Applied Antineutrino Physics Workshop

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Workshop Overview

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The Goals of this Workshop and White Paper

1. **Provide the nonproliferation community with a definitive resource about antineutrino detection technologies.**

2. **Help the physics community understand the scope of the nonproliferation problem as it relates to nuclear explosions and nuclear materials, and explain what methods are used now.**

3. **Highlight the considerable scientific and technological overlap between antineutrino research and nonproliferation and nuclear materials/arms control research.**

Volunteers for White Paper will be Coerced over Dinner

What Nonproliferation Problems Are We Talking About ?

1. Find all the Special Nuclear Material in the world and track or reduce inventories as best we can

- IAEA Safeguards: Verify that civil material is not transferred to weapons programs
- **Cooperative Monitoring**: Formal and informal agreements for international monitoring of fissile materials and production facilities

- Arms/materials reductions – drawdown of nuclear weapons and materials in weapons states – e.g. Nonproliferation Treaty**,** Plutonium Disposition Agreements, Fissile Material Cutoff Treaty, Strategic Offensive Reductions Treaty

Approximate Worldwide Inventories **(source - isis.org)**	**Where is it**	**IAEA "significant quantity"**
1,830,000 kg of Pu worldwide	Most in civil spent fuel, several hundred tons of separated Pu in global civil and military stockpiles	8 kg separated Pu
1,900,000 kg of HEU worldwide	mostly in military stockpiles -	25 kg HEU

