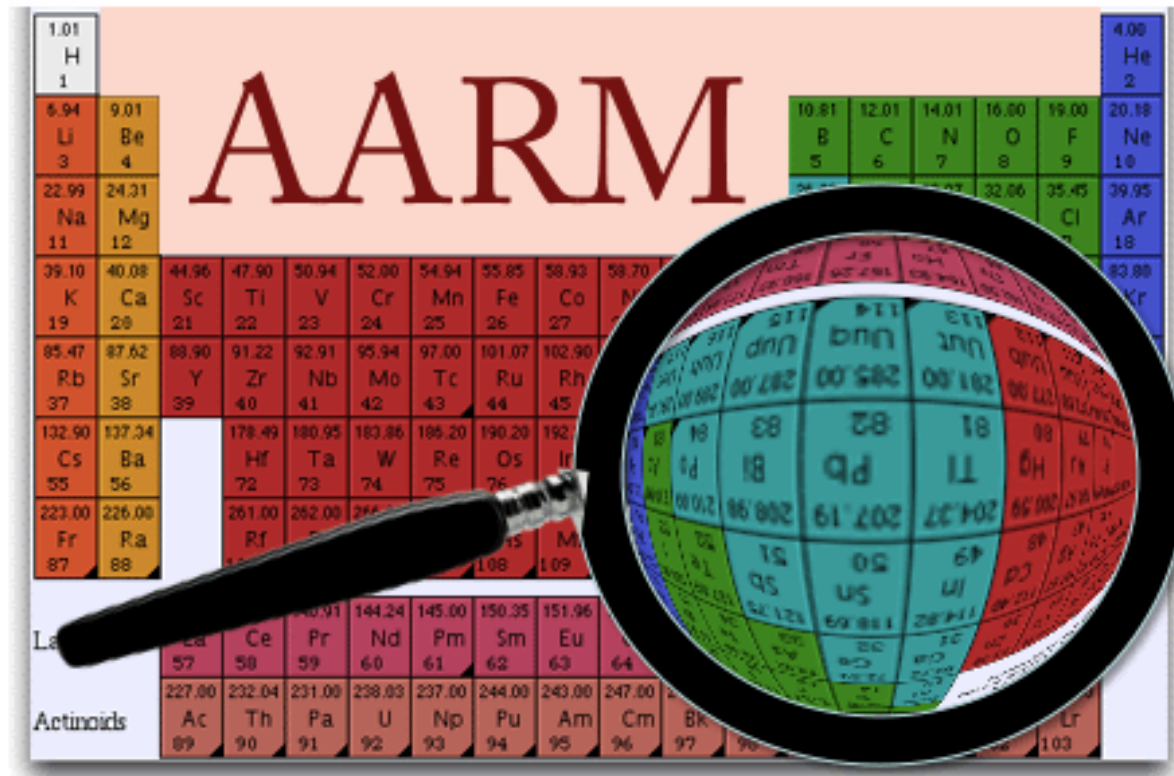


# Toward a coherent program in Assay and Related Technologies



*Priscilla Cushman*  
*University of Minnesota*

*LRT2013*  
*LNGS April 10, 2013*

# Introducing: Assay and Acquisition of Radiopure Materials

The **AARM Scientific collaboration** is open to all interested parties

**Original Goals** were tied to DUSEL: A 3 year NSF grant to

- *Characterize backgrounds at all levels of Homestake*
- *Design a common low background counting facility: **FAARM***
- *Develop common screening tools (R&D as needed)*

**Current Goal** is to forge an alliance between experiments searching for rare events, to help understand and mitigate backgrounds.

**Simulation** recognized as a major “infrastructure”

Validate and improve current simulation tools

**Background characterization** more broadly defined as

Community Materials Assay Database

Neutron benchmarking (data vs sim)

Integration of existing assay resources around the world

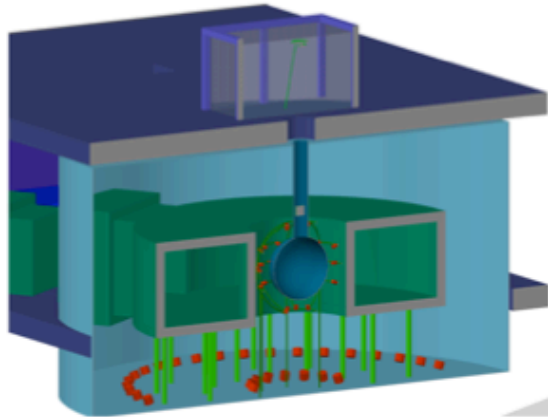
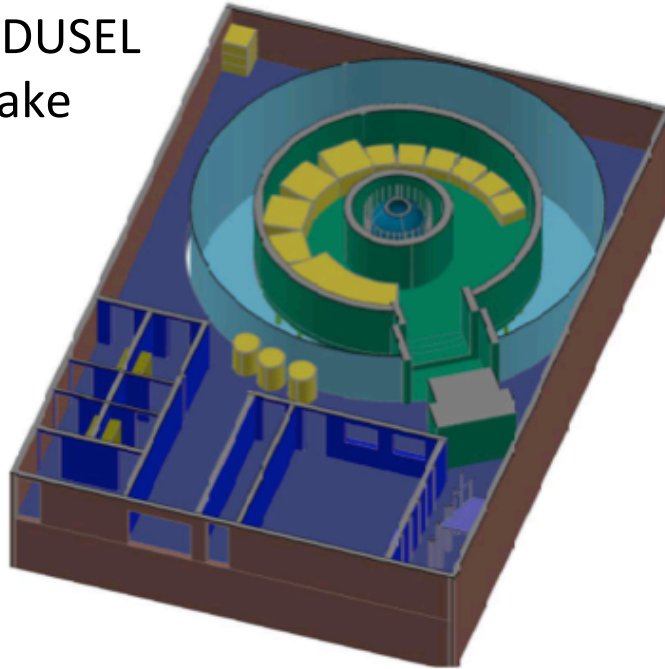
and the development of a unified plan to increase availability

**FAARM** (A 3<sup>rd</sup> generation counting facility) needs to be re-imagined

# FAARM:

## Facility for **A**ssay and **A**cquisition of **R**adiopure **M**aterials

Original Design fit into Lab  
Module 2 in the DUSEL  
plans at Homestake



### Inner Tunnel Lab

$\gamma$ -flux  $7.974 \times 10^{-5} \text{ cm}^{-2} \text{ s}^{-1}$   
n-flux  $4.817 \times 10^{-10} \text{ cm}^{-2} \text{ s}^{-1}$

4 < ppt (GeMPI, arrays)  
6 < ppb (well, clover, coax)  
2 Beta Cages  
Prototyping Space  
(DM or  $0\nu\beta\beta$  or novel assay)

Radon Mitigation  
Common cryogen plumbing and  
LN boil-off for screeners

### Central Pool

0.1 counts/day,  $E > 250 \text{ keV}$

sensitivity of  $10^{-14} \text{ g/g U/Th}$   $10^{-12} \text{ g/g K}$   
modeled on Borexino CTF

