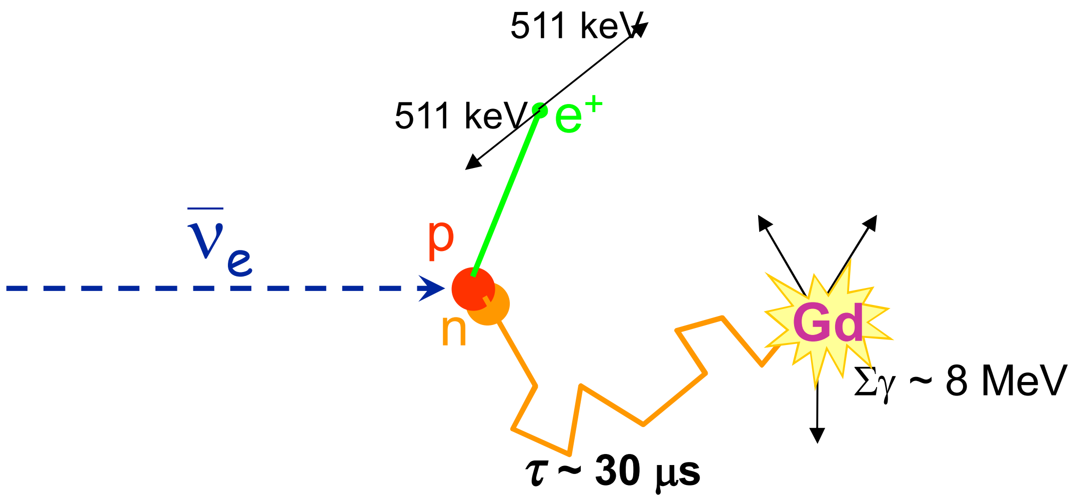
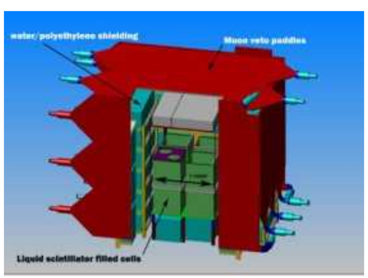
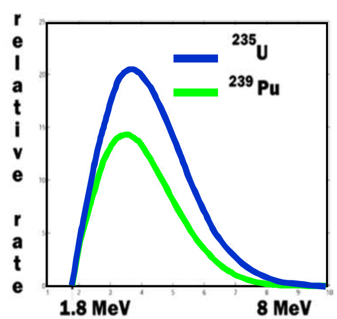
SAND2014-18270PE

Monitoring of Reactors with Antineutrinos







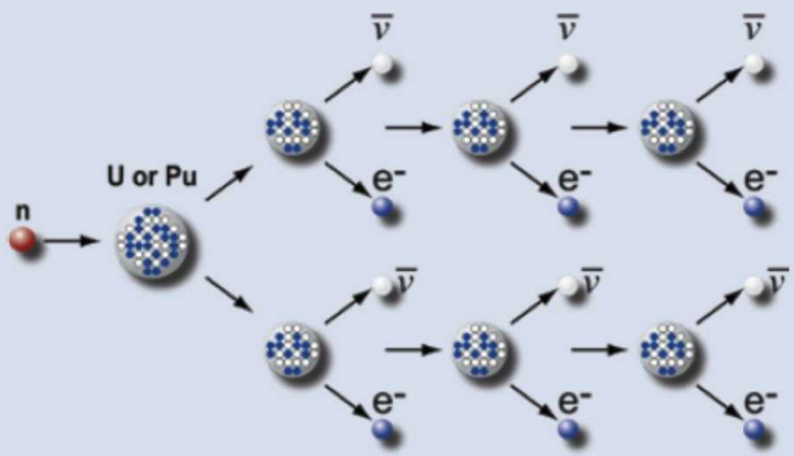
A Novel Technology for Reactor Monitoring

