Updated results from the 3-ton Gd loaded liquid scintillator target after 2 years of data taking at LNGS

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Abstract. We performed a 3-m³ Gd experiment by doping (up to 0.1% in weight) two counters of the LVD experiment at LNGS, with a Gd organic salt developed and produced as the result of a joint INFN/INR research activity. Feasibility of the experiment and performances of the Gd-doped liquid scintillator (Gd-LS) have been presented. The chemical and physical properties of the Gd-LS and its performance as a neutron detector, namely neutron capture efficiency and average capture time are being monitored since the doping time in 2005. From laboratory survey we can state the stability of the trasmittance (T) at the reference wavelength (425 nm) with a C.L. of 81% and 96% respectively for the first and the second doped counter. This is the largest stable Gd-doped organic liquid scintillator target ever produced and continuously operated for a long period.

1. Introduction
The interest of loading the liquid scintillator (LS) used to detect inverse β-decay νe interactions with Gd, lies in the effectiveness of this element as neutron capturer. Adding ∼ 1 g/l of Gd to the scintillator produces a substantial reduction in the mean n-capture time and the visible energy is significantly above natural radioactivity background (8 MeV instead of 2.2 MeV), increasing the sensitivity to νe. An example of detector that could benefit for the Gd loading is LVD, devoted to detection of neutrino bursts from Gravitational Stellar Collapses in our galaxy [1]. The main goals of Gd doping 2 LVD detectors are the study of the feasibility of Gd-doping an existing large scale apparatus, the evaluation of the new Gd-LS performances on ton scale and the monitor of their stability when scintillator is kept in contact for few years with detector materials at extreme environmental conditions (large temperature and humidity variability).
2. Properties of the liquid scintillator and the adopted Gd doping technology

LVD uses two kinds of LS: one (LS1) contains \(\sim 16\%\) of aromatics and the other (LS2) \(\sim 8\%\). They show slightly different characteristics, the higher percentage of aromatics causing a higher light yield, measured in laboratory to be about 18\% [2]. For both of them the light attenuation length at 425 nm, is \(\Lambda \geq 16\) m.

A 15 kg batch of the organic Gd compound (Gd-2Methylvalerate) was prepared at LNGS chemical laboratory in spring 2005, following the recipe developed [3]. The adopted salt formulation was chosen and optimized to be highly soluble in organic solvent even having low aromatic content, minimizing light quenching while keeping good optical properties of final Gd-LS.

Each LVD counter is a 1.5 m\(^3\) stainless steel tank containing 1.2 ton of LS. To dope such a large amount of LS handling a minimum aliquot of the latter, a master solution highly Gd-doped was first prepared and subsequently diluted in the tank; 31 l of LS were extracted from one counter, doped at a Gd concentration of 48 g/l level and then poured back in the counter. We chose to dope one LS1 counter (T40 located in the LNGS external laboratory at [Gd]= 1.05 g/l in May 2005) and one LS2 counter (T3131 in the underground laboratory at [Gd]=0.93 g/l in October 2005) reaching Gd concentrations that differ of 15\%. Concentration of stabilizing agent was different as well.

3. Performances of Gd LS and stability survey

The impact of Gd doping on optical characteristics has been determined both through

- **in-tank** measurements: the global counter gain (light yield\,* transparency) in tank 3131 has been measured before and after Gd introduction by using the cosmic muon signal and the result is a gain decrease of (17\%\,2\%).
- and laboratory measurements on small size LS samples: Gd doping at 0.1 g/l impacts of -15\% on the light yield (LY) of the Gd-LS compared to the unloaded and produces a decrease of \(\Lambda\) down to \(\sim 10\) m.

The observed neutron mean capture times are \(< \tau_n >= 24.5\pm0.1\mu s\) and \(< \tau_n >= 27.0\pm0.2\mu s\) for T40 and T3131 respectively, corresponding to a decreases of a factor of \(\sim 10\) respect to the value on the mean n-capture time on H \(< \tau_{nH} >\sim 200\mu s\). This impacts of the same value on the S/N ratio. The neutron detection efficiency passes from 70\% to \(< \eta_n >= 87.5\pm 0.1\%\) and \(< \eta_n >= 86.1\pm 0.1\%\) respectively for T40 and T3131.

We are monitoring Gd-LS stability

- on large scale: by measuring cosmic muons, neutron detection efficiency and mean n-capture time;
- on small scale: by directly measuring Gd concentration, transmittance and light yield of LS samples periodically extracted from the counters.

4. Results and perspectives

The doped counters have been continuously monitored for a total time of about 700 days. Both of them do not show any indication of variation and degradation in Gd-LS performance, all the parameters monitored turn out to be stable. On the basis of the know-how acquired in metal loading of organic LS and on the satisfactory results obtained on large scale production, the next steps of our R&D phase, ongoing at the LNGS since 2000, will be the development of Neodymium and Cadmium doped scintillators for 0\nu/\beta/\beta\,-decay experiments and the production of Gd doped target based on LAB (Linear Alkyl Benzene) for \(\tau_e\) detection at reactors.

[1] Aglietta M et al. 1992 Il Nuovo Cimento A 105 1793
[2] di Vacri A 2007 Ph.D. Thesis L’Aquila University
[3] Danilov N A 2007 Radiochemistry 49 281-9