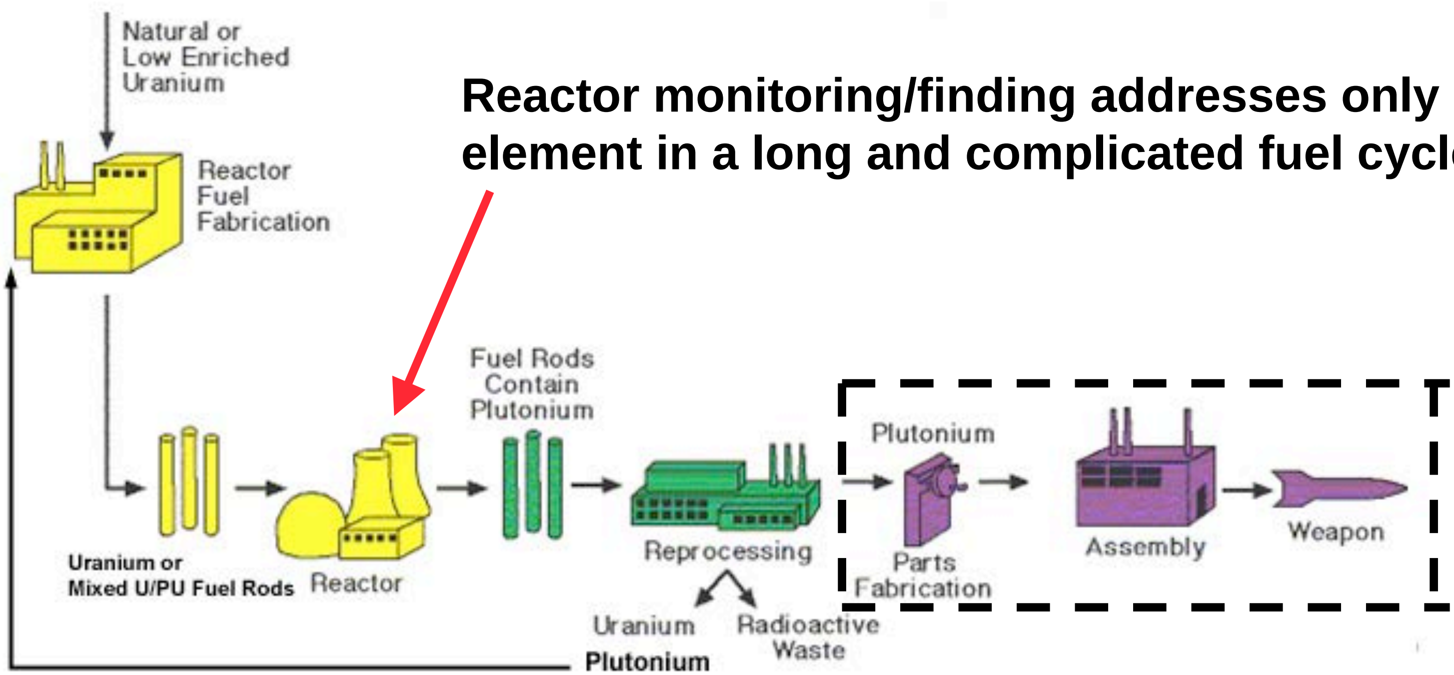
Brian Boyer and George Baldwin talks

2. Monitor Nuclear Explosions

Detect, locate and characterize nuclear explosions worldwide - *Jay Zucca talk*

Workshop Lesson Zero: Antineutrino detectors can't solve either problem !

Reactor monitoring/finding addresses only one element in a long and complicated fuel cycle



The current international nuclear explosion monitoring regime already has excellent global coverage for a wide range of interesting cases

What antineutrino detectors actually *can* offer is a central question for our research and this workshop

The Main Technical Ideas Related to Near-Field Cooperative Monitoring

1. Ton-scale detectors at tens of meters from power reactors can detect hundreds to thousands of antineutrinos per day

2. Antineutrino detection is highly evolved and practical to use now

3. The neutrino count rate is just about proportional to reactor power P_{th} - *but not quite*

4. *Proportionality is violated*: number of antineutrinos and fission rates vary with **isotope and in time**

Constant (geometry, detector mass)

k evolves with isotopics and depends on number of antineutrinos per fission per isotope

