

The Underground Counting Facility (UCF) at Savannah River National Laboratory (SRNL) and Shallow Underground Laboratory Backgrounds

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Introduction

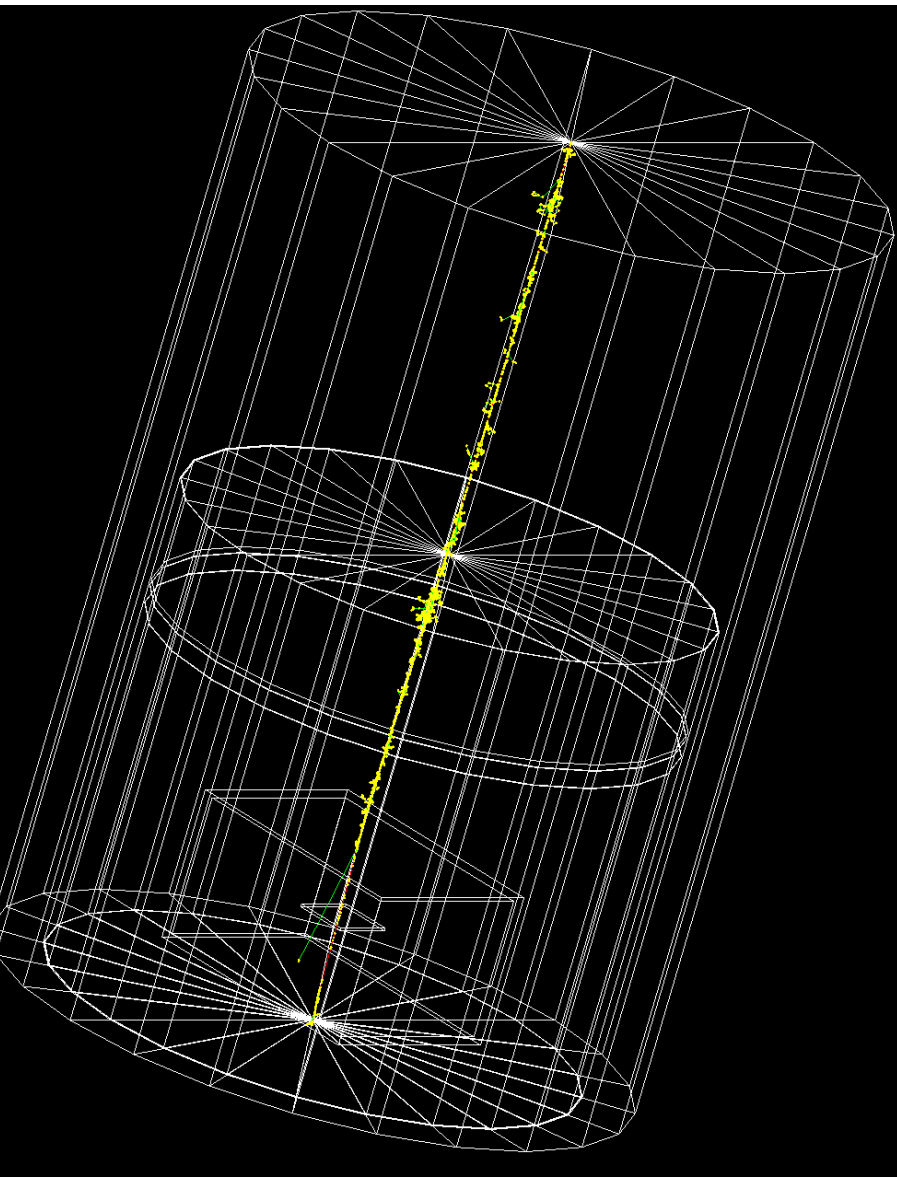
Shallow underground laboratories (< 50 m underground) are more accessible and well suited for a wide variety of measurements than their deep underground counterparts. While cosmic induced backgrounds in deep underground laboratories are largely insensitive to local design choices, shallow underground labs are significantly affected by design choices.

Here, we study the radiation backgrounds in the Underground Counting Facility (UCF) at Savannah River National Lab (SRNL). Several design choices made during the construction of the UCF appear to lack documented quantitative justification. Here, we evaluate the radiation shielding efficacy of the design choices relative to simply backfilling with the excavation soil, suggest an alternate design constructed in the same footprint, and study how the designs compare when applied to locations with different soil composition and higher density.

