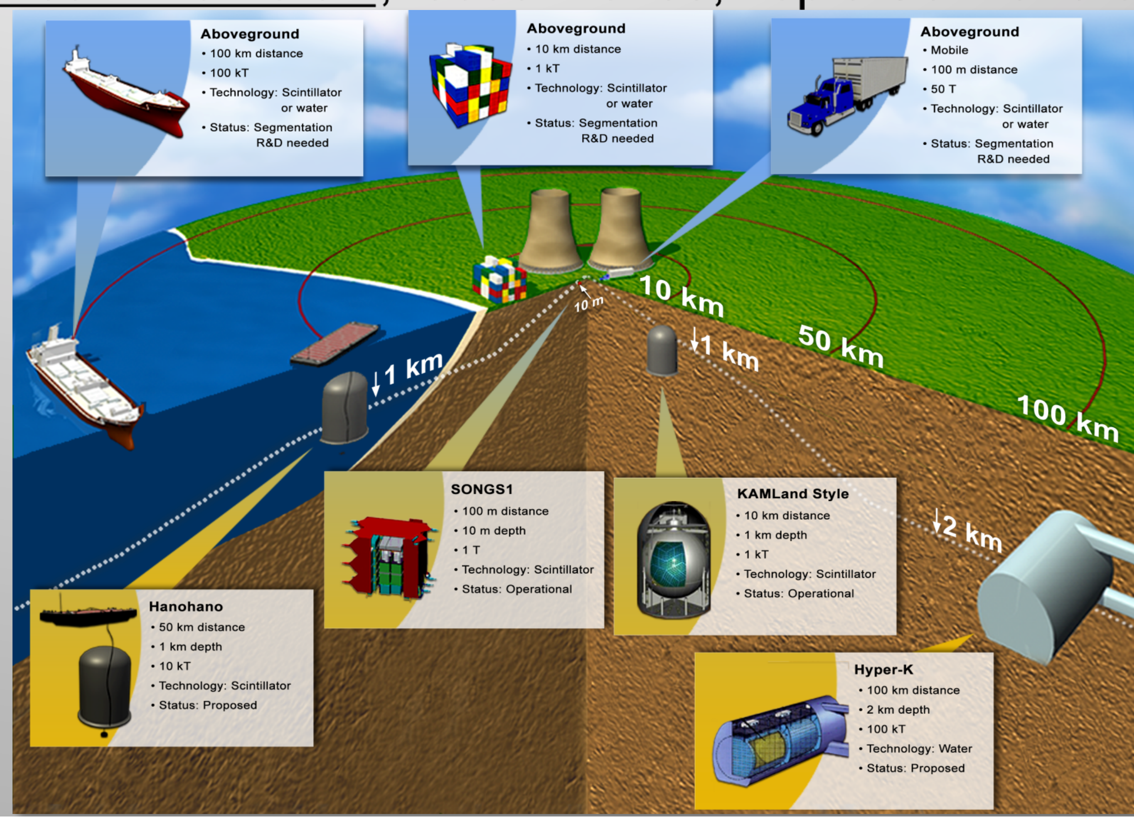
Nu7 Neutrinos and Society – Summary of Charge and Working Group Activities

Snowmass on the Mississippi

July-August, 2013

<u>Adam Bernstein</u>, Jose Alonso, Topic Conveners

Lawrence Livermore National Laboratory



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Neutrinos and Society Working Group Charge

1. Identify synergies between fundamental and applied neutrino physics
   - Reactor antineutrinos
   - Geo-antineutrinos
2. Encourage physicists to learn how neutrino detection technology applies to problems of broad social import
   - Requires educating physicists in nonproliferation and geo-physics
3. Effectively present the short but eventful history of neutrino science to non-scientists
   - 1 and 2 above help make the case for neutrino science

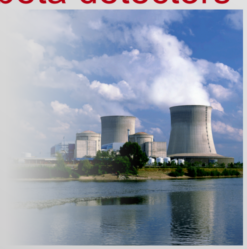
Rare neutral particle detection
underlies nuclear security and fundamental nuclear science

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

Rare Event Detection

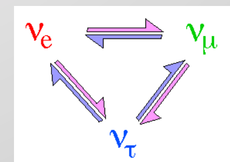
Dark Matter and Neutrino Physics are top priorities in 21rst century physics