$$N_{\bar{\nu}} = \gamma(1+k)P_{th}$$

Example: Net change in fissile content over one cycle

^{235}U – 1500 kg consumed
Pu – 311 kg produced

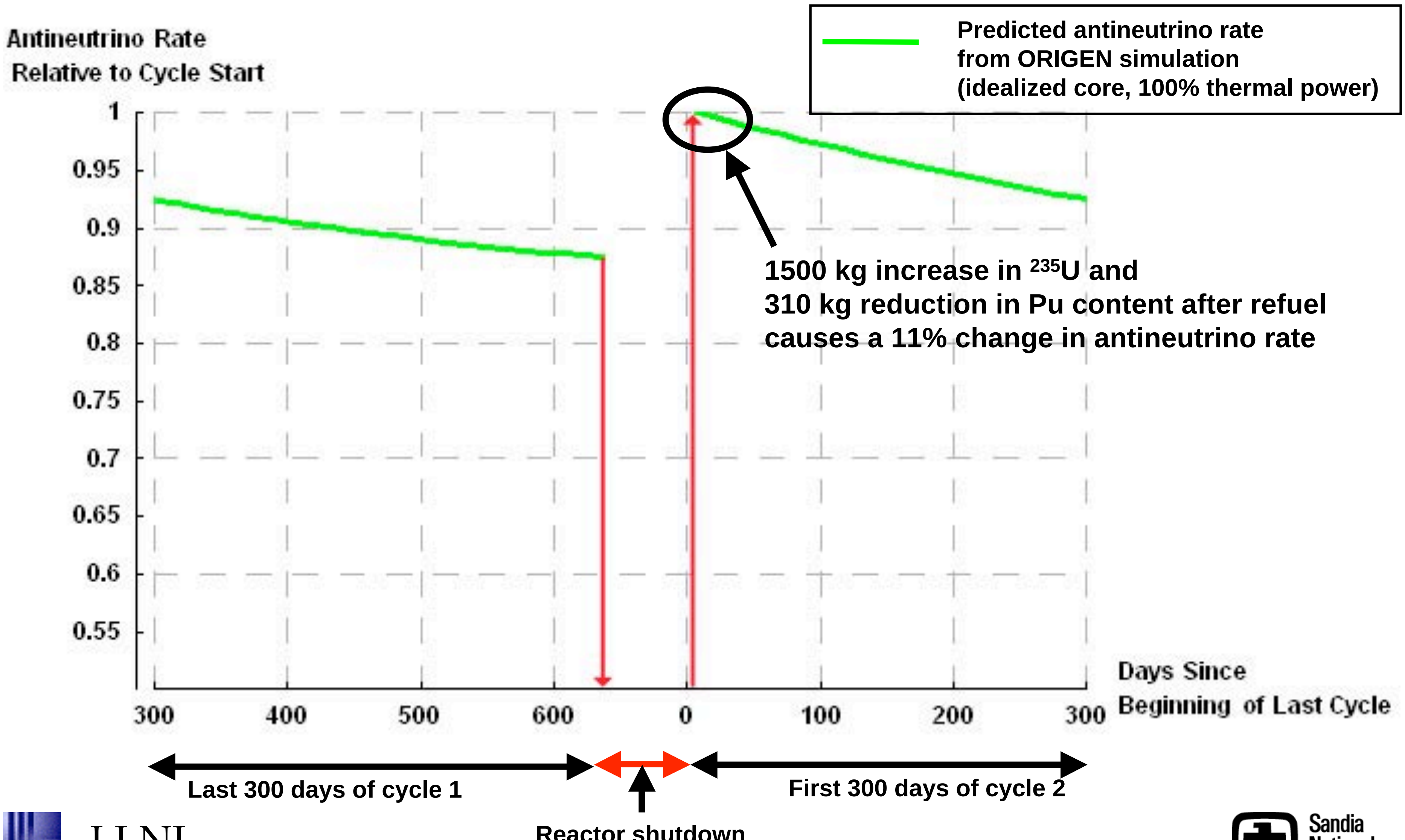
→

consequent change in the factor k over one cycle from a simulation and our data

-11% ± 2%

5. The antineutrino energy spectrum is also sensitive to the reactor fissile content

The Simplest Implementation – Monitor Relative Antineutrino Count Rate Within and Across Cycles



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The Near Term Program for Near-Field Monitoring (A Partial List)

- **Physics is not the main immediate problem**
  - Improved spectral densities are useful but not essential for first steps *'spectral' talks*
  - Better detector designs can increase efficiency, signal to background, and reduce cost , and impact other areas of NP– *detector talks*
  - Moving detectors to the Earth's surface would be a major step forward *Suekane talk*
- **Deployment and operator/inspector constraints are central**
  - Example – our current 2.5 m cube footprint is 'too big' according to the IAEA
  - Example – our research indicates many reactors have tendon galleries
- **Ease of operation is a top priority for the IAEA and other regimes**
  - Inspectors are very capable but won't be trained antineutrino physicists
- **Clear and simple results are paramount**
  - No demarches issued or invasions pursued for a one sigma effect
- **Quantify costs and benefits, and compare to the current regime**
  - *Lambert talk*

Important Progress In Experiments Establishing Utility and Feasibility Has Already Been Made Worldwide

1. Approximately track fissile content directly at the moment Pu is born

2. Measure thermal power to 1-3%, constraining fissile content

3. Operate continuously, non-intrusively, and remotely

4. Self-calibrated, unattended, few channels, low cost materials, operable for months to years with rare maintenance

- Historical first – Russia clearly accomplished steps 1-2 at Rovno in the 1980s – *Skorokhatov/Cribier talks*