- Antineutrino Monitoring of Reactors provides independent measurements of Thermal Power and Fissile Inventory
  - Non-intrusive with NO connection to plant systems
  - Continuous Remote Monitoring
  - Highly tamper resistant
- Potential Applications: Present and Future
  - Independent Confirmation of Operator Declarations
  - Provide fissile content information for Next-Generation fuel cycles (MOX, Th, bulk process)

Reactors Produce Antineutrinos

Reactors emit huge numbers of antineutrinos

- 6 antineutrinos per fission from beta decay of daughters
- 10^{21} fissions per second in a 3,000-MWt reactor



About 10^{22} antineutrinos are emitted per second from a typical PWR unattenuated and in all directions

Detected rates are quite reasonable

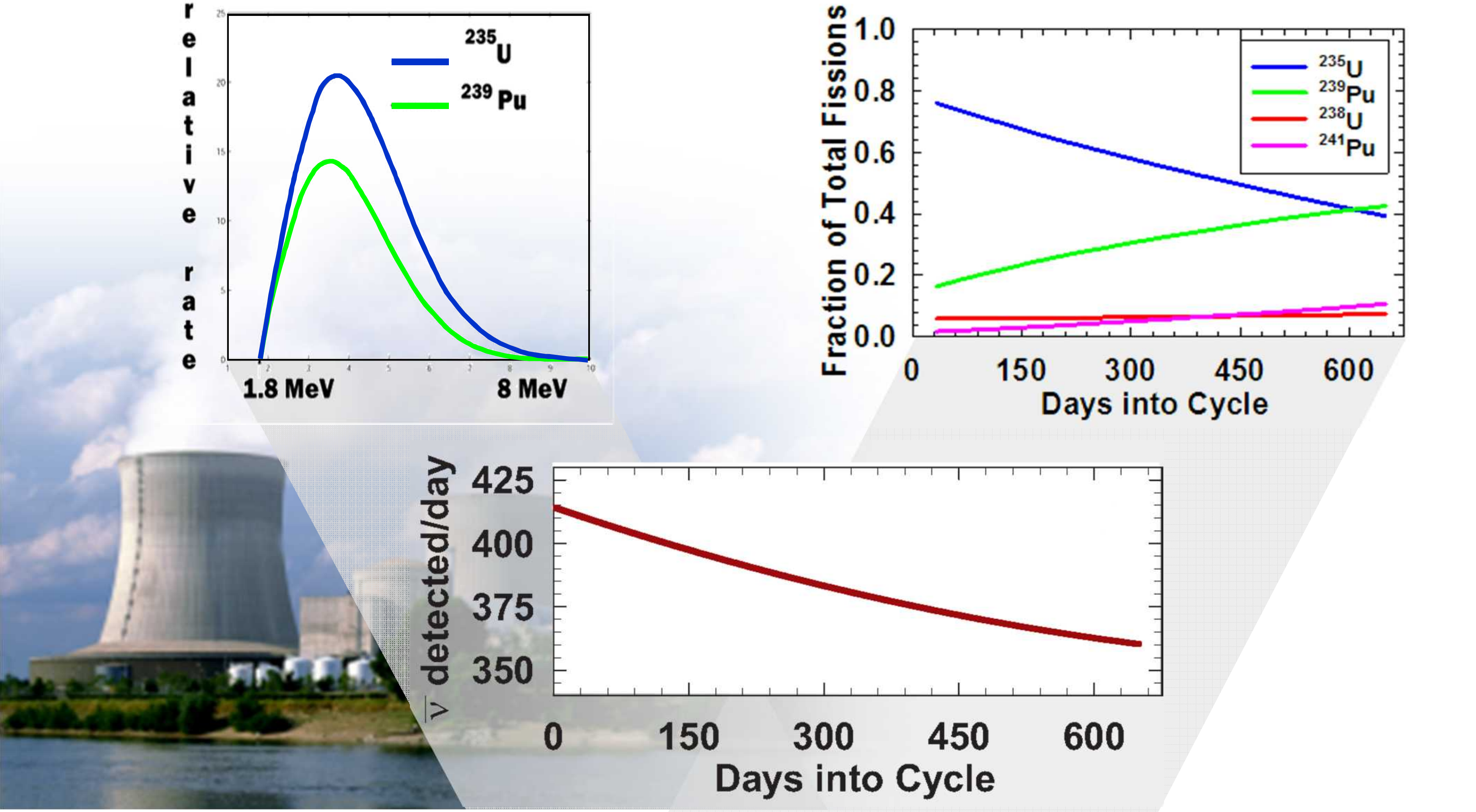
- 10^{17} antineutrinos per square meter per second at 25-m standoff
- 6,000 events per ton per day with a perfect detector
- 600 events per ton per day with a simple detector (e.g., SONGS1)

