Current Attempts at Aboveground Antineutrino Monitoring at the San Onofre Nuclear Generating Station (SONGS)

A Joint Project Between
Sandia and Lawrence Livermore
National Laboratories

David Reyna

Sandia National Laboratories, CA

Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory in part under Contract W-7405-Eng-48 and in part under Contract DE-AC52-07NA27344.

Lawrence Livermore National Laboratory

Sandia National Laboratories

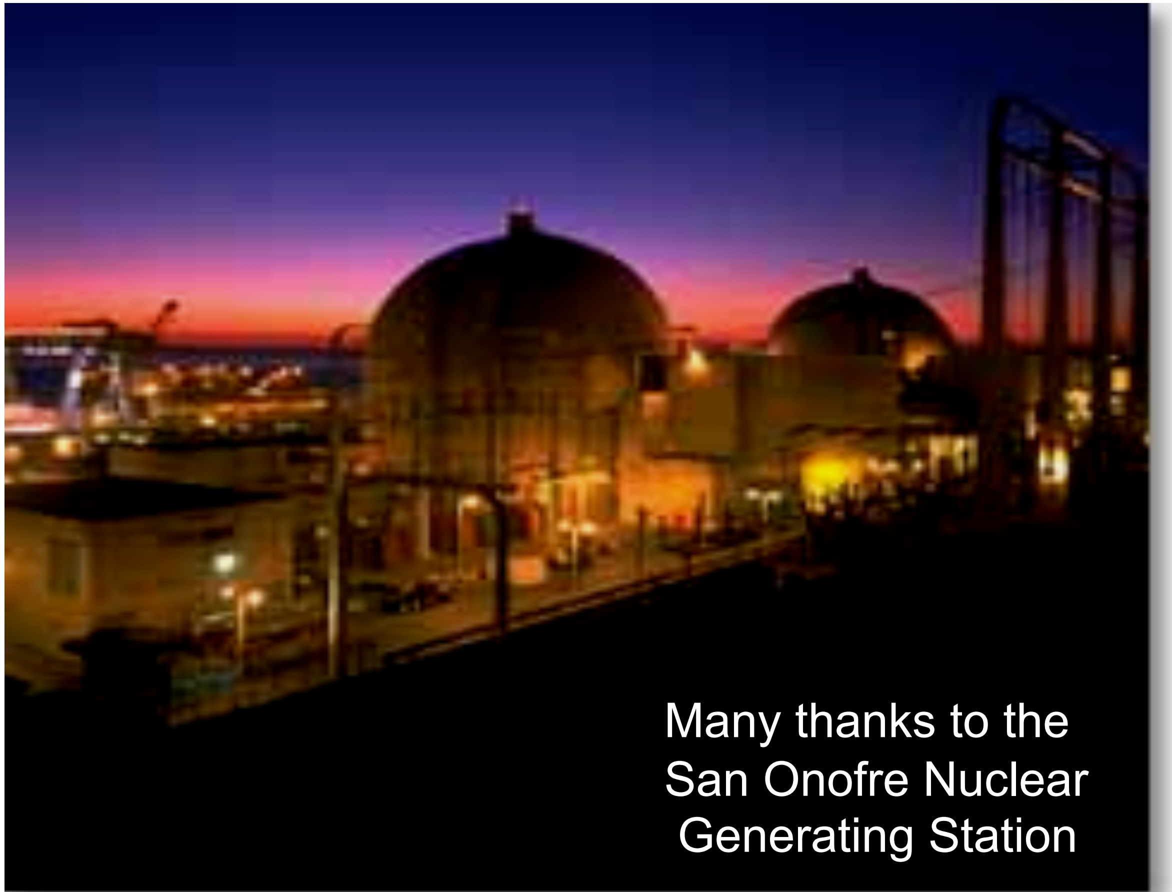
Acknowledgements and Project Team

Sandia National Laboratories

David Reyna
Jim Lund
Belkis Cabrera-Palmer
Scott Kiff

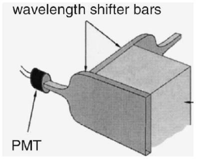
Lawrence Livermore National Laboratory

Nathaniel Bowden
Adam Bernstein
Steven Dazeley
Greg Keefer



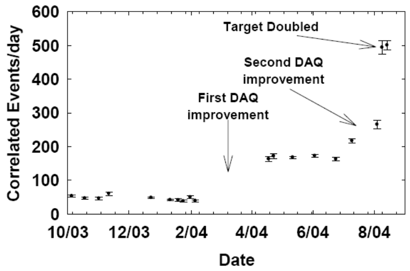
This Work is supported by DOE-NA22
(Office of Nonproliferation Research and Development)