- LLNL/SNL work has demonstrated 1-4 *N. Bowden talk*

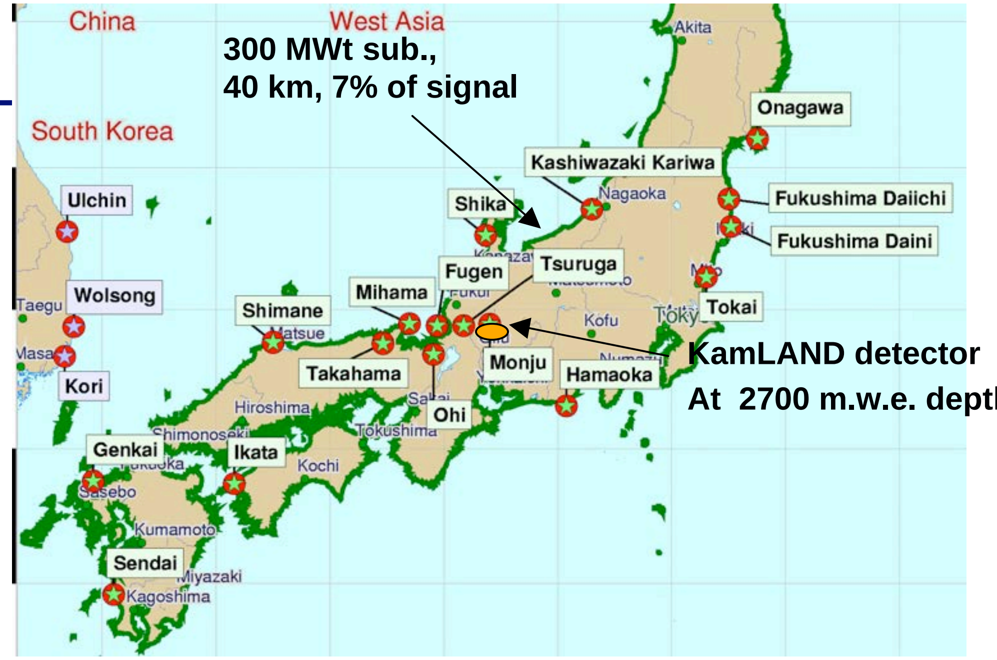
- France, Brazil are now proposing deployments of this kind

Dos Anjos, LaSerre talks

The Main Technical Ideas Related to Far-Field Cooperative Monitoring

- **Standoff distance and the neutrino oscillation parameters allow firm predictions of rates in detectors from both explosions and reactors**
- **KamLAND and earlier oscillation experiments have already made (at least) two essential contributions to the problem of remote reactor finding**
- **Enormous - thousands to millions of ton - detectors are required to approach far-field explosion or reactor monitoring capabilities of interest**
- **Advances in antineutrino detection technology are required to enable detection of interesting scale reactors (10-50 MWt) at significant standoff**

Oscillation Experiments Have Introduced the Idea of Distant Reactor Monitoring



1. KamLAND definitely sees remote reactors:

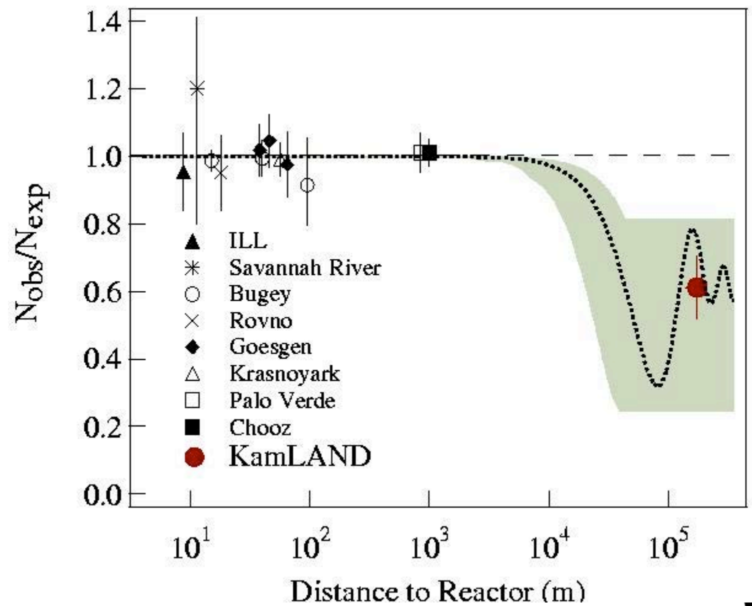
- 1000 tonnes sees 130 GWt of reactors
- 5.4 Events per Week,
- Signal/Background: 50
- 2700 m.w.e
- **4% of signal from South Korea !**
- **7% of signal from hypothetical 300 MWt sub at 40 km standoff (Detwiler et. al)**