Example: detector total footprint with shielding is 2.5 meter on a side at 25-m standoff from a 3-GWt reactor

The Antineutrino Rate varies with Isotope

The energy spectrum and integral rate produced by each isotope is different

The fuel of a PLWR evolves under irradiation: ^{235}U is consumed and ^{239}Pu is produced

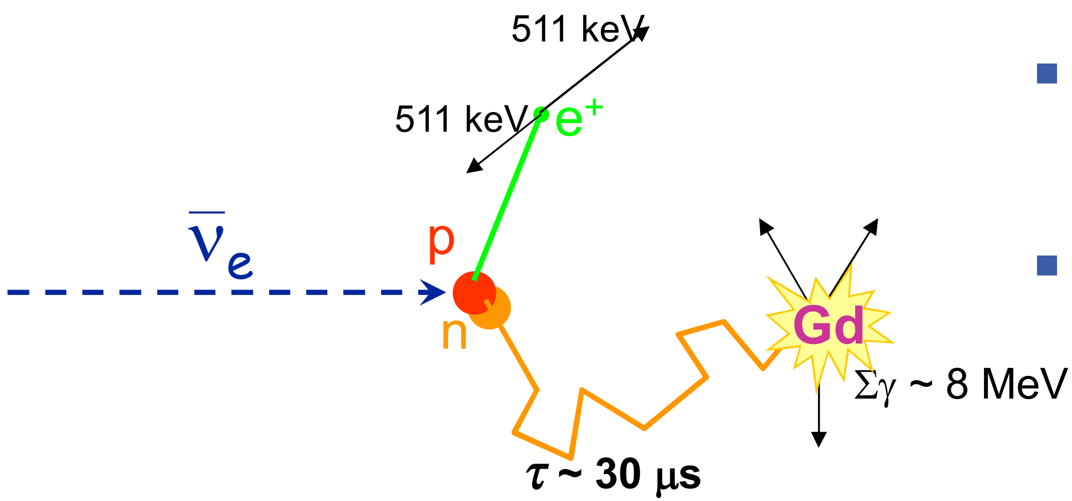


Antineutrino Detection:
Standard Detector Technology

- **We use the same antineutrino detection technique used to first detect (anti)neutrinos:**

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

- **Standard detectors of gammas and neutrons are sufficient to find this correlated signature**



