Homestake Mine Background Characterization and Sanford Lab Counting Facility

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the university of south dakota.

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NSF Review

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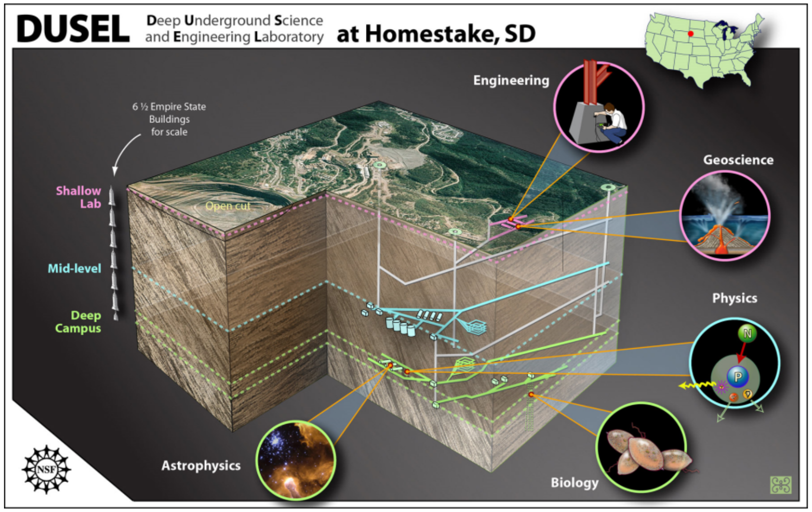
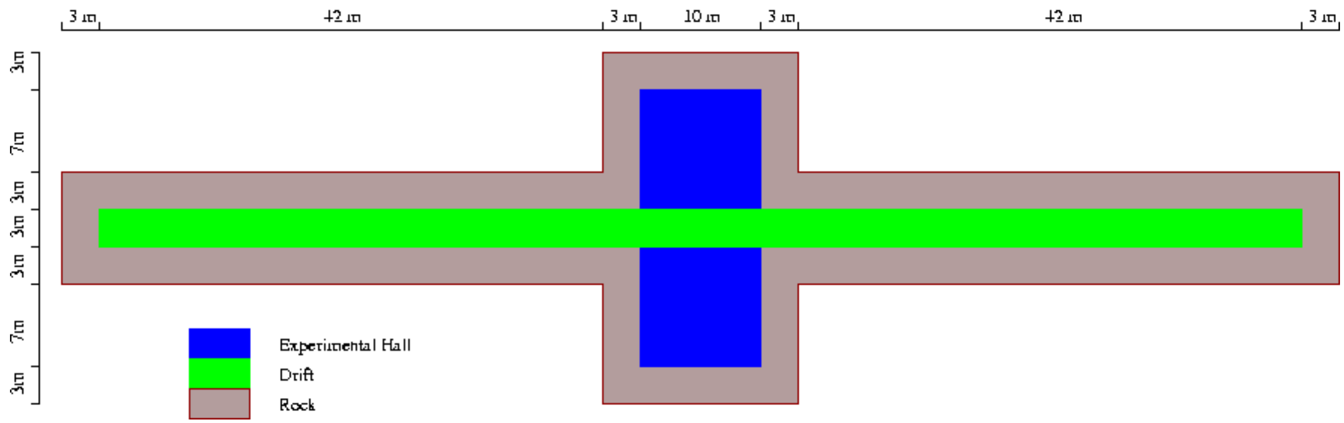
External Backgrounds At Homestake

- **Measuring external sources of radioactivity at the DUSEL site is key to success in low-energy neutrino and dark matter (WIMP searches) experiments**
  - **Shielding design, radon mitigation, and active veto**
- **The Sources of External Background**
  - **Radioactivity in the rock**
    - **Gamma-rays, (alpha, n) neutrons, radon**
  - **Muon-induced processes**
    - **Muon-induced neutrons**
    - **Muon bremsstrahlung**
- **How the measurements are being pursued**
  - **NaI detectors for measuring gamma-rays**
  - **Plastic scintillators for measuring muons**
  - **Liquid scintillators for measuring neutrons**
  - **RAD 7 and AlphaGuard for measuring radon levels**



Background Simulation



Rock Component (Sample 278-2)	Composition (% weight)
SiO_2	43.7
TiO_2	1.22
Al_2O_3	13.6
FeO	12.7
MnO	0.13
MgO	7.0
CaO	7.9
Na_2O	2.87
K_2O	0.21
P_2O_5	0.07
H_2O	10.7
$^{232}Th(\alpha,n)$ Yield	0.34/g/ppm/y
$^{238}U(\alpha,n)$ Yield	0.86/g/ppm/y

http://neutronyield.usd.edu

NIM A 606(2009)651-660 (arXiv:0812.4307)

Neutron Yield in Materials

We developed a web database to calculate (a,n) neutron yield for user-input element/compound/mixture.

The result of neutron energy spectrum is taken as an input for MC simulation.

Table 1: The equilibrium yields from ^{238}U, ^{232}Th and Samarium($E_n > 0.1 MeV$).

Element	^{232}Th $(n \cdot ppm^{-1} \cdot g^{-1} \cdot y^{-1})$	^{238}U $(n \cdot ppm^{-1} \cdot g^{-1} \cdot y^{-1})$	Samarium $(n \cdot ppm^{-1} \cdot g^{-1} \cdot y^{-1})$
Boron	1.32e+01	5.00e+01	8.32e-03
Carbon	1.13e-01	3.78e-01	
Oxygen	4.53e-02	1.45e-01	2.57e-06
Neon	1.65e+00	5.02e+00	
Sodium	1.75e+00	5.43e+00	
magnesium	1.47e+00	4.14e+00	
Aluminum	2.04e+00	4.95e+00	
Silicon	2.12e-01	5.54e-01	1.49e-08
Phosphorus	2.01e-06	5.63e-07	
Argon	3.06e+00	6.12e+00	
Potassium	2.84e-02	5.36e-02	
Calcium	1.90e-02	3.54e-02	
Titanium	8.60e-01	1.38e+00	
Manganese	4.03e-01	4.61e-01	
Iron	1.71e-01	1.61e-01	
Copper	3.77e-02	1.77e-02	
Xeon	6.07e-07	1.33e-08	

Background Simulation

- The gamma ray flux in the experimental hall induced by radioactivity in the rocks.

