

# R&D project for Gd-doped water Cherenkov detector

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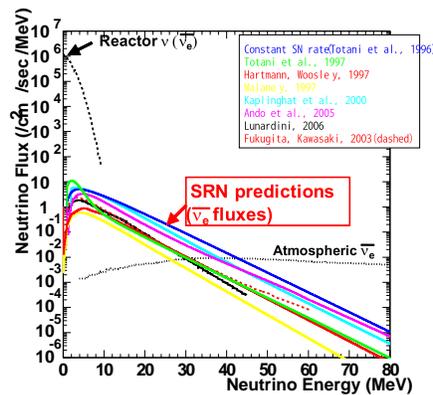
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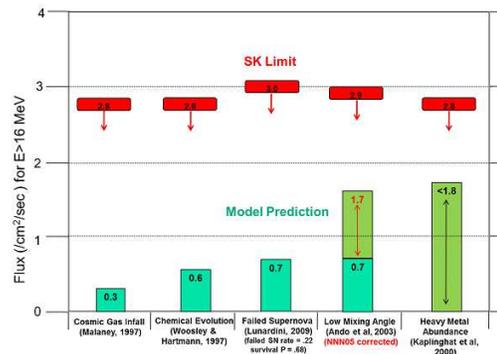
**Abstract.** A dedicated test facility for a proposed Gadolinium doped water Cherenkov detector is being constructed in the Kamioka mine near the Super Kamiokande detector. Anti-electron neutrinos ( $\bar{\nu}_e$ ) from inverse beta decay can be identified with high efficiency by taking advantage of Gd's large cross section on thermal neutron capture and by taking coincidence of a prompt positron and the delayed 8 MeV gamma cascades.

## 1. Introduction

In the universe, there exists supernova relic neutrinos (SRN) from all past supernovae. Super Kamiokande (SK) [1] search for these SRN events via inverse beta decay interaction ( $\bar{\nu}_e + p \rightarrow e^+ + n$ ) having the largest cross section in visible mode for the SRN interactions. The colored lines in Figure 1 show the theoretical neutrino flux for different models. We have a narrow window of 10-30 MeV to search for the electron anti-neutrino SRN due to the reactor and atmospheric neutrino backgrounds. The expected number of SRN signals in SK is 0.8-5 per year in 10-30 MeV region. Figure 2 shows the expected SRN signals at the SK for different models, and their current SK limits. It is still difficult to observe the SRN signals even with a detector as large as SK.



**Figure 1.** Colored lines show predicted SRN spectrum for different models at SK. Black dotted lines are representing background neutrinos.



**Figure 2.** SRN flux limits at the SK with the threshold of 16 MeV.

Thus addition of 0.1% gadolinium (Gd) solution in the SK detector is proposed [3]. The proposed detector is named GADZOOKS! [Gadolinium Antineutrino Detector Zealously Outperforming Old Kamiokande, Super!]. We take advantage of the large cross section of Gd on thermal neutron capture. Neutrons from the inverse beta decays are quickly thermalized in the detector volume and captured by the Gd. Gd subsequently emits about 3-4  $\gamma$  rays having the total energy of about 8 MeV. By taking the coincidence of the prompt positron and the delayed gamma cascade, we can uniquely identify the antineutrino events and lower the energy threshold down to 10 MeV. This will lead us to the first observation of a SRN signal in SK.

### 1.1. Gd compound

Soluble Gd is in powdered forms as chemical compounds, so we determined first which Gd compound to be dissolved in the SK water. The candidates of Gd compounds are  $GdCl_3$ ,  $Gd(NO_3)_3$ ,  $Gd_2(SO_4)_3$ . Corrosion tests show  $GdCl_3$  highly corrodes the stainless steel, while no damages were apparent on the other two. However in  $Gd(NO_3)_3$  solution, strong absorption by nitrate was evident below 350 nm, in the Cherenkov light wavelength region. Although  $Gd_2(SO_4)_3$  is not so easily dissolved into water, we can help dissolving it with the help of  $H_2SO_4$ .  $Gd_2(SO_4)_3$  is found to be the best candidate thus far.

