The road to SuperK-Gd

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Super-Kamiokande Detector in big numbers

Large variety of studies are conducted at SuperK:
- Solar neutrinos
- Atmospheric neutrinos
- Proton decay
- Supernovae
- Supernova Relic Neutrinos
- Indirect search for DM
- and more

~165 collaborators
10 countries

Super-Kamiokande looks into the future:
SuperK-Gd
Super-Kamiokande Detector

- **50 kton water**
- **~2 m OD viewed by 8-inch PMTs**
- **32 kt ID viewed by 20-inch PMTs**
- **22.5 kt fid. vol.** (2m from wall)
- **Trigger efficiency:** >99% @ 3.5 MeV $E_{\text{kin}}$

<table>
<thead>
<tr>
<th>Phase</th>
<th>SK-I</th>
<th>SK-II</th>
<th>SK-III</th>
<th>SK-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of PMTs</td>
<td>ID (coverage)</td>
<td>11146 (40 %)</td>
<td>5182 (19 %)</td>
<td>11129 (40 %)</td>
</tr>
<tr>
<td>OD</td>
<td>1885</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The road to SuperK-Gd: how it started

Once upon a time...

It was proposed to add gadolinium to the ultra-pure water of SuperK. Adding Gd would make neutrons visible, which would allow the detection of neutrons with high efficiency.

Many advantages. I hope you saw previous talk by Charles Simpson!
Because of all the exciting possibilities, in June 2009 the SuperK collaboration launched the EGADS project.

**Evaluating Gadolinium's Action on Detector Systems**

**Our Goals:**
- Water purification system
- Monitor the water transparency
- Effects on detector components
- Adding/removing Gd
- Neutron background
The road to SuperK-Gd: EGADS

Dissolution and pre-treatment system

200-ton detector with 240 photomultipliers

Water Transparency measurement

Selective band-pass filtration system

The EGADS detector was built using the same materials as in SuperK
0.2 % Gd sulfate is as transparent to Cherenkov light as pure-water. Our water system achieves the above with no Gd losses. Gd concentration is homogeneous in our detector.
On June 27, 2015, the Super-Kamiokande collaboration approved the SuperK-Gd project
## Backgrounds

Relevant radioactive contamination, typical impurities in untreated Gd sulfate and our requirements from our physics goals:

<table>
<thead>
<tr>
<th>Chain</th>
<th>Part of the chain</th>
<th>Typical (mBq/Kg)</th>
<th>SRN (mBq/Kg)</th>
<th>Solar (mBq/Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}\text{U}$</td>
<td>$^{238}\text{U}$, $^{226}\text{Ra}$</td>
<td>50, 5</td>
<td>&lt; 5, -</td>
<td>-</td>
</tr>
<tr>
<td>$^{232}\text{Th}$</td>
<td>$^{232}\text{Th}$, $^{228}\text{Th}$</td>
<td>10, 100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$^{235}\text{U}$</td>
<td>$^{235}\text{U}$, $^{227}\text{Ac}/^{227}\text{Th}$</td>
<td>32, 300</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
We plan to use resins AJ4400 and AJ1020 to further remove U and Ra after dissolving Gd sulfate and our requirements from our physics goals:

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<thead>
<tr>
<th>Chain</th>
<th>Part of the chain</th>
<th>Typical (mBq/Kg)</th>
<th>SRN (mBq/Kg)</th>
<th>Solar (mBq/Kg)</th>
<th>Company A</th>
<th>Company B</th>
<th>Company C</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$U</td>
<td>$^{238}$U $^{226}$Ra</td>
<td>50 &lt; 5</td>
<td>-</td>
<td>-</td>
<td>&lt; 0.04</td>
<td>&lt; 0.4</td>
<td>&lt; 0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 &lt; 5</td>
<td>-</td>
<td>&lt; 0.5</td>
<td>&lt; 0.2</td>
<td>&lt; 0.2</td>
<td>~ 1</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>$^{232}$Th $^{228}$Th</td>
<td>10 &lt; 0.05</td>
<td>&lt; 0.05</td>
<td>0.02</td>
<td>0.06</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100 &lt; 0.05</td>
<td>&lt; 0.05</td>
<td>&lt; 0.3</td>
<td>&lt; 0.26</td>
<td>~ 2</td>
<td>~ 2</td>
</tr>
<tr>
<td>$^{235}$U</td>
<td>$^{235}$U $^{227}$Ac/$^{227}$Th</td>
<td>32 &lt; 3</td>
<td>&lt; 3</td>
<td>&lt; 0.4</td>
<td>&lt; 0.3</td>
<td>&lt; 1.3</td>
<td>&lt; 3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>300 &lt; 3</td>
<td>&lt; 3</td>
<td>&lt; 1.5</td>
<td>&lt; 1.2</td>
<td>&lt; 3.1</td>
<td>~ 3.1</td>
</tr>
</tbody>
</table>

Measurements done at Canfranc, Boulby and Kamioka

Company names hidden
Leak fix

Two types of sealant materials: BIO-SEAL 197 (strong but rigid) and MineGuard-C (flexible)

Seal all submerged welded areas
New Water System for SuperK-Gd

EGADS

Current main water system

New Gd water purification system

Nov 2016

2016 Apr. 8mx7mx50m

Nov 2016
New Water System for SuperK-Gd

Cavern for the new water system has been excavated

Equipment has been already installed (Gd solution, etc)
About 140 ID PMTs are ready to be replaced

Cables and connections of problematic PMTs being checked
OD work

- About 200 OD PMTs are expected to be replaced (about 100 on the top)
- Tyvek replacement: B-W and W-W Tyvek
Adding Gd sulfate at 0.2% in mass adds neutron tagging capabilities to Super-Kamiokande.