Reactor antineutrino monitoring via inverse beta detectors



1-10 MeV antineutrinos

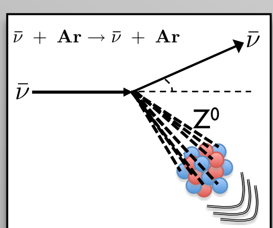
Neutrino Physics:
oscillations and mass hierarchy

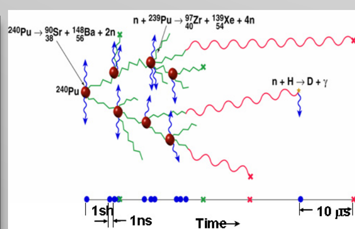


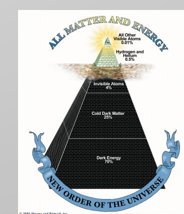
1 keV to 10 MeV
Neutrons and Gamma-rays

Reactor monitoring
via coherent scatter; improved fissile material monitoring

Dark Matter signatures:
Axions and WIMPS



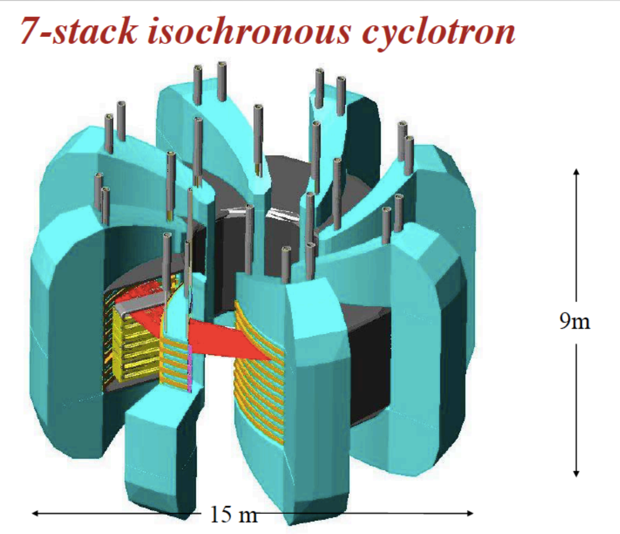




Nuclear Security and Nuclear Science both require improved keV to MeV-scale neutral particle rare event detectors

Accelerators used in neutrino experiments are used and/or contemplated for a wide range of industrial and medical applications

- Current, Low energy: medical therapy, biological research, nuclear security, environmental monitoring, semiconductor industry, oil well logging
- Near-term, Medium energy: Isotope production
- Longer-term, High Energy: Accelerator-driven reactors for energy production



Example: Daedalus-like cyclotrons (M. Toups talk Anderson 250, 11:05 AM today)
may be useful for accelerator driven reactors

Shown: Rol Johnson, Bruce Vogelaar – accelerator for GEMSTAR reactor concept

http://www.phys.vt.edu/~kimballton/gem-star/workshop/presentations/mcintyre.pdf

Aside from the physics and technology connections, a sociological one

- Like science, the nonproliferation regime is inherently <u>open</u>, <u>international</u>, and <u>collaborative</u>

- Classified work is largely irrelevant or counterproductive for global nonproliferation

The IAEA and Nuclear Nonproliferation

- The **International Atomic Energy Agency (IAEA)** is responsible for implementing the Nuclear Nonproliferation Treaty worldwide
- The IAEA Safeguards Regime tracks fissile material in the civil nuclear fuel cycle

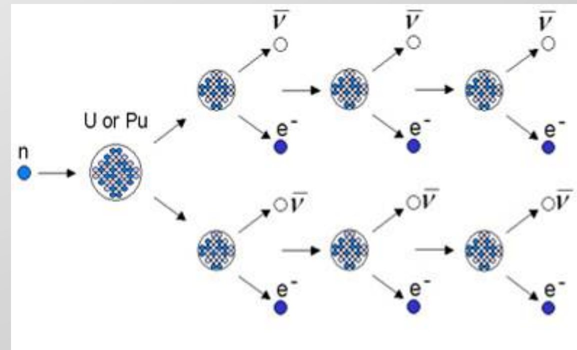
IAEA International Atomic Energy Agency	Report	Version Date:	2012-08-29
	Proceedings of the first meeting of the Ad Hoc Working Group on Safeguards Applications utilizing Antineutrino Detection and Monitoring	Version No.:	2
Department of Safeguards	SG-EQ-GNRL-RP-0002	Page:	1 of 53