FOM: Power/Distance^2 – well almost

↓

2. KamLAND sees the effect of neutrino oscillations on reactor antineutrinos - a variation in flux from 1/(distance)^2 dependence is seen at ~10^5 meters.

Earlier experiments have confirmed the **absence** of this variation at shorter distances



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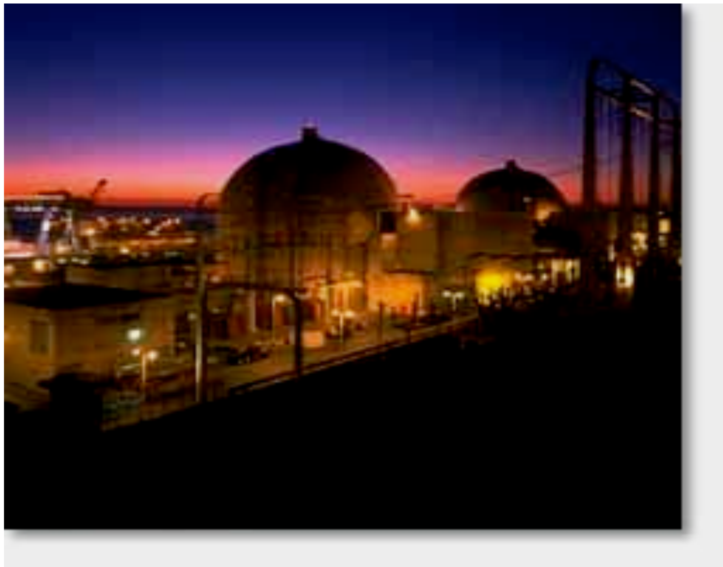
The Long Term Program for Far-Field Monitoring (A Partial List)

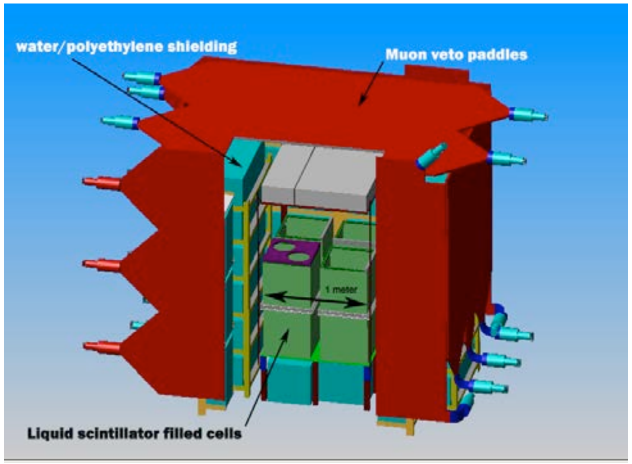
Detector Physics and Engineering is the Immediate Problem

- **Build bigger liquid scintillator detectors for basic physics**
  - *Learned talk*
- **Make water-based antineutrino detectors**
  - *Vagins talk (and LLNL experiments)*
- **Discover and exploit coherent neutrino scattering**
  - *Collar talk*
- **Invent low-cost 'wallpaper' photodetectors**
  - *Ferenc talk*
- **Quantify costs and benefit, compare to the current regime**

Near-Term, Near-Field Summary

- Near field cooperative monitoring is a practical possibility
- Simpler and more precise detectors are a straightforward extension of today's detectors
- Much work remains to be done on integration of detectors into the Safeguards Regime





Long-Term, Far Field Summary

Hyper-Kamiokande, Hano-Hano and coherent scatter detection are important next steps for far-field detection