Methods

Modeling the radiation environment in the UCF with GEANT4 simulations:

- Assess radiation flux across the center of the counting room
 - $h = 1.2$ m from floor
 - Exclude 0.5 m outer edges



A GEANT4 simulation rendering of a 10 GeV primary muon and its secondary products as it travels downward from the surface into the UCF.

- Generate μ^+ and μ^- across 150 m radius at the surface assuming relatively flat overburden
 - Compare radiation flux with “informed” silo design
 - Compare radiation flux with combinations of no silo and denser rock
- Test Configurations (8 in total):**

SRNL configuration: SRNL Sand + “as built” silo

SRNL config w/ clay instead of borated (white) concrete

SRNL config w/ clay instead of specular hematite

Plus all permutations of (5 additional designs):

Soil types (2):

 - SRNL Sand ($\rho = 1.6$ g/cm³)
 - Standard Rock ($\rho = 2.65$ g/cm³)

Silo designs (3):

 - SRNL “as built” silo
 - “Informed” silo design
 - No silo (keep steel, backfill with existing soil)

References

Chatzidakis, S.; Tsoukalas, L. H. Monte-Carlo simulations of cosmic ray muons for dry cask monitoring. *Trans. Am. Nucl. Soc.* **2015**, 112, 534-536.

Gordon, M. S.; Goldhagen, P.; Rodbell, K. P.; Zabel, T. H.; Tang, H. H.; Clem, J. M.; Bailey, P. Measurement of the flux and energy spectrum of cosmic-ray induced neutrons on the ground. *IEEE Trans. Nucl. Sci.* **2004**, 51, 3427-3434.

Winn, W. G.; Bowman, W. W.; Boni, A. L. Ultra-clean underground counting facility for low-level environmental samples. *The Science of the Total Environment* **1998**, 69, 107-144.

Sramek, O.; Stevens, L.; McDonough, W.; Mukhopadhyay, S.; Peterson, R. Subterranean production of neutrons, ³⁹Ar and ²¹Ne: rates and uncertainties. *Geochimica et Cosmochimica Acta* **2016**, 196, 370-387.

SRNL and the SRNL UCF

The Underground Counting Facility (UCF) at Savannah River National Lab (SRNL) is about 12 m underground (from ground level to ceiling). It is uniquely accessible via a ramp from a clean lab space. The soil that surrounds the silo is composed of mostly sand and some kaolinite clay. The average soil density is a relatively low 1.6 g/cm³. The counting room is constructed from pre-WWII battleship steel with interior dimension of 4.3 x 3.0 x 2.4 m. The counting room was lowered into a (watertight) sheet piling silo, itself filled with successive material layers to aid in shielding cosmic rays. The effectiveness of the specific design choices (material layers within the silo) does not appear to have been evaluated or justified prior to construction.

SRNL’s expertise in clean sample preparation chemistry combined with the easily accessible underground space and expertise in ultra-low background radiation detection provide an ideal environment for radiation detection needs that are less stringent than in large physics experiments but still benefit significantly from the reduced background.