2m diam nylon vessel filled with LS

Observed by low rad QUPIDs

Top-loading from dedicated Clean Room

# FAARM:

## Facility for **A**ssay and **A**cquisition of **R**adiopure **M**aterials

Re-engineered original DUSEL plan for a new non-site-specific location  
But kept the principles and lessons learned

### **Dedicated facility, class 10,000 clean room, < 20 Bq/m<sup>3</sup>**

Labs, Clean machine shop, offices, several class 1000 clean rooms  
Radon-mitigated zones (<1 Bq/m<sup>3</sup>) and assembly areas (<0.1 Bq/m<sup>3</sup>)  
Radon-free storage and unified LN system

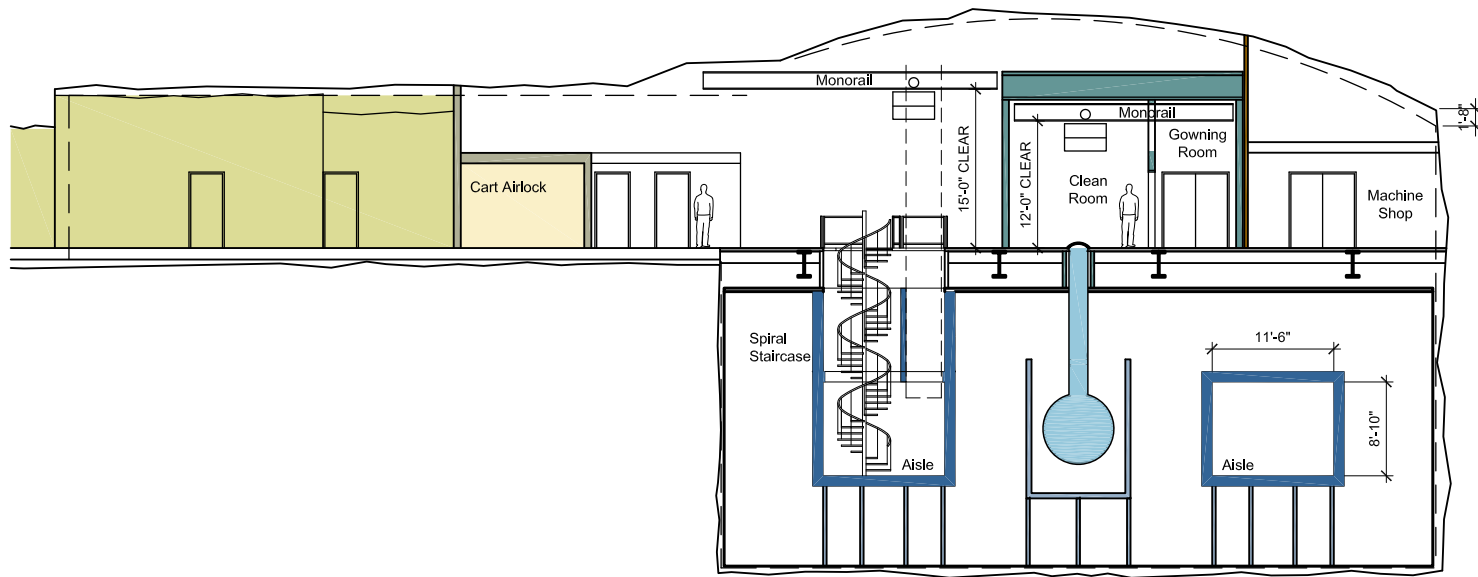
### **Instrumented common water shield with toroidal interior acrylic room**

individual lead shields too expensive and not radiopure  
neutron shielding requires hydrogenous materials  
muon rejection is easily added with photodetectors  
upgrades could include LS or Gd/Li/B loading to create a true neutron veto.

### **Top-loading Immersion Tank**

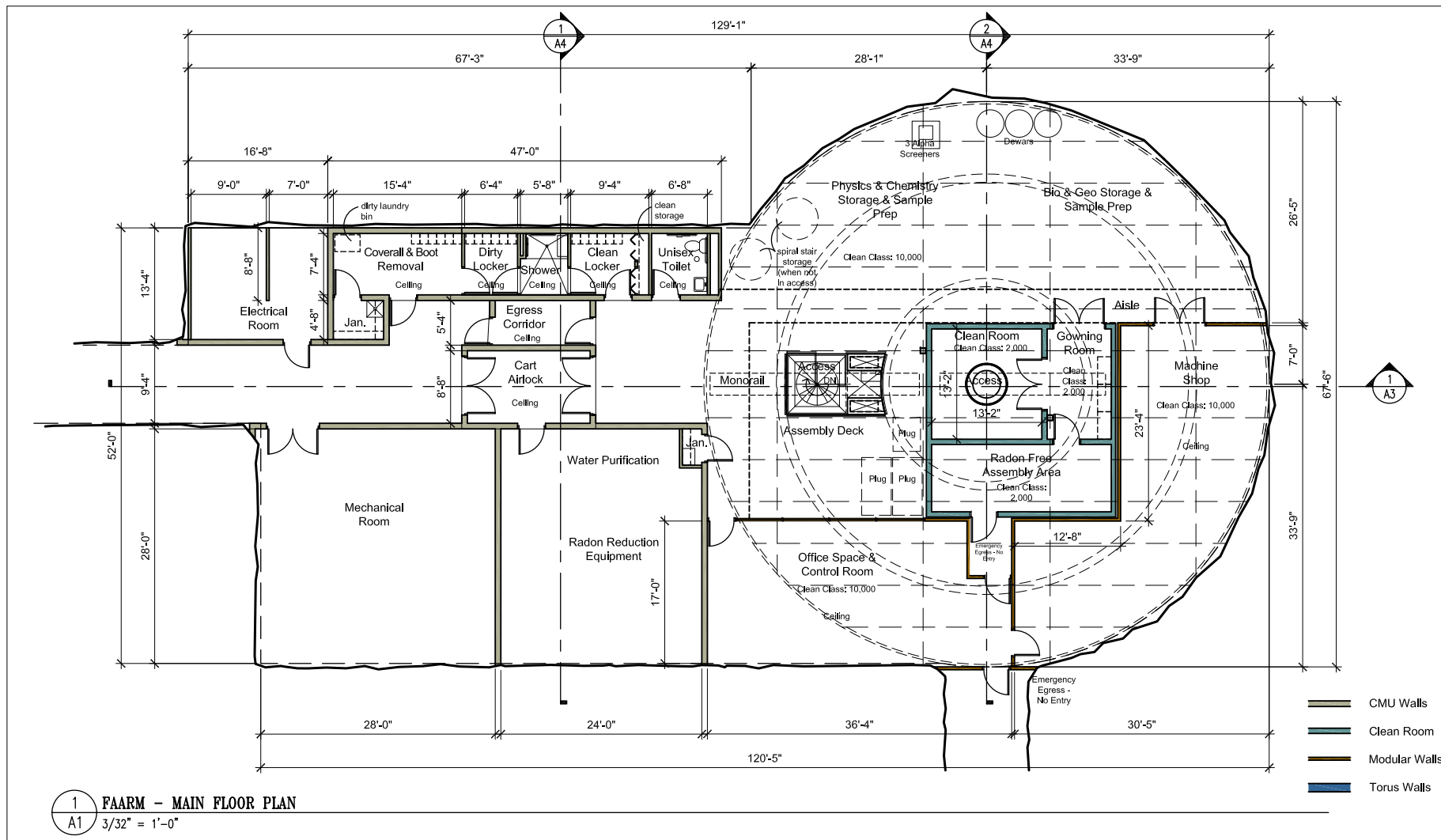
Cost-effective design with ultra-sensitive central location