Range (MeV)		0 – .1	.1 – .2	.2 – .3	.3 – .4	.4 – .5	.5 – .6	.6 – .7	.7 – .8	.8 – .9	.9 – 1	Sum
E_γ	Source	γ-ray flux ($ppm^{-1}cm^{-2}s^{-1}$)										
0	^{238}U	9.1e-2	1.4e-1	6.5e-2	4.1e-2	1.6e-2	1.1e-2	2.5e-2	7.6e-3	5.0e-3	5.2e-3	4.0e-1
	^{232}Th	3.5e-2	5.5e-2	3.3e-2	1.2e-2	6.7e-3	1.2e-2	3.0e-3	5.3e-3	2.7e-3	7.5e-3	1.7e-1
	^{40}K	6.6e-2	1.4e-1	7.1e-2	3.4e-2	2.3e-2	1.9e-2	1.5e-2	1.2e-2	1.2e-2	1.1e-2	4.0e-1
1	^{238}U	5.7e-3	1.1e-2	7.4e-3	6.1e-3	4.1e-3	1.7e-3	1.0e-2	1.4e-2	1.5e-3	2.2e-4	6.2e-2
	^{232}Th	5.0e-3	1.4e-3	5.8e-4	5.1e-4	4.3e-4	1.4e-3	8.0e-4	2.2e-4	2.9e-4	1.4e-4	1.1e-2
	^{40}K	1.2e-2	1.3e-2	9.4e-3	8.7e-3	1.6e-1	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	2.0e-1
> 2	^{238}U	0.0e+00	1.5e-3	3.5e-3	0.0e+00	4.4e-4	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	5.5e-3
	^{232}Th	2.9e-4	6.5e-4	2.2e-4	4.3e-4	1.4e-4	7.2e-4	9.3e-3	0.0e+00	0.0e+00	0.0e+00	1.2e-2
	^{40}K	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00

- The neutron flux in the experimental hall induced by ^{238}U and ^{232}Th radioactivity in the rocks.

The neutron flux induced by ^{238}U and ^{232}Th radioactivity in the simulated experimental hall.

Source	Thermal Neutron E_n <1 eV ($ppm^{-1}cm^{-2}s^{-1}$)	Slow Neutron E_n in [1 eV, 0.1 MeV] ($ppm^{-1}cm^{-2}s^{-1}$)	Fast Neutron E_n >0.1 MeV ($ppm^{-1}cm^{-2}s^{-1}$)
^{238}U (α, n)	1.17e-6	6.79e-7	6.46e-7
^{232}Th (α, n)	4.19e-7	2.48e-7	2.64e-7
^{238}U fission	5.73e-7	3.26e-7	3.04e-7

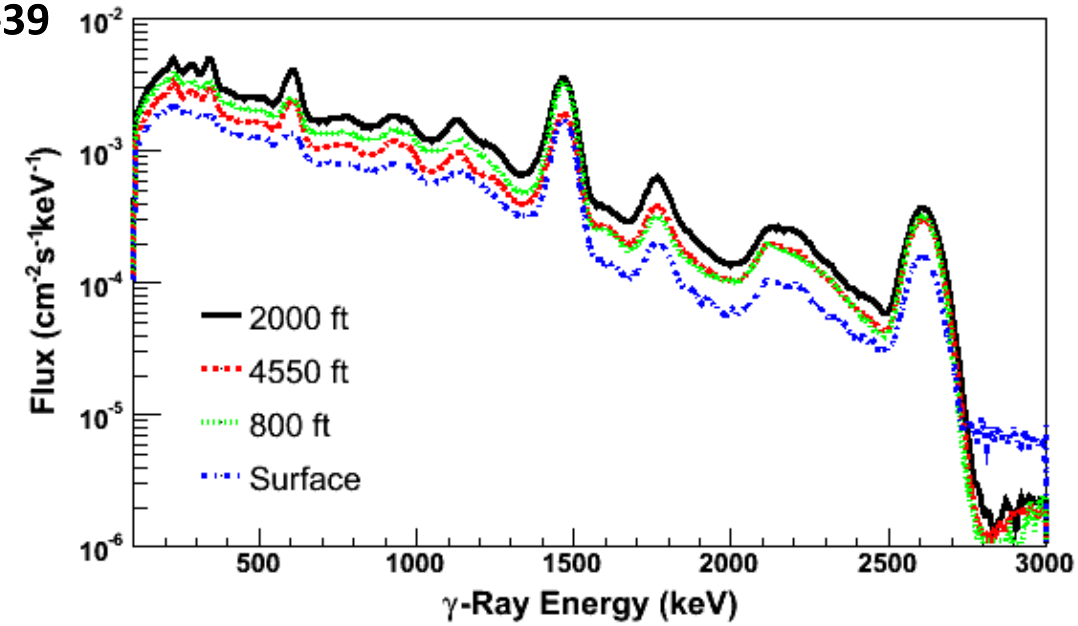
- Predictions based on the radioactive concentration, i.e., for the 4850-ft level, 238U: 0.55ppm, 232Th: 0.3ppm and 40K: 2.21%; for the7400-ft level, 238U: 0.49ppm, 232Th:0.20ppm and K: 0.57%.

Depth	γ-ray flux ($cm^{-2}s^{-1}$)		Neutron flux ($cm^{-2}s^{-1}$)
	^{238}U and ^{232}Th	^{40}K	
4850 ft	0.32±0.10	1.46±0.44	$(2.3\pm0.8)\times10^{-6}$
7400 ft	0.27±0.08	0.38±0.11	$(2.0\pm0.7)\times10^{-6}$

Gamma Ray Background

Early Results on Radioactive Background Characterization
for Sanford Laboratory and DUSEL Experiments

Astroparticle Physics 34 (2010) 33-39
arXiv:0912.0211



Levels surveyed thus far include locations on the surface, 800L, 2000L, and 4550L. Results depend most upon local geology. More measurements are planned for the 4850L soon when appropriate areas become available.