Timeline of LLNL/SNL Presence at SONGS



Conceptual Paper,
Detector Design

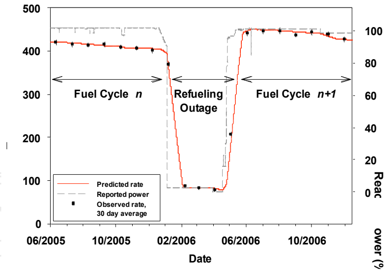
2002



First $\bar{\nu}$ observation

Large efficiency gains

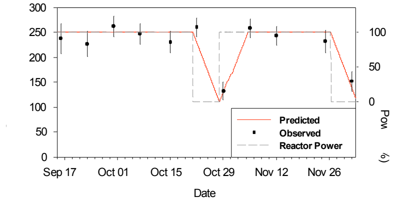
2004



Isotopic evolution

SONGS extension

2006



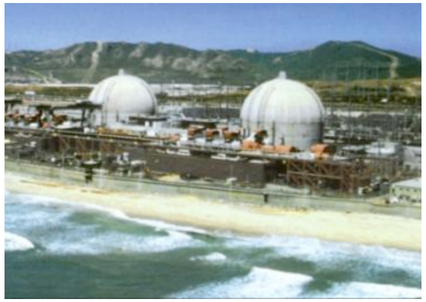
Deployable Results

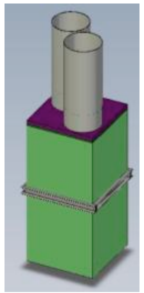
Detector Removal

2008

2003

Design Refinement,
Deployment at SONGS

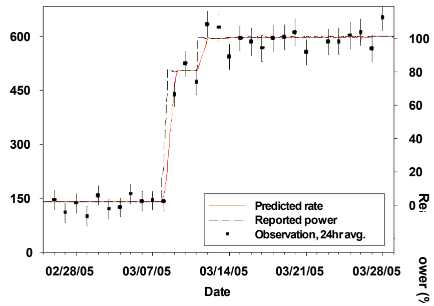




2005

Power Monitoring

Detector Stabilisation



2007

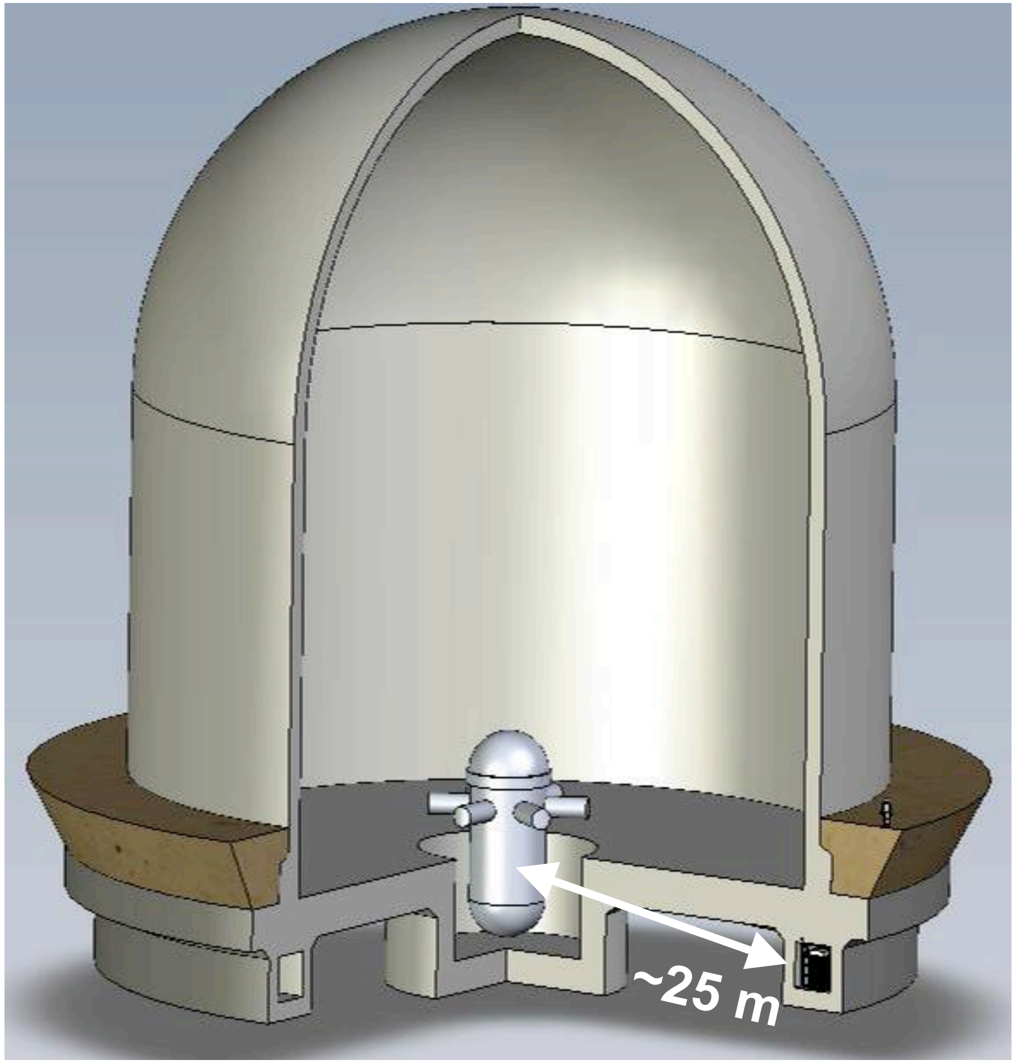
Deployable Detectors Designed, Constructed, Deployed

2009

New Deployment In SONGS Unit-3

SONGS Unit 2 Tendon Gallery

- Tendon gallery is ideal location
  - Rarely accessed for plant operation
  - As close to reactor as you can get while being outside containment
  - Provides ~20 mwe overburden



Interest Developing from Safeguards Agencies

- **We are very pleased that as a result of our work, and other projects getting under way elsewhere, IAEA is considering this new tool**
- **Experts meeting (Vienna 2008)**
  - **Assessing where it might fit**
  - **Bulk accountancy mentioned**
  - **Online refueled mentioned**
- **Expecting an SP-1 (official IAEA request for further development and study)**

IAEA
International Atomic Energy Agency
Atoms for Peace

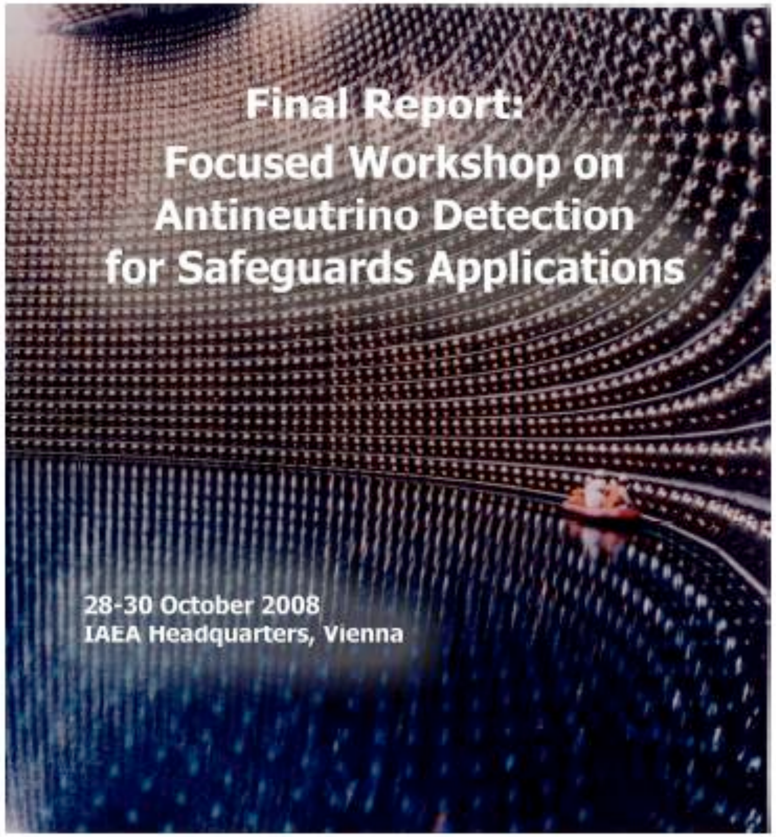
7.2 Medium Term:

If the above near-term goals are met, it is the opinion of the workshop conferees that antineutrino detectors will have demonstrated utility in response to the stated inspector needs in some specific areas of reactor safeguards. To further expand the utility of antineutrino detectors, several useful medium term (5-8 year timeframe) R&D and safeguards analysis goals are proposed.