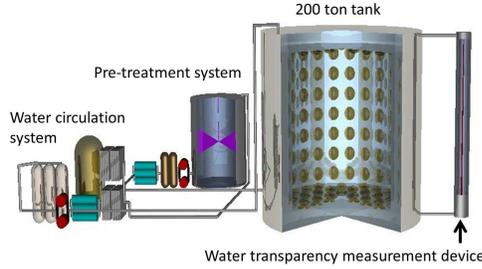
### 1.2. Material soak test

We have performed the material soak test for all components (31 elements) of the SK detector to check any corruptions and deteriorations. We put each piece into a polypropylene bottle filled with 500 ml of 0.1% Gd solution or pure water. Only affected material is the PMT support rubber in the Gd solution. Further studies with this rubber show the effects on the SK detector with much greater volume is expected to be small, if water temperature is kept 15°C. We will further examine the effects of the SK detector materials in the Gd doped water at Gd test facility.

## 2. Test Gd facility

We are building the Gd test facility called EGADS [Evaluation Gadolinium's Action on Detector Systems] in order to demonstrate the principle of GADZOOKS!. EGADS facility is consisted of 200 ton water Cherenkov detector with the same 20 inch the photomultiplier tubes (PMT) used for SK, a Gd mixing pre-treatment device, a main Gd-water circulation system, and a water transparency measurement device. The following items will be tested at this facility:

- (i) Transparency of the Gd doped water. The transparency should be long enough to do as various physics analysis as in SK.
- (ii) Gd-water purification system. Gd doped water should be as pure as that of the SK with only Gd compounds.
- (iii) Effect of Gd on detector materials. Any corruptions and deteriorations of SK materials by Gd should be checked.
- (iv) How to introduce/remove gadolinium. Is the Gd uniformly mixed in the tank? How quickly/economically/completely can Gd be removed?
- (v) Ambient neutron level in the tank. Does it cause significant increase in the trigger rate for solar analysis?
- (vi) Neutron capture efficiency. We can measure the efficiency of neutron capture by inserting a neutron source in the tank.



**Figure 3.** Schematic view of the EGADS system. From left to Right: Gd-water purification system, Gd-water mixing system with 15 ton tank equipped with a sterer, a 200 ton tank with 20 inch PMTs, and a transparency measurement device.

### 2.1. Gd water circulation system

The circulation system consists of two parts:pre-treatment system where we mix the Gd compunds into water and main circulation system.

The  $Gd_2(SO_4)_3$  powder is first mixed into water at the 15 ton pre-treatment tank to make the 0.1% solution. The tank has a built-in stirrer to completely dissolve  $Gd_2(SO_4)_3$ . With a small amount of  $H_2SO_4$ ,  $Gd_2(SO_4)_3$  can be dissolved much quickly. The pre-treatment system is equipped with a UV filter to kill bacteria and Amberjet resin to remove uranium and thorium with more than 99% efficiency, along with mechanical filters.

The water at EGADS must be kept ultra pure without removing  $Gd_2(SO_4)_3$ . We call the system "Selective filtration" [4], since multivalent ions such as  $Gd^{3+}$ , and  $(SO_4)^{2-}$  should be selected out. Schematic view of of this system can be seen in Figure 4. Gd and  $SO_4$  ions are rejected at the nanofilters (NF), because the pore size of the membrane is smaller. Total Oxidizable Carbon (TOC) can be a food source to bacterial. Ultraviolet photons from TOC destruction system can excite the organic molecules and products ionized carbonic acids which in truth can be removed by deionizer (DI) unit. The Gd-rejected water is then sent through the Reverse Osmosis (RO), where only  $H_2O$  molecules can pass through the membrane. The pure water and  $Gd_2(SO_4)_3$  are combined at collection buffer tank and circulated to the 200 ton tank. Details of this water system can be found in [4] [5].

The current Gd removal system installed at the EGADS site consists of ion exchange resin. This system can remove Gd in the efficiency of more than 99%. In the near future, we will install a removal system with a mechanical filter press which is currently in development.

### 2.2. Water transparency measurement device

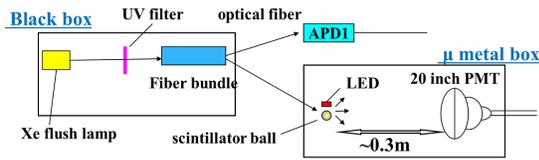
To evaluate the quality of the water in the EGADS system, a water transparency measurement device is installed. Keep long light attenuation length would be key issue in a Gd-doped water Cherenkov detector. This device can measure light intensity continuously as a function of light travel distance and monitor relevant Cherenkov region using multiple leasers with different wavelength. Details of this device can be found in [5].

