The Deployment of Three Prototype Detectors for Reactor Monitoring and Safeguards

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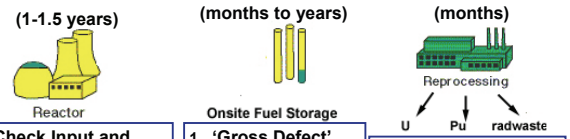
Current Reactor Safeguards

IAEA and Other Safeguards are Designed to Detect Diversion of Fissile Material (Plutonium, HEU) from Civil Fuel Cycles



Reactor	Onsite Fuel Storage	Reprocessing
1. Check Input and Output Declarations	1. 'Gross Defect' Detection	1. Check Declarations
2. Verify with Item Accountancy	2. Continue Item Accountancy	2. Verify with Bulk Accountancy
3. Containment and Surveillance	3. Containment and Surveillance	

Operators *Report* Fuel Burnup and Power History

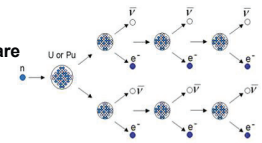
No Direct *Power History Measurement* is Made

No Direct *Plutonium Inventory Measurement* Until Reprocessing

Compact antineutrino detectors could provide continuous, non-intrusive, unattended measurements for safeguards regimes

Reactors and Antineutrinos

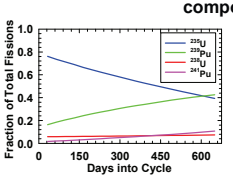
About 6 antineutrinos are emitted after each fission



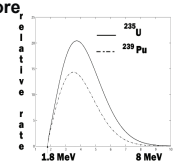
Detection rates near reactors are high:

- e.g. 0.64 ton detector 25 m from 3.5 GWth core
- 3800 events/day for a 100% efficient detector

Antineutrino rate and energy spectrum are sensitive to the isotopic composition of the reactor core



- antineutrino rate changes by ~5-10% through a 500 day PWR fuel cycle, caused by ~ 250 kg Pu ingrowth



- Short term monitoring can measure reactor power
- Long term monitoring may be able to provide direct measurements of fissile inventory

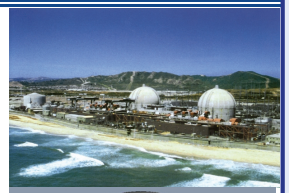
Prototype Deployments

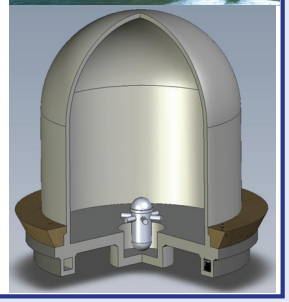
To demonstrate the feasibility of this technique we have deployed several detectors at SONGS

(San Onofre Nuclear Generating Station)

The detectors is located in the "tendon gallery" of SONGS Unit 2, an ideal location

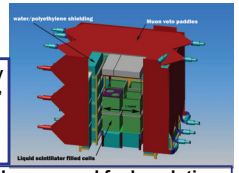
- outside containment
- Rarely accessed for plant operation
- only 25m from the reactor core
- provides 20 mwe overburden





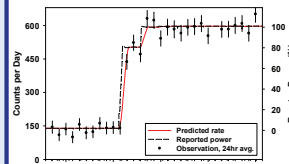
Liquid Scintillator

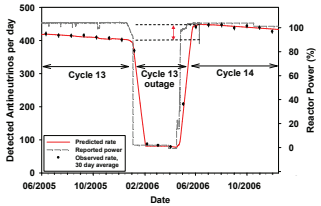
Our first deployment used 0.6 tons of Gd doped liquid scintillator – a proven reactor antineutrino detection technology. This device was very successful, but deployment of the slightly flammable scintillator placed some burden on the reactor operator



- ✓ Simple, homogeneous design
- ✓ Relatively good energy resolution
- ✓ High neutron capture fraction on Gd
- X Scintillator is slightly flammable and toxic, rather combustible
- X Possibility of liquid leakage or spill

This device clearly observes reactor power changes and fuel evolution

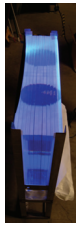




See Nucl. Instr. Meth. A 572 (2007) 985, J. Appl. Phys. 103, 074905 (2008)

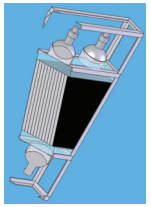
Plastic Scintillator

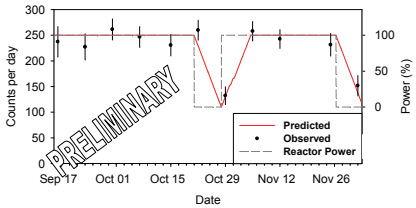
The liquid scintillator detector was very successful, but the detection medium was less than ideal from the point of view of the reactor operator and the safeguards community. Therefore, we investigated a solid state alternative based upon plastic scintillator slabs interleaved with a Gd coated sheets



- ✓ 40% Reduction in combustible inventory
- ✓ No leakage or flammable vapour concerns
- ✓ No transportation of hazardous material required
- ✓ Preassembled
- X Lower neutron capture efficiency on Gd (LS: 80% / 20% Gd/H PS: 60% / 40% Gd/H)
- X ~ 10% fewer protons/cc
- X Dead material in main volume

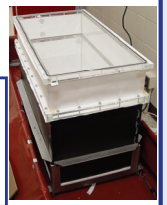
This device clearly observes reactor outages





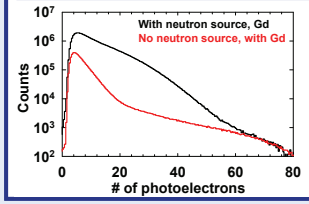
Water Cherenkov

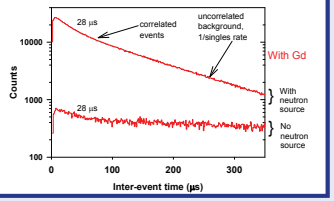
Another path towards deployable devices that we are following is the use of a Gd-doped water Cherenkov detector. A 0.25 ton (unshielded) prototype has been deployed at SONGS.



- ✓ Non-flammable, non-combustible
- ✓ Less expensive material and ES&H overhead
- ✓ No transportation of hazardous material required
- ✓ Largely insensitive to proton recoils (major correlated background)
- X Very low light yield, poor energy resolution, forces high e+ threshold

This device is clearly sensitive to neutrons and correlations, but we are yet to observe reactor antineutrinos





Conclusions

1. Antineutrino detectors can be used to monitor nuclear reactors remotely and non-invasively – this has been established by prior physics experiments and is being confirmed by us with several practical devices.
2. The technology may fill an important safeguards niche, IAEA has expressed strong interest
3. Ongoing Effort :
   - Improve deployability through materials choices
   - Increase range of possible deployment locations by developing devices that can work closer to the surface

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Sandia National Laboratories

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