1. Above ground deployment. Above ground deployment will enable a wider set of operational concepts for IAEA and reactor operators, and will likely expand the base of reactors to which this technology can be applied;

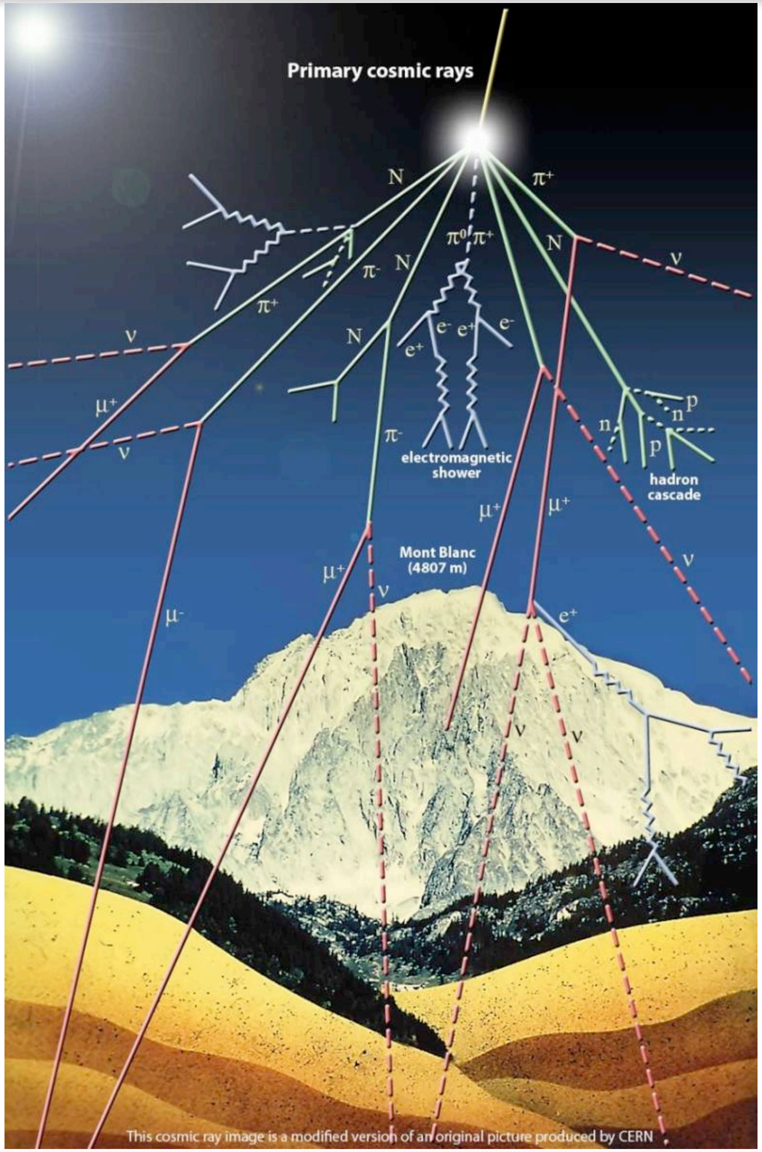
2. Provide fully independent measurements of fissile content, through the use of spectral information. This will allow the IAEA to fully confirm declarations with little or no input from reactor operators, purely by analysis of the antineutrino signal;

3. Develop improved shielding and reduced detector footprint designs, to allow for more convenient deployment. Current footprints are of order 2-3 meters on each side; modest reductions in footprint would expand the general utility of antineutrino detectors. .In this regard, a possible deployment scenario is envisaged where the component parts of the detector, shielding and all associated electronics are contained within a standard 12 metre ISO container, facilitating ease of movement and providing physical protection to the instrument. It should be noted that due to size and weight restrictions of ISO containers (approximately 25,000 kg net load) the



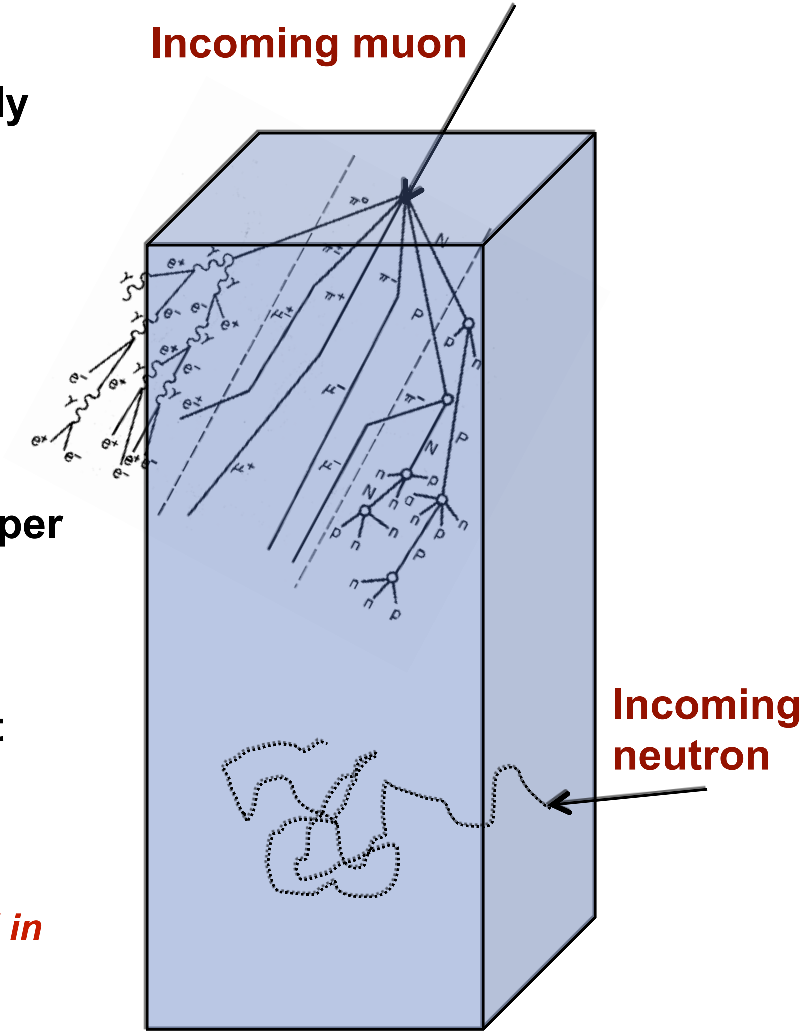
Aboveground Challenge: Increased backgrounds