### 2.3. Quality check of PMTs before the installation

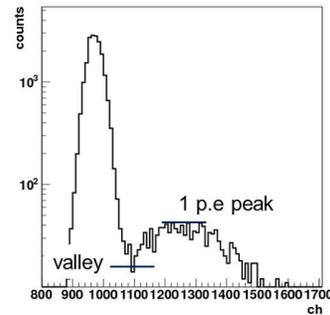
We plan to use 240 20 inch PMTs in EGADS tank. Since available PMTs have been left unused for 7 years, we had to check the quality of all candidate PMTs in terms of dark rate, uniform gain, and peak-to-valley ratio, and select good 240 PMTs to be used for installation. This pre-calibration system is schematically shown in Fig.4. We used two light sources for the precalibration: 1) a xenon flash lamp and a scintillation ball to produce a uniform light intensity, and 2) an LED to measure 1 photo-electron (p.e) peak, thus providing a Gain and a peak-to-valley (P/V) ratio. The output charge of a PMT (Q) illuminated by a scintillation ball is expressed as follows:

$$Q = N_{photon} \times QE \times Gain = N_{photon} \times QE \times (\alpha \times V^\beta) \quad (1)$$

where  $N_{\text{photon}}$  is the number of photons hitting cathode of PMT, QE is quantum efficiency.  $\alpha$  and  $\beta$  is the parameter for each PMTs. We determined an operational HV for a PMT to produce a charge of 30 photo-electrons within 2%, which should be equivalent to a Gain of  $10^7$ . The absolute Gain at the operational HV has been measured as one photo-electron peak generated by LED. This 1 p.e measurement also provided the P/V ratio. Fig.5 shows a 1 p.e. measurement. With thus determined operational HVs, we measure an average Gain of 2.25 pC/1p.e which is similar to 2.23 pC/1p.e, being the Gain of SK PMTs. Thus, we selected good 240 PMTs which all have good properties for noise ratio (<35 kHz), P/V ratio (>1.2), and similar occupancy ( $\sim$ QE). It is important to evaluate the sensitivity of each PMT to 1 p.e since a signal of 1 p.e or a few p.e.s are expected from  $\gamma$  rays by neutron captured on Gd.



**Figure 4.** The schematic view of pre-calibration system. A test PMT was set in a  $\mu$ -metal box to suppress a extra-terrestrial magnetic field down to 40 mG.



**Figure 5.** Measurement of Gain of PMT which will be installed in 200 ton tank by 1 photo electron distribution.

### 3. Current status and future plan

All equipments of EGADS without PMTs are ready in the laboratory in Kamioka mine. We checked water circulation system with pure water for about 6 month. Measurement of water transparency shows EGADS water purification system can keep the pure@water as clean as the SK water. Gd<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> has been dissolved successfully in the pre-treatment system. This year, we focus on the operation of the circulation system with Gd, where selective filtration, pressure sensor, and some membrane will be tested to achieve the best efficiency of Gd recovery and transparency of Gd-doped water. After the stable condition can be obtained, we plan to circulate the Gd-doped water through the 200 ton tank. Installation of PMTs follow then.

In the 2012-2013, we plan a complete proof-of-principle test of Gd-loaded water Cherenkov technology using EGADS. The new neutron tagging technology with Gd will have a large impact on future large neutrino experiments exploiting neutrino oscillation and neutrino astronomy.

### References

- [1] Fukuda Y *et al.* 2003 *Nucl. instrum. Methods Phys. Res. A* **501** 418
- [2] Malek M *et al.* 2003 *Phys. Rev. Lett.* **90** 061101
- [3] Beacom J F and Vagins M R 2004 *Phys. Rev. Lett.* **93** 171101
- [4] Vagins M R 2010 *Detection of Supernova Neutrinos Int. Conf. on Neutrino Physics and Astrophysics*
- [5] Renshaw A 2011 *R&D project for a Gadolinium Doped Water Cherenkov Detector Technology and Instrumentation in Particle Physics*