Gd-H20 Detectors from San Onofre to Deadwood

Daadalus Workshop Feb 3-4 2010 M.I.T.
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Outline/Summary– LLNL Gd-water Cerenkov Detector R&D

Motivation

Proof of Concept Studies
• Neutron detection at LLNL and at Super-K
• LLNL antineutrino detection effort at San Onofre Nuclear Generation Station

Scaling studies
• Attenuation effects in GdXXX-doped water + various materials
• Effects of wavelength shifters
• Project plan and CD-0 design for LBNE water systems (baseline and Gd) - WBS Level III LBNE water systems project manager - R. Bionta @ LLNL
Why is LLNL interested in Gd doped water detectors?

**Nonproliferation motivations:**

1. **Few ton neutron and antineutrino detectors**
   - SNM detection via multiple neutrons
   - Cooperative reactor monitoring
   - We have built 3 of these
2. **0.1-1 megaton antineutrino detectors**
   - We want to build 1 of these

**Science motivations:**

1. **0.1-1 megaton antineutrino detectors**, for: CP violation ($\delta$), oscillations, supernovae, geoantineutrinos, proton decay
2. **Low cost large active shields** for DM/DBD experiments
Reminder of the interaction of interest, the problem and the proposed solution

- Very large H₂O Cerenkov detectors exist – SuperK IMB,.. and are highly successful neutrino detectors
- H₂O detectors can detect >~ 2 MeV e⁺ or e⁻, but aren’t sensitive to thermal neutrons, since H capture generates little or no Cerenkov light

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

The problem for Daedalus and others - sensitivity to thermal neutrons is needed to identify this antineutrino interaction

Proposed solution – use the old trick in liquid scintillator – add Gd to H₂O generate a high energy cascade of gammas

New piece: collect Cerenkov light from Compton electrons arising from this gamma cascade
Some questions of interest for Daedalus and others

Can neutrons be detected in Gd-H20 water detectors?
- Yes LLNL and Super K results published

Can 2-10 MeV antineutrinos be detected in Gd-H20 water detectors
- Probably, LLNL/SNL is close to doing this
- Even harder than the Daedalus problem (20 MeV IBD e+ threshold)

Can the detectors be scaled to 0.1 to 1 MT and work for long periods of time?
- Study attenuation effects and stability of response from materials and compounds
- LLNL CD-0 input and planning for LBNE project
- Purification in the presence of a dopant
LLNL 250 Liter Detector Prototype Neutron Detector

~10% PMT coverage combined with 50% reflectivity

Used for:
- Neutron detection
- Antineutrino detection
- Wavelength shifting studies

8 eight inch PMTs

Pure water

250 liter pure water +0.2% GdCl₃

0.2% wt. GdCl₃

Reflective Tyvek + acrylic walls
Construction
Prototype 250 Liter Detector Energy spectrum

Gamma-shielded Cf source

With neutron source, Gd
No neutron source, with Gd

Approx. # of photoelectrons
Inter-event times (with and without a neutron source)

Correlated events
28 us lifetime

Inter-event time
\(^{252}\text{Cf source}\)

Inter-event time
(no \(^{252}\text{Cf source}\))

Same detector looked for antineutrinos at the San Onofre reactor in a shield-free configuration - 2.7 sigma on versus off effect – weak and preliminary

- 1 ton well shielded detector will be deployed
  In March 2010

Adam Bernstein
A four ton neutron detector for detection multiple neutrons emitted by ‘Special’ Nuclear Material (SNM)

- PMTs top and bottom + higher photocathode coverage
- Potted PMTs in water

Basic motivation for the detector:
- development of very large “car wash” style neutron detectors for cargo or vehicle screening

This project’s goals:
- Test background suppression and neutron detection at large scales (4 ton)
- DUSEL R&D studies of wavelength shifting (water soluble) chemicals and plastics
4 Ton Assembly Pictures
First light from 4T Gd-H2O det– (muons only ~ 200 MeV signal)
The Super-K Gd-doping test

Step 1: Tagged AmBe neutron source is inserted into Super-K
Step 2: Super-K PMTs detect Cerenkov light from Gd-cascade gamma-rays

Estimated 66% neutron tag efficiency with a 3 MeV threshold in SuperK

SuperK dopant of choice for now is Gd2(SO4)3. UV transparent and stable

n.b. only 4.5 MeV of visible energy – not ~8 MeV

Not all gammas in cascade are above the Cerenkov threshold

Attenuation Arm studies
(Serge Ouedraogo and Steve Dazeley)

Inside the Light-Tight Box:
- 337 nm laser system
- integrating spheres
- light Guides
- CCD Camera
- Optics
- PMT

far end motorized mirror

Light transmission Arm (LTA)

8 meters

Acrylic window

PMT light integrator

beam splitter

reflected beam integrator

primary beam integrator
Relative attenuation length measurement

Method:

Laser beam pulse intensity is measured before and after transmission through attenuation arm filled with water sample.