- Without overburden, an aboveground detector is exposed to:
  - An increased muon rate
  - Hadronic showers
  - Electromagnetic showers
  - Secondary particles produced by all of the above in the detector and its surroundings
- Belowground (only a few meters) many of these cosmic backgrounds are significantly reduced
- We have deployed a suite of background detectors at various locations (above and below ground) to better assess the expected increase



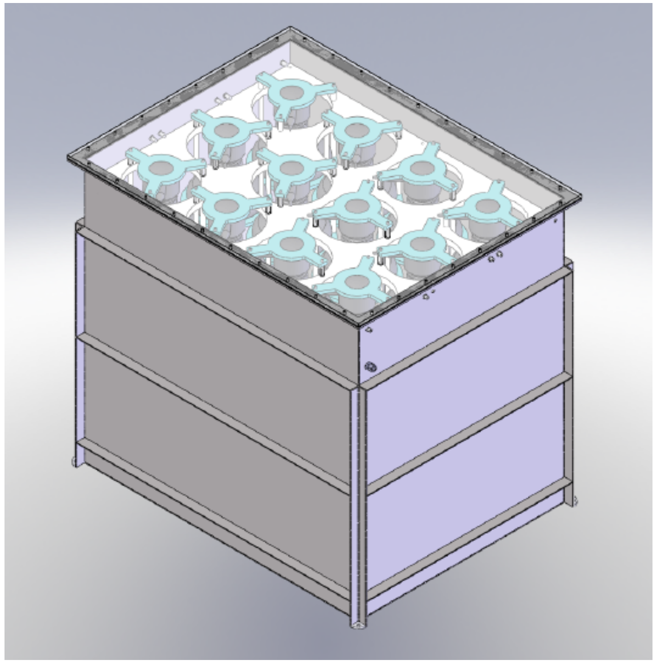
Need for Shielding and Muon Veto

- A shield can control backgrounds more simply than detector design
  - Need to reduce neutron impact is severe
- Fast neutron calculation is sobering
  - Proton recoils of >10 MeV will look like positron signal
  - Calculation based on Hess Spectrum and differential n-p cross-section
    - Expect 5×10^5 events per day (~6Hz) per ton of LS (unshielded)
- Neutron shielding and muon vetos can be improved from SONGS1
  - Improved material choice can improve fast -neutron moderation by ~25% and reduce thermal neutron flux
  - Previous veto was only ~95% efficient
    - allowed cosmogenic neutrons (***produced in the shield***) to contaminate the detector



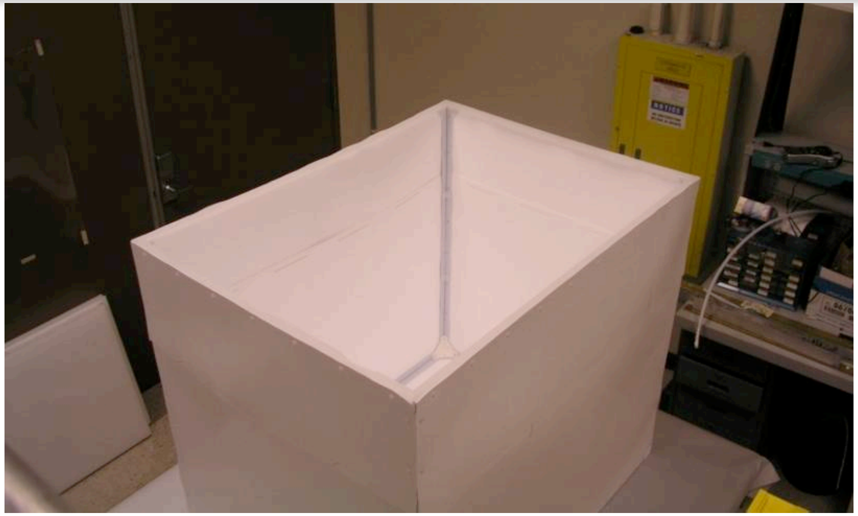
A Water based *Antineutrino* Detector

- Water Cerenkov commonly used for *neutrino* detection
  - deployability – fire safe and environmentally safe
  - Reduced sensitivity to fast neutron backgrounds
    - (Cerenkov threshold ~ 500 MeV)
  - Poor energy resolution, due to:
    - Directionality of photons
    - Low number of photons
    - Minimum electron/positron energy required to produce any photons
      - 0.25 MeV kinetic energy
- Addition of a neutron capture agent (~0.2% $GdCl_3$) allows for antineutrino detection via inverse beta decay
  - known to be stable in water
  - Does not affect light attenuation in small detectors