EGADS has shown its feasibility: we can remove impurities and maintain high transparency water, with basically no Gd losses, we can remove Gd efficiently when needed, etc.

Faulty OD and ID PMTs are being replaced. Detector structure being refurbished

We are fixing the leak at SuperK using two sealants: BIO-SEAL 197 and MineGuard-C

We are paving the road towards SuperK-Gd. Hard work ahead! **STAY TUNED!**
Soaked Mine-guard-C in Gd loaded water with good results: Cherenkov light loss in 15 m is 77.64 % (well within the typical SK-III SK-IV values)
EGADS detector

Sampling positions at 1660 mm, 3320 mm and 4990 mm from top of the tank (for water transparency, UDEAL, and Gd concentration measurements)

240 PMTs were installed in summer 2013
Atmospheric $\nu$ backgrounds

- **Charge Current:**
  \[
  \bar{\nu}_e \text{ CC}
  \]

- **Neutral Current:**
  \[
  \nu_\mu \text{ CC}
  \]

Invisible $\mu$:
\[
\nu_\mu \rightarrow \mu \rightarrow e + n \quad T < 50 \text{ MeV}
\]

$\mu$ generation:
\[
\nu_\mu \rightarrow \mu \rightarrow e + n
\]

Total Energy [MeV]

Graph showing energy distribution with NC elastic and Total BG.
SRN flux:
Horiuchi, Beacom, Dwek

The detection of SRN depends on the typical SN emission spectrum

\[ T_{\nu} \sim 5 \left( \frac{M_{NS}/1.4M_\odot}{10} \right)^{1/3} \left( \frac{R_{NS}/10\text{km}}{10} \right)^{-3/4} \]

SRN number of expected events after 10 years of observation

<table>
<thead>
<tr>
<th>HBD models</th>
<th>10-16MeV (evts/10yrs)</th>
<th>16-28MeV (evts/10yrs)</th>
<th>Total (10-28MeV)</th>
<th>significance (2 energy bin)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_{\text{eff}} ) 8MeV</td>
<td>11.3</td>
<td>19.9</td>
<td>31.2</td>
<td>5.3 ( \sigma )</td>
</tr>
<tr>
<td>( T_{\text{eff}} ) 6MeV</td>
<td>11.3</td>
<td>13.5</td>
<td>24.8</td>
<td>4.3 ( \sigma )</td>
</tr>
<tr>
<td>( T_{\text{eff}} ) 4MeV</td>
<td>7.7</td>
<td>4.8</td>
<td>12.5</td>
<td>2.5 ( \sigma )</td>
</tr>
<tr>
<td>( T_{\text{eff}} ) SN1987a</td>
<td>5.1</td>
<td>6.8</td>
<td>11.9</td>
<td>2.1 ( \sigma )</td>
</tr>
<tr>
<td>BG</td>
<td>10</td>
<td>24</td>
<td>34</td>
<td>----</td>
</tr>
</tbody>
</table>

With SuperK-Gd the first SRN observation is within our reach!!
Step 1: pure water

- Step 1: Circulation through the 200 ton tank with pure water (first half 2011 pure water circulation)  Done!

EGADS Progress

ICRC'13, Rio de Janeiro
Step 1: Circulation through the 200 ton tank with pure water (first half 2011 pure water circulation) **Done!**

- **Step 2:** Circulation through the 15 ton tank with $\text{Gd}_2(\text{SO}_4)_3$ (from middle 2011 to end 2012) **Done!**
- **Step 1:** Circulation through the 200 ton tank with pure water (first half 2011 pure water circulation)  
  **Done!**

- **Step 2:** Circulation through the 15 ton tank with $\text{Gd}_2(\text{SO}_4)_3$ (from middle 2011 to end 2012)  
  **Done!**

- **Step 3:** Circulation though the 200 ton tank with $\text{Gd}_2(\text{SO}_4)_3$  
  **Done!**
- **Step 1:** Circulation through the 200 ton tank with pure water (first half 2011 pure water circulation)  **Done!**
- **Step 2:** Circulation through the 15 ton tank with Gd$_2$(SO$_4$)$_3$ (from middle 2011 to end 2012)  **Done!**
- **Step 3:** Circulation though the 200 ton tank with Gd$_2$(SO$_4$)$_3$  **Done!**
- **Step 4:** PMT mounting (240 in total).  **Done!**
- **Step 5:** Full realization of the EGADS project  **Done!**