- In 2012, an IAEA review encouraged R&D into antineutrino-based reactor monitoring for Safeguards:

1. Near reactor deployments for detailed analysis of fissile content in known reactors – demonstrations, above-ground technology
2. Far-reactor (10-1000 km) deployments for discovery or exclusion of small unknown reactors

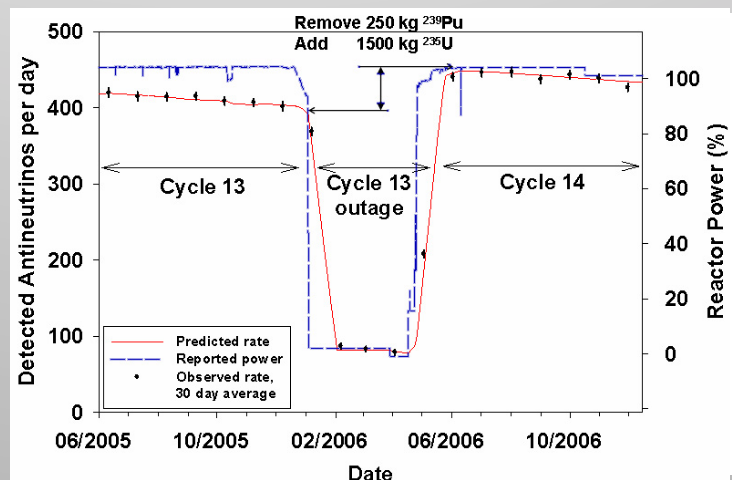
Neutrinos for Nuclear Reactor Monitoring

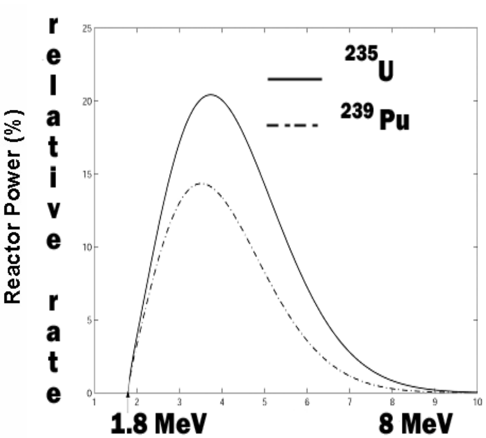
- Several antineutrinos are produced per fission 10^21 fissions/second → lots of antineutrinos
- Ton-scale detector ~ 5000 events/day @ 25 meters from a power reactors (3000 MWt)
- Megaton detector ~16 events/year @ 400 kilometers from a small reactor (10 Mwt)



Antineutrino rate and energy spectrum are sensitive to fissile content

- Now, we can see a **70 kg switch** of U for Pu assuming knowledge of reactor power
- **Spectral analysis** - increase precision, no need for independent knowledge of the reactor power



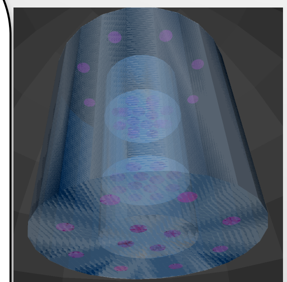


Research topics in Applied Antineutrino Physics that apply to Neutrino and Dark Matter Physics

Nonproliferation

- Long range reactor monitoring
- Improved neutron detection

Water Cerenkov detectors



Neutrino/DM Physics

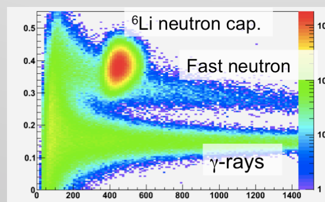
- Supernovae antineutrinos

Relevant to:

- accelerator and/or reactor oscillation experiments
- Geo-antineutrinos

- Precision neutrino spectra
- Above-ground detection
- Improved neutron/gamma detection