Water Detector Construction

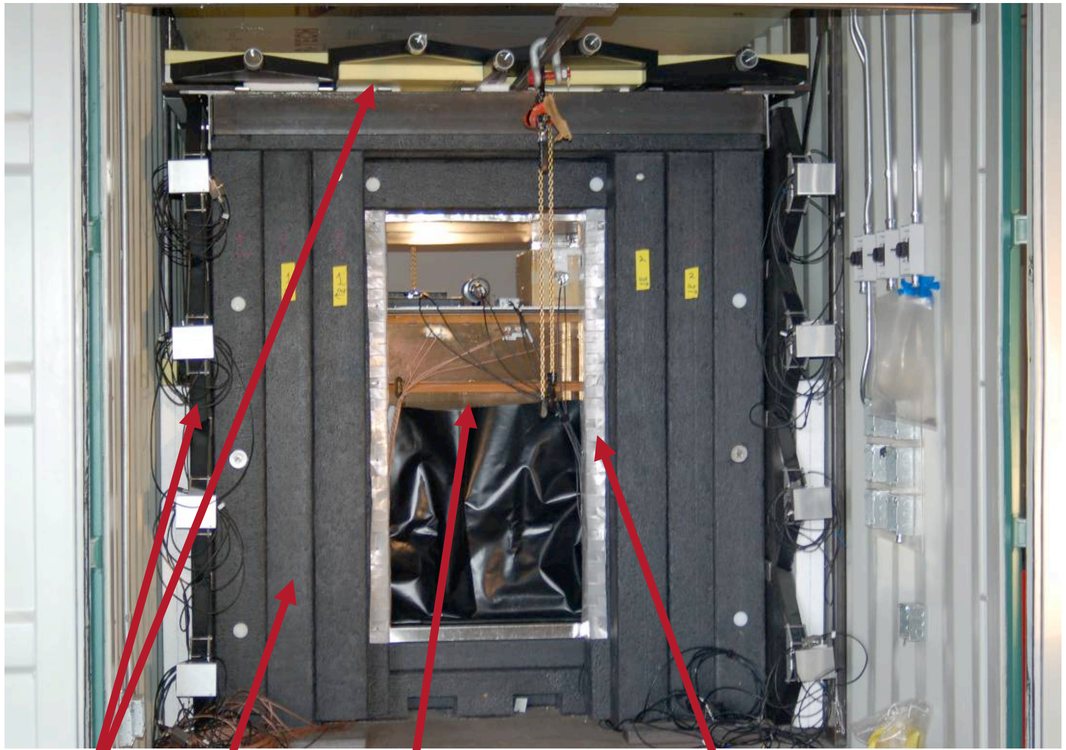
- Previous small-scale test showed promise so we have improved it
  - 4 x larger volume
  - Better light collection efficiency
    - Use diffuse reflective walls (>98% reflectivity)
    - Increased PMT coverage
  - Using 12 Hamamatsu 10” PMTs
- Detector Details:
  - Total Mass ~ 1 ton
  - Total PMT Coverage 12%
  - ~0.2% $GdCl_3$