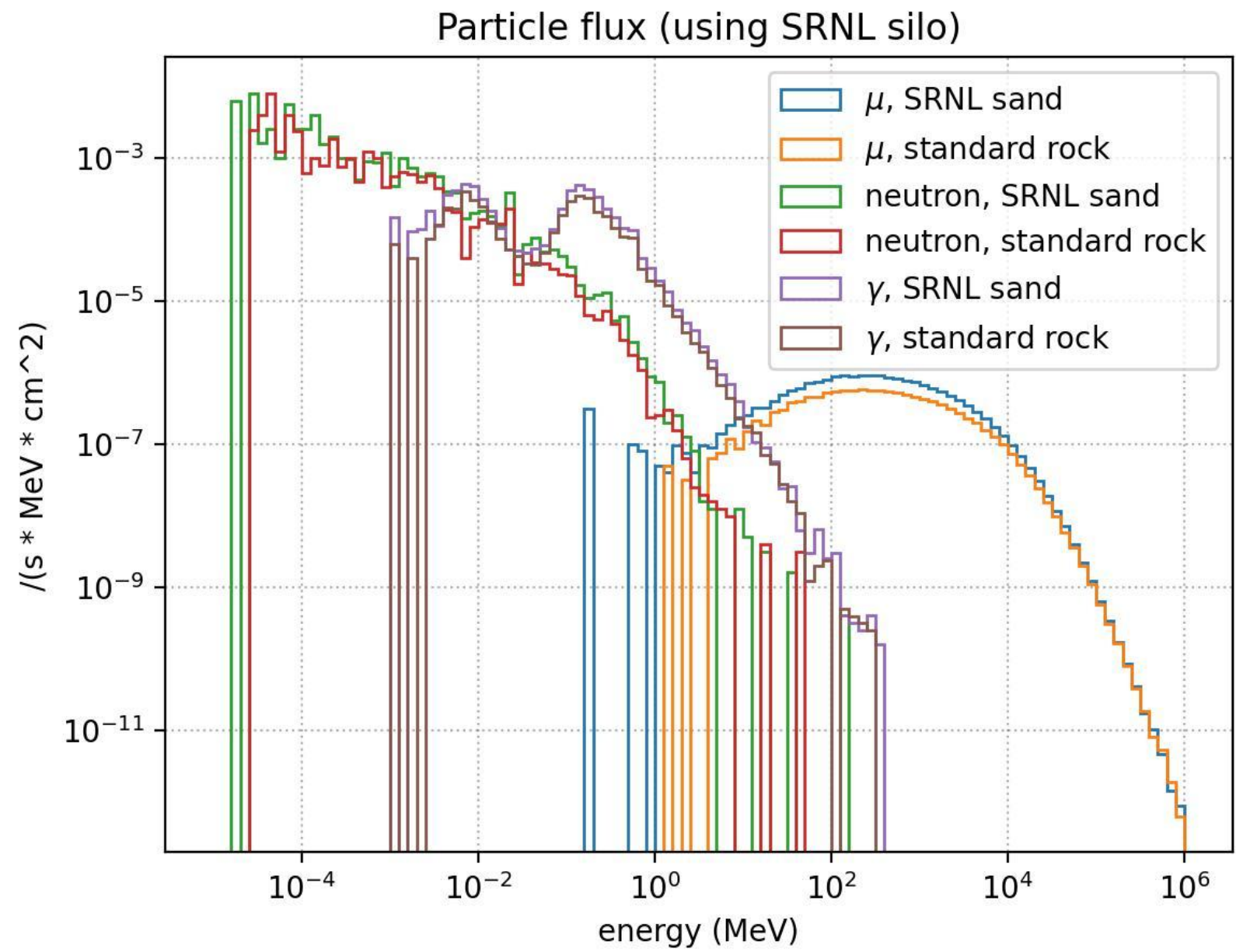
Silo Design

The “as built” silo design’s inclusion of clay and specular hematite succeeds in increasing the density and overburden relative to the surrounding sand, which successfully decreases the muon flux in the counting room. The high density, low background pre-WWII battleship steel counting room shell acts as a final shield for gammas and neutrons produced in the surrounding layers. However, placing the borated white concrete layer nearly 3 m from the counting room does not seem to make sense given that most neutrons created above this depth would not otherwise reach the counting room.

