Applied Antineutrino and Dark Matter Science - Underground Facility Needs

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Rare neutral particle detection
connects Nuclear Security to Neutrino and Dark Matter Physics

Fissile Material Search and Monitoring are top priorities for global nuclear security

Rare Event Detection

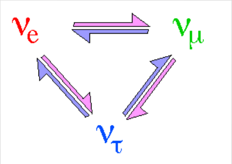
1-10 MeV antineutrinos

1 keV to 10 MeV
Neutrons and Gamma-rays

Dark Matter and Neutrino Physics are top priorities in 21rst century physics

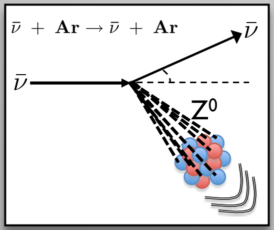
Reactor antineutrino monitoring via inverse beta detectors

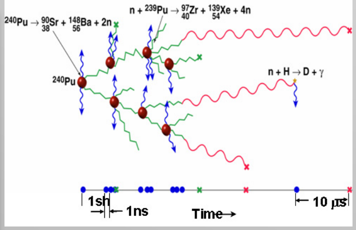
Neutrino oscillations and sterile neutrinos

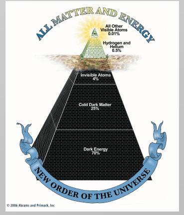


Reactor monitoring via coherent scatter; improved fissile material monitoring

Dark Matter signatures: Axions and WIMPS

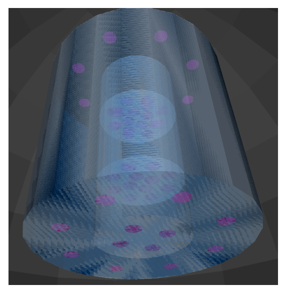






Nuclear Security and Nuclear Science both require improved keV to MeV-scale neutral particle rare event detectors

Nuclear Security applications that require deep underground facilities

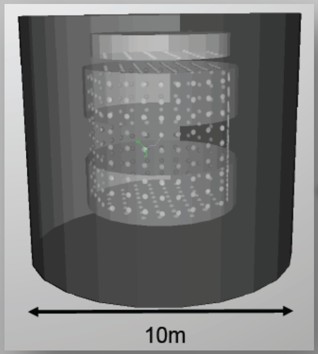
Nonproliferation Application	Common Facility Need	Fundamental Physics Goal
1. Demonstration of remote discovery or exclusion of undeclared reactors with large water/LS detectors	Underground facilities supporting multi-kiloton Gd-doped water and liquid scintillator detectors 	• Supernova antineutrinos • Long baseline reactor oscillation/mass hierarchy • Geo-antineutrinos • Proton decay • long baseline accelerator oscillations/mass hierarchy
2. Analysis of trace fissile elements with high resolution, low background gamma-ray alpha and beta detectors	Low background detectors in underground locations ←shallower - deeper→ 50-300 mwe - 300-2000 mwe	• Dedicated screening facility for materials used in: • WIMP or Axion searches • Neutrinoless Double Beta Decay experiments

The **WATCHMAN (Water Cherenkov Antineutrino Monitoring)** project is now in its first phase in the United States

- Goal: demonstrate sensitivity to reactor antineutrinos using a gadolinium-doped water detector at 0.1-1 kilometer standoff from a 10-150 MWt US research reactor, or several kilometers from a 3000 MWt scale US commercial power reactor.

1-20 km standoff

Research or power reactor



Kiloton scale detector

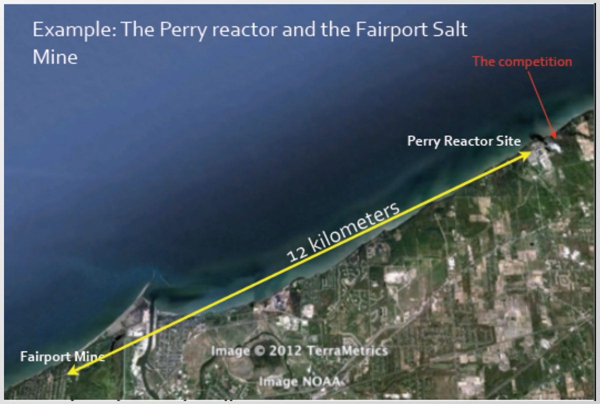
100-2000 meters overburden

- Current work in the US to **identify site,** measure backgrounds, and develop a design envelope for the detector