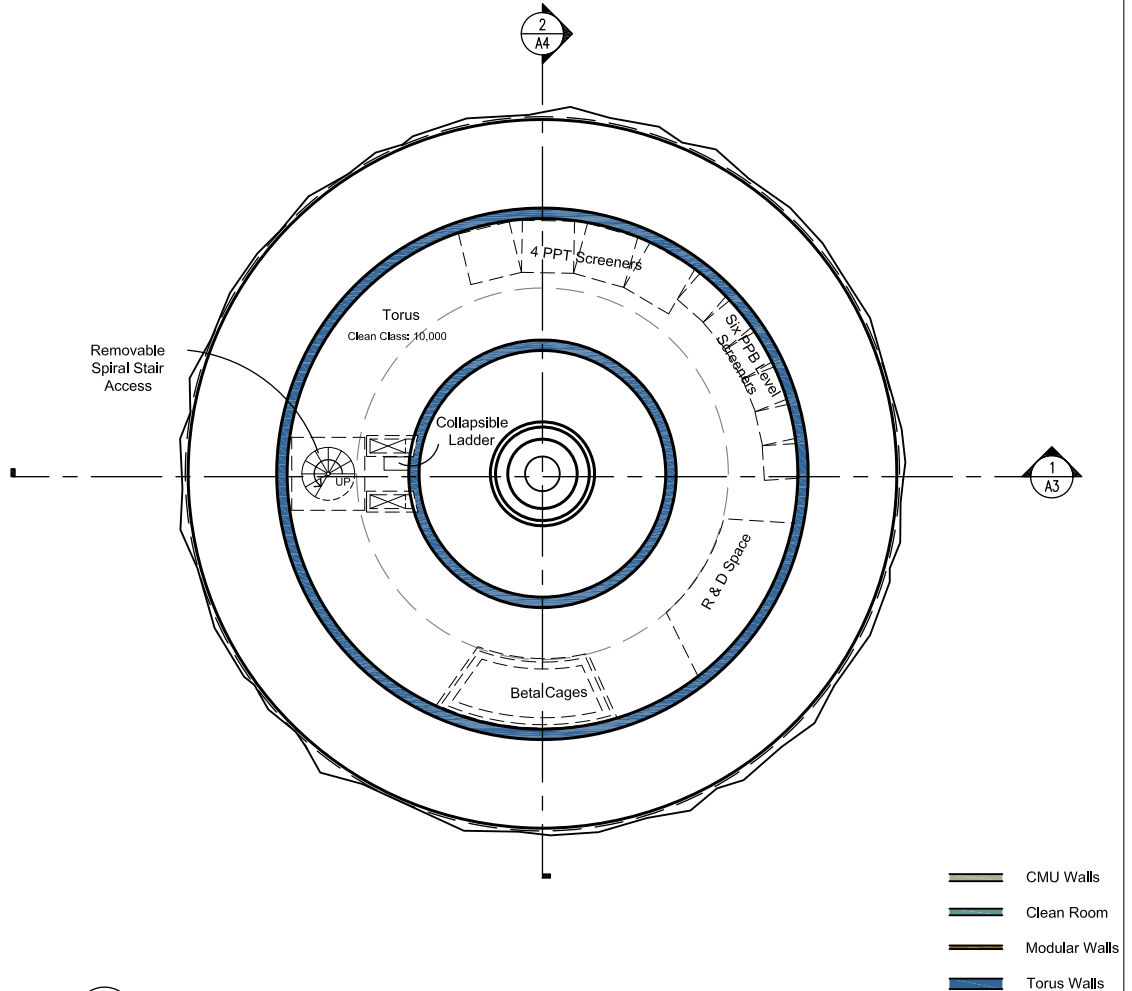
Complete drawings and a new cost estimate:  
Final deliverable from AARM grant - Ready for a proposal if space is identified  
<https://zzz.physics.umn.edu/lowrad/newfaarm>



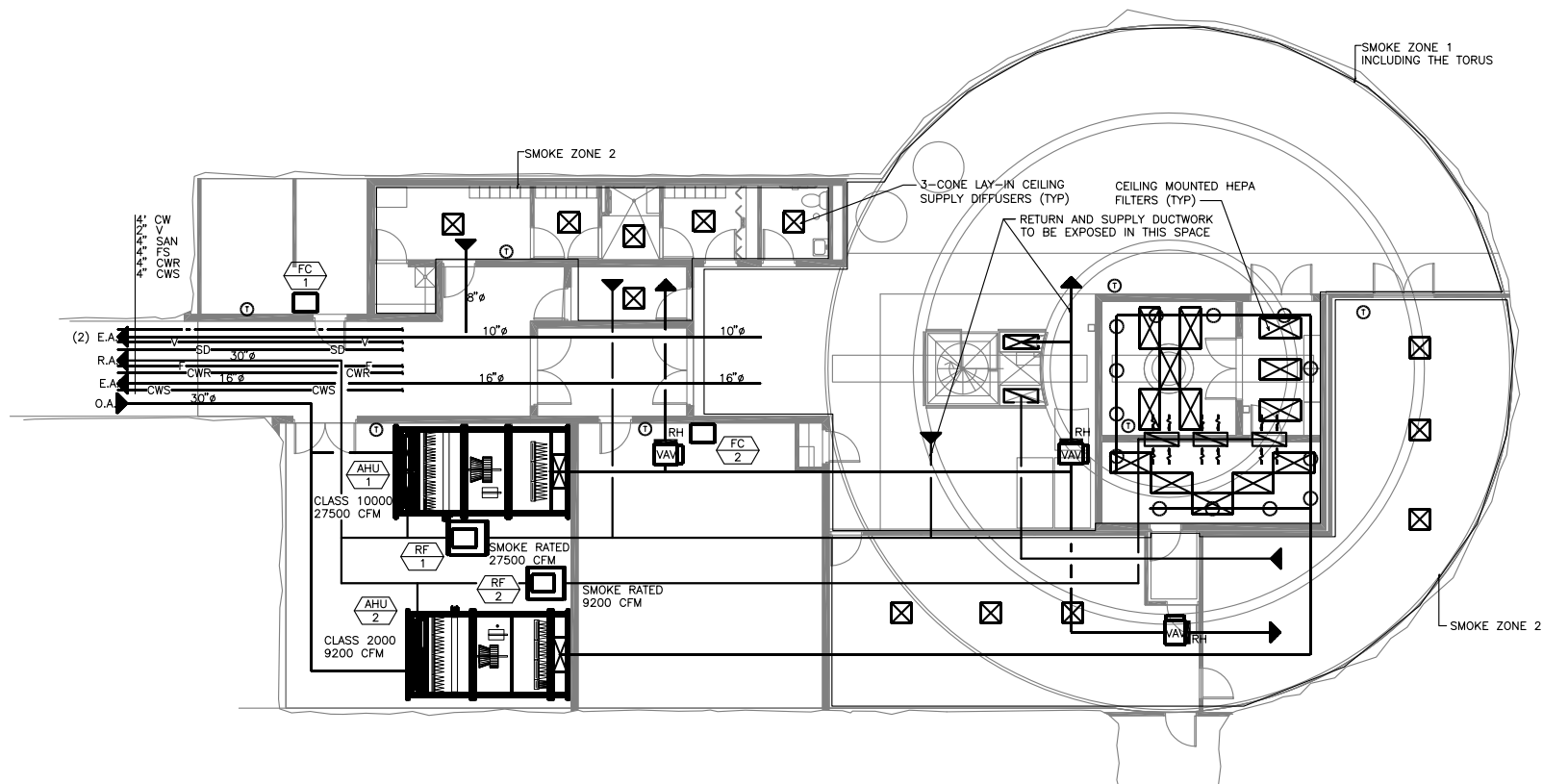
1  
A3 FAARM - LONGINTUDINAL SECTION  
3/32" = 1'-0"