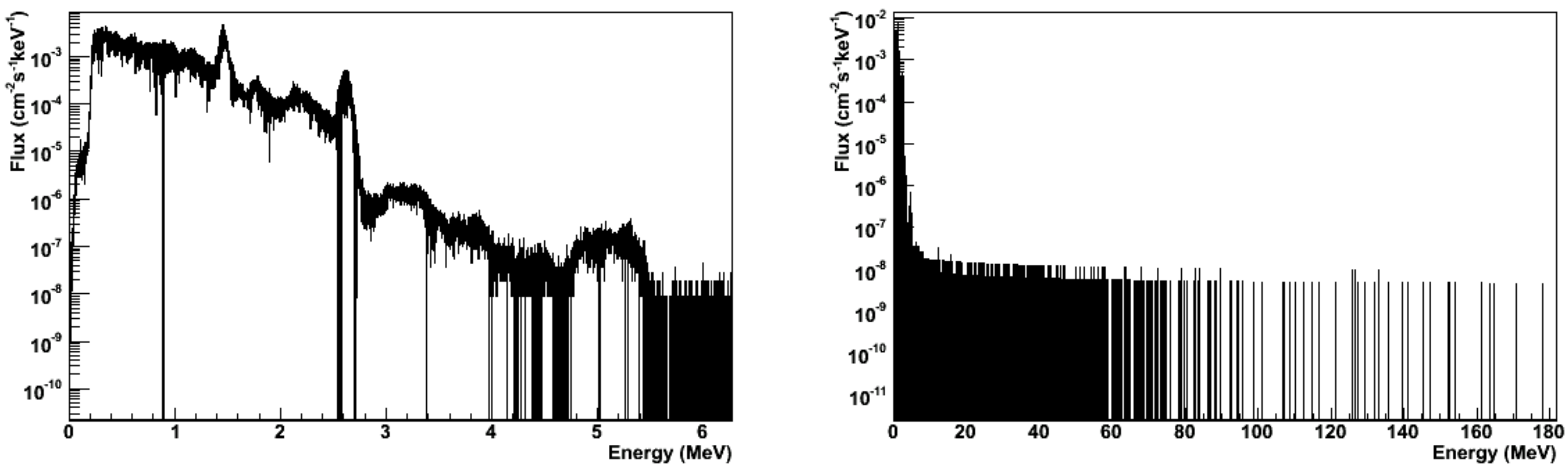
The measured γ-ray flux ($cm^{-2}s^{-1}$)

	E>0.1 MeV	E>1 MeV	E>2 MeV	E>3 MeV
Surface	1.56	4.63×10^{-1}	5.52×10^{-2}	1.09×10^{-3}
800 ft	2.65	7.97×10^{-1}	9.49×10^{-2}	4.81×10^{-4}
2000 ft	3.42	1.04	1.26×10^{-1}	7.05×10^{-4}
4550 ft	2.16	6.32×10^{-1}	9.64×10^{-2}	6.01×10^{-4}

Gamma Ray Background, cont'd

Long-term measurements are being conducted in an effort to characterize the higher energy gamma ray flux, as a result of muon bremsstrahlung. This has been done on the 800L and it is currently operating on the 2000L with plans to relocate to the 4850L soon.

The system will be augmented by larger NaI crystals soon.

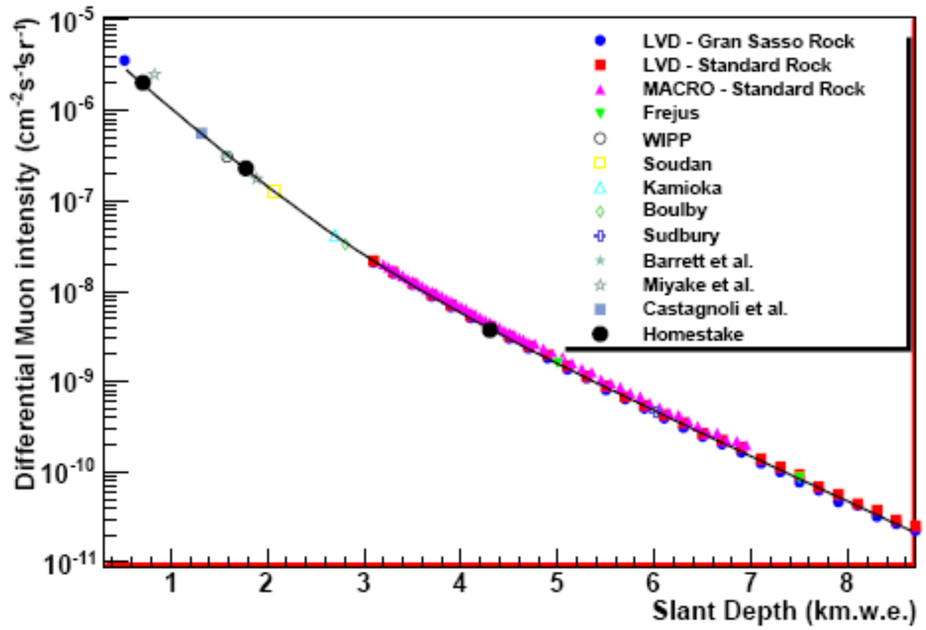


~30 day background spectrum from the 800 ft Level.

Muons

Early Results to be released to arXiv soon, followed by Nuclear Instruments and Methods.

