Benchmarking Breakout Sessions—Summary Report

Primary Question → *What should we measure and what kind of detector could do it?*

(alpha,n)

General agreement that (alpha,n) neutrons are of primary importance for next-generation rare-event searches (DM in particular).

- Explored idea of an (alpha,n) screener … assay via neutrons by placing sample inside neutron detector in well-shielded installation, e.g. (perhaps in the middle of a FaNS-style detector or large water tank with inner volume doped to be sensitive to neutrons)
- Could be part of a multi-purpose neutron detector (alpha-n and cosmogenics?)
- But such a detector would have to be large (as would the assay samples)
    - So we run into the classic problem of how do you convince the agencies to fund something large for benchmarking only?
- **Concluded that (alpha,n) screening is likely impractical for this reason (& low rates)**
- Better to focus on the input physics to something like SOURCES
- Dedicated thin-film alpha-beam measurements are probably the right approach
    - Has this been done before? … how well? … what are the deficiencies?
- Continued pursuit by AARM to organize/maintain/distribute the relevant cross sections, simulation techniques probably makes sense

Benchmarking Detector Response

There appears to be interest in benchmarking detailed detector response vs. technology in a collaborative/consortium fashion (e.g., verification of NEST and Lindhard-like models)

- For example, with a shared, dedicated facility for measuring nuclear-recoil response in liquid nobles and solid-state detectors
- Each project contributes a small target and some share in the development of the overall setup
- Is there an obvious, pre-existing site for this?
- This may be difficult for cryogenic detectors like SuperCDMS due to dilution fridge requirement

Muon-induced neutrons and showers underground

It's desirable to have more measurements of high-energy neutrons versus depth. However, it's not clear that this can be done with a single detector on a scale that we can propose as a benchmarking experiment because you appear to need something like Borexino.

- It's no longer clear that mu-nuclear neutron production is a problem … in fact, the Borexino measurement seems to demonstrate that the input physics works well and that we may actually have a problem with the E&M and/or delta-ray production … but this is a work still in progress and needs to be cross checked with Geant4 simulation to see if similar to FLUKA
    - In any case, Borexino is only one measurement in one material
    - Clear need to understand what other detectors are telling us about other targets
- Perhaps we can get the neutron energy distribution with a relatively modest detector that measures the neutron energy very well (e.g., FaNS-style detector). It need not be large if it can be operated at a series of relatively shallow depths, which would probe a wider range of muon energies … the key is true neutron spectroscopy, but not too shallow such that you're overwhelmed by low energies & high rates. Such a measurement program may only be good for differential energy spectrum (and not multiplicity, e.g.).

    - This program would be more versatile with a muon tag (via full-cavern veto, e.g.).
    - Such a detector could then be relocated to a deep installation (like Soudan Veto Shield) once shallow measurements are done (e.g., FaNS and MARS … what will they do with these detectors when they original programs are completed?)
- How we simulate showers may be more of a problem … are we getting the multiplicity (of neutrons and muons, e.g.) and topology of shower propagation through rock correct?
    - We need to understand in detail how muon bundles affect neutron yield
    - Do shower simulations need to be more sophisticated? (e.g., start from cosmic primaries?) … or do we need more detailed parameterization? (e.g., correlated muons)
    - What about muon-coincident/induced gammas, pions, etc? (can we measure this too?)
        - There seems to be a true lack of such measurements underground
        - Detectors just now turning on may have sensitivity (e.g., DarkSide)
- Other major challenges for simulators? (e.g., correct muon spectra?)
- Better use of fixed-target beam experiments to constrain production-process physics?
    - Probably not useful for understanding the development of showers deep underground
    - Older studies (e.g. NA55) were seriously limited by systematics
    - New experiment at CERN will provide data on the time scale of 2-3 years
- Shower constraints?
    - On shower development using existing experiments?
    - What aspects of showers are interesting to simulate/benchmark?
        - Is it different for hadronic vs. E&M? (& can this be measured? … isn't this what HEP detectors have already done?)
    - What can be said with large-volume neutrino experiments? (bundles?)
    - Info from air-shower experiments like Auger, HAWC, and Veritas?
    - IceCube w/ IceTop to reduce systematic of rock propagation?
- Shower topology could be studied inside something like the Soudan Veto Shield with an array of small neutron detectors readout in concert.
    - Perhaps high-pressure xenon gaseous detectors are a technology worth considering
    - Also, doping with heavy elements may provide desired additional information vs. Z
        - Admittedly, this is a bit messy because it involves a mixture
        - For example, LENS experiment and indium doping
    - Maybe we should consider repurposing the NMM:
        - Fill with doped liquid scintillator for improved low-multiplicity sensitivity
        - Separate the two tanks and/or adjust target geometry and/or composition

Misc

It might be worthwhile for AARM to pursue some kind of neutron standard (AmBe?)

- Maybe this includes standardization of neutron calibration techniques, which ties back into the idea of collaborative detector-response benchmarking

Other:

- Is the spectrum of neutron energies resulting from muon capture well known?
    - Perhaps shallow-depth neutron spectroscopy can answer this as well.