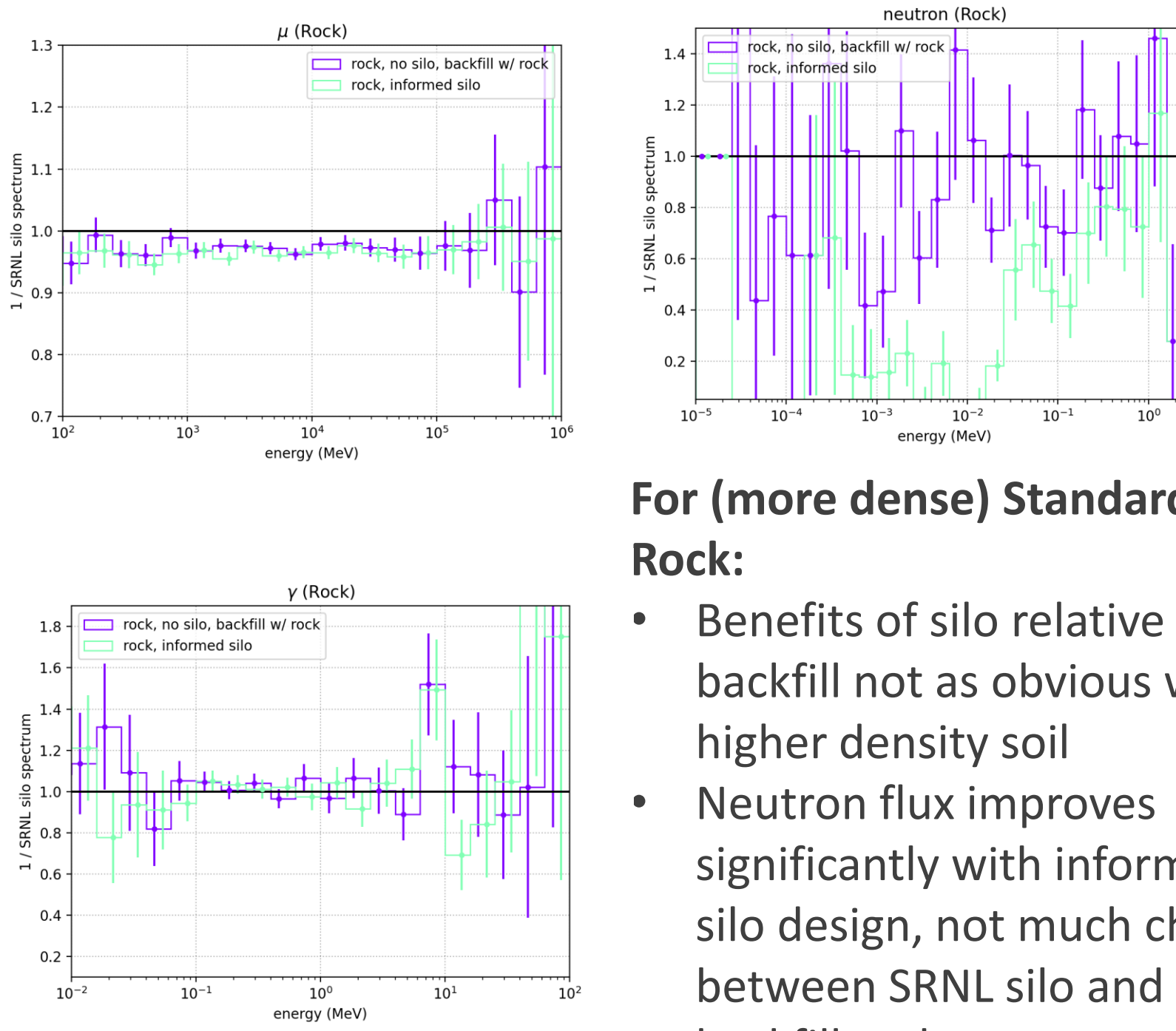
Increasing density and overburden should be prioritized over neutron absorption in the area where the borated concrete is currently placed. Borated layers should be placed closer to the counting room to take advantage of neutron capture properties and increase solid angle coverage. Additional neutron moderation could be placed just above the borated layer to increase capture rates. Small amounts of H in clay could accomplish this. A small amount of (higher-density) material should be placed between the borated layer and the counting room steel to absorb subsequent boron capture gammas.

The “informed” design silo uses an identical footprint, uses the same counting room material and placement in the silo, and is placed at the same depth. The alternate silo designs use many of the same bulk materials to stay cost-effective for large amounts of material. “Informed” design (from top to bottom): 3.7 m of specular hematite, 0.5 m of clay, 0.1 m of borated concrete, 3.9 m of clay (counting room is in this layer). 0.102 m (4”) layer of borated polyethylene added to surround counting room steel.