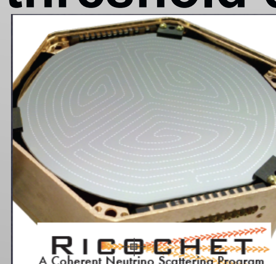
Scintillator detectors



- Sterile neutrinos
- Reactor anomaly

- Smaller detectors
- Improved spectral measurements*
- neutrino directionality*

Coherent Scatter/ Low threshold detectors



- WIMP or Axion searches
- sterile neutrino search
- Nuclear physics studies

1) Long Range Monitoring Test – the WATCHMAN (Water Cherenkov Antineutrino Monitoring) project

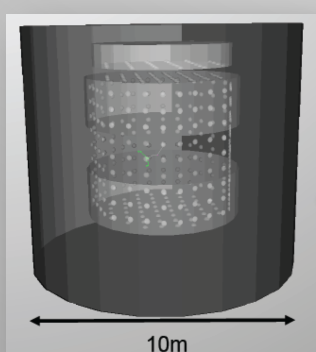
Nonproliferation Goal: demonstrate sensitivity to reactor antineutrinos using a 1000-10000 ton **gadolinium-doped water detector**
at ~2 km from a 100 MWt US research reactor, or
~20 km from a 3000 MWt US commercial power reactor

- Phase I – 2012 start- **identify site,** measure backgrounds, and develop a design envelope for the detector

Research or power reactor

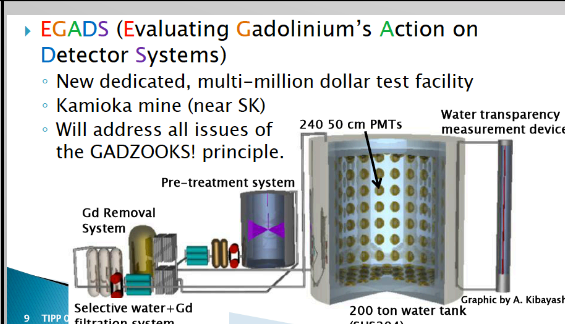
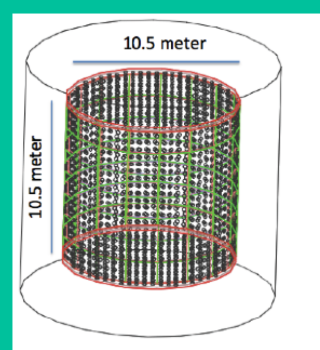
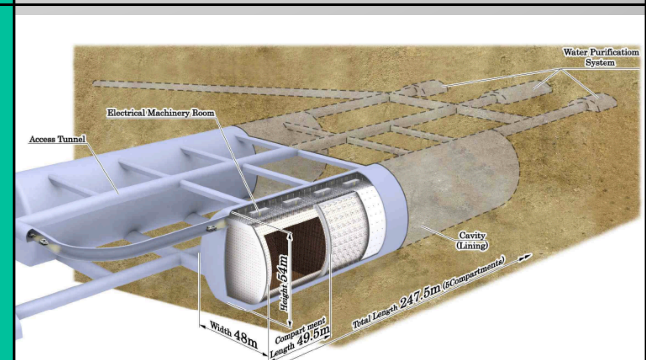
1-20 km standoff

100-2000 meters overburden



Kiloton scale detector

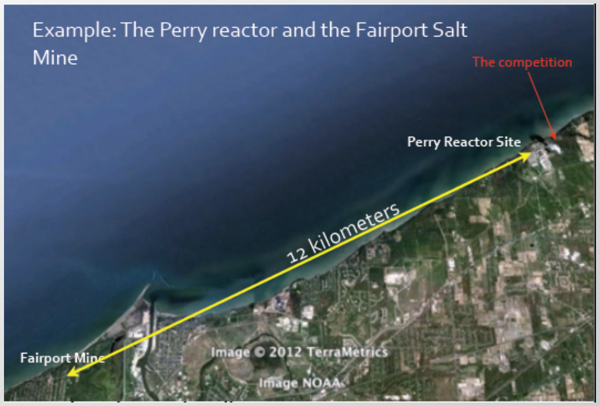
How does this relate to other large water detector R&D ?