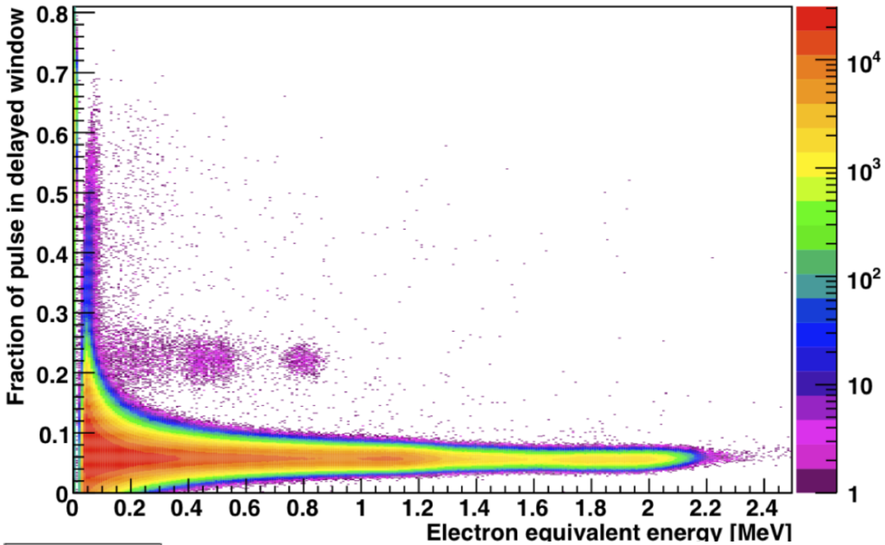
Muon detector system on the 2000L



Muon measurements conducted thus far have been consistent with other models/measurements.

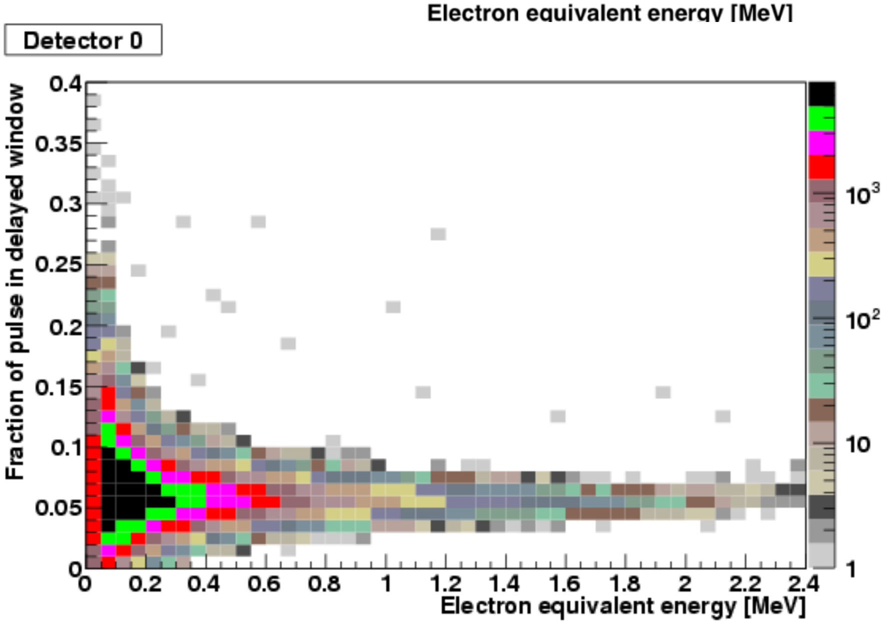
Surface	$(1.149 \pm 0.017) \times 10^{-2}\ s^{-1}\ cm^{-2}\ sr^{-1}$
800L	$(2.67 \pm 0.06) \times 10^{-6}\ s^{-1}\ cm^{-2}\ sr^{-1}$
2000L	$(2.51 \pm 0.25) \times 10^{-7}\ s^{-1}\ cm^{-2}\ sr^{-1}$

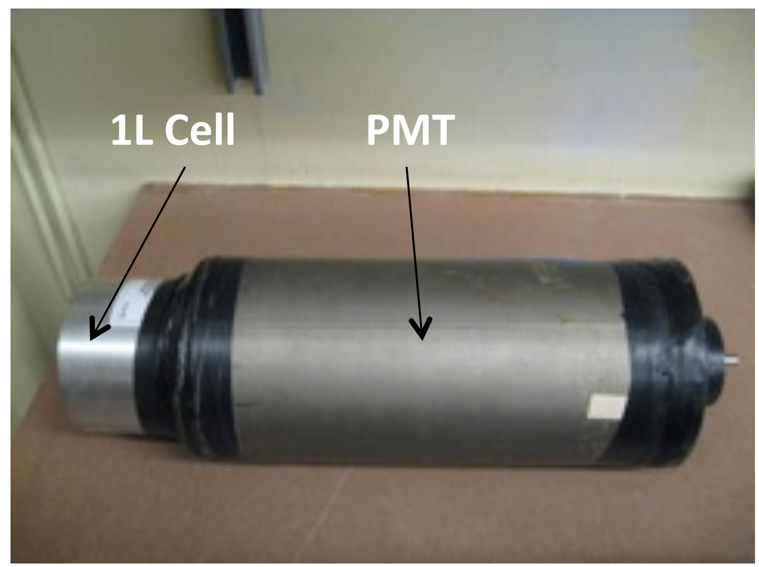
Neutrons



Neutrons are produced in rock through (a, n) reactions, spontaneous fission, and muon-induced process.

Current measurements are being conducted with approximately a 1L scintillation cell containing Eljen Technologies EJ301 Liquid Scintillator, chosen for its pulse shape discrimination.





Big Neutron Detector

- A 12L liquid scintillation counter has been built and is being tested at USD.

- 5" in diameter, 1 meter in length ,Aluminum tube filled with EJ-301 liquid scintillator. EJ-520 reflective paint is uniformly painted on the inner surface of the tube.

- Two PMTs (R4144 , hamamatsu) installed at the both ends of the counter.