Results

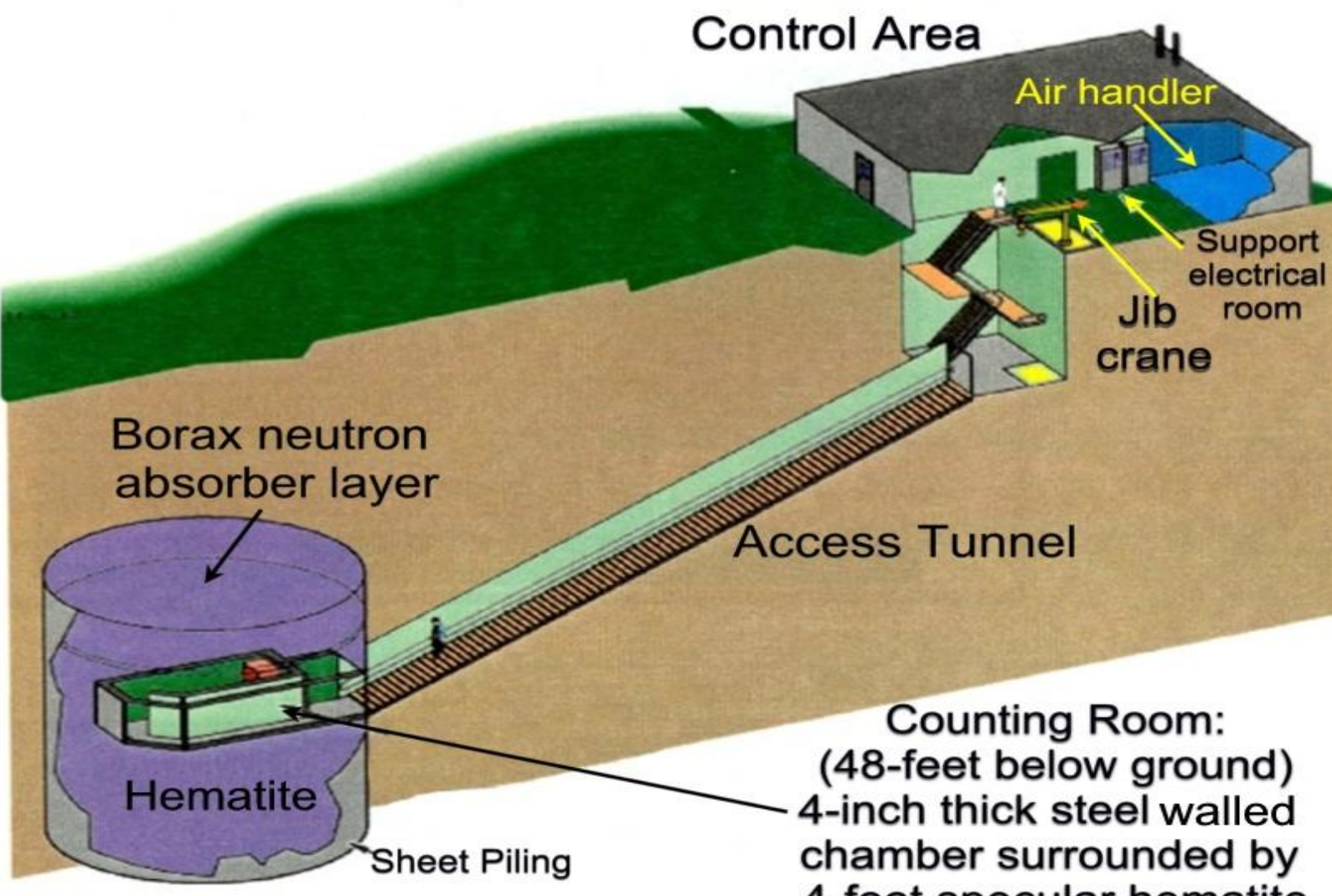


Energy spectra of downward traveling particles passing through the center of the UCF from simulation of surface muons. The muon flux in the UCF is about 30% of the surface muon flux. Obvious decrease in muon and gamma flux seen for more dense standard rock.