Unclassified Space	CMU Walls
Transition Space	Clean Room
	Modular Walls
	Torii Walls



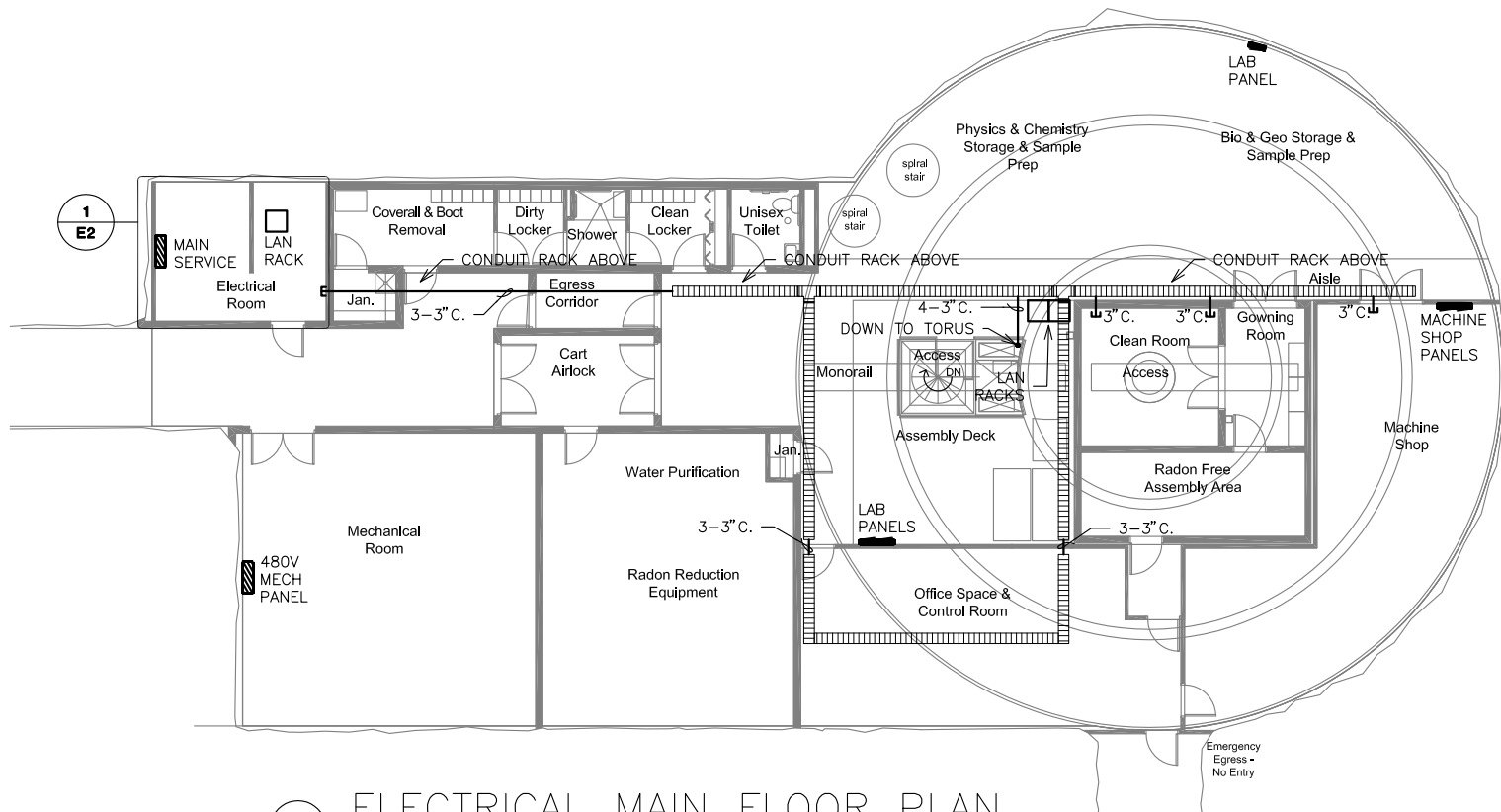


1  
A2 FAARM - TORUS FLOOR PLAN  
3/32" = 1'-0"



① MECHANICAL MAIN FLOOR PLAN  
3/32" = 1'-0"





1 ELECTRICAL MAIN FLOOR PLAN  
3/32" = 1'-0"

# “Integrative Tools for Underground Science”

## Principle Investigators

Priscilla Cushman (University of Minnesota)

Jodi Cooley (Southern Methodist University)

Toni Empl (University of Arkansas, Little Rock)

Angela Reisetter (Evansville University)

Richard Schnee (Syracuse University)

A new 2-year proposal starting last October to continue AARM work in following areas

1. Development of community-wide simulation tools,
2. Confirmation of simulation physics models and cross sections relevant to underground science by comparing to data worldwide and supporting specific efforts in neutron benchmarking,
3. Establishment of a community materials database, and
4. Continuation of the integration workshops centered around simulation, material screening, and underground physics.

