen and 2000 cable bolts [6].

EXPLORING NEW FRONTIERS

SNOLAB is a world-class facility with a broad science program focused on neutrino experiments (SNO+ and HALO) and dark matter experiments (SuperCDMS, DEAP-3600, MiniCLEAN, PICO, DAMIC, NEWS-G, and CUTE). While the lab continues to be the location of choice for particle physics, new innovative partnerships have been established that are pushing developments in other fields such as mining innovation, bioinformatics and subsurface biology.

The creation of the MODCC (Mining Observatory and Data Control Centre) [8] capitalizes on existing data integration and sharing expertise at SNOLAB as well as the significant investments already made in the deep underground facility. The MODCC represents a powerful user — and data-interpretation interface that searches, collects, filters and analyzes mining/exploration related datasets. The result will be a data processing facility with accessibility and capability unlike anything currently available to mining/exploration companies and researchers anywhere in the world. This project will address the mineral and related R&D industry's data access and integration needs by creating a service that collects, integrates and securely stores and then distributes data. Streaming data that will originate from sensor arrays in operating mines will eventually be assessed in real-time, thereby making the MODCC a "living data centre" [9].

Fruit flies may not be the first thing that comes to mind when you think of a lab focused on sub-atomic particles, but recent work from Dr. Thomas Merritt (Laurentian University) may change that. Merritt's research group, FLAME (Flies in a Mine), uses flies to study genetics and metabolism and has recently turned their attention to the effects of working in a mine, specifically working deep underground. The unique features that make SNOLAB an ideal location for studying subatomic particles, a controlled environment deep underground, also make it an ideal location for studying the biological response to pressure. Working underground means working under higher atmospheric pressure and the deeper we mine, the higher the pressure — and mines are going deeper and deeper in search of resources. Mining companies are interested in understanding physical responses to working under higher pressure in order to address the effects and support a healthier workforce. In SNOLAB, the atmospheric pressure is approximately 20% greater than on the surface; using techniques they developed for studying metabolic responses in flies, they are measuring the response to mining pressures across thousands of individual metabolites (sugars, amino acids, lipids, etc.). The work is in the early stages, but suggests that at least 10% of metabolites change with even a single trip down to mining depths. The long-term effects of this change aren't known, and are a central

question in Merritt's work. Ultimately, Merritt and his students hope that through understanding this response in flies they can help to develop strategies to address the changes observed to make mining, and any work done under high atmospheric pressure, safer and healthier [10].

The REPAIR (Researching the Effects of the Presence and Absence of Ionizing Radiation) project [7], run by the Northern Ontario School of Medicine and Laurentian University, is currently examining the biological effects of prolonged growth and development in SNOLAB. It is hypothesized that organisms have adapted to oxidative stress produced by natural background radiation, which promotes and maintains DNA stability, and that removal of background radiation will be detrimental to living systems. Several different model systems are being utilized to test this hypothesis. Human cell cultures grown in SNOLAB will be examined for cancer risk, oxidative stress, and genomic damage such as DNA double strand breaks. Lake whitefish embryos raised in SNOLAB will be examined for whole-organism survival, growth and development [7].

SNOLAB enables research that will accrue benefits in the future; these include technology developments in high-efficiency photon sensors that are expected to have an application in medical imaging, national security, public safety solutions and are also expected to facilitate the development of low background techniques. SNOLAB supported initiatives such as the MODCC will deliver direct benefits to the Canadian mining industry by enhancing productivity and supporting job creation. SNOLAB continues to strengthen its position as one of the premier underground laboratories in the world, increasing scientific leadership and contributions across many areas of Canadian science.

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REFERENCES

1. A. Bettini, "New Underground Laboratories", *Physics of the Dark Universe*, **4**, 36-40 (2014).
2. A. Bettini, "Underground Laboratories", *Journal of Physics*: Conference Series, **120**, 082001 (2008).
3. Smith NJT. "The SNOLAB deep underground facility", *European Physical Journal Plus*. **127**, 108-116. (2012).
4. Technical Reference Manual, *SNOLAB Internal Publication*, SL-SCI-RES-00-001-P. 2016.
5. S. Bhan, F. Duncan, I. Lawson, and C. McDonald, "Shotcrete Application in SNOLAB", *Shotcrete*. **9**, 4-7 (2007).
6. F. Duncan, A. Noble, and D. Sinclair, "The construction and anticipated science of SNOLAB", *Annual Review of Nuclear and Particle Science,* **60,** 163-180 (2010).
7. C. Thome *et al*., "Examining the Biological Impacts of Sub-Background Radiation Exposure within SNOLAB, a Deep Underground Laboratory", *Radiation Research*, **188**, 470–474 (2017).
8. N. Tollinsky, "SNOLAB hosts incubator for data analytics", *Sudbury Mining Solutions Journal*, **13,** 12-13 (2016).
9. Centre for Excellence in Mining Innovation. Mining Observatory Data Control Centre (MODCC). Retrieved from: https://www.cemi.ca/ValueMine/mining-observatory-data-control-centre-modcc/. 2014.
10. Research Matters. How fruit flies can help the mining industry. Retrieved from: http://yourontarioresearch.ca/2017/08/fruit-flies-can-help-mining-industry/. 2017.