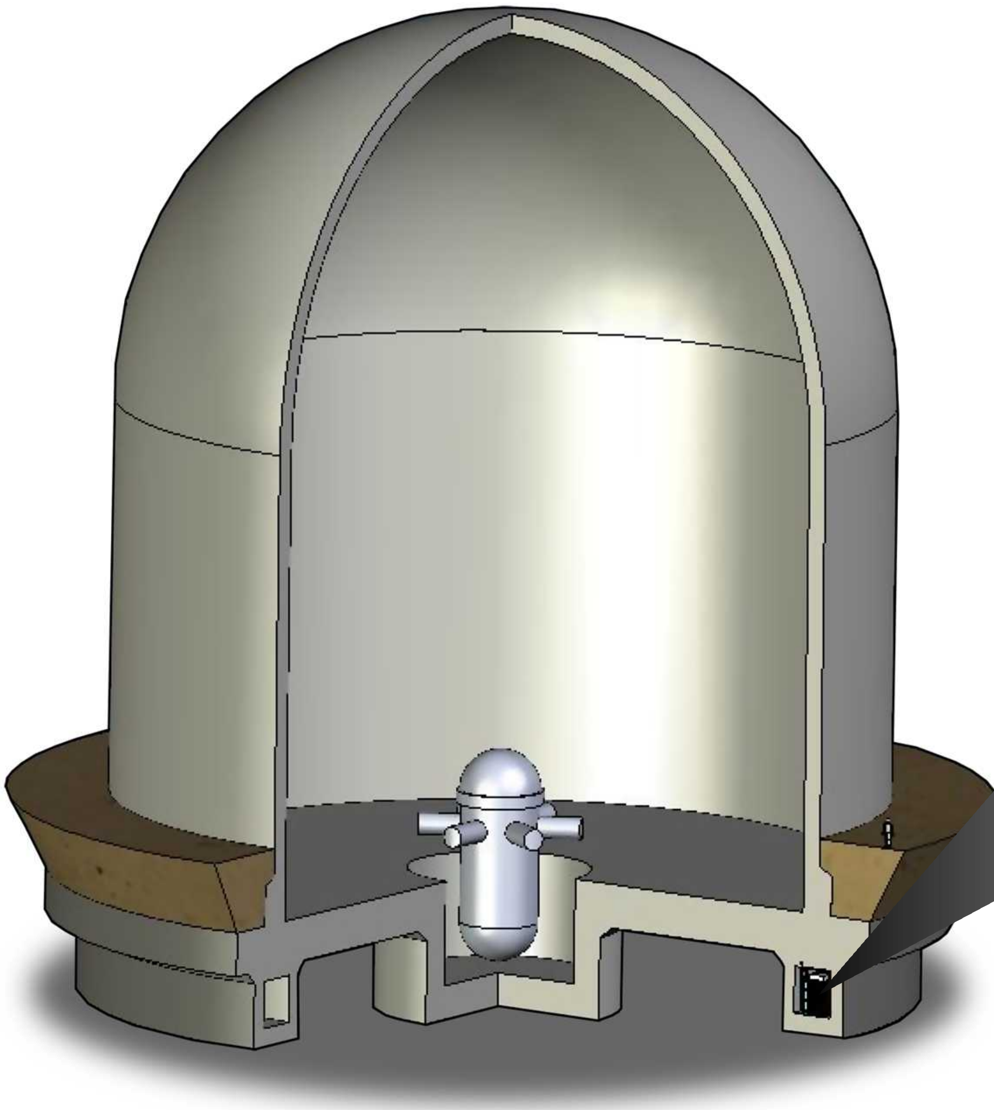
prompt signal + n capture on Gd

- **Positron**
  - **Immediate**
  - **1- 8 MeV (incl 511 keV γs)**
- **Neutron**
  - **Delayed (τ = 28 μs)**
  - **~ 8 MeV gamma shower**

(200 μs and 2.2 MeV for KamLAND)