WATCHMAN US possible deep site: the Fairport Mine

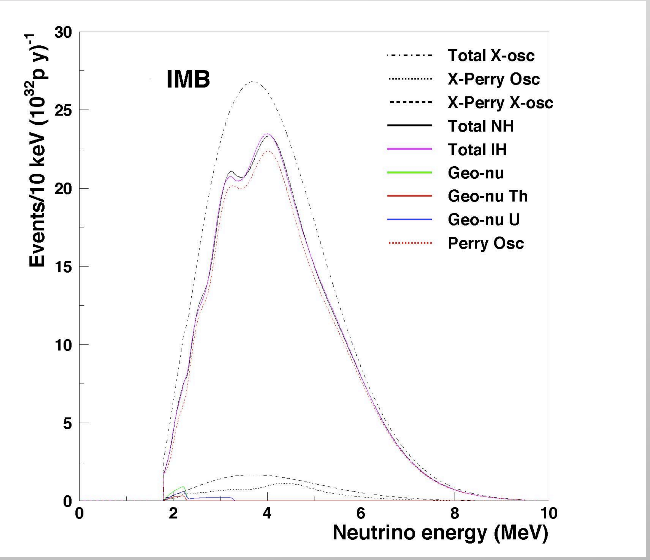
Perry Reactor Nuclear Generating Station to IMB cavern in the Fairport Salt Mine (Ohio)

- Existing 20 m cubic cavern – other excavations possible
- 1570 m.w.e.
- 13 km standoff
- 3875 MWth



Antineutrinos from Perry @ 12 km

1. **The only mine in the United States within 20 km of a reactor**
2. **ideal for this demonstration - ~10-fold cost-savings compared to new excavation at shallow depth**
3. **Would be the only US detector sensitive to supernova antineutrinos**
4. **Upgraded detector physics potential for geo-antineutrinos and mass hierarchy being investigated..**

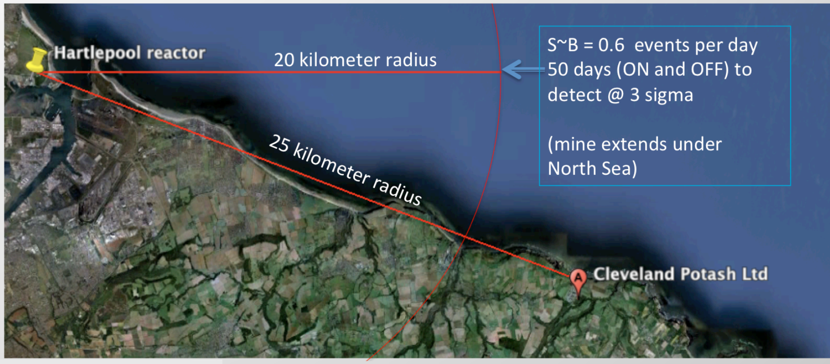


Plot courtesy Steve Dye, Hawaii Pacific Univ.