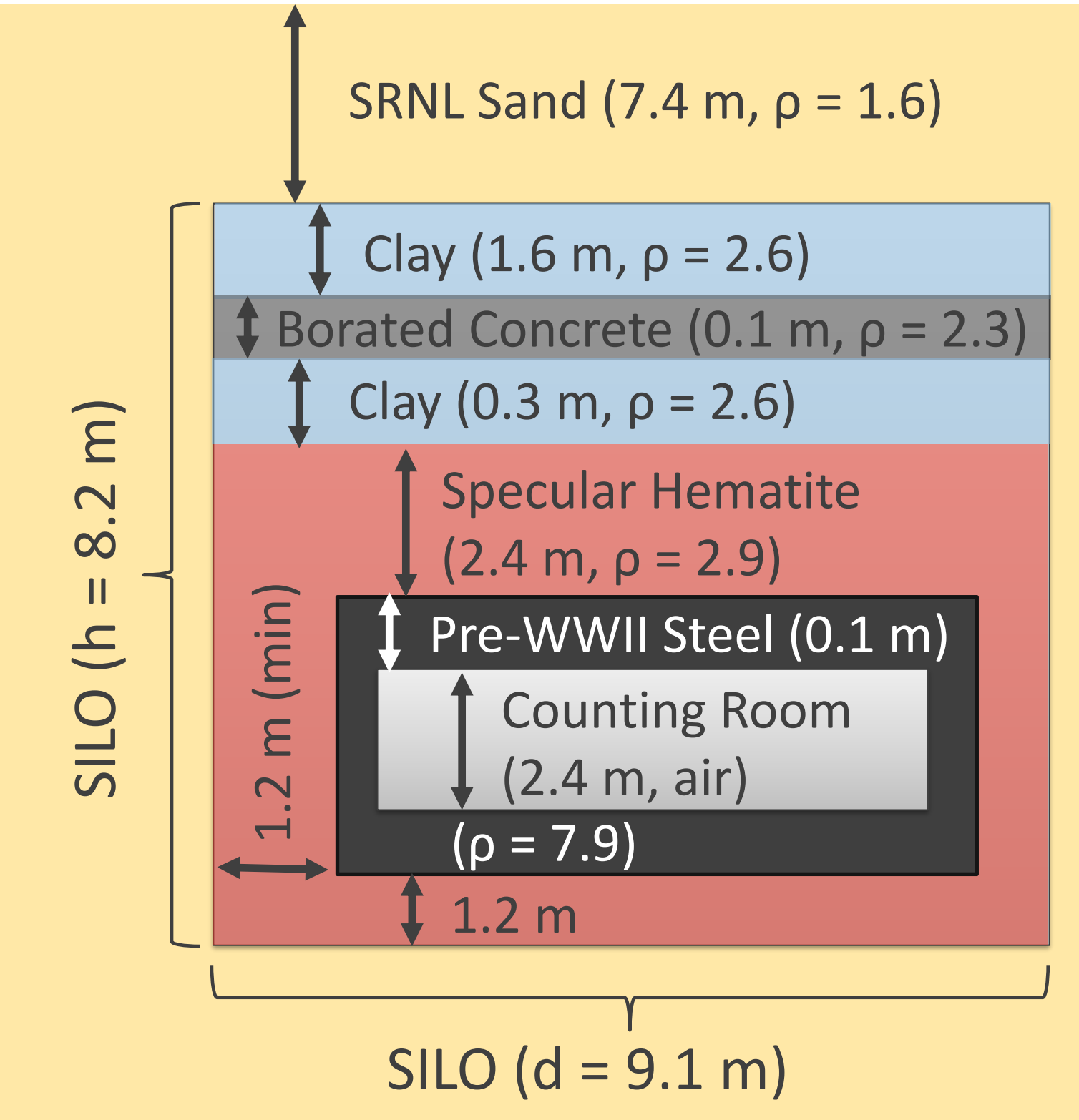


For (more dense) Standard Rock:

- Benefits of silo relative to backfill not as obvious with higher density soil
- Neutron flux improves significantly with informed silo design, not much change between SRNL silo and backfill rock



A schematic of the SRNL UCF, the silo it is placed in, the access tunnel, and the above ground clean lab entry space.



A diagram of the “as built” UCF silo layers. Several thin (~0.01 m) plastic sheets used to separate silo layers are not displayed here. All densities listed above in units of g/cm³.

- For SRNL Sand:**
- SRNL Silo (vs SRNL sand backfill):
- Much higher muon flux for backfill, mostly higher gamma flux, and significantly lower neutron flux
- Borated concrete (vs clay):
- Slightly increase neutron flux at low energy when replaced w/ clay
 - Borated concrete in its current position generally provides little shielding benefit
- Specular hematite (vs clay):
- Replacing hematite with clay significantly decreases neutron flux (possibly due to extra moderation from H in clay) and gamma flux between 100 keV and 10 MeV
- Informed Design:
- Principles: maximize overburden higher in the silo, moderate neutrons nearer to counting room, surround counting room with relatively dense, cheap, lower neutron creation clay and borated polyethylene
 - Significant decrease in neutron flux across both rock types

Conclusions:

Despite potential design tweaks that could slightly improve backgrounds in the SRNL UCF, the “as built” design significantly reduces cosmic backgrounds relative to the surface. The “informed design” silo generally reduces cosmic induced backgrounds for all particles across most energies. There are still additional considerations (engineering, ambient radioactivity, practical) that must be accounted for when designing a shallow underground lab. The clean, surface-level underground access at Savannah River National Laboratory provides a productive environment to fully leverage the clean sample preparation chemistry and low background radiation detection expertise for local low background radiation measurements.

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