Containerized Shield

December 2009

February 2010



2" Plastic Scintillator Muon Veto

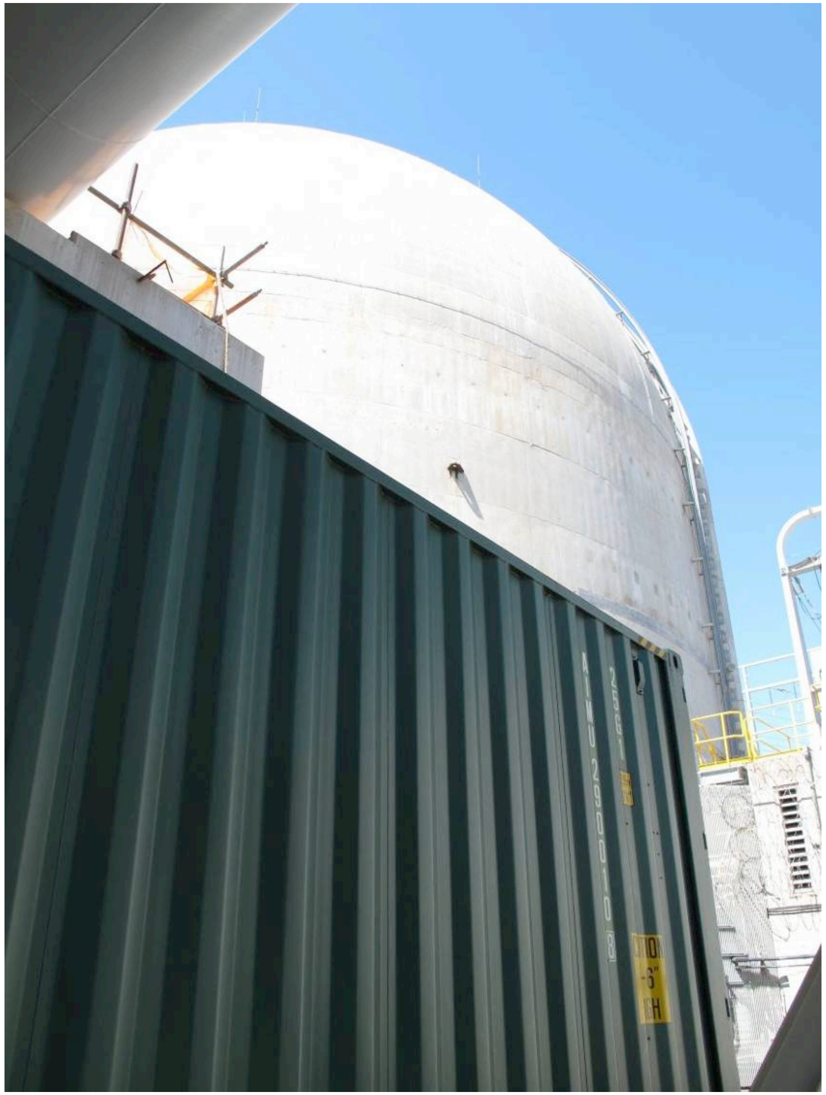
1" Borated Poly with Mu-metal Liner

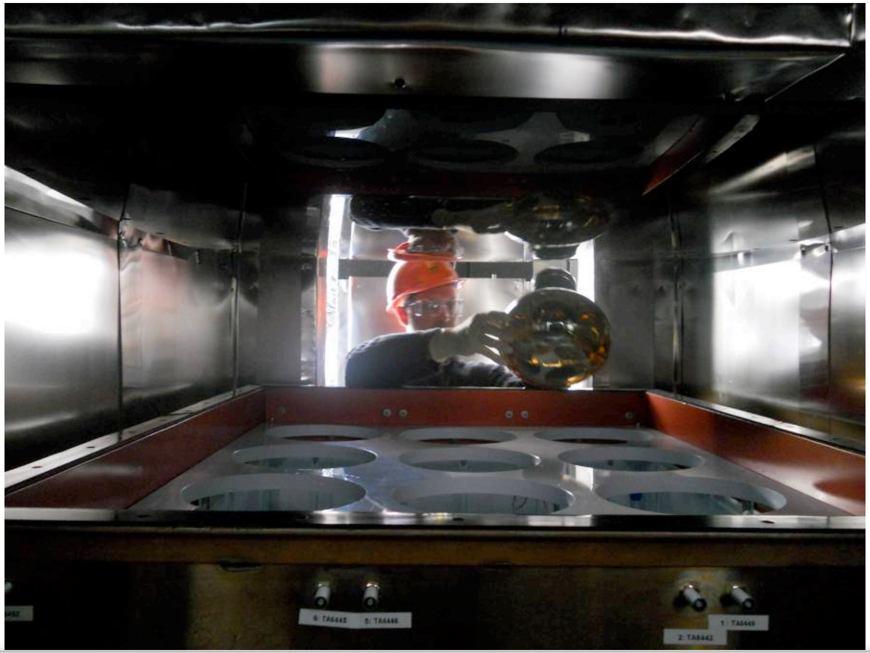
45 cm HDPE Neutron Shield

Central Water Detector
+ secondary containment

Next Stop….San Onofre

Final Deployment at SONGS



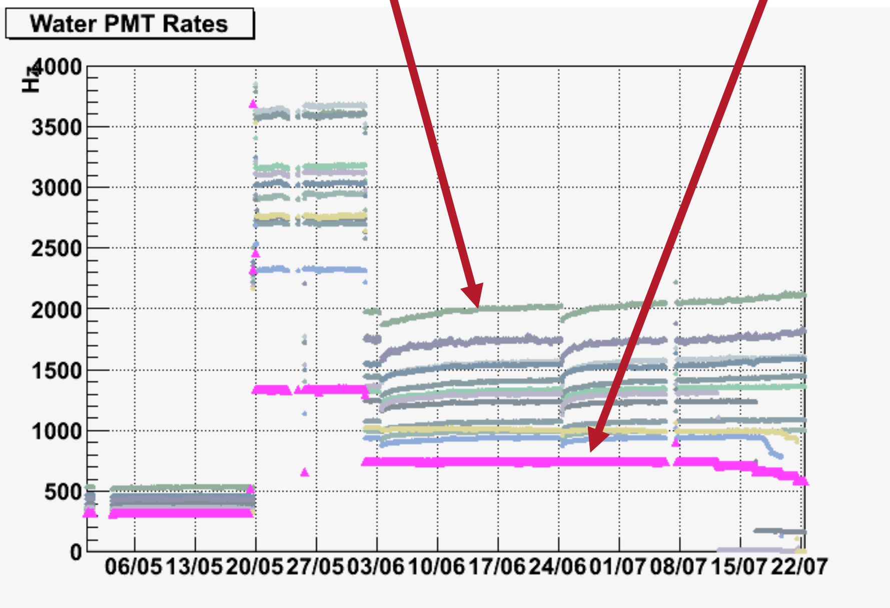


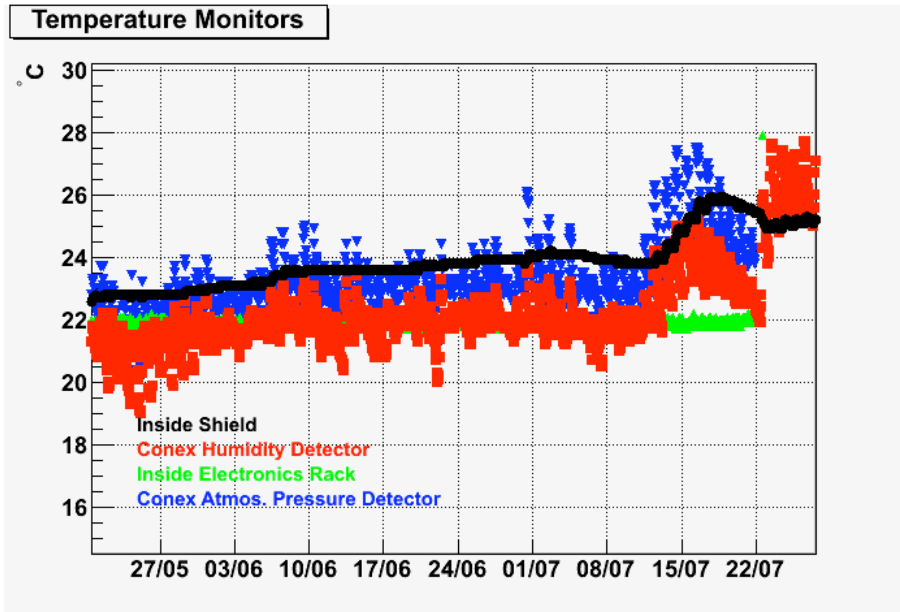
Operating Since End of May

- Continuous Monitoring of Environment (temperature and humidity)
- Continuous Monitoring of PMT triggers and High-Voltage
  - Changes in PMT rates due to alterations in trigger threshold
- Preliminary Analysis based on data from July 1-5