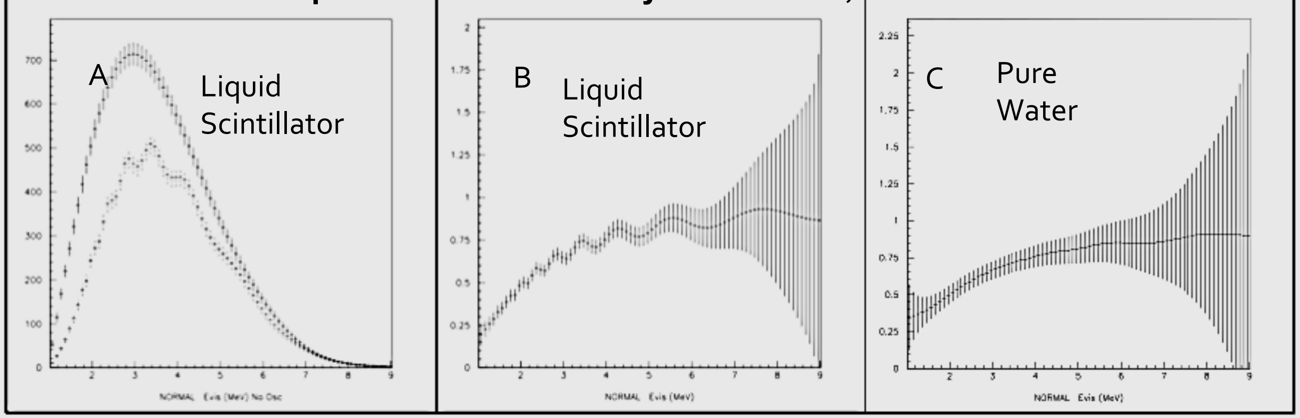
A preliminary look at the antineutrino spectrum - 1 year of operation, errors not yet incorporated

WATCHMAN possible non-US deep site: the Cleveland Potash mine in Boulby, England

- 2800 mwe depth
- 20-25 km standoff
- Hartlepool reactor thermal power = 1570 MWth (2 cores)
- *Some sensitivity to oscillations with LS or WBLS upgrade*



Estimated response curves courtesy R. Svoboda, UC Davis



Potential for oscillation sensitivity at 25 km

A: unoscillated and distorted spectrum showing effects due to "theta12" oscillations (overall suppression) and theta13 (small wiggles). Resolution is 3%/sqrt(E). Distance is 25 km.
B: Ratio showing low energy suppression due to theta12. Error bars assume 20 kton-yr exposure at Boulby. The theta12 sensitivity comes from the low energy shape.
C: With pure water, this is still there but much less apparent due to 20%/sqrt(E) resolution and Cherenkov threshold.

Nuclear Forensics and HEP Facility requirements overlap

Science goals

- Measurement of intrinsic backgrounds in materials is essential to current and future rare event detection experiments
- Depths similar to those at which experiments are deployed – ~500-5000 mwe

Example: Assay and Acquisition of Radiopure Materials (AARM) program at Homestake

Common Facility needs

- Depth - to suppress backgrounds from muons/muogenic neutrons
- Well-characterized ambient backgrounds
- Background-suppressed HPGe detectors
- Alpha/beta spectroscopy
- Sample preparation and wet chemistry
- Muon veto and gamma/ neutron shielding

Nonproliferation goals

- Characterizing trace fissile content of various materials for a range of nonproliferation goals
- Many nonproliferation needs are met by relatively shallow depth underground facilities
- The most pressing issue is expertise: nonproliferation sponsors maybe willing to fund underground facilities for this reason

Example: Naval Research Lab facilty at Kimballton Mine – joint with Virginia Institute of Technology

Summary and conclusions

Remote Reactor Monitoring Facility need

- A new US nonproliferation initiative requires a 500-5000 mwe site to demonstrate sensitivity to reactor antineutrinos using a large Gd-water-Cherenkov detector
- Paves the way for future very large scale detectors which exclude the existence of small reactors in wide geographical regions
- The 1600 mwe Fairport mine near Cleveland Ohio and the 2800 mwe Boulby mine in England are viable deep underground options
- A 1-10 kiloton-scale device will have world-class supernova sensitivity
- Upgrading to LS may enable geo-antineutrino and limited oscillaiton sensitivity
- Detector R&D well suited for Hyper-K and other large water detectors

Nuclear Forensics Facility Needs

- Low background detectors in underground are required for several applications
- Much work can be done at relatively shallow depth sites – 50-300 mwe
- Nonproliferation sponsors might be persuaded to support operation of deeper sites in order to maintain US expertise in rare event detection
- AARM collaboration in the US and the CELLAR consortium in Europe are examples of cooperation among disciplines and sites (see Cushman talk)