Detector	EGADS	WATCHMAN	Hyper-K
Status	Ongoing	2016 start	2018-19 start
Mass (ton)	200	1,000 - 10,000	560,000
Type	Gd-WCD	Gd-WCD	Pure H2O or Gd-WCD
Purpose	Measure background materials,energy threshold Too small to see reactors	Remotely detect reactor antineutrinos – some oscillation sensitivity	Neutrino oscillations, proton decay, supernovae - WATCHMAN would demonstrate Gd option for HyperK
			

WATCHMAN US possible deep site: the Fairport Mine

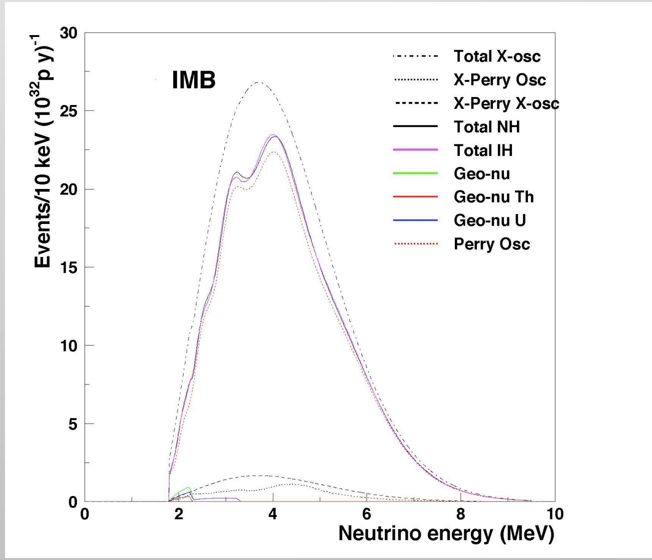
Perry Reactor Nuclear Generating Station to IMB cavern in the Fairport Salt Mine (Ohio)

- Existing 20 m cubic cavern – other excavations possible
- 1570 m.w.e. – pretty deep
- 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. **Existing cavern ideal for this demonstration**
3. **Would be the only US detector sensitive to supernova antineutrinos**
4. **Upgraded detector physics potential for geo-antineutrinos and mass hierarchy being investigated..**
5. **Nstural precursor/demonstrator for Hyper-K or other large water detectors**

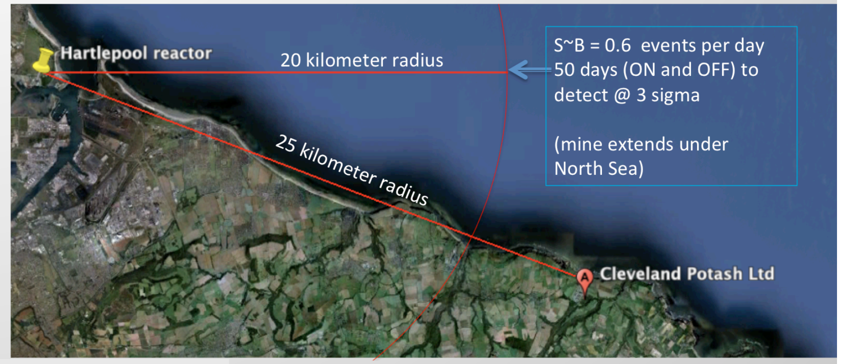


Plot courtesy Steve Dye, Hawaii Pacific Univ.

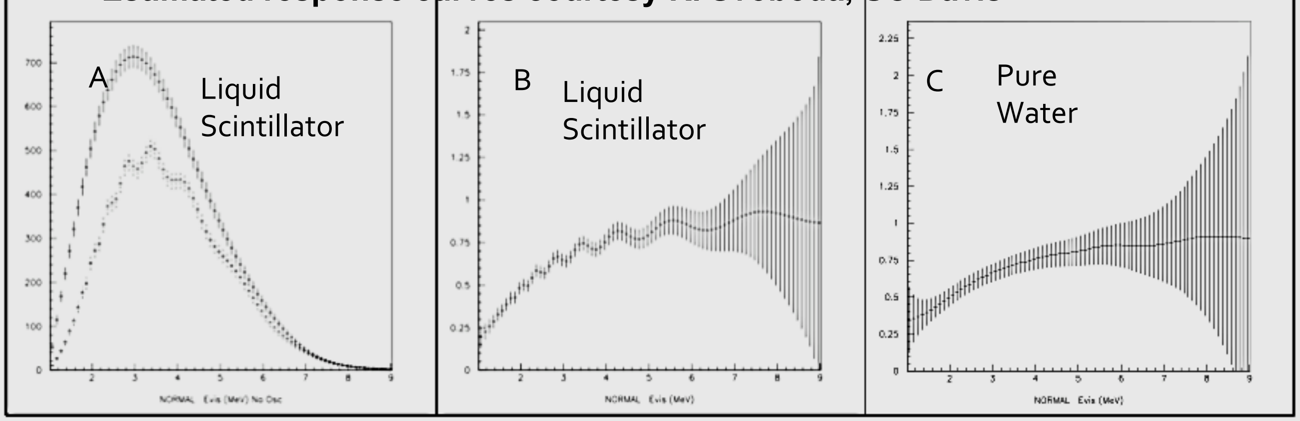
A preliminary look at the LS antineutrino spectrum - 1 year of operation, systematics not incorporated

