Gadolinium study for a water Cherenkov detector

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for Super-Kamiokande Collaboration

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Introduction

- Supernovae emit huge numbers of neutrinos.

- In the Universe, there exist diffuse neutrino background emitted from the past supernovae.
  - Supernova Relic Neutrino (SRN)

- Detection of SRN can give us knowledge of
  - Galaxy evolution
  - History of star formation
  - Neutrino properties
  - ...

Predicted SRN flux

- Constant SN rate (Totani et al., 1997)
- F.S. Mollner, 1997
- Hartmann, Woodley, 1997
- Kaplan (2000)
- Fukuda, Kawasaki, 2003 (dashed line)
- Ando, et al., 2005
- C. Lunardini, 2006

0.8~5.0 evt./SK/year
• SK is the best SRN detector so far
  – Latest limit 1.08/cm²/s @90%C.L. (T.Iida, TAUP09)
  – M. Malek et al., PRL 90, 061101 (2003)

• Main backgrounds
  – atmospheric nu
  – invisible muons.

• Current limit is 3 times larger than predictions

• Need 3 times sensitivity
GADZOOKS!
Gadolinium in SK


- Large cross section of Gd for neutron capture
  - ~49,000 barns (0.3 barns on free proton)

- Coincident signal detection to suppress background

- Tagging neutron with Gd will lower threshold!
  - Down to 10 MeV
    - Spallation event suppression
  - Invisible muon reduced by a factor of 5
Prototype Detector before introducing Gd into SK

- Effect on SK material?
- Water transparency?
- How to purify Gd water?
- How to introduce/remove Gd?
- Effect on solar neutrino trigger rate?

EGADS - Evaluating Gadolinium’s Action on Detector Systems

- A test facility consisting of
  - 200-ton water detector,
  - water purification system,
  - attenuation length measurement system

- Full budget for EGADS has been approved!
Gd Candidates

search for the best compound

<table>
<thead>
<tr>
<th>Gd compound</th>
<th>corrosion</th>
<th>light attenuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>GdCl$_3$</td>
<td>X*</td>
<td>O</td>
</tr>
<tr>
<td>Gd(NO$_3$)$_3$</td>
<td>O</td>
<td>X**</td>
</tr>
<tr>
<td>Gd$_2$(SO$_4$)$_3$</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

- Corrosion tests mainly on stainless steel
- Gd sulfate is the best candidate found so far
- Material soak test is being carried out
  - All samples from SK components: rubber, plastic, acryl, FRP, tyvek, cable tie, cables...

(*) for example, arXiv:0805.1499v2 [physics.ins-det]
(**) strong absorption by Nitrate below 350nm, study done at UCI with UV/VIS spectrometer
Transparency Measurement at UCI

IDEAL
Irvine Device Evaluating Attenuation Length

- Measure attenuation length for several wavelengths
  - $\lambda$: 337~650nm

- Light attenuation measured by varying the height of water.
Selective Filtration at UCI

A prototype system is being constructed at UCI.

Demonstrates Gd sulfate is removed with 99.99% efficiency, and <0.05 ppm for RO output.
**Neutron Tagging Eff. Measurement at SK**

- Am/Be source emits 4.43MeV gamma and neutron simultaneously
  - the prompt gamma detected by BGO simulates the positron from inverse beta reaction.
- The vessel is deployed in SK.

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**GdCl₃ test vessel**

- 0.2% GdCl₃ solution
- 5 cm
- 13 cm
- 18 cm
- BGO

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• The energy and time distributions are within expectations.
• The tagging efficiency is measured to be 66.7%.
  • accidental BG is $< 2 \times 10^{-4}$ with $E>10\text{MeV}$
Summary

• A large Gadolinium dissolved water Cherenkov detector is considered for SRN detection.
  • GADZOOKS! at Super-Kamiokande

• A small scale prototype detector (EGADS) will be built, as R&D for GADZOOKS!

• EGADS construction in the Kamioka mine will start at the end of this year.

• Ongoing tests
  – Filtration and transparency systems
  – Material corrosion tests

• Results from EGADS in 2011!
<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cavity excavation</td>
<td>EGADS Water System Construction @ Kamioka</td>
<td>Gd Removal Trials &amp; Draining of EGADS Tank</td>
<td>Add Gadolinium</td>
</tr>
<tr>
<td></td>
<td>IDEAL Construction @ Kamioka</td>
<td>Selective Filtration Tests w/o PMT’s/PMT prep</td>
<td>PMT Mounting in EGADS Tank/DAQ Assembly</td>
<td>Add Gadolinium</td>
</tr>
<tr>
<td></td>
<td>EGADS Test Tank Construction @ Kamioka</td>
<td>Corrosion Tests</td>
<td>Data Taking and Selective Filtration Tests with PMT’s</td>
<td></td>
</tr>
</tbody>
</table>
Possibility of SRN detection


If invisible muon background can be reduced by neutron tagging

Assuming 67% detection efficiency.

With 10 yrs SK data, Signal: 33, B.G. 27
($E_{\text{vis}} = 10-30$ MeV)

Assuming invisible muon B.G. can be reduced by a factor of 5 by neutron tagging.
Vertex resolution
120~200 cm depending on cut

Vertex resolution
120~160 cm depending on cut
Super Kamiokande (SK) 
a water cerenkov detector

Inner Detector (ID)
~11,000 20 inch-PMTs
40% photo coverage

39.3m

41.4m

1km (2700mwe)

2km

3km

SK
Possible location of the New Cavity

- Super-Kamiokande
- SK water purification system
- To Atotsu entrance
- Parking place
- EGADS place

神岡地下坑道図

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<table>
<thead>
<tr>
<th>Membrane Type</th>
<th>Gd Remaining in Product Stream vs. Original Tank Concentration</th>
<th>SO$_4$ Remaining in Product Stream vs. Original Tank Concentration</th>
<th>Gd in Reject Streams</th>
<th>SO$_4$ in Reject Streams</th>
</tr>
</thead>
<tbody>
<tr>
<td>NF Stage 1 (Nitto)</td>
<td>0.15%</td>
<td>&lt;0.11%</td>
<td>99.85% (returned to “SK” by NF1)</td>
<td>&gt;99.89% (returned to “SK” by NF1)</td>
</tr>
<tr>
<td>NF Stage 2 (Nitto)</td>
<td>&lt;0.006%</td>
<td>&lt;&lt;0.11%</td>
<td>&gt;99.994% (returned to “SK” by NF1+NF2)</td>
<td>&gt;&gt;99.89% (returned to “SK” by NF1+NF2)</td>
</tr>
<tr>
<td>RO (Koch)</td>
<td>&lt;&lt;0.006%</td>
<td>&lt;&lt;0.11%</td>
<td>&lt;&lt;0.006%</td>
<td>&lt;&lt;0.11%</td>
</tr>
</tbody>
</table>

Ran continuously for six weeks – no filter or membrane clogging

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• Expected rates at SK (Beacom & Vagins, 2004)
  – /22.5 kton
  – SRN neutrino 5 /year
  – Reactor neutrino 5000 /year

• Reactor neutrino at EGADS
  – Photosensitive Vol. ~114 ton: 25 /year
  – 2m from wall fiducial vol. ~1.5 ton: 1 /3 years