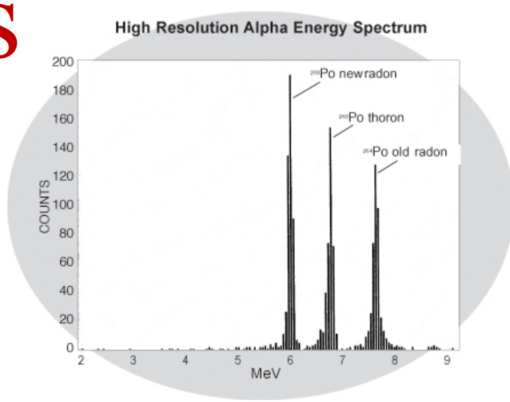
- To be deployed underground soon.

- Additional Gd-doped neutron detector in development to create a hybrid neutron detector array.

A student viewed through the filled cell.

Radon: Instruments

- Started (in earnest) in May 09
- Instruments on loan from various institutions and labs.
  - 2-3 Rad7's (USD, Brown, BNL)
  - 3 Alphaguards (LBNL)
- Advantages/Disadvantages for each type of detector.
- Concerns/Limitations underground: humidity, power availability, access



Radon

Relevant factors affecting Radon levels at Homestake:

Primary

Dominant factor for Radon levels underground.

Ventilation- Drastic changes in radon levels completely associated with the variations in the ventilation system. Ventilation is 30-50% of historical capacity, so improvements to the ventilation system (air doors, CFM increases, etc.) should yield changes in the radon levels.

Secondary

These may cause a higher baseline level than historical records.

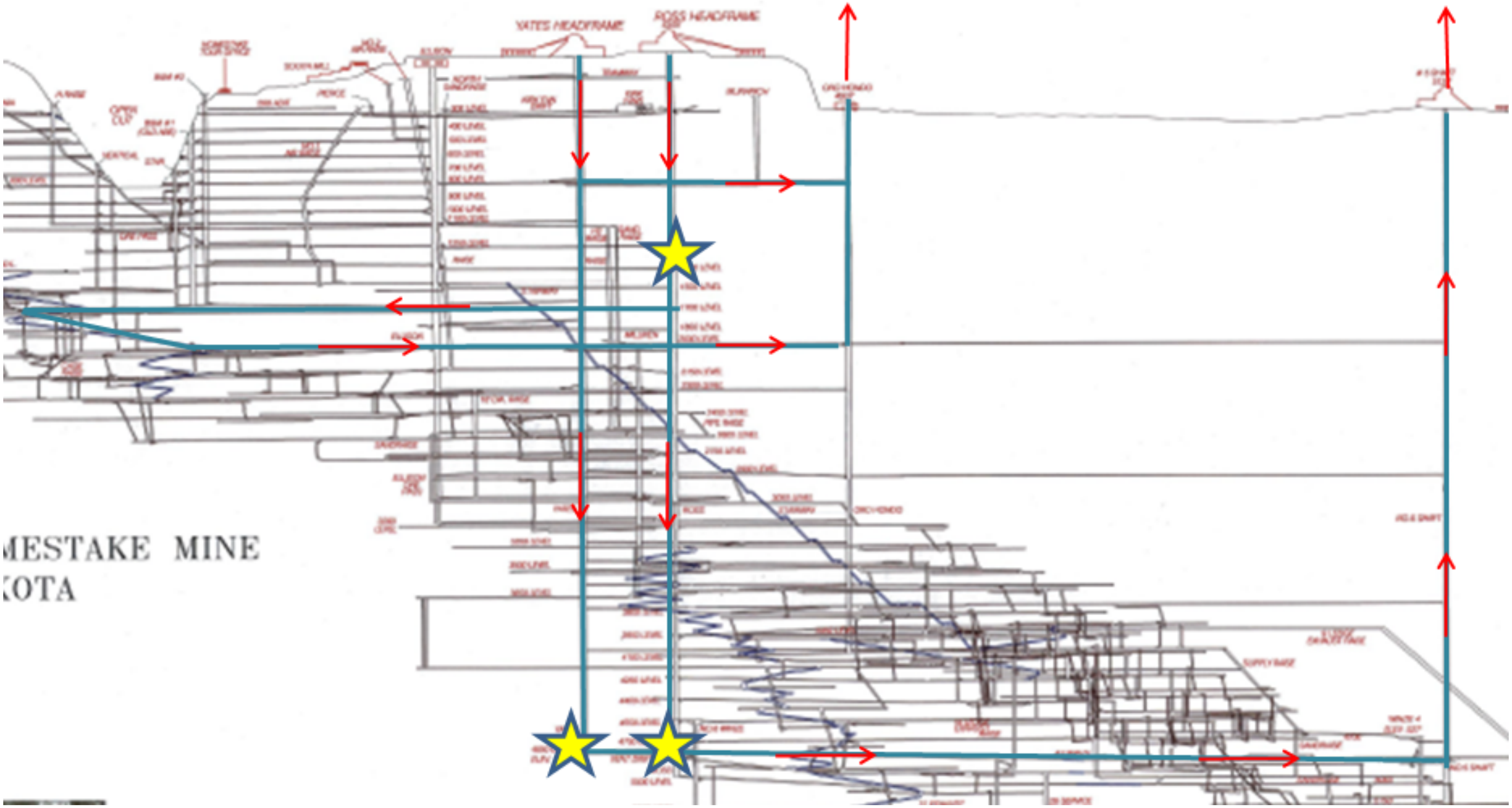
Iron Oxide- enriched Ra content, high Rn emanation.