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*



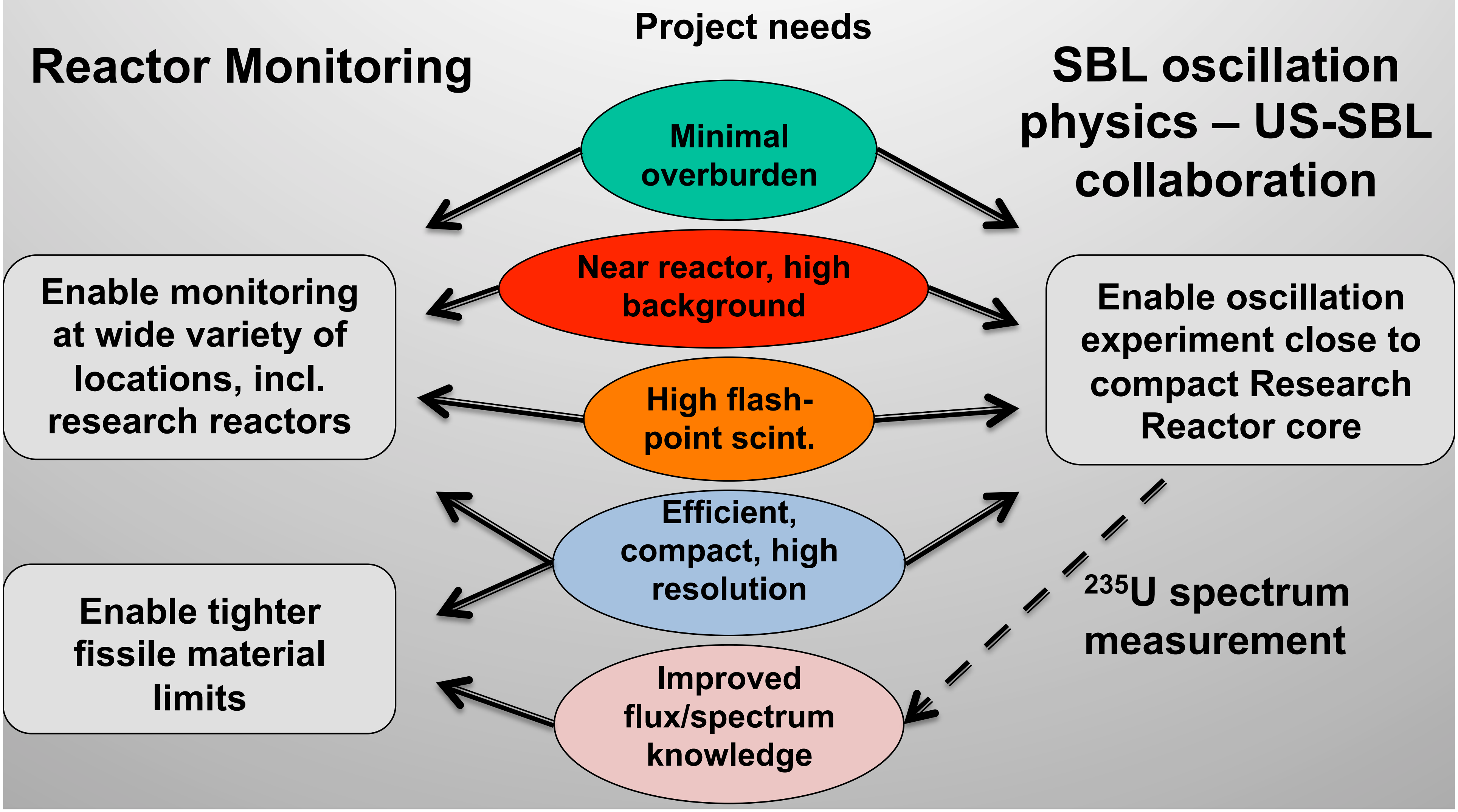
Estimated response curves courtesy R. Svoboda, UC Davis



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.