# Organization of AARM

**We are split into Working Groups with very specific tasks**

**You can always go to the Group Wiki to learn about it and to join meetings**

**[http://zzz.physics.umn.edu/lowrad/#working\\_group\\_wiki\\_pages](http://zzz.physics.umn.edu/lowrad/#working_group_wiki_pages)**

- Depth Task Force
- Cosmogenic Simulation Group
- Universal Materials Database
- Radiogenic Cross Section Working Group
- FLUKA-Geant4 Comparative Study Group
- Neutron Benchmarking Data Group

# Cosmogenic Working Group

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## Members:

- Angela Reisetter
- Chao Zhang
- Dongming Mei
- Vitaly Kudryavtsev

## Goals

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- Track the cosmic ray background from surface down to underground and calculate the flux at different level of depth.
  - Validate Geant4 muon propagation
  - Establish whether to employ MUSUN in C++ as a standard, or just work with Geant4?
- Estimate the uncertainty of the cosmogenic background in different levels underground.
- Establish a standard method for each site to prevent having to re-generate the muons each time
- Continue to interact with Geant4 collaboration on the physics lists relevant to muon production of neutrons
- Link to the Fluka v Geant working group on physics issues

# Ongoing Geant4 and FLUKA comparison (and development)

## Working Group Goals and People

People:

- Vitaly Kudryavtsev (The University of Sheffi aly?)
- Anton Empl (University of Arkansas at Little Rock)
- Sarah Lindsay (University of Arkansas at Little Rock)
- Anthony Villano (University of Minnesota)
- Allison Kennedy (University of Minnesota)
- Chamkaur Ghag (University College London)

Goal:

To produce a coherent Geant4 to FLUKA comparison across most modern versions of the codes and including all observables related to cosmogenic neutron production. In addition a detailed understanding of the modeling approaches used in each of the codes is desired.

Help to improve FLUKA physics relevant to the simulation of cosmogenic muon-induced backgrounds at deep underground facilities. Investigate a FLUKA user interface/framework for cosmogenic background simulation.

## Initial Comparison

The initial comparison includes one suggested by Vitaly Kudryavtsev, to observe the simulations for monoenergetic muons at several energies traversing large homogeneous media of various compositions which are of interest to underground science.

- The plots for the initial comparison are stored here: [link](#)

## Meetings

# Universal Materials Database Working Group

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**Charge:** Our goal is to develop a Universal Materials Database for use by the community of researchers who need materials with low radioactivity for the construction of their experiments. This database will be portable and downloadable with a well-designed data format and high quality interface. It is envisioned to be a reference guide for the low-background community to organize and share data, much like the Particle Data Group (PDG) provides for the particle-physics community.

**Goal:** Our year 1 goal is to have a working version 1 of the database for use and demonstration to the community at the LRT2013 conference. In year 2 our goal is to polish and refine the database into a well developed tool.

## Members:

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Core Group		
Name	Institution/Experiment	Email
Jodi Cooley	SMU/SCDMS	cooley.physics.smu.edu
James Loach	LBNL/Majorana	james.loach@gmail.com
Keith Adler	SMU	kadler.smu.edu
Matthew Bruemmer	SMU	mbruemmer@mail.smu.edu
Ben Wise	SMU	bwise@mail.smu.edu

Advisory Group		
Name	Institution/Experiment	Email
Adam Cox	KIT/Edelweiss	adam.cox@kit.edu
Prisca Cushman	U Minnesota/SCDMS	prisca.physics.umn.edu
Klaus Eitel	KIT	klaus.eitel@kit.edu
Alfredo Ferella	U Zurich	ferella.physik.uzh.ch
Richard Ford	SNOLAB	ford@snolab.ca
Jules Gascon	Edelweiss	j.gascon@ipnl.in2p3.fr
Josef Jochum		josef.jochum@uni-tuebingen.de
Vitaly Kudryavtsev	U. Sheffield	V.Kudryavtsev@shef.ac.uk
Jean Lanfranchini		jean.lanfranchini@ph.tum.de
Ian Lawson	SNOLAB	Ian.Lawson@snolab.ca
Pia Loaiza		ploaiza@ism.in2p3.fr
Alan Poon	LBNL	AWPoon@lbl.gov
Franz Proebst		proebst@mpp.mpg.de
Keenan Thomas	LBNL	kjthomas@lbl.gov
Mani Tripathi	UC Davis/LUX	mani.physics.ucdavis.edu
Anthony Villano	U. Minnesota/SCDMS	villaa.physics.umn.edu

## Meetings

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Date	Agenda and Minutes	Keywords
2013/01/23	<a href="#">Agenda and Minutes</a>	Current Progress and Goals
2012/12/19	<a href="#">Agenda and Minutes</a>	tasks
2012/12/12	<a href="#">Agenda and Minutes</a>	tasks

# Radiogenic Data and Cross Section Working Group

## Members:

- Dongming Mei
- D'Ann Barker
- Iseley Marshall
- Chao Zhang
- Silvia Scorza
- Hang Qiu
- Kimberly Palladino
- Jodi Cooly

## Goals

- Calculate more (alpha,n) neutron yields and energy spectra for the materials used in ultra-low background experiments
- Validate the calculations with other simulation packages
  - Compare cross sections from EMPIRE vs TALYS
    - EMPIRE provides the excited states and x-sections for SOURCES
  - Dongming's website at USD ([neutronyield.usd.edu](http://neutronyield.usd.edu)) using TALYS to do his calculations
  - Want to compare for common materials such as Cu, poly, Pb, norite and PMT glass
  - Kimberly Palladino (MIT) to visit SMU in January to work with Silvia and Hang
- Convert the calculated (alpha,n) cross-sections into GEANT4 data format
- Create physics links in GEANT4 for (alpha,n) reaction
- Make GEANT4 package available for (alpha,n) simulation
- Compile the measured radioactive background data at the Homestake Mine to be useful for large

# Neutron Benchmarking Data Group

## Members

Name	Affiliation	Contact	Interest(s)
Dan Akerib	Case Western	akerib@phantom.phys.cwru.edu	NMM
Ray Bunker	Syracuse	raybunker@gmail.com	NMM, Soudan Veto Shield, Detector Development
Yu Chen	Syracuse	ychen87@syr.edu	NMM, Soudan Veto Shield, Detector Development
Prisca Cushman	Minnesota	prisca@physics.umn.edu	NMM, Soudan Veto Shield, Detector Development
Emily Dragowsky	Case Western	michael.dragowsky@case.edu	NMM
Anton Empl	UALR	anton.empl@gmail.com	FLUKA Sim of NMM
Paul Hennings	Yosemite	paulhennings@gmail.com	NMM, FLUKA Sim of NMM