Proof-of-Principle Demonstrations

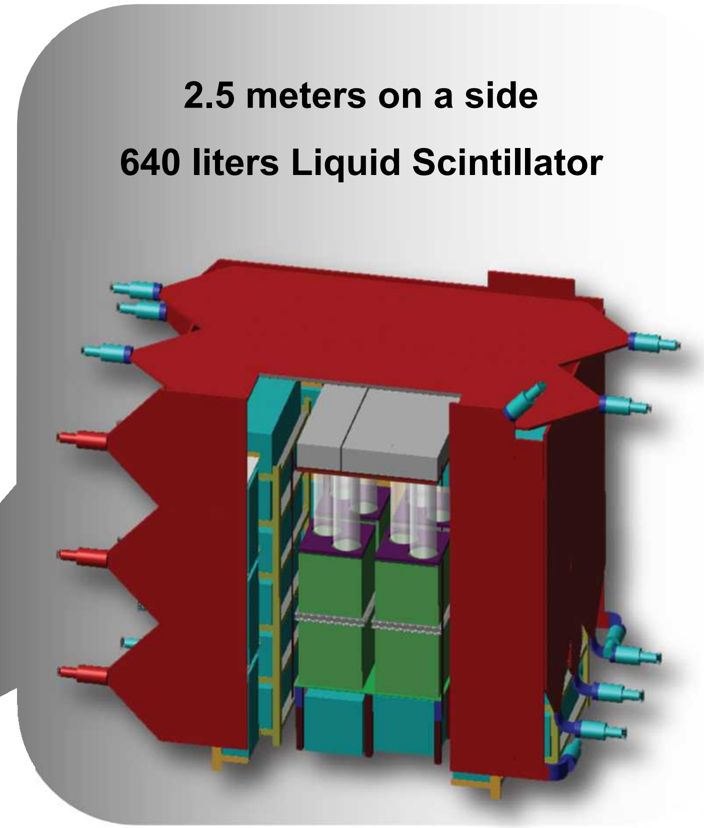
The “SONGS1” Antineutrino Detector



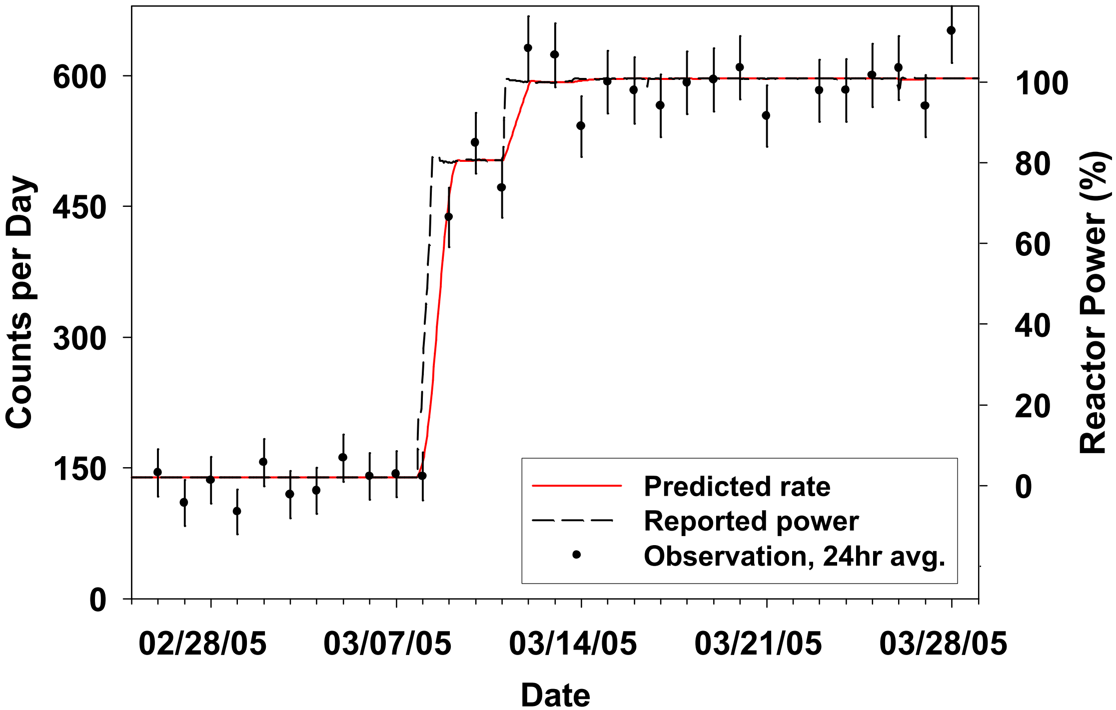
A simple, robust and automated design

2.5 meters on a side

640 liters Liquid Scintillator



Reactor Power Monitoring using **only** $\bar{\nu}$



Timescale

1 – 3 Hours:

Sudden changes in operational status (on/off)