2) Near-field reactor monitoring: detector requirements nearly identical to those for a SBL reactor experiment

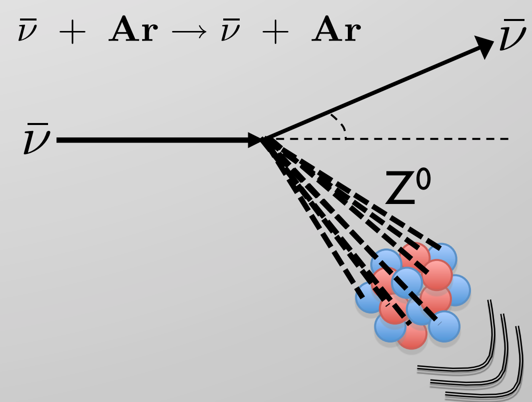


3) Coherent Elastic Neutrino-Nucleus Scattering – what is it ?

A flavor blind process – the neutrino elastically scatters on a nucleus via Z0 exchange

- An undisputed, unmeasured prediction of the Standard Model since 1974
- The cross section, delightfully large

$$\sigma_{\rm cs} \simeq \frac{G^2 N^2}{4\pi} E_\nu^2$$



- The induced signal, unpardonably small

$$\langle E_r \rangle = 716\,{\rm eV}\,\frac{(E_\nu/{\rm MeV})^2}{A}$$

- possible sterile neutrino oscillation search – e.g. Ricochet
- A,Z sensitivity proposed as a probe for nuclear structure arXiv:1207.0693 [nucl-th]

Who is doing it and why ?

- Considerable effort worldwide, most often from the Direct Dark Matter Search community
- Nearly identical to a Dark Matter detector
- Without ton-scale directional detectors (e.g. Nygren concept), coherent scatter is the irreducible background to WIMP dark matter sensitivity and thus needs to be studied
- It has the pleasing bonus feature that we know it exists…
- Nonproliferation goal is to exploit high cross section to make smaller monitoring detectors

Coherent ν Scattering at Nuclear Reactors

- Solar neutrinos
- Supernovae

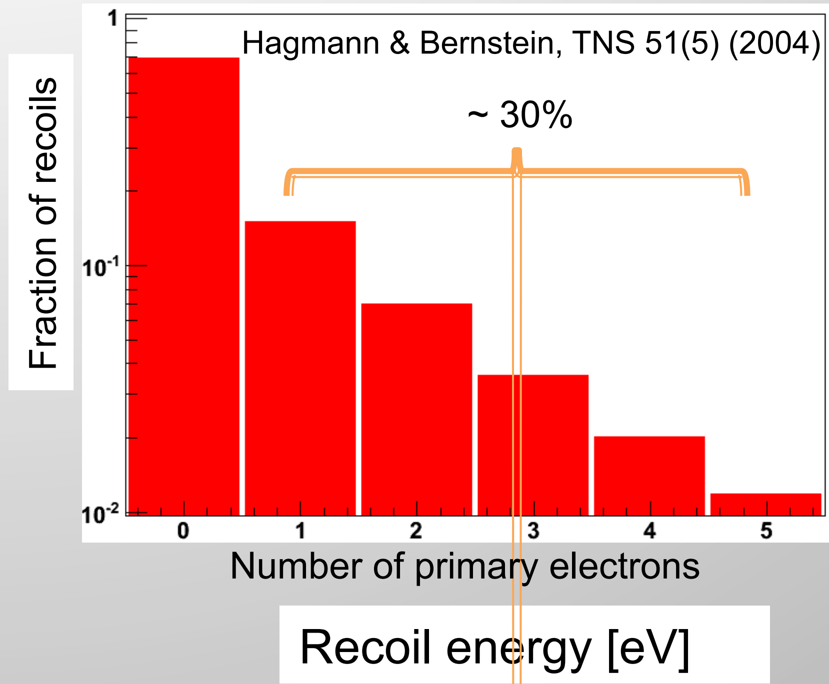
⟹ Neutrino beams *~30 MeV neutrinos from ORNL spallation source are a great discovery tool*