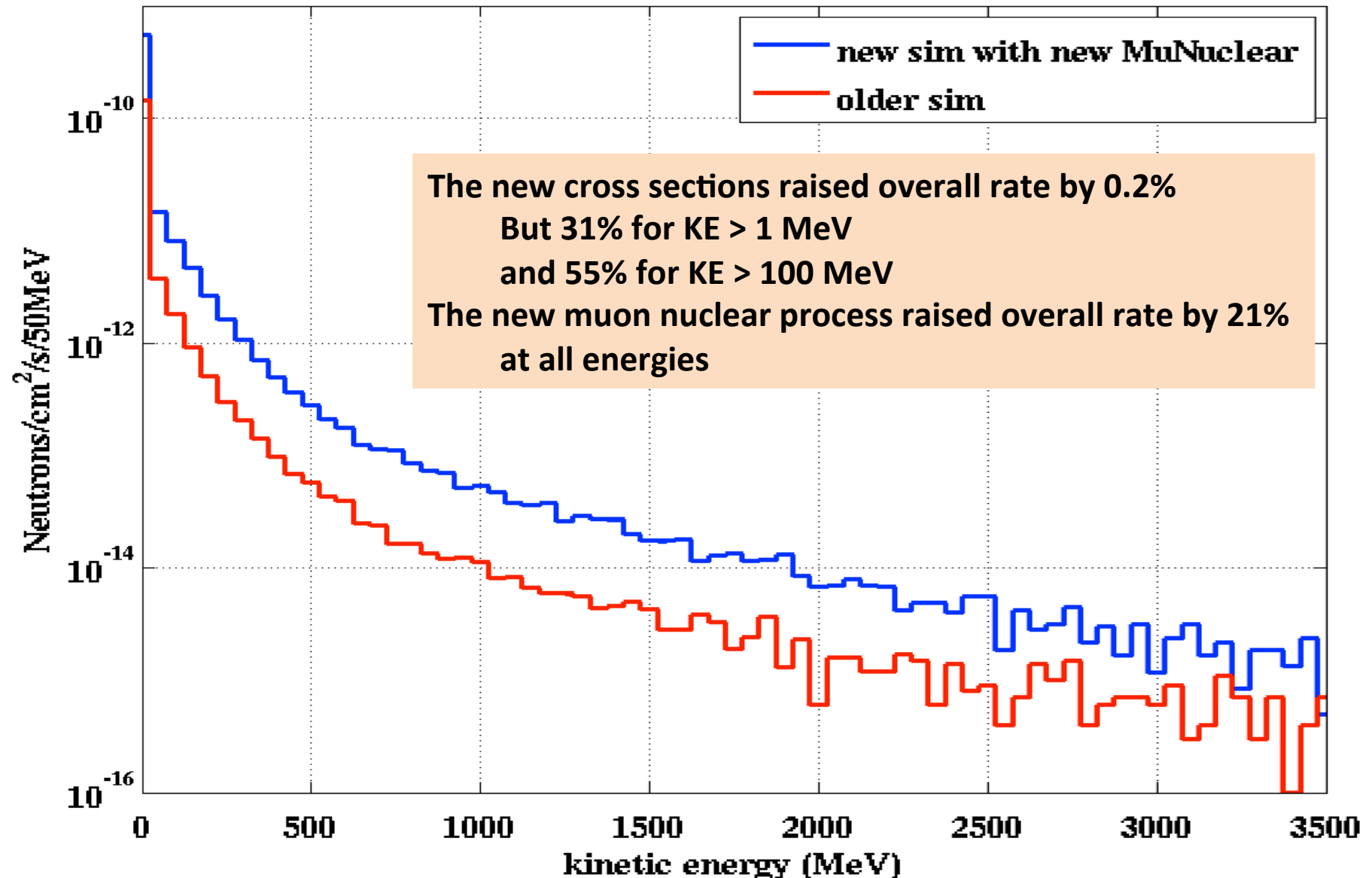
## Goals

To improve the accuracy of the Monte Carlo simulations used to estimate the rare-event-search background due to muon-induced high-energy neutrons in deep underground laboratories. Currently, this entails ongoing efforts to:

- Understand data recorded by the Neutron Multiplicity Meter (NMM) using a Geant4 detector model, and publish an NMM high-energy-neutron flux measurement (**NMM**, short-term);
- Better constrain the flux of radiogenic and muon-induced neutrons using data from the USD liquid-scintillator neutron detector at Soudan (**USD Neutron Detector**, short-term);
- Measure the neutron flux in the Davis cavern (**Davis Cavern**, long-term?);
- Fully instrument the NMM (and other LBCF experiments) with timing signals from the Soudan veto shield (**Soudan Veto Shield**, medium- to long-term);
- Conduct simulations that will inform next-generation neutron-detector and -veto designs (**Detector Development**, long-term);
- Develop a FLUKA model for understanding NMM data (**FLUKA Sim of NMM**, medium- to long-term); and
- Reach out to members of other collaborations (*e.g.*, LVD and Edelweiss) who share common interests (long-term).



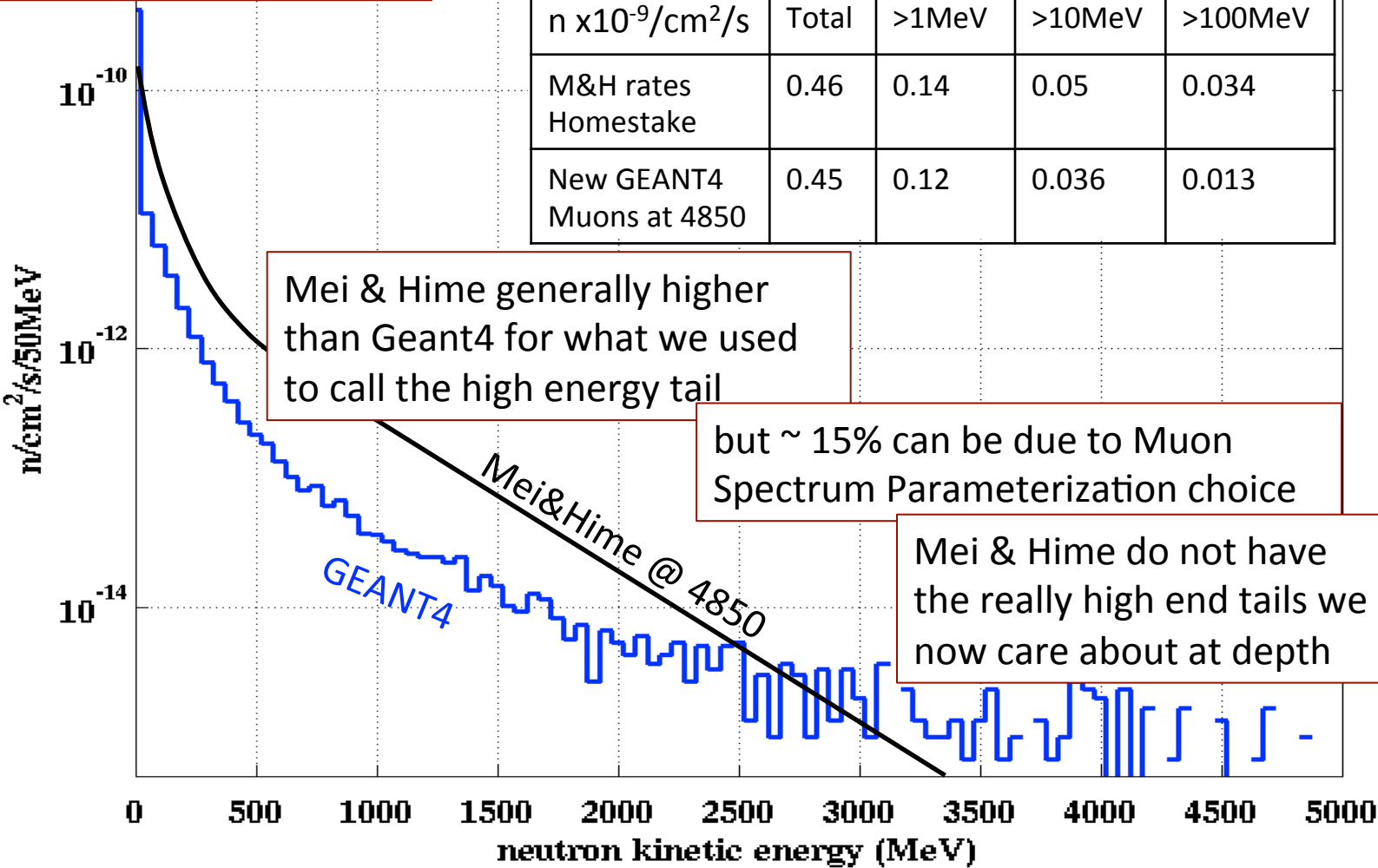
Neutron spectra entering cavern at 4850 level