Both primary (P) and Reflected (R) beam intensities are measured with same PMT.

Measure changes in ratio $\rho = R/P$

Adam Bernstein
Our 2x8 m photometer needs 2% or better systematic stability to be useful for large detector studies

- Super-K achieves - and LBNE/Daedalus need - water attenuation lengths in the near UV of ~100 meters (attenuation coeff ~0.01 m\(^{-1}\))

- Our goal - measure ~10% relative changes in ~100 meter attenuation length

- What does this imply for our measurement systematics?
  
  - We measure changes \( \rho = \frac{R}{P} \) (reflected/primary PMT pulses)
  
  - Between two measurements of \( \rho \), the relative change in attenuation coeff. is \( \Delta \alpha = \frac{1}{L} \ln \left( \frac{\rho_1}{\rho_2} \right) \)
  
  - So if we have a 16 meter long arm + 2% sensitivity to changes in \( \rho \), then the estimated change in \( \Delta \alpha \) is .0012 m\(^{-1}\)
    \( \Rightarrow \) ~10% atten coefficient uncertainty for 2% uncertainty in \( \rho \)
  
  - 2 m column would require a systematic uncertainty of .2% to get the same result
Early Measurement - water quality test of 0.2% GdCl$_3$ in water + Stainless Steel vessel

Conclusion: GdCl3 instantly attacks stainless steel and decreases light transmission

1) 0.2% GdCl$_3$ has no immediate effect on water quality

2) Subsequent deterioration is constant in time – suggesting exposure of GdCl$_3$ to surface of stainless pipe is the problem
   - Note: leaching of iron from stainless steel was suspected (Fe is a strong UV and blue absorber)

3) Later additions to pipe from GdCl$_3$ water stored in polypro tank showed no sign of deterioration

4) Tests with FeCl$_3$ suggest that 14ppb iron is enough to destroy water quality instantly
   - Again suggests iron leaching from stainless steel

This system measurement stability was about 3% - manual beam alignment, etc..


Test of GdCl3 Addition at 337 nm
Stability of our recently upgraded system (test in air):

Stability of the system is 1.4% - target was ~2%
Measurement in pure water with ABS, a common industrial plastic (no Gd)

Degradation rate of ~ 50% per day

ABS happens not to be stable even in pure water
Measurement in pure water with polypropylene

Preliminary result: water quality decreased by ~ 2% in ~ 1 day with this PPO sample
Wavelength shifting studies in 0.1 L and 250 K cells - UCD/LLNL

John Felde ¹
Bob Svoboda ¹,²
Adam Bernstein ²
Steven Dazeley ²
Jessica Dunmore ³
Melinda Sweeney ¹,²

Tap Water
1ppm 4-MU

Tap Water
1ppm 4-MU after ~5min in DI system

No wavelength shifter

1ppm 4-Methyl-umbeliferone
Conclusion

Conceptual and Applied studies

• Neutron detection in Gd-H20 water is clearly demonstrated by LLNL and SuperK
  • SuperK – Gd sample in a large pure water Cerenkov detector
  • LLNL – Gd mixed directly into the Cerenkov detector
• ~ 4 MeV antineutrino detection in small detectors is likely to be demonstrated soon (2010)
• Detectors have operated stably at few percent level for ~ 6 months at a time – longer tests in progress for neutron and antineutrino detection

Scaling to large masses

• Long photometer at LLNL can see <2% changes in attenuation length caused by Gd compounds, Wavelength Shifters, and materials interactions
• Further material testing and analysis will continue in FY10-11 at LLNL/BNL
• WLS and reflectivity studies may help boost light at cost of directionality
• Initial design and cost estimates are available for LBNE large scale water purification system – Gd-doping a secondary option
4 ton detector wall reflectivity MC study (Melinda Sweany UCD)