Moisture- enhanced emanation (from both rock and iron oxide) (both from mine filling with water while decommissioned)

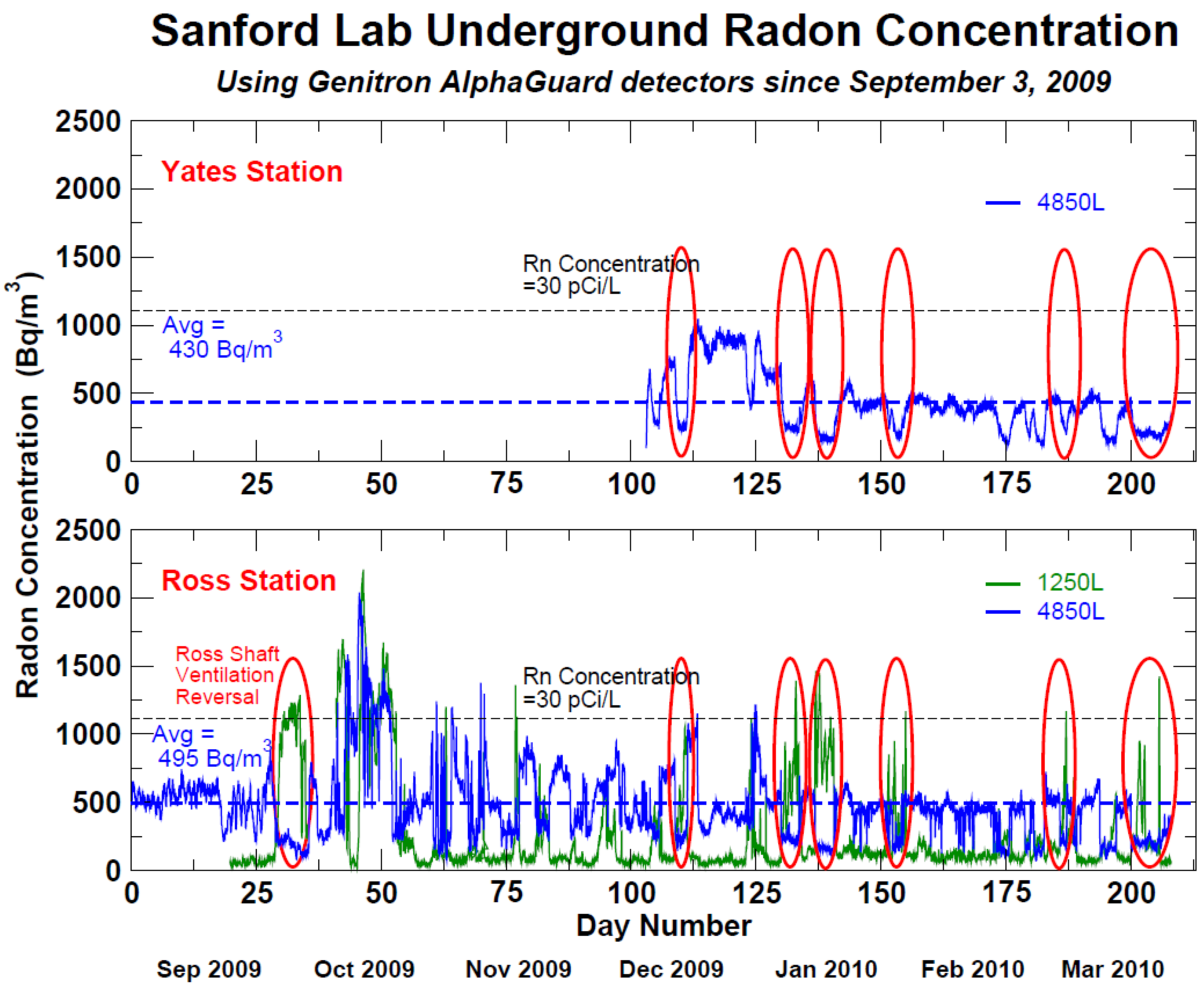
Mine Ventilation

Only 30-50% of Historical Capacity. (and very dynamic)

Long term Rn monitors stationed at 1250L & 4850L Ross Stations, and 4850L Yates Station, for vertical and horizontal comparison along primary ventilation routes.