1 Day:

Large power changes

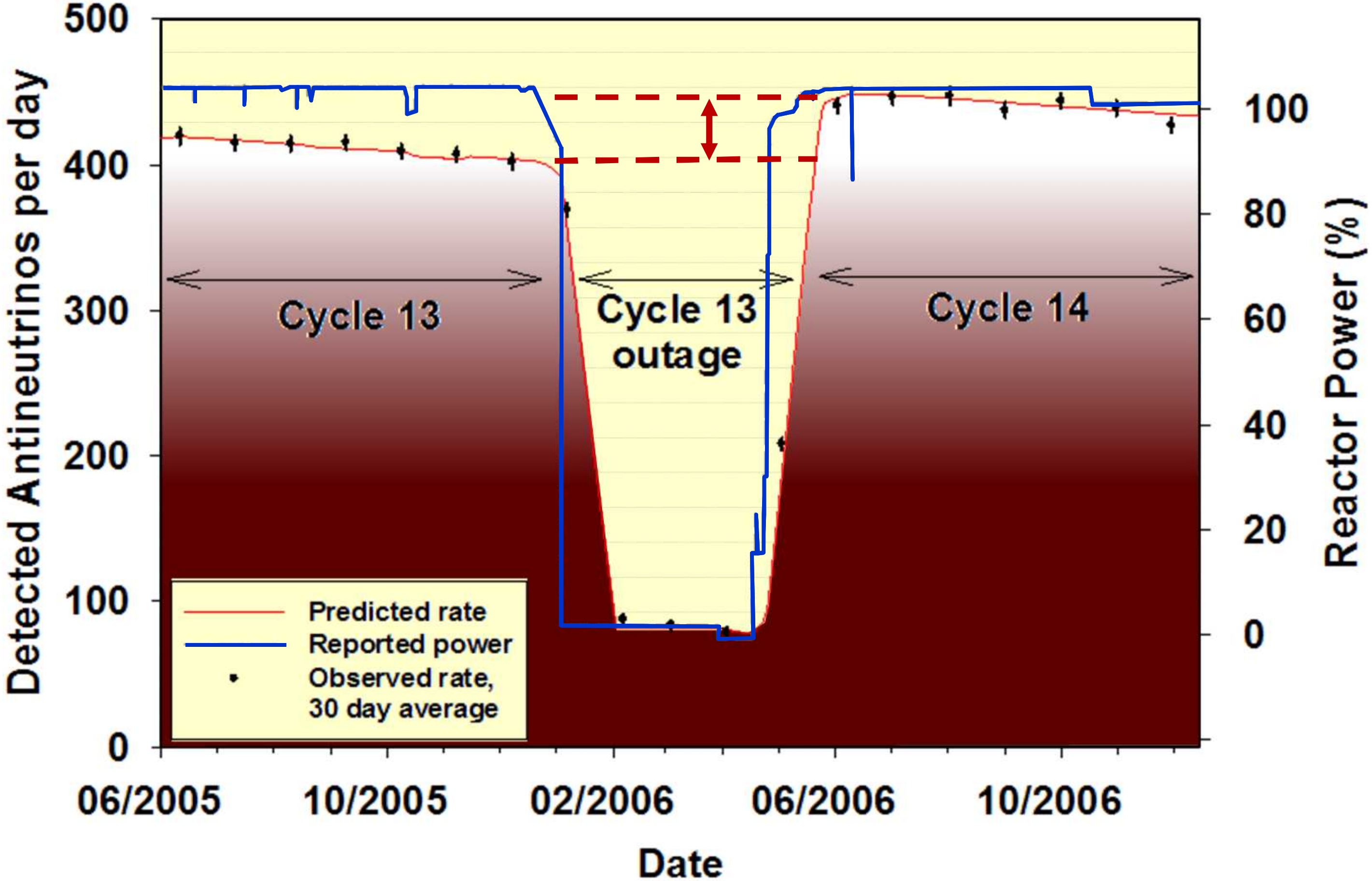
7 Days:

Relative thermal power measurement (2 – 3%)

Large power changes are readily observed with no physical connection to the plant