Individual PMT Rates

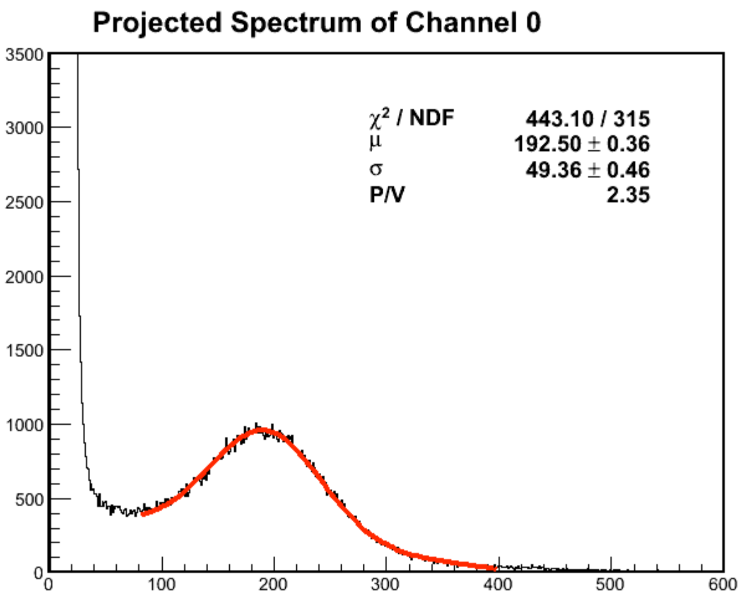
PMT Multiplicity Trigger Rate

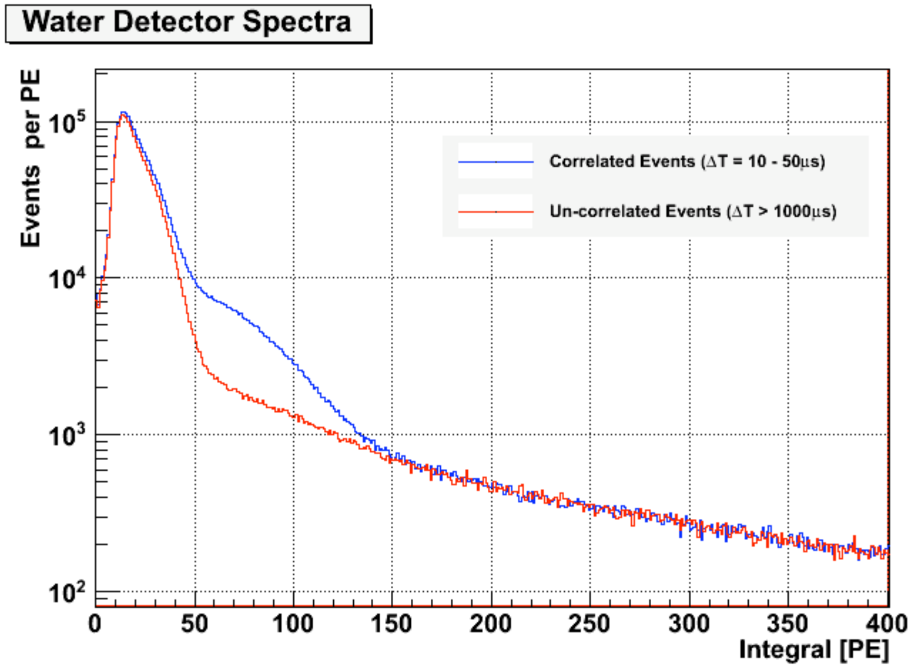




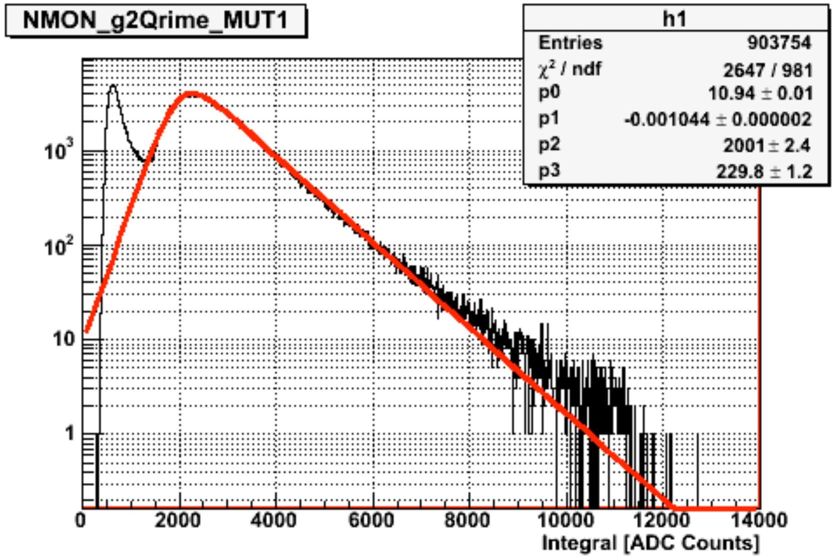
Water Detector Performance

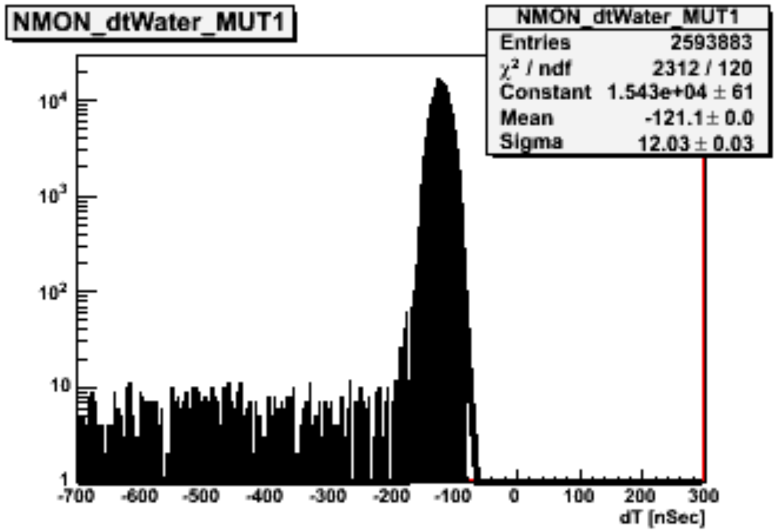
- Good Single PE resolution from 10" PMTs
- Added coverage makes separation of neutron capture on Gd
  - Initial Candidate Selection [30 – 200 PE]
- Careful Calibrations have not yet been performed
  - Data taking includes periodic LED runs and source calibrations



