Neutrino Detection by Water Based Liquid Scintillation

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Abstract

Water based Liquid Scintillator (WbLS) particle detectors are being researched as the next generation of neutrino detector technology. WbLS is formed by suspending traditional liquid scintillator in water with a surfactant. Since material is new, we must develop the existing support technology to maintain the detectors. We proposed a two stage filtration system to separate the micelles and organics before deionization. We found that a 600-800 Da nanofilter was a suitable candidate for the first stage filter.

1 Background

When ionizing radiation passes through a medium, it can excite molecules as it passes through a medium. When these molecules return to ground state they emit photons. This effect is radioluminescence or more commonly known as scintillation. Particle detectors based on this phenomena use the light signal generated by the effect to tell if a particle has passed through the detector.

Organic Liquid scintillators are organic liquids possessing this scintillation property. They are composed plastic scintillators dissolved in a solvent. The plastic scintillates in the UV spectrum for a short distance. Typically a wavelength shifter called a fluor is used to absorb the UV light and re-emit the photon at a longer wavelength.

Cherenkov detectors act on a similar principle to liquid scintillation detectors except their light producing mechanism is based on the Cherenkov effect in water. A high energy particle passing through the water the detector generating a light signal.

Optical detection methods such as liquid scintillators or Cherenkov based detectors are both used for experiments involving large scale neutrino events. Typically liquid scintillator or water is kept in monolithic detectors where a neutrino reaction occurs. Photo-multiplier tubes (PMT) are used to detect the signal and quantify the event.

2 Next Generation Neutrino Detectors with Water Based Liquid Scintillator

Today neutrinos are being researched in large scale mass neutrino detectors that look at multiple events. In order for detectors to scale with the experiments being performed, new materials must be created or we must increase the amount of information we can extract from existing materials.

The development of Water based Liquid Scintillator (WbLS) is an example of the former.

WbLS is created by mixing traditional Liquid Scintillator in water with a surfactant. The surfactant creates small micelles or bubbles that encapsulates Liquid Scintillator keeping it separate from the water. This separation gives us a combined light signal of Cherenkov and scintillation light.

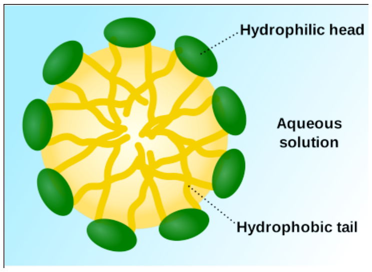

Figure 1: Artist rendering of a micelle. Surfactant with a hydrophophillic head and hydrophobic tail in solution encapsulates a droplet of organic liquid scintillator

WbLS offers a tuneable detection target. Pure water targets are sensitive to high energy interactions above the Cherenkov threshold while pure scintillator targets are sensitive to low-energy events. By mixing the ratio of scintillator to water or introducing other additives such as Gadolinium to solution, the target can be tuned to the specific energy required for the experiment.[1]

The two light signals can be analyzed to reveal more information about the particles detected. A Cherenkov light cone can indicate the direction of travel of a particle through the detector. The ratio of scintillation light to Cherenkov light can be used for particle and event classification.[2]

WbLS based detectors offer more benefits besides scientific. Pure Liquid Scintillator detectors are oil based. They require expensive support equipment to maintain the detector. Rising oil prices make large detectors prohibitively expensive. Additionally, care must be taken in the disposal of the oil used in Liquid Scintillator detectors. Since WbLS is mainly water based, it uses Liquid Scintillator in much smaller quantities. WbLS is more environmentally friendly and can be stored and used without special environmental equipment.

3 Contamination in WbLS Detectors

Since WbLS is mainly water it suffers from the same issues that other water based detectors face, namely contamination. Water is a universal solvent and picks up contaminants very easily. We are primarily concerned with contaminants that absorb light in the UV range as that would have the greatest effect on light signal. In addition to plasticizers, we are concerned with metal ions and radioactive isotopes present in the environment of the detector. Since the formula is so new we are not yet sure what is compatible with WbLS. Compatibility tests are being run with samples of all detector materials that would come into contact with the WbLS.

A two stage filtration system has been proposed to filter contaminants from solution before it is run through an industrial water deionizer. The first stage would separate out the micelles from solution so they are not damaged by processing. The second filter would remove the rest of the contaminants before the final deionizing stage. The cleaned solution would then be recombined in the detector for reuse.

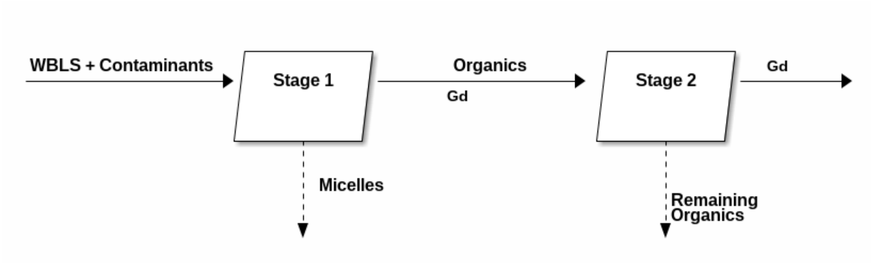

Figure 2: Diagram of proposed two stage filter system

4 Preliminary Nanofilter testing

We were working with gadolinium-doped WbLS. Testing showed that gadolinium in solution produced a characteristic absorption peak between 270 nm and 280 nm.