$\overline{\nu}$ Provides Information on Fuel Composition

Standard Refueling is Clearly Visible



Sensitive to undeclared removal of 70 kg ^{239}Pu

Engagement with IAEA

- **Introduction of technology – 2003**
  - **Called for further development**
- **Focused Workshop – 2008**
  - **Requested Improvements in**
    - **Robust Deployability**
    - **Fully Independent measurement of fissile content**
- **Ad Hoc Working Group – 2011**
  - **Expressed interest in potential future applications**
    - **Gen-IV reactors**
    - **Bulk Process (i.e. PBMR)**

Antineutrino Program Past and Present

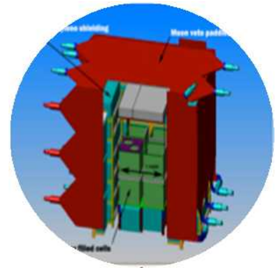
Joint SNL/LLNL Work

- Phase I (2002) Concept Inception
- Phase II (2003-2006) Proof of Principle
  - Initial deployment at SONGS
  - Refinement of basic Liquid Scintillator detector
  - Successful demonstration (SONGS1)
- Phase III (2007-2012) Aboveground
  - Detector technology innovation

Phase IV (2012-)

- Large Standoff (Watchman)
  - Large liquid detectors
  - Effort led by LLNL
    - Primarily focused on Water Cerenkov Technology development
- Near Field Monitoring
  - Requires compact, robust detectors
  - Effort led by SNL
    - development of aboveground technology

Antineutrino Detector Technology Tree



2005-6
SONGS1
(Liquid Scintillator)

Liquid Scintillator

Optimized

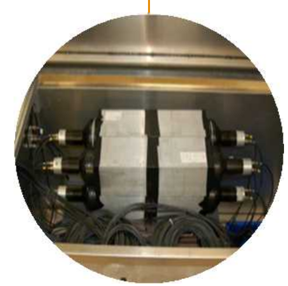
Water Cerenkov

2007
250 liter
prototype

2010
Improved 1-ton

Plastic Scintillator

2007
+ Gd sheets

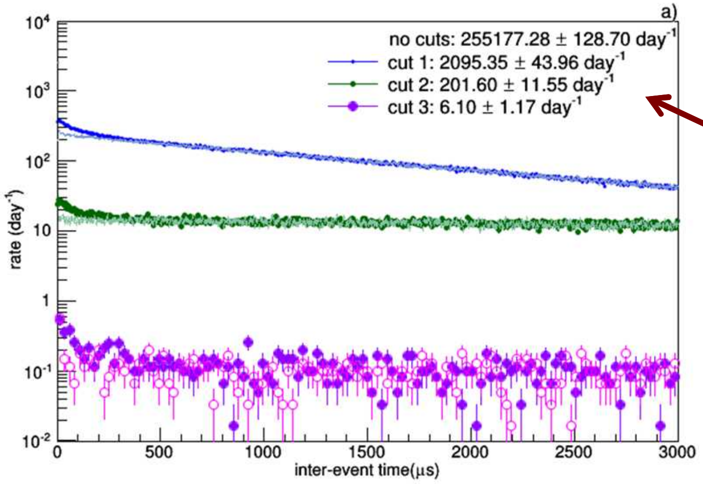


2011-12
+ Li:ZnS

Germanium

2008
1kg first test

Near-Field Monitoring



- **Demonstrated capability for short and long term relative monitoring of power, operational status, and fissile content in reactors**
- **Exploring potentially broader applications space**
  - **Antineutrinos provide a capability to detect and monitor any man-made nuclear fission process**
    - **Post disaster (reactor meltdown) characterization**
    - **Unilateral Monitoring**
    - **Treaty verification (CTBT, FMCT, PMDA)**
- **Very encouraged by performance of Segmented Scintillator prototype**
  - **This technology is focused on reducing the overall footprint and enabling a transportable detector that can be deployed in high-background or unshielded locations**
  - **Demonstrated rejection of backgrounds of 5 orders of magnitude even without an external shield**
    - **Data from unshielded deployment at SONGS showing rejection of backgrounds as successive selections are applied**
    - **Patent application filed based on recent improvements**