Lower energy depends on the details of the rock composition and slant path

on Rate Spectrum entering cavern at 4850m

$n \times 10^{-9}/\text{cm}^2/\text{s}$	Total	>1MeV	>10MeV	>100MeV
M&H rates Homestake	0.46	0.14	0.05	0.034
New GEANT4 Muons at 4850	0.45	0.12	0.036	0.013



# Depth Task Force White Paper

1. Present our best understanding of Simulation and Measurement of cosmic muon-induced neutron background in underground labs.
2. Define what restrictions that places on depth as a function of technology and shielding.
3. Identify the remaining systematic errors and suggest means for reducing them

## I. Introduction

## II. Existing Measurements of Underground Neutron Backgrounds

LSD, LVD, Borexino, Kamland, Zeplin II/Boulby, Edelweiss/LSM, SNO, Soudan NMM

## III. The Simulation Challenge

### A. Simulation Overview

### B. Muon Flux Estimations

### C. Muon-induced Secondaries

## IV. Implications for Dark Matter experiments at Homestake 4850

Direct Comparison of LAr, LXe, Ge with the same input muons and same shield

## V. Scaling to Different Depths

## VI. Conclusion

# Compare Different Technologies

Start with a common water shield based on the LZ20 design:

*12 m diameter, 12 m high cylindrical water tank*

Inside, place a 2 m diameter, 2 m tall experiment

*Detailed geometry moving from the outside in to the detector volume as follows:*

## **L Ar**

2.5 cm thick SS Outer Vessel of 4 m diam + vac  
2.5 cm thick SS Inner Vessel of 3 m diam + vac  
0.5 cm thick PMT shell + 1.0 cm of Acrylic  
2m x 2m Liquid Argon Volume

## **L Xe**

75 cm thick Liquid Scintillator  
3 mm thick Titanium shell  
2m x 2m Liquid Xenon Volume

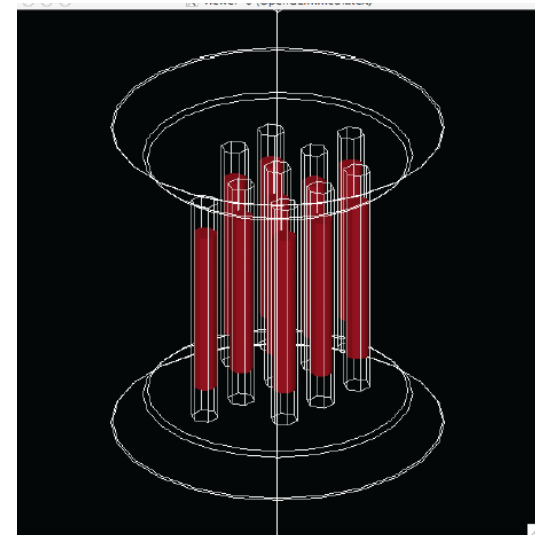
## **Ge**

1 cm thick SS outer Vessel of 2.2 m diam  
20 cm thick poly  
3 cm thick Cu cryostat

## **1.5 Ton Payload**

10 Towers of 30  
detectors each

Each detector is  
6" diam, 2" thick



## Workshops a.k.a. AARM Collaboration Meetings

Two 3-day Workshops per year continue under the new proposal.

Find previous talks at <http://zzz.physics.umn.edu/lowrad/meetingn> (n=1→6)

This Spring it was a little different.

- 1-day meeting at Snowmass Cosmic Frontier Workshop (March 4)

- Travel fellowships to LRT2013 to increase US attendance (13 awardees).

- Presentations of AARM work at LRT2013

At LRT2013 we would like to expand the AARM Collaboration

- Invite participation in our Working Groups

- Explore Cooperative Agreements between Europe and North America

- Formalize collaboration and programs between AARM and LRT  
and a European/Asian counterpart?

If there is interest here, we propose a 4 day workshop this Autumn with time to coordinate international strategies, incl. tighter coordination with LRT2015

### **Notice:**

Thursday Lunch Meeting to discuss contributions to the Community Database

# So what about screening and Low Background Facilities?

Dark Matter   Double Beta Decay   Solar and Astro physics   Nucleon Decay

They all need ever more sensitive radiopurity measurements and products  
As well as more throughput at existing sensitivities

But a **FAARM** needs up-front money

Perhaps we can create a Multi-site Low Background Facility  
by pooling existing resources and  
creating centralized management, shared resources and common scheduling.

Proposal to NSF and DOE (very preliminary!!)

**A Consortium of U.S. Centers of Excellence in Assay and Radiopurity Techniques**

## Which aspects of “Low Background” require an Underground Facility?

### **New highly sensitive screeners**

*GeMPI style gamma spectroscopy (ultralow background shielding and crystals)*

*R&D on new types of screeners (e.g. beta cage, XIA alpha counter, ..)*

### **Stockpiling of materials to avoid cosmogenic activation**

### **Prototyping new experiments: How do you stage a new experiment?**

1. Prove the technique works (in a convenient lab)
2. Make it “low background”
  - a. decide on materials (requires use of screening detectors)
  - b. run it underground and get a physics results as well as proof of principle
3. Discover unexpected background sources (run underground)
4. Scale up and run for a long time (deeper underground)

### **Develop new active veto strategies for $\alpha$ -n, SF neutrons**

### **Benchmarking Simulations to improve underlying physics in Geant4 and FLUKA**

# Counting isn't the whole story.

## *Surface analysis:*

Probe elemental composition, sub-micron position and depth profiles.. using ion or electron beams, X-rays, etc: RBS, XRF, FReS, NRA, Auger, PIXE ...

Available in many institutions, but in-house capability provides fast turn-around and expertise

## *Mass Spectroscopy: ICPMS, GDMS, TIMS, SIMS, AMS*

Extract and accelerate charged ions from a sample and measure the trajectory corresponding to the correct charge-to-mass ratio for the element in question.

Quoted sensitivity depends on magnetic spectrometer and sample dispersion technique

Real sensitivity depends on details of the sample prep and chemistry

Range of materials depends on R&D in digestion and dissolution techniques.