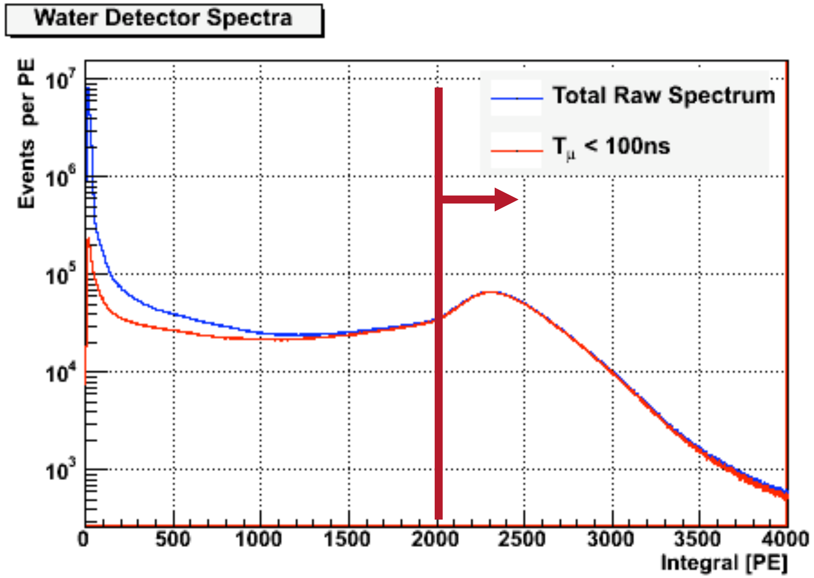


Muon Veto Performance

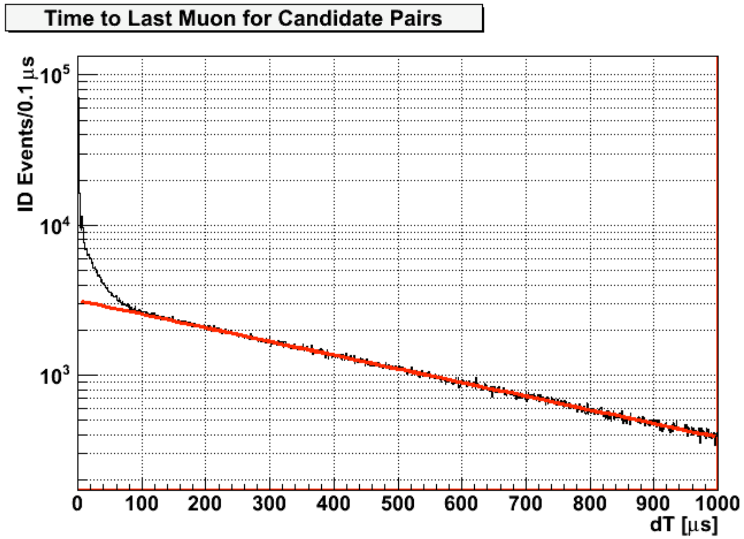


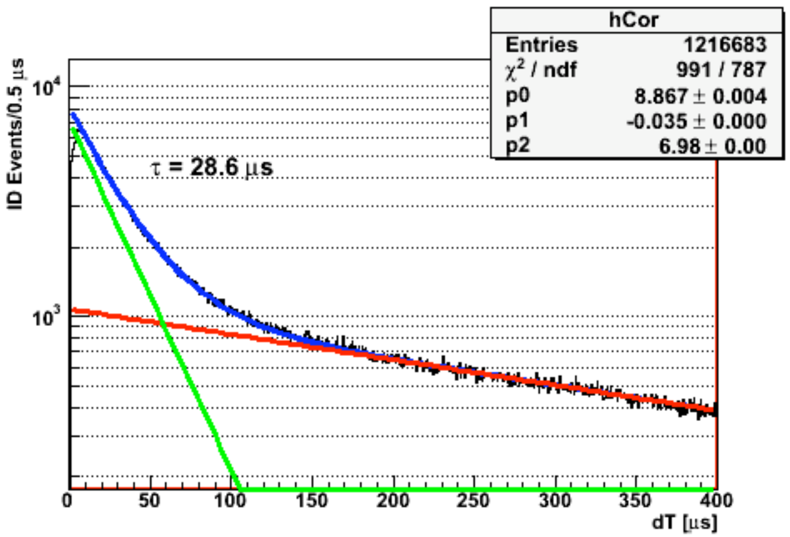


- Clean muon/gamma separation
- Very good timing correlation between Veto and Water Detector
- Estimate Veto efficiency at 98.3% by using high-energy depositions in the water as a definition of muons



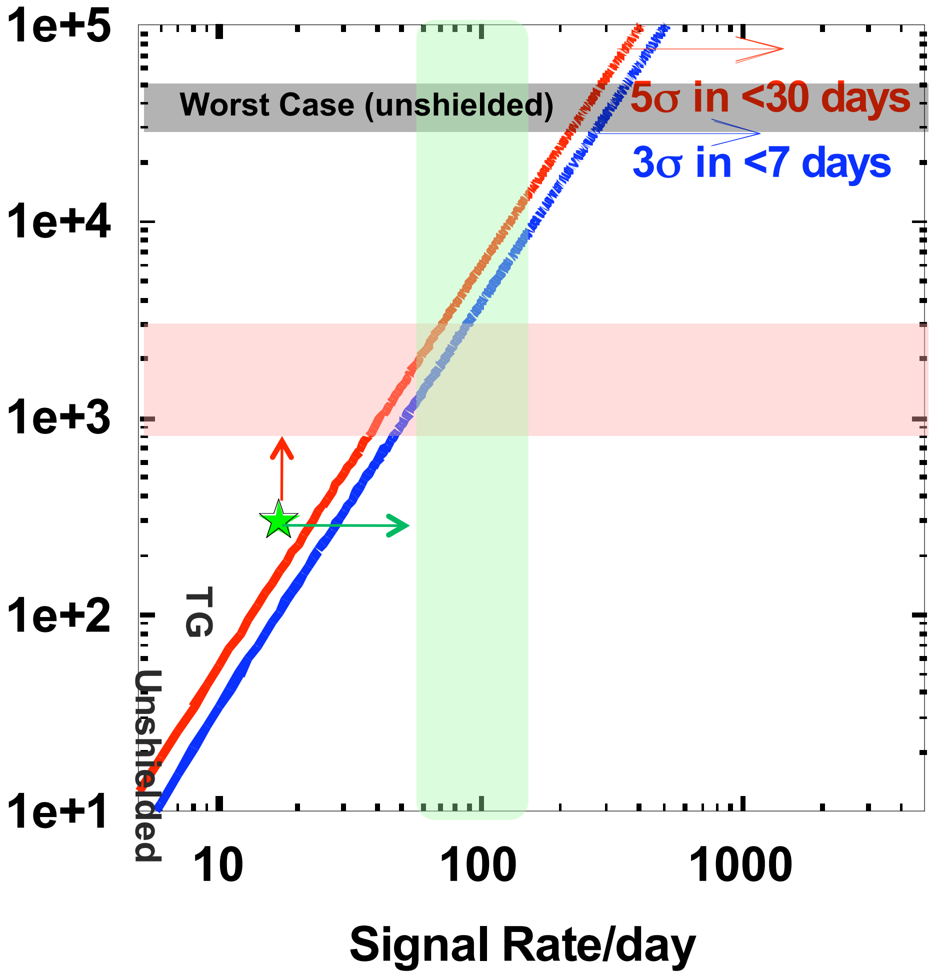
Preliminary Analysis is Underway





- 100 µs veto around muon detection eliminates most cosmic induced showers
  - Gives 21% deadtime
- Clean separation of correlated events from uncorrelated backgrounds
  - Time constant of ~28 µs for neutron capture on Gd
- Still working to finalize extraction of correlated event sample
  - Without muon veto we see ~70,000 - 100,000 events/day

Expectation of Signal/Background for Water Detector



Current Preliminary Analysis is ongoing…

(we expect improvements as we refine our analysis)

Soon to Come…

- Initial estimates of correlated event sample need improvements in data analyis
  - Better muon veto handling
  - Better calibrations of water detector
  - More complete optimizations of cuts
- Longer running
- Reactor Transition
  - SONGS Unit-3 will begin a 3-month shutdown on October 10, 2010
- Our goals are difficult, but not impossible
  - Detection of a reactor transition (on/off) with 3σ precision in less than 7 days or 5σ precision in less than 30 days
  - We are not there yet, but look forward to the challenge