⟹ Nuclear Reactors

Reactors an attractive source for CENNS

- High flux ($\Phi > 10^{12}$ $cm^{-2}s^{-1}$)
  Can be turned off
  Energy in coherent regime
- Expected event rates @ 25 m (before detection efficiencies):
  - 56 events/(kg day) for CNS off Argon
  - 5.2 events/(kg day) for the inverse β decay reaction on CH_2

Simulated ionization spectrum from reactor neutrinos on Ar



Average reactor ν recoil energy on argon ~ 240 eV !!

For the sake of both fields, neutrino/DM physicists should learn about nonproliferation

- Despite many common elements, neutrino applications differ from fundamental science in important ways

  1. Policy context matters as much or more than the technology
  2. Detectors have to be robust, safe, and easy to deploy
  3. Outputs must be easy to interpret

- For neutrino physics to have an impact on nonproliferation, physicists need an education in the history and practice of nonproliferation, and the coming challenges – Nuclear Science and Security Consortium a highly effective example at UCB, UCD, UCI, USCD

  - Many schools - mostly nuclear engineering but also some physics departments (e.g. Virginia Tech and UC Davis) provide training in nonproliferation

The public and Congress need to be educated and re-educated about neutrino physics

- The field's diversity makes this a challenge to explain compared to say particle discovery (Z0, W, charm, bottom, top, Higgs, dark matter..)
- But we enjoy a rich record of discovery - oscillations, neutrino mass, a galactic supernova - and a bright future – new neutrinos, CP violation, extra-galactic supernovae..
- Simple explanations of the mysterious physics of neutrinos have been successful in maintaining the profile of neutrino physics in the public mind
- <u>The overlap with applications</u> has helped make the case for neutrino physics that appeals to Congress and the public <u>and can provide new funding sources</u>

Applied Antineutrino Physics – a growing global community with strong ties to Dark Matter and Neutrino Science

Neutrinos and Arms Control Workshop

5-7 February 2004, University of Hawaii

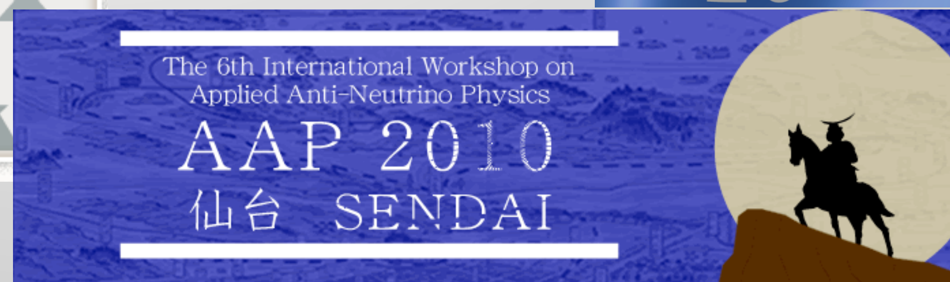
Neutrino Sciences 2005

Neutrino Geophysics

Honolulu, Hawaii

December 14-16, 2005

AAP2006 WORKSHOP SEPT 24-26 LIVERMORE, CA



The meeting will be dedicated to discuss applications of antineutrino detection in the field of non-proliferation, geophysics and other applied areas.

AAP-2009

V Applied Antineutrino Physics Workshop

Vienna, Austria

AAP 2012 at the University of Hawai`i

Summary

- Applied antineutrino physics is a burgeoning and exciting field
- Current neutrino/dark matter physics – sterile neutrinos, LBL oscillations, and dark matter detection, relate very directly to this research
- The potential impact on nonproliferation helps strengthen the case for fundamental neutrino physics with all stakeholders
- The Neutrino and Dark Matter Physics communities should self-educate, and exploit the overlap in technologies and methods - both in research and in funding requests
- « Par ma foi ! il y a plus de quarante ans que je dis de la prose sans que j'en susse rien. – Le Bourgeois Gentilhomme, Moliere

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