Analysis was made using UV/Visible Photospectrometry. A filter was installed into stage one. WbLS is added as input to the stage one hopper. The system was gradually brought up to a flow rate of 2.5 L/m and pressure kept at around 25 bars. The run is given 10 minutes to allow the pressure, flow rate, and concentration of solution to reach equilibrium before being tested. A sample is then taken from the permeate line while the temperature, pressure, and flow rate of the system is recorded. The sample is tested against a baseline of deionized water.To determine the gadolinium concentration that passes through stage one, the height of the gadolinium absorption peaks is measured. To account for the baseline introduced by the remaining organic components, a best fit line

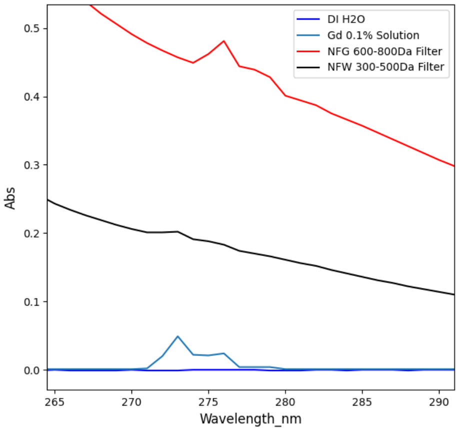

Figure 3: Absorption curves of varying concentrations of gadolinium in permeate along with a 0.1% gadolinium standard. Each curve bears the characteristic two peak absorption pattern of Gd in solution.

is plotted from the start and end of the wavelength range of the peaks. This baseline is subtracted off and compared to a standard 0.1% gadolinium-water solution.

The NFG filter with the pore size of 600-800 Da allowed almost all the gadolinium through the filter making it a viable candidate for a stage one filter.

Filter	Peak 1	Peak 2	Baseline 1	Baseline 2	Background Subtracted Peak 1	Background Subtracted Peak 2
NFW (300-500 Da)	0.202	0.118	0.1938	0.1866	0.0082 ± 0.01	0.0014 ± 0.01
NFG (600-800 Da)	0.481	0.439	0.433	0.417	0.048 ± 0.01	0.022 ± 0.01
Gadolinium 0.1% Solution	0.0485	0.0241	0	0	0.0485	0.0241

Table 1: Table of peaks, baselines,and background subtracted by peaks. $Peak - Baseline = background\ subtracted\ peak$.

5 Applications of WbLS Detectors

One of the largest sources of man-made neutrinos are nuclear fission reactions. Anytime a nuclear reactor is run, the fission process produces unstable nuclei that emit neutrinos as they decay. This reaction is known as the inverse beta decay reaction.

Neutrinos produced in this reaction can be used to identify nuclear sites where plutonium or other nuclear weapons materials are being developed. The goal of the WATCHMAN collaboration is to use an underground WbLS neutrino

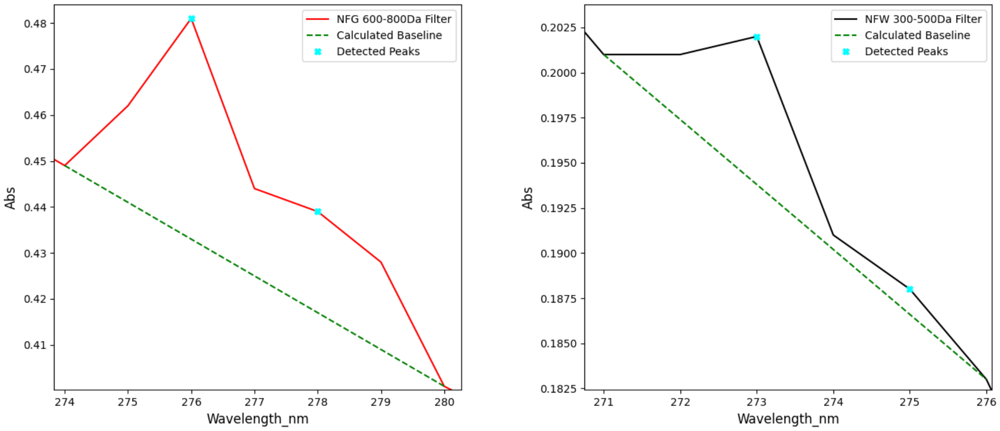

Figure 4: Results of nanofilter testing. The NFG filter in red let through significantly more gadolinium than the NFW filter in black. A stage one filter must separate out micelles letting only gadolinium and other ions through to the stage 2 filter

detector to detect monitor nuclear reactors at a distance.

Antineutrinos emitted by the fission reaction react with hydrogen in the detector to produce an antimatter electron and a neutron. The antimatter proton annihilates with an electron releasing a few photons lasting about a billionth of a second. The neutron travels longer for about 200 millions of a second before being captured by another large atom producing a larger flash.

This beta decay process is a quantum mechanical interaction. Neutrinos that normally penetrate kilometers of shielding have a very low probability of interacting. Several tons of water is needed to reliably produce a signal. A properly tuned WbLS target is much more efficient than water alone. Other projects that have been interested in WbLS detectors are Sudbury Neutrino Observatory (SNO+), the Accelerator Neutrino Neutron Interaction Experiment (ANNIE) project, and the Theia project.

6 Future Questions

A viable stage one nanofilter was found for the water processing system of the detector. The next step would be to identify a suitable stage two filter. Reverse osmosis was one proposed filter technology that could be used to separate the remaining organics out of solution.

There are still uncertainties about how the gadolinium acts in solution or how the micelles affect the rate of flow across the filters. Do the organics “clog” the filter? Do the ions build up a charge that impedes flow? The full size system

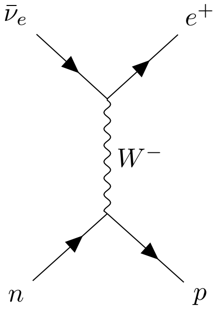

Figure 5: Feynman diagram of the inverse β decay reaction.

will have to move several tons of water so we will need to determine the rate of permeate production across filters.

7 Acknowledgments

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