## *Neutron Activation Analysis*

Induce neutron capture on sample and detect (via HPGe)  $\gamma$ -rays from de-excitation

Either prompt (usually in-situ) or delayed (ship to site).

Requires reactor  $> 10^{13} \text{ n cm}^{-2} \text{ s}^{-1}$  (or DT plasma generator)

Technique limited by the nuclear properties of trace element (~60% of elements activate)  
and substrate (activation of substrate masks lines)

ICPMS and NAA have proven their worth for HEP

Experienced Personnel (and maintaining that expertise beyond projects) is VITAL.



# PROPOSAL

## Nuclear and Particle Physics Infrastructure Funding for Centers of Excellence in Assay and Related technologies

### Assay

HPGe, ICPMS, NAA, atom trap  
 $\alpha, \beta$  counting, Rn emanation, etc.

#### Different Depths

Required for different modalities

### Related technologies

Irradiation facilities for NAA,  
Radiochemistry for ICPMS

#### Location & People matter

e.g. Near to reactors,  
University partners with expertise

### **Process**

- Capture the existing capability of each Assay Center (shallow and deep)
- Establish centers of specific expertise
- Find a mechanism to integrate these under an umbrella funding and organizational entity

### **Build on the collaborative work already done by**

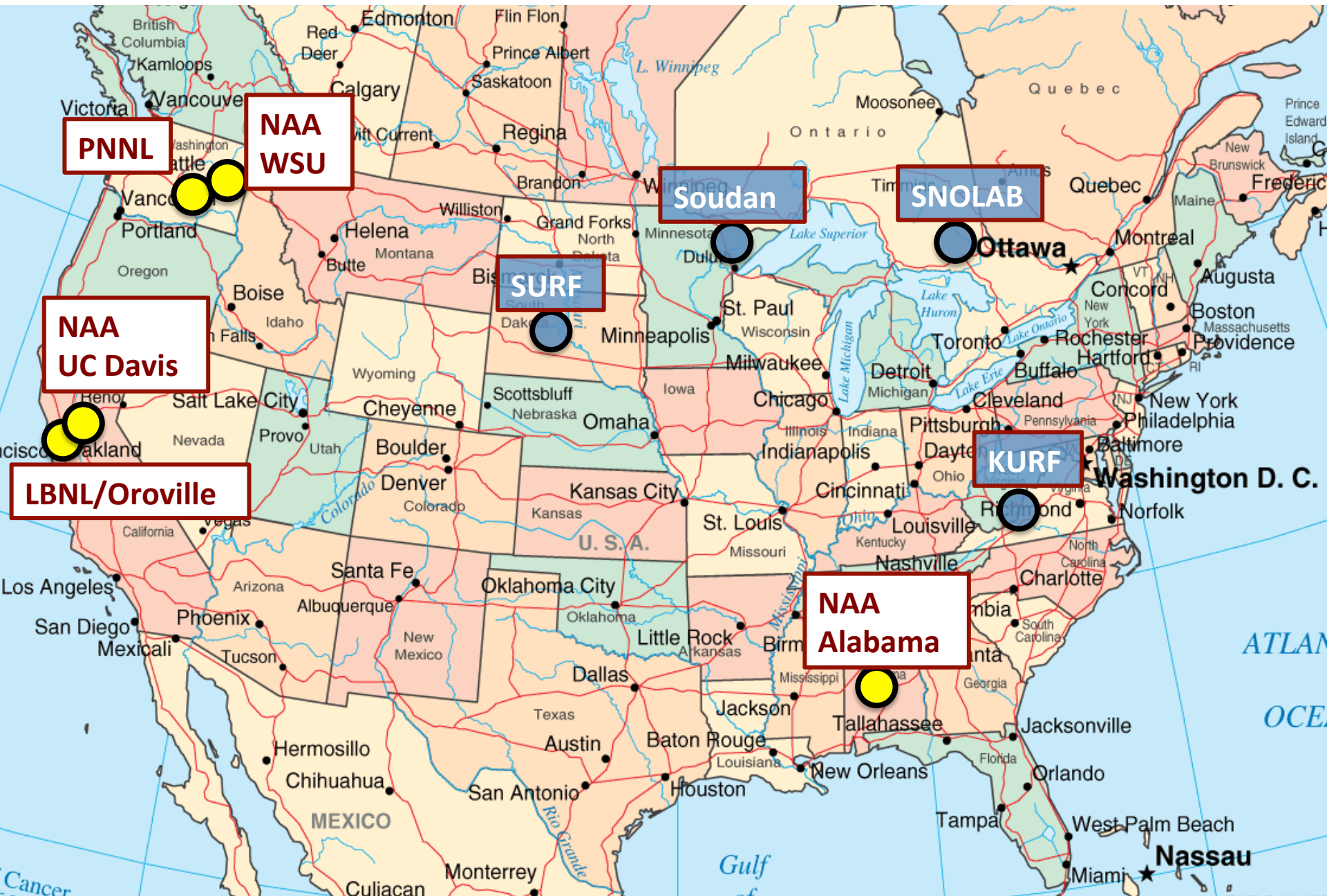
LRT (Low Radiation Techniques – Biennial International Workshop)

AARM (Assay and Acquisition of Radiopure Materials – DUSEL S4 funding)

Integrative Tools for Underground Science – NSF May 2012 Solicitation

*Planning for Common Assay Infrastructure should be part of the Snowmass Process.*

# Link these sites for HEP/NP Low Background Characterization



# Initial Suite of Assay Centers of Excellence

PNNL (perhaps also the lead institution)

ICP-MS and electro-refinement and actinide chemistry

Gamma Counting

LBNL LBCF, SURF/CUBED, Soudan LBCF, KURF LBCF, PNNL UL

Neutron Activation Analysis

Alabama and UC Davis

*Add surface alpha, RN emanation, beta counting as we identify a need.*

*Then add another center or add to capabilities at one of the existing centers.*

Fund as DOE-SC User Facilities with budgets to cover measurements and analyses as well as facility maintenance and upgrade. R&D costs as needed (via new proposal from the Consortium) to establish capabilities needed for next-gen experiments.

Think of it as transitioning existing facilities into User Facilities to retain capabilities

Large Scale QA/QC campaigns will require their own additional project funding.

Managed by a board formed from the members. Grant renewed on a 3-yr cycle  
Internal and Independent review processes established. Program Advisory Panel.

# Conclusions

We have some structures in place already (AARM, LRT)

How can we capitalize on them to be more efficient and share resources?

- Use the tools we are introducing, so they become generally useful

- Contribute to the work and disseminate the results

- Help us Link to partner organizations

Increase Sensitivity and Quantity of assay resources

- U.S. Consortium of Centers of Excellence in Assay and Related Technologies

- MOU's with other Labs and Centers worldwide

- Scheduling Tools which cross boundaries

- Progress towards centralized Assay Facilities (FAARM)

GOAL:

The establishment of a Research Community centered on Low Radiation Techniques with tools to provide

- Research Direction, Information Exchange (journals and conferences)
- and the ability to successfully capture funding