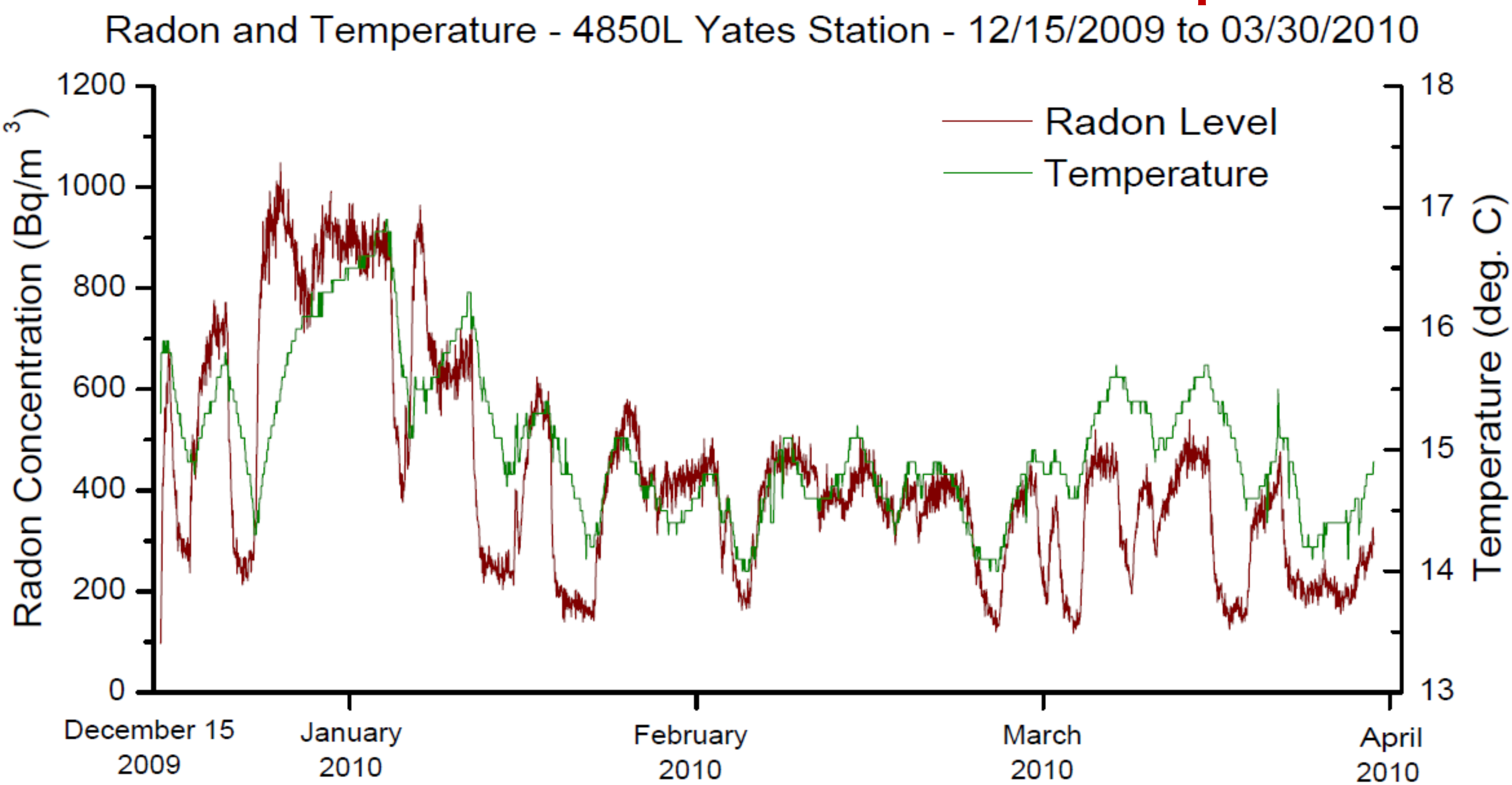


1250L vs 4850L

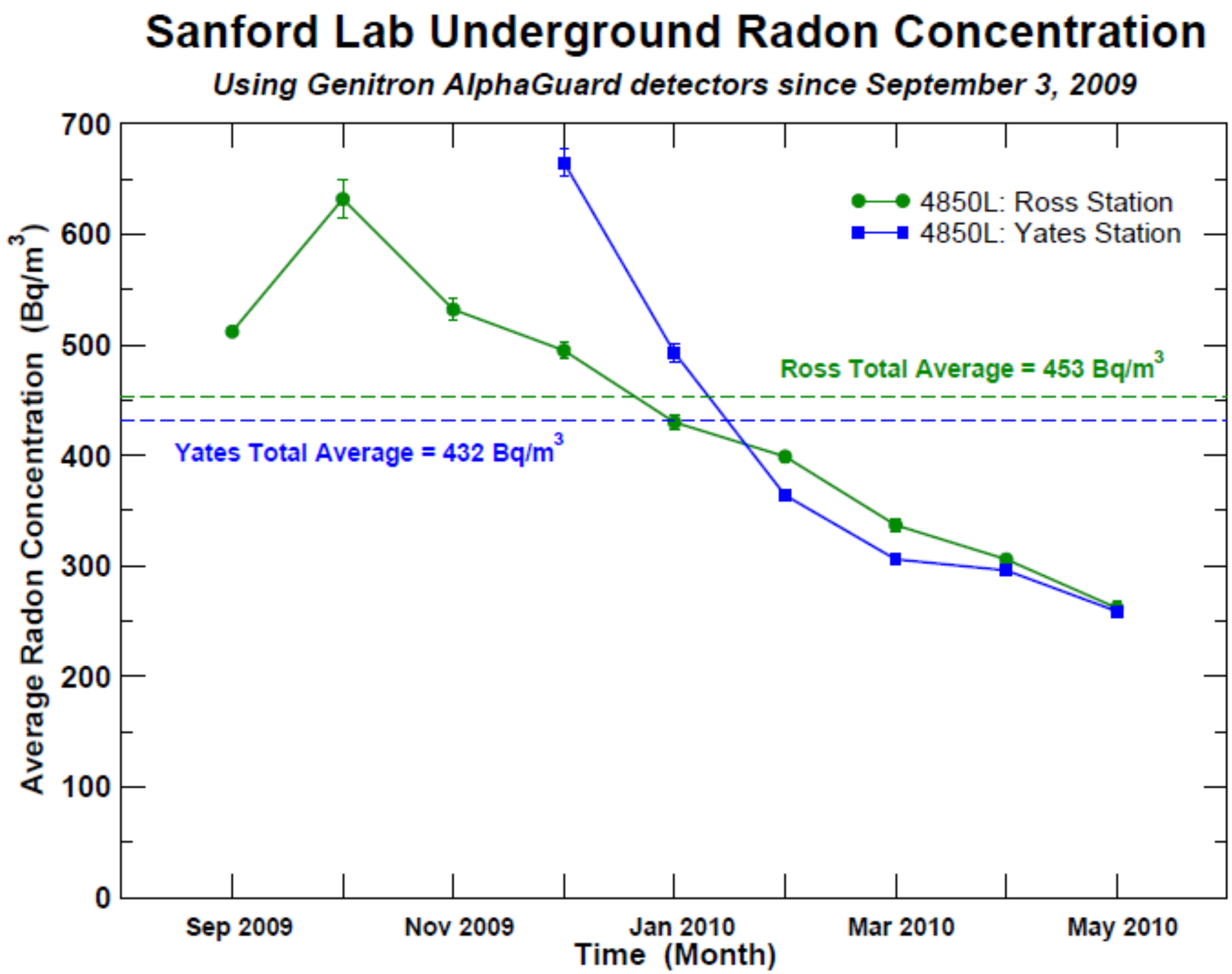


Comparisons of vertical locations on the Ross shaft reveal some ventilation events, such as air direction reversals in the Ross Shaft. Some understood/accounted for, others not. Note in the first circled event on the left, the 1250L (close to surface) has low Rn levels and it suddenly swings to show high Rn from deep below; while at the same time the 4850L high Rn levels reduce and stabilize. This is an air reversal along the Ross Shaft. The 1250L suddenly is sampling 'exhaust' air from below.

Yates Station Rn vs. Temp.



Temperature changes can imply changes in how ‘fresh’ the air is entering the location. Air from deeper parts of the mine is warmer and also typically higher in Rn concentrations, whereas low-Rn air from the surface is cooler than the underground rock. This relationship can help optimize ventilation improvements to improve direct surface (low Rn) airflow to priority areas underground.



Summary plot of average radon levels– overall they are going down, likely due to ventilation improvements.

Radon Comments

- Measurements underground reflect radon levels with little or no mitigation efforts in place: minimal/unstable ventilation *(30-50% of historical capacity),* no layers resistant to diffusion, no radon removal systems.

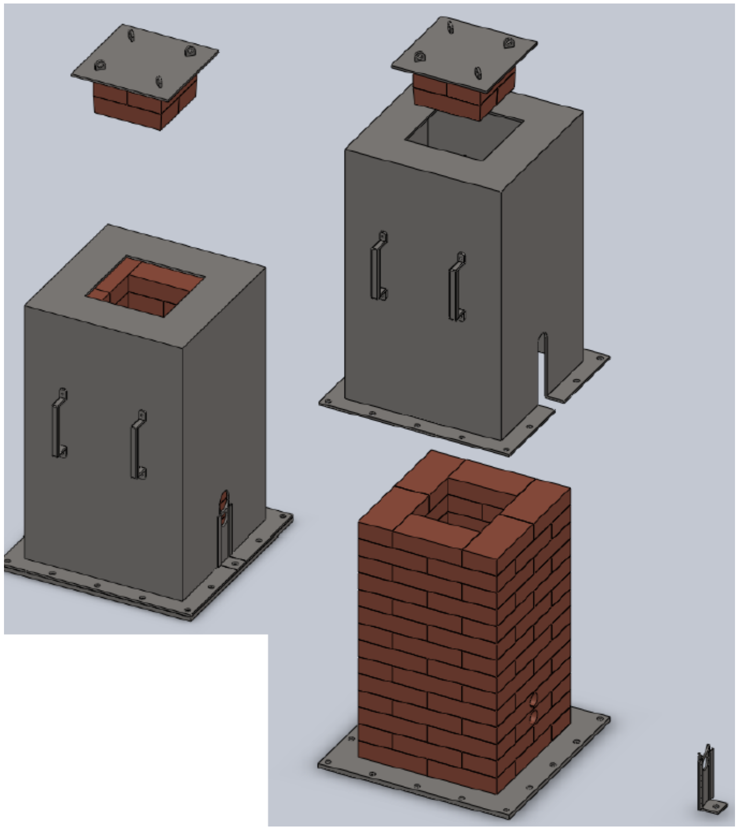
- Measurements reflect relationship of radon with exposure to path length through mine– i.e. (1250L swing 'exhaust' Rn levels 3 slides back)

- Moisture in the rock, presence of iron oxide may play a role in enhancing the radon levels on 4550L and below. Sampling and testing on rock and iron oxide samples is currently being studied (Summer 2010).

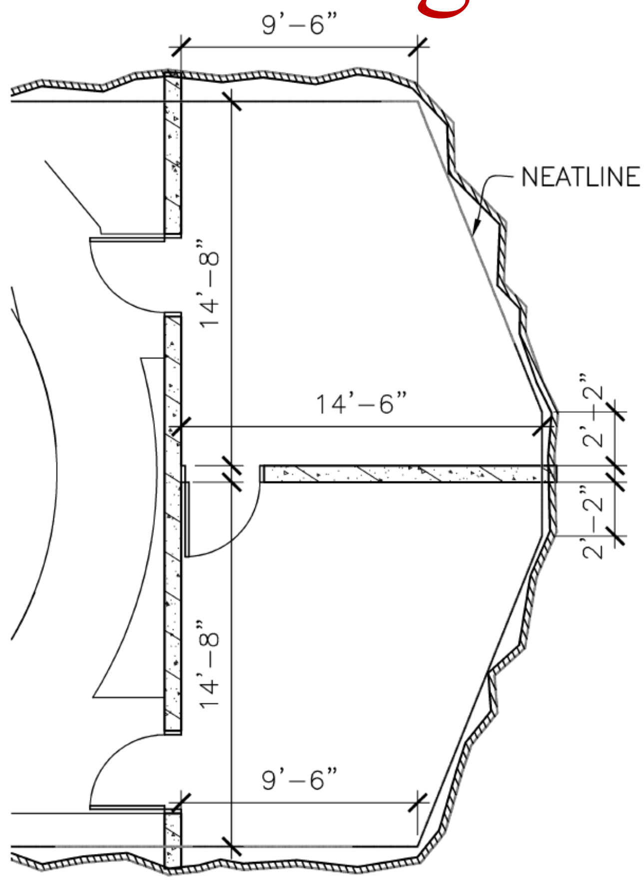
- Improvements to the ventilation system (fans, air doors), receding water levels will change the ventilation conditions underground and therefore also the radon levels.

- Long term measurements still running on the 1250L/4850L Ross Stations, 4850L Yates. Will soon incorporate two more long term measurement locations.

Low-Background Counting



Prototype shield under is currently under construction at USD for use with already purchased HPGE detector. Shield will incorporate an inner layer of OHFC copper, stainless steel radon-exclusion box, and outer layer of lead.



Space reserved for low-background counting with HPGE detectors in the LUX refurbishment of the Davis Cavern on the 4850L. The Davis Cavern is currently under construction.

Status

- Gamma flux measured on surface, 800L, 2000L, and 4550L. Preliminary results are published.

- High energy gamma's are being measured right now underground on the 2000ft level. System will be relocated to the 4850L soon.

- Muon measurements have been made on the surface, 800L and 2000L. Results agree with predictions/measurements taken in past. The setup will relocate soon to the 4850L. Preliminary results will be published soo.

- Neutrons are currently being measured on the 800L, and will soon incorporate a 12L detector to improve efficiency.

- The simulation results agree with the measured results on muons and gamma rays pretty well. Prediction can be done for levels